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TROPICAL FORESTRY PAPERS 42

Acacia senegal and the gum arabic trade



C.W. Fagg and G.E. Allison

OXFORD FORESTRY INSTITUTE
DEPARTMENT OF PLANT SCIENCES
UNIVERSITY OF OXFORD
2004

FRP
FORESTRY RESEARCH PROGRAMME

COVER ILLUSTRATIONS

Front cover Subsistence farmer showing gum arabic collected from 25 year old *Acacia senegal* trees planted in the Damokia research forest, 30 km east of EI Obeid, Kordofan Province, Sudan, at 13°11.36'N, 30°13.94'E on sandy *qoz* soils in July 2001 (Justin Mathews).

Back cover **Top.** Nomads herding cattle through Acacia savanna including *A. senegal* with Jebel El Ain in the background, 30 km east of E1 Obeid, Kordofan Province, Sudan, at 12°55.00'N, 30°35.80'E on sandy soils in September 2001 (Justin Mathews).

Below. A 15 year old plantation of *Acacia senegal* near Bambey, central Senegal, with staff from the ISRA and ORSTOM Institutes in Dakar. Photo taken in March 1994 (Chris Fagg).

Oxford Forestry Institute
South Parks Road
Oxford
OX1 3RB
United Kingdom

Telephone 01865 275 000
Fax 01865 275 074

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No. 42

Acacia senegal and the gum arabic trade

MONOGRAPH
AND
ANNOTATED BIBLIOGRAPHY

C W Fagg and G E Allison

Oxford Forestry Institute
Department of Plant Sciences
University of Oxford

2004

This book is dedicated to the memory of Dr Richard Barnes (1934–2004). He had a life long interest in the Acacias of Southern Africa, and enthusiastically believed in their potential for rural development in Sub-Saharan Africa.

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PREFACE

This is the last of four major monographs and annotated bibliographies on African acacia species that are of major importance for human survival and national economic development in many countries of the African continent and some other tropical countries. Tropical Forestry Paper (TFP) 32 considered *Acacia karroo*, TFP 35 covered *A. erioloba,* and TFP 41 summarized *Faidherbia albida.* This present monograph (TFP42) covers the species *Acacia senegal* but also summarizes its biological and economic links to several related species that are significant producers of gum. The first Section treats the taxonomy, genetics, reproductive biology, ecology and properties of *A. senegal* while the second and third Sections provide fascinating accounts of the historical and modern trade in gum arabic.

These OFI Tropical Forestry Papers are the result of a number of research projects financed by the UK Government's Department for International Development (formerly the Overseas Development Administration). They were undertaken by the Oxford Forestry Institute (OFI) and led by Dr Richard Barnes who has outstanding experience and understanding of forests, forestry and acacias in Africa. Dr Christopher Fagg was a Research Officer and Ms Gaia Allison an MSc student at the OFI who compiled a history of the gum trade. Additional material on the current state and economics of the gum trade was provided by Dr John Coppen, formerly of the Tropical Products Institute (now Natural Resources International Limited), London and Chatham, UK. Dr Fagg, with the contributions from Ms Allison and Dr Coppen, has produced an outstanding report that will have lasting value for commercial users of gum arabic, for government and private growers of acacias and extension workers supporting them, for policy makers concerned with land use decisions in the countries where *A. senegal* is indigenous, and for Africanists and historians.

As for the other acacia species and indeed for many other tropical tree genera, considerable information has been obtained by professional agronomists, foresters and scientists about the biology, management and uses of *A. senegal*; this has been published in a wide range of books and journals that are not easily available to rural populations, and often not to other scientists and managers. This series of monographs therefore aims to review and bring together all such information in a form that can be easily disseminated and widely understood by the scientist, manager and policy-maker.

The ultimate beneficiaries of such research should be the local populations who depend on woodlands and tree products for their subsistence. The TFP series is therefore accompanied by two other books that are of more immediate value to rural dwellers and to the extension workers who advise them – a field guide to the acacias of Zimbabwe, the first of a planned series of field guides for various countries and regions in Africa, and a handbook for extension workers, farmers and teachers. These will assist the integration of the newer, more formal information into the practices of local people to help them use the acacias to the best advantage in a fully sustainable manner.

Professor Jeffery Burley
Director-Emeritus
Oxford Forestry Institute

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INTRODUCTION

Increasing population pressures coupled with periodic droughts have brought about deforestation and land degradation in the dry zones of Africa. Without trees, soil fertility declines, and annual grasses and less palatable herbs and shrubs replace the more nutritious perennial species reducing the land productivity. Many exotic tree species have been introduced into sub-Saharan Africa; however they have not proved very successful in the semi-arid areas, where the ravages of droughts, termites and browsing animals drastically reduced their survival. It has now been generally accepted that a solution to combat this decreasing land productivity is to manage and cultivate the indigenous species, particularly the pioneer legumes that are the natural re-colonizers of these disturbed and degraded lands. Prominent among these are the acacias, and for this reason a series of projects was started in 1987 at the Oxford Forestry Institute, funded by the Overseas Development Administration (now Department for International Development) of the Government of the United Kingdom, to explore, assemble and evaluate the genetic resources of the most widespread and economically important African acacias, including *Acacia senegal*.

Gum arabic is harvested principally from the tree species *Acacia senegal* and *A. seyal*, however the superior properties of gum from the former means that it has dominated international trade. It offers a wide number of benefits to the people who live in the semi-arid zones of sub-Saharan Africa. This is particularly so in Sudan where gum production is an integral part of many of the farming systems. Gum has provided an important source of cash income for the subsistence farming population and for many thousands of families the income from it has become crucial especially during years of poor agricultural harvests. Apart from the commercial benefits, the trees also provide invaluable environmental benefits. They produce browse and fuelwood as well as ameliorating and protecting the soil. Although not always perceived as such, possibly their greatest benefit in these drought stricken regions is to halt long term declining soil productivity.

The gums are obtained by scarring or tapping the bark of the trees. The gum consists of highly water soluble proteinaceous polysaccharides. These are odourless, recognised as non-toxic and safe for use in confectionery production, and have adhesive, anti-crystallisation, thickening and protective properties. In beverages, they are important as emulsifiers and suspensoids, for flavouring and wine stabilisation. The same properties are valued in pharmaceuticals and in their many technical uses.

Gum arabic is a truly ancient article of trade, dating back to the first Egyptian Dynasty (3400 BC). International trade increased dramatically in the first half of the twentieth century with increasing demand from the European confectionery industry in particular. The lion's share was produced from Sudan, from which exports peaked around 60,000 tonnes in the 1960s. However the world demand for gum arabic is sensitive to many factors including price, quality and supply. The severe Sahelian drought of 1973/74 resulted in a world shortage of gum arabic and high prices which, in turn, accelerated the replacement of gum arabic by substitutes such as modified starches. With increased supplies of gum arabic after the drought, consumers did not necessarily switch back, and exports from Sudan plumetted as low as 20,000 tonnes in the mid 1980s. Increasing supplies from other countries such as Chad and Nigeria have helped to increase the African exports to over 40,000 tonnes in the final years of the 20th Century.

Acacia senegal was first described as *Mimosa senegal* by Linnaeus in 1753, probably from a specimen collected in Senegal, hence its specific name, and subsequently Willdenow (1806) transferred it to *Acacia*. It is a very variable species, and its delimitation is still problematic, with the four varieties as defined by Brenan and Ross, relying partly on growth forms to separate them. Current thinking is that these taxa may be divided into three separate species; however for practical purposes it is the typical variety that is of overwhelming economic importance and has had the most research undertaken. Variety *senegal* is the most widespread, dominating the Sudano-Sahelian belt (south of the Sahara desert from Senegal to the Red Sea) and from which nearly all commercially marketed gum arabic is collected. It also stretches across Arabia to India and Pakistan and as far south as Mozambique in Africa. The other varieties occur in east and southern Africa as far south as Transvaal (Republic of South Africa) until frost determines their limit around 27°S. It has been recorded from near sea level to around 2000m.

The best known documented use of the tree in agriculture is in the gum gardens in Sudan. These evolved from the traditional bush-fallow system, where the staple cereals (millet and sorghum) when planted year after year in the same area exhausted the soil and allowed the parasitic *Striga* plant to build up populations with consequently declining cereal yields. Cultivation then moves on to a neighbouring fallow area, and *A. senegal* regenerates or is planted in the recently worked abandoned area. After a few years the abandoned area provides fodder and the

trees are tapped for gum arabic until soil fertility, helped by nitrogen fixation and leaf litter, is restored for a further cropping cycle.

This book is presented in three sections, including a synthesis of the literature on the species, followed by a historical and modern account of the gum arabic trade. There exists a large amount of literature on the chemical and physical structure of gum arabic, and especially its modern food and industrial uses that are not necessarily included in the annotated bibliography. The annotated bibliography contains references and abstracts of greater or lesser length, depending on the accessibility and originality of the material, so that the reader can assess the document's likely use before setting about acquiring it. The plates have been grouped in a central section.

I. *ACACIA SENEGAL*

TAXONOMY, ORIGIN AND DISTRIBUTION

Linnaeus first described the species as *Mimosa senegal* L. in 1753, probably from a specimen collected in Senegal (Ross 1975b) and subsequently Willdenow (1806) transferred it to *Acacia.* However, the delimitation of *Acacia senegal* (L.) Willd. has proved to be very difficult (see number of synonyms in nomenclature) and it is still not altogether clear today. Schweinfurth (1896) recognised var. *kerensis*, based on his specimens from Eritrea, as differing from the typical form in being a bush, branching from the base up to 5 m tall. This was maintained with reservations by Brenan (1959) and Ross (1979). In 1953 Brenan recognised two new varieties, var. *leiorhachis* based on a Greenway specimen (2192) from Tanzania, which was separated from var. *senegal* and var. *kerensis* by having a glabrous or sub-glabrous inflorescence axis, and var. *rostrata* based on a Verdoorn specimen (2264) from Transvaal, in having strongly beaked or rostrate apices to its pods and a southern African distribution. Variety *rostrata* also had a pubescent inflorescence axis and was either a shrub or small tree like the var. *senegal* and var. *kerensis*.

Later, in 1959, Brenan, in the Flora of East Tropical Africa, merged var. *leiorhachis*, including the type, with *A. senegal var. senegal* with the exception of two specimens from the Mpwapwa area of Tanzania (Hornby 140 and Burtt BD 3845) which were referred to as *A. circummarginata* Chiov. He relied on the field observations of Jan Gillett and others who noted the striking yellow peeling bark of the tree. Brenan later changed his opinion again, and Ross and Brenan (1967) decided that the differences between *A. senegal* and *A. circummarginata* were not distinct in the herbarium and merged the two as var. *leiorhachis* Brenan. This was followed by Brenan (1970) in the Flora Zambesiaca, Brenan (1983) and Ross (1979), but they both agreed that the taxonomy of the species was still far from clear and lacking more detailed investigations in Somalia. In the herbarium it is difficult to attribute some specimens to a particular variety without adequate field notes about the habit and habitat. In the field the four taxa can develop into different growth forms; varieties *rostrata* and *kerensis* form a low sometimes multistemmed shrub, although var. *rostrata* can also form a small tree in southern Africa, while var. *senegal* and var. *leiorhachis* can develop into larger trees, although var. *leiorhachis* can also form a low bush with tall whip-like stems.

The two growth forms in *A. senegal* var. *leiorhachis* Brenan are strikingly different in the field. The more widespread form is found both in southern and eastern Africa, and is a dense bush with a small number of tall whippy stems that can reach 12 m or more. This form is very distinctive, with the flowers and fruits produced on the end of the poles; weaver bird nests are often found at the tips. This distinctive habit is also found in a number of *Acacia* species from Somalia (*A. caraniana* (Chiov.), *A. ogadensis* (Chiov.), *A. sarcophylla* (Chiov.) and *A. condylocada* (Chiov.), from Kenya (*A. thomasii* (Harms)), and from Namibia *(A. robynsiana* (Merxm. and Schreiber)) and is probably an adaptation to herbivore pressure. It is often found isolated from the other varieties on rocky outcrops. It usually has a glabrous inflorescence axis, but where it occurs closer to the typical form in the Kajiado region, Kenya (near the road from Kajiado towards Magadi as opposed to the well known populations along the Ngong to Magadi road), intermediate forms between the two can be found.

The other growth form of *A. senegal* var. *leiorhachis* Brenan is very different, being a large tree with a rounder crown than the flattened crown of the normal *A. senegal.* It also has the peeling yellow bark and glabrous inflorescence of the whippy form. It grows both in the arid north east of Kenya and southern Somalia and in Tanzania. In north eastern Kenya, on the road from Isiolo to Merti it is found along the luggas or seasonally dry watercourses, where it occurs close to the shrub form of *A. senegal* (var. *kerensis*); but intermediates cannot be found there. Interestingly, a few kilometres before Isiolo the whippy form is also found; but as yet no overlap of these two growth forms has been encountered possibly due to different habitats. In Somalia, *A. circummarginata* Chiov. is recognised as a tree 5-10 m high, and when growing with *A. senegal* is easily distinguished by being larger with yellowish papery peeling bark, glabrous purplish brown branchlets with long internodes and a glabrous inflorescence axis. The whippy form is not found there (Thulin 1993).

In contrast to the striking field differences, the two growth forms have many morphological characteristics in common on herbarium specimens. Gachathi (1994) suggested that the two forms could be separated in that the whippy form had sparingly pubescent more or less straight greyish branchlets and rounded pods, whilst the tree form had glabrous more or less zigzag purplish-brown branchlets with pods tapering at both ends. Studying this complex, he also found that the tree form is distinct from the other taxa of *A. senegal* in having

longer internodes and greater numbers of leaflet pairs. Larger leaflets also tend to be associated with the tree form. There is a great deal of variability in inter-node length in the whippy form, from the dense much branched bush (shorter internodes) to the longer internodes on the straggly leaders; hence where the herbarium specimen is collected on the plant is important.

Although some of the varieties can be easily distinguished in the field there are still difficulties in identifying them from herbarium sheets (Brenan 1983). In fact a number of workers since 1983 do not recognise the infraspecific taxa but prefer to treat them as one very variable species. Somalia appears to be the centre of diversity of the species and its related species in the sub-genus Aculeiferum. Extensive collections undertaken there suggest that the shrub forms (var. *rostrata* and var. *kerensis*) of *A. senegal* cannot be distinguished from variety *senegal*, and all three varieties grade into each other. The tree form of var. *leiorhachis* is separated off from the species and named *A. circummarginata* (Hassan and Styles 1990; Thulin 1993); however the whippy form is not found in Somalia. Gachathi (1994) suggested that the whippy form should also be separated off from *A. senegal*. This complex will be treated in a forthcoming paper.

For the purposes of this report the four varieties are kept separate to highlight the extremes of variation in *A. senegal,* and because their end uses are very different. The four varieties are separated by the pubescence on the inflorescence axis, habit (tree, bush or whippy form), and the shape of the pods.

Key to varieties (after Ross 1979; Brenan 1983)

1a. Inflorescence axis glabrous or subglabrous, except sometimes for some basal hairs:

2a. young branchlets glabrous or subglabrous, rather smooth, generally purplish-brown; tree often with slender straggling branches or sometimes with a rounded crown; bark on trunk yellow, papery and peeling; inflorescence axes often purplish; flowers often produced before the new leaves . . . . . var. *leiorhachis*

2b. young branchlets sparsely to densely pubescent, dull grey to grey-brown; tree with lax rounded or flattened and spreading crown; bark on trunk not papery or peeling; inflorescence axes olive-green; flowers produced after the new leaves . . . . . var. *senegal*

1b. Inflorescence axis sparsely to densely pubescent:

3a. Tree with a distinct trunk

4a. Pod rounded to acute (sharply pointed), seldom acuminate (tapering gradually to a narrow tip with concave sides) at apex . . . . . var. *senegal*

4b. Pod markedly acuminate or rostrate (beaked) at apex. . . . . var. *rostrata*

3b. Shrub or bush, usually without a distinct trunk:

5a. Pod rounded to acute, seldom acuminate at apex; leaves with up to 4 pinnae pairs . . . . . var. *kerensis*

5b. Pod markedly acuminate or rostrate at apex; leaves with up to 12 pinnae pairs. . . . . var. *rostrata*

Bibliography: 159, 160, 161, 162, 328, 329, 384, 650, 651, 652, 653, 654, 745, 746, 747, 748, 749

Nomenclature

Acacia senegal (L.) Willd. in Species Plantarum 4: 1077(1806) pro parte excl. syn. fere omnibus. Type: unknown, neotype Adanson 16899 (P) selected by Ross (1975b).

Acacia senegal* (L.) Willd. var. *senegal Brenan in F.T.E.A. : 93 (1959). Type: Herbier Adanson 16899 (P, neotype, K, photo neotype)

Synonyms:

Mimosa senegal L. Sp. Pl. 1: 521 (1753) pro parte excl. syn. fere omnibus. Type uncertain, presumably a specimen collected by Adanson in Senegal[1]

Mimosa senegalensis Houtt., Nat. Hist. 3: 614 (1774) nom illegit.

Acacia verek Guill. & Perr. in Fl. Seneg. Tent. 1:245, t.56 (1832) nom illegit. Syntype: Senegal, locality not stated, Huedelot sn. (P syntype)

Acacia rupestris Stocks ex Boiss., Fl. Or. 2:638 (1872). Type: Baluchistan, Stocks 502 (K, holo.)

Acacia virchowiana Vatke & Hildebr. in Ost. bot. Z. 30: 275 (1880) pro parte quoad fol. et flor. tantum. Type: Kenya, Teita Dist., Voi River and elsewhere, Hildebrandt 2486 (?B. holo.; BM)

Acacia senegal var. *typica* Fiori in L'Agric. Coloniale 5: 93 (1911)

Acacia senegal var. *platyosprion* Chiov., Result. Sci. Miss. Stefanini-Paoli: 72 (1916) syntypes: Somalia, Mogadiscio, Senni 191 (FI, K photo); Chisimaio, Senni 116 and 201 (FI); da Bur Gao e Cu Daio, Senni 87 (FI); Gobuin, Gorini 421 (FI); between Bug Berde and Ato, Guidotti 3 (whereabouts unknown)

Acacia senegal subsp. *modesta* (Wall.) Roberty var. *rupestris* (Stocks ex Boiss.) Roberty in Candollea 11: 154 (1948). Type: Baluchistan, Stocks 502 (K, holo.)

[1] Note: There are 3 specimens collected by Adanson in 1749 from Senegal I have seen at P: 16897, 16898 and 16899.

Acacia senegal subsp. *senegalensis* Roberty var. *verek* Roberty in Candollea 11: 156 (1948). Syntypes as for *A. verek*.
Acacia pseudoglaucophylla (Chiov.) Chiov. (1916) type: S2, Mogadishu, Paoli 83 (FT lecto.)
Acacia oliveri Vatke Ost. Bot. Z. 30:274 (1880)
Acacia unispinosa (Fiori) Chiov. Fl. Somala 1:169 (1929)

***Acacia senegal* var. *kerensis* Schweinf.** in Bull. Herb. Boissier 4, app. 2:216 (1896) Syntypes: Ethiopia, near Keren. Schweinfurth 745 (B, K); Bogu valley. Schweinfurth 741 (B); near Djuffa. Schweinfurth 998 (B).

***Acacia senegal* var. *rostrata* Brenan** in Kew Bull. 8:99 (1953) Type: South Africa, Transvaal, Dongola reserve Verdoorn 2264 (K holo, SRGH holo photo, PRE isotype)

Synonyms:
Acacia spinosa Marloth & Engl. in Bot. Jb. 10:20 (1888), nom. illegit. Type: Namibia, near Usakos Marloth 1257 (K, PRE)
Acacia rostrata Sim, For. Fl. P.E.Afr. 55, t. 37a (1909) Type: Mozambique, Maputo. Sim 6263 (whereabouts unknown)
Acacia oxyosprion Chiov. var. *oxyosprion* Fl. Somala 2:188, fig 115 (1932) Type: Somalia, Pozzi di El Meghet. Senni 651 (FI holo)
Acacia senegal sensu Burtt Davy, Fl. Transv. 2:337 (1932) pro parte
Acacia senegal subsp. *trispinosa* (Stokes) Roberty in Candollea 11:155 (1948) pro parte quoad specim. Dinter 222 et Rogers 6266
Acacia senegal var. 'Geelhaak' Codd in Trees and Shrubs of the Kruger National Park. 51 (1951)
Acacia volkii Suesseng. in Mitt. bot. Stsamml. Munch. 2:40 (1954). Type as for *A. spinosa* Marloth & Engl.

***Acacia senegal* var. *leiorhachis* Brenan** in Kew Bull. 8:98 (1953) Type: Tanzania, Pare district, Same Greenway 2192 (K, holotype; EA, FHO isotypes)

Synonyms:
Acacia senegal var. *senegal* sensu Brenan in Flora of East Tropical Africa 93 (1959) pro parte quoad syn. *A. senegal* var. *leiorhachis*
Acacia sp. 1. F. White in Forest Flora of Northern Rhodesia 82 (1962)
Acacia circummarginata Chiov. in Annali Bot. 13:394 (1915) Syntypes: Ethiopia, Ogaden, Paoli 794, 913 bis, 920 (FI)

Vernacular names

Being so widespread and utilized by man, *A. senegal* has a large number of common names and variants of them. The most commonly found in the literature are listed below, in alphabetical order of language bold in brackets after the name(s), and many can be orthographic variants of others. The trade names for the gum are given in section III. A list generated by the BRAHMS database from herbarium specimens linked to a locality is given in Appendix 1.

Arabia: Tur, Tulh, Harheyr (**Jibbali**); Temmar (**Dhofari Arabic**);

West Africa: Abu gebala, Asharat, Askab, Awarwar, Baggara, Erwar, Kitir, Kitir abiet, Ketr el Abyad, Hashab, Um gebala (**Arabic**); Guerasa (**Baguirmi**); Dibe, Dankari, Dunkari, Patuki, Manchiu (**Bambara**); Burkutu (**Bari**); Kundo (**Baule**); Goniminiga (**Berber**); ga-kandyar (**Bedik**); Shana (**Bura**); Danja, Danngha, Deligna (**Djerma**); Fish hook Acacia, Gum arabic tree (**English**); Gommier blanc, verek (**French**); Dibehi, Patuki (**Fulani**); Dibehi, Dacere (**Fula-Fulfulde**), Garandak (**Hames**); I Konsindi, Li konguabli (**Gourmanche**); Akoria, D'akwara, Dakworo (**Haussa**); Kolol (**Kanuri**); Donkoro (**Mandika**); Konkombu (**Moba**); Gomiga, Goniminiga, Gonmihougou, Kunkwina (**More**); Delbi, Dibehi, Dioshi, Patouki, Patouni, Patterlahi (**Peulh**); Dogoragayob, Ngobop, Uki (**Serer**); Irwar, Oraf, Orof-torah, Tamat, Turreuft (**Tamachek**); Danngha, Kassane (**Songhai**); Verek (**Wolof**); Bonni (**Yoruba**) - var. *leiorhachis* Acondok (**Dinka**), Subahi (**Arabic**).

East Africa: Qontr, Qwentr, Sbansa-grar (**Amharinya**); Hedado, Idado, Golole (**Boran**); Chikwata (**Digo**); Gum arabic (**English**), Akkrsa (**Gamonya**); Garbi (**Gallinia**); Mkalankanga (**Irangi**), Mung'ole (**Kamba**); Umukonji, Umkodji (**Kinyarwanda**), Lyadulele (**Kii-Arusha**), Mahara (**Kunaminya**); Oiti-orok, Olmunishui, Osbiti, Oldenkensi, Olkiloreti (**Masai**); Idado, Sabansa-dima, Sapessa (**Orominya**); Chemenglyom, Chemangayan, Chemanka, Danyukit (**Pokot**); Lderikesi, Loerikesi (**Samburu**); Adad, Adad hini, Adad medu, Adat, Cadaad, Edad, Idaad (**Somali**); Kikwata, Mgunga (**Swahili**); Qentb, Qentbi, Qentiba, Sfri-dmmu (**Tigrinya**); Chemanka, Ngolpelwo (**Tugen**), Ekonoit (**Turkana**); Betuba (**Welaytinya**); - var. *leiorhachis* Mongolli (**Kamba**); Upe (**Karasuh**); Entangoringoroi (**Masai**); Cadaad geri, Far yer, Ferix, Adad geri (**Somali**), Burega (**Tarme**), Hluktu (**Tindija**), Mugagauko (**Tindija**).

Southern Africa: - var. *rostrata* diehaakdoring, Geelhaak (**Afrikaans**); Three-hook thorn (**English**); Omuryangava (**Herero**), Driedoringakasia, Dreidornakazie (**Namib**); Mdangana (**Sotho**); Munkhondo (**Muquilenqe**), N'aonde (**Muquilen**); - var. *leiorhachis* gomdoring (**Afrikaans**); umHlahlalinye (**Ndebele**); Munana (**Sepedi**); Calincahtu (**Tete**); IsiKhaya (**Zulu**).

India: Kumbat, Kumatiyo, Kumta (**Rajputana**), Khor (**Punjab**).

Description

Description of the tree: In the field the four taxa can develop into very different growth forms. Varieties *rostrata* and *kerensis* form only low obconical shrubs (up to 2 m high) with a flat crown, although var. *rostrata* can also form a small tree (up to 5 m high) in southern Africa. Varieties *senegal* and *leiorhachis* can develop into larger trees to 12 m high, although var. *leiorhachis* can also form a low bush with tall whippy stems that can reach 15 m.

Bark: On trunk yellowish to grey or greyish brown, rough and fissured or smooth and papery and peeling off in strips; young branchlets yellowish or greyish brown to purplish black, glabrous to densely pubescent, bark not conspicuously peeling off. Its stipules are not spinescent, they very soon become deciduous on the young growth and are often not encountered on herbarium specimens. It has prickles 2-8 mm long on its branches, grouped in threes at the nodes (leaf axils), with the central one hooked downwards and the two laterals more or less curved upwards, or a single prickle with the laterals absent. Branches with internodes up to 4 cm long.

Leaves: Alternate bipinnate leaves are usually hairy (pubescent), and can vary from sparingly to densely clothed with spreading hairs, particularly on the petioles, rachides and rachillae. Petioles can vary from 0.2-2 cm long, and are usually glandular, the distinctly raised small petiolar gland varying from 0.5-0.75 mm in diameter. The rachis varies from 0.2-7 cm long, with a gland at the junction of the top 1-5 pinnae pairs, between each pair or sometimes absent, and sometimes with prickles along the rachis. The pinnae vary from 1-12 pairs but mostly 3-8 pairs and the leaflets pairs 5-27 per pinnae. Each leaflet varies from 1-9 mm long by 0.5-3 mm wide, linear to elliptic-oblong, sparingly pubescent on both surfaces or glabrous.

Flowers: The whitish or yellowish white scented flowers occur on elongated spikes up to 12 cm long, its axis densely pubescent or glabrous. Peduncles vary from 0.5-2 cm long. Each spike bears 20-85 or more flowers. The calyx is 2-3.5 mm long, glabrous to slightly pubescent, and the corolla 2.7-4 mm long. Stamen filaments are numerous (80-240 per flower), united in a tube at the base for about 1 mm, and up to 7 mm long. The pistil 5-10 mm long, with a cup-shaped stigma and the ovary is shortly stipitate.

Pods: They are dehiscent, the two papery thin walls splitting open when mature on the plant. Pods are yellowish or greyish brown, 1.8-19 cm long x 1.2-3.4 cm wide, rounded to acuminate apically, venose, sparsely to densely appressed pubescent or puberulous. Seeds are nearly round and flattish (disc shaped), 8-12 mm in diam., with a horse-shoe pleurogram 2.5-6 x 2.5-5 mm, impressed in the surface of the seeds.

For details of habit and morphology, see Figures 1 to 4.

Origin and natural distribution

The origin of the family Leguminosae is unknown but pollen and wood fossil specimens have been found of the subfamily Mimosoideae, to which *Acacia* belongs, from the Maastichtian period, some 65-70 million years ago (Raven and Polhill 1981). This sub-family may have had a western Gondwanaland origin, evolving in a portion of the ancient continent that comprises present-day Africa and South America, perhaps in a tropical lowland forest setting (Raven and Axelrod 1974). Limited fossil pollen evidence shows that the sub-genera of *Acacia* appear in different periods. The oldest belonged to sub-genus *Aculeiferum* from the upper Eocene in Africa, whereas sub-genus *Acacia* appeared later in the Oligoene in America (Guinet and Ferguson 1981). Primitive characters of species in sub-genus *Aculeiferum* suggest that they evolved from a prototype *Aculeiferum*, probably climbers in tropical forests. Serological evidence suggests that *Acueliferum* evolved independently from *Acacia* (Brain 1987), as borne out by studies on DNA sequence data (see Miller *et al.* 2003 and references therein). By the middle of the Miocene (14-15 million years ago), drier climates developed in both Africa and South America forming savannas (Axelrod 1992) probably allowing the arid adapted genus *Acacia* to diversify. More recent major climatic fluctuations in the last 2.5 million years would have favoured further diversification and distribution.

The genus *Acacia* is pan tropical with around 1352 described species. At present *Acacia* is divided into three sub-genera *Aculeiferum, Phyllodineae* and *Acacia.* However, recent analyses of DNA sequence data show that *Acacia* is polyphyletic, i.e. it does not form a natural group. Instead these analyses provide compelling evidence for five separate groups scattered across the Mimosoideae sub-family. Currently *Acacia senegal* is placed in the sub-genus Aculeiferum, but under the proposed segregation into five genera it would be placed in the genus Senegalia (see Miller *et al.* 2003 for discussion).

In Africa, only two of the three sub-genera occur, sub-genus *Acacia* which has spinescent stipules (paired straight thorns), capitate inflorescences and polyploid chromosomes (2n = 52), and sub-genus *Aculeiferum* which has non spinescent stipules and prickles (hooked thorns without vascular connections) flowers clustered in spicate or capitate inflorescences and diploid chromosomes (2n = 26). The polyploid species of *Acacia* appear to occupy a greater range of habitats and tend to be more widely distributed than the diploid species, possibly due to greater genetic plasticity.

Sub-genus *Aculeiferum*, which in Africa is further subdivided into two sections, section Monacantha which has scattered thorns and spicate or capitate inflorescences and section Aculeiferum, which only has spicate inflorescences and paired thorns or thorns in threes. It is the latter group, with the presence of three prickles at or near

the nodes that forms the *Acacia senegal* complex, a group of around 20 species (see related species). *A. mellifera* which forms a natural hybrid with *A. senegal* belongs to the paired thorn group of around 38 species in Africa.

A. senegal var. *senegal* is the most widespread variety. It dominates the Sudano-Sahelian belt (south of the Sahara desert) and stretches across Arabia to India and Pakistan and as far south as Mozambique in Africa (Lock 1989; Lock and Simpson 1991; Troup 1983) and is the source of nearly all commercially marketed gum arabic. The other varieties occur in east and southern Africa as far south as Transvaal (Republic of South Africa). It has been recorded from near sea level to around 2000 m.

Each taxon is dealt with in the section on variation below. The localities of herbarium specimens are listed in the Appendix 2, and those that have their longitude and latitude determined are plotted in maps in Plates 1 and 2. However, the map is incomplete because localities for Oman (Miller and Morris 1988), Iran (Parsa 1948) and Pakistan (Stewart 1972) as well as more in India have yet to have their position determined. Interestingly, in the Arabian peninsula it has only been registered in Oman while *A. laeta* R. Br. ex Benth., a species derived from the hybridisation of *A. senegal* with *A. mellifera,* is far more widespread there.

A. senegal var. *senegal* has been introduced into Australia, Indonesia, Puerto Rico, Sri Lanka and the Virgin Islands, mostly for ornamental purposes (Booth and Wickens 1988; Hellinga 1949). It is also being planted in its native range, e.g. in Sudan, Kenya, Niger, Mali and Senegal principally for gum production, sand dune stabilisation and windbreaks and in the Indian sub-continent for fodder and fuelwood, sand dune stabilisation and windbreaks. More recently it has been introduced into Zimbabwe at seven sites as part of genetic evaluation trials (Barnes *et al.* 1999).

Bibliography: 81, 87, 105, 107, 146, 157, 160, 161, 305, 364, 393, 481, 482, 519, 520, 553, 581, 626, 627, 650, 653, 713, 755, 762, 763.

Karyotype

Diploid chromosome numbers (n = 26) have been recorded by various authors (Khan 1951; Sharma and Bhattacharyya 1958; Darlington and Wylie 1955; El Amin 1972; Nongonierma 1976; Ross 1979; Obunga 1995; Bukhari 1997) for the gum arabic variety *A. senegal* var. *senegal*. There are no known chromosome counts for the other varieties of *A. senegal*. The chromosomes are small about 1 μm in length which makes detailed cytological investigations difficult, and Bukhari (1997) discussed the techniques involved.

Khan (1951) was the first to record an apparent triploid hybrid between *A. senegal* var. *senegal* x *A. mellifera* subsp. *mellifera,* showing 2n = 39 or 40 in the somatic nucleoli of its progeny. This hybrid was later noted to be *A. laeta* (Jackson and Peake 1955) and confirmed by El Amin (1976). Goldblatt (1981) gave the base number of x = 13 as typical of the Mimosoideae. Polyploidy appears to be well developed only in the sub-genus *Acacia* (series Gummiferae) with x = 26, with diploids in the other two sub-genera.

Bibliography: 167, 168, 224, 445, 455, 456, 552, 556, 653, 681.

Related species

The closely related species of *Acacia senegal* (L.) Willdenow, are those that form the *Acacia senegal* complex group, in the subgenus *Aculeiferum* (Ross 1975a; 1979). Ross attributed all those *Acacia* species with spicate inflorescences and the presence of three prickles at or near the nodes to the *Acacia senegal* complex. Since his paper, there have been more species added and some changes to the complex. Gum from any of these species could have been marketed as gum arabic for food additives until 1998, when the new JECFA specification excluded the related species while including the unrelated *Acacia seyal* (Food and Agriculture Organization/ World Health Organization 1998). The complex now includes around 20 species: *A. asak* (Forssk.) Willd. (1806), *A. cheilanthifolia* Chiov. (1929), *A. circummarginata* Chiov. (1915), *A. condyloclada* Chiov. (1915), *A. caraniana* Chiov. (1929), *A. densispina* Thulin (1989), *A. dudgeoni* Craib ex Holland (1911), *A. flagellaris* Thulin (1989), *A. hunteri* Oliv. (1880), *A. hamulosa* Benth (1842), *A. mahrana* Thulin & Gifri (2000), *A. moggii* Thulin & Tardelli (1988), *A. ochracea* Thulin & Hassan (1990), *A. ogadensis* Chiov. (1915), *A. senegal* (L.) Willd. (1806), *A. somalensis* Vatke (1880), *A. thomasii* Harms (1914), *and A. zizyphispina* Chiov. (1929).

A. dudgeoni has been previously known as *A. senegal* ssp. *senegalensis* var. *samoryana* (A. Chev.) Rob. (Berhaut 1975). The fertile hybrid species *A. laeta* R. Br. ex Benth. (1842), while usually found with two prickles like its parent *A. mellifera* (Vahl) Benth., can also occasionally have three prickles on the same plant, and therefore could be included in the complex (see natural hybrids).

Vassal (1969) based on a study of the morphology of young seedlings of African Acacias of the series Vulgares and Gummiferae, found that series Vulgares appeared to be heterogeneous, comprising (1) species of the group *pennata* (climbing Acacia), (2) *A. ataxacantha* DC. and (3) a group comprising *A. caffra* (Thunb.) Willd., *A. galpinii* Burtt Davy, *A. laeta*, *A. nigrescens* Oliv., *A. polyacantha* ssp. *campylacantha* (Hochst. ex A. Rich.) Brenan , and *A. senegal*. In the same series Vulgares, El Tinay *et al.* (1979) found from serotaxonomic studies of the seed proteins that both *A. mellifera* and *A. laeta* were

closely related and grouped in a sub-group with *A. polyacantha,* while *A. senegal* was grouped with *A. asak* and *A. ataxacantha* (climbing *Acacia*) in the only other sub-group. Further immunological studies on the gums of 12 *Acacia* species however demonstrated greater differences in the composition of the cell wall epitopes within a taxonomically related group or species than from taxonomically unrelated species (Baldwin *et al.* 1999).

Natural hybrids

Acacia laeta R.Br. ex Benth.was first described by Hooker as long ago as 1842 as a separate species although it has been known as a closely related species to *A. senegal* and *A. mellifera* (Giffard 1966). Khan (1951) was the first to record an apparent triploid hybrid between *A. senegal* x *A. mellifera,* showing 2n = 39 or 40 in the somatic nucleoli of its progeny. The two putative parents were both diploid with 2n = 26. This fertile hybrid was later noted to be *A. laeta* (Jackson and Peake 1955). Anderson and Smith (1967) also noted that *A. laeta* was a hybrid species and studying its gum composition found it to be similar to *A. senegal.* Gum of this species also enters the gum Arabic trade along with *A. senegal.* El Amin (1976) collected specimens of *A. laeta, A. mellifera* subsp. *mellifera* and *A. senegal* var. *senegal* from throughout their ranges in Sudan; 33 morphological characters were studied and compared between the species. Characteristics of *A. laeta* were intermediate, though slightly closer to those of *A. mellifera. A. mellifera* and *A. senegal* var. *senegal* were found to be diploid (2n = 26) while *A. laeta* was confirmed to be a fertile triploid (2n = 39). Collections of this hybrid have been found in eastern Africa (Kenya) see plate 30 where the two putative parents also occur together. More recently, Danthu *et al.* (1998) found that both *A. laeta* and *A.senegal* var. *senegal* have 100% grafting compatibility.

GENETIC VARIATION

Morphological variation

Acacia senegal shows a great deal of morphological variation (Brenan, 1983) indicative of high levels of genetic variation.

Variety *senegal*

The type variety grows as a tree up to 14-15 m high, with a lax and rounded or flat and spreading crown. Bark on trunk not papery and peeling but greyish to yellowish-brown, rough, fissured and sometimes flaking. Pubescent branchlets and inflorescence axis. Pods rounded to acute (Figure 1). This is the most widespread variety which dominates the Sudano-Sahelian belt and from which most of the gum arabic is collected, and it stretches across Arabia to India and Pakistan and as far south as Tanzania. Pods are very variable in this variety.

In Senegal, variation has been noted between two "phenotypes" of *A. senegal* var. *senegal.* These are distinguished by bark colour, light or dark grey, and the dark grey type also produces more gum, at a faster rate and of a better quality than the light grey bark type (Dione 1988, Gaye 1988). Differences were also noted in the survival, speed of germination, and early growth between the two (although sample sizes were small and not subject to statistical analysis). The two types can occur in the same area. Gaye (1988) also noted that seed size was greater and more variable in the dark grey type, and the seed colour was light brown versus a greenish brown in the light grey type. The dark grey bark type is naturally more abundant at the base of the dunes and depressions and should be selected for planting there.

Variety *kerensis*

This variety differs from the typical variety in only developing into a shrub or bush to 1-5 m high, branching from the base with a very short trunk if any. The leaves have up to 4 pinnae pairs. In Kenya it grows in more arid sites than the typical variety, and consequently produces the most gum. The shrubby habit is possibly an adaptation to the arid conditions. The shrubby forms in Kenya (not always possible to distinguish between *kerensis* and *rostrata,*) have bark that can vary between smooth grey to yellow brownish sections peeling off the trunk. In Kenya two types of shrub forms are recognised by the Il Chamus (Njemps) and have different local names. The larger pod form is called 'ilderkesi' and the smaller podded variant 'ilngendedi', the larger form apparently producing greater quantities of sweeter gum.

Variety *rostrata*

This variety is distinguished by having strongly beaked or rostrate apices to its pods (Figure 2E), and is often a low shrub or bush although it can also form a tree to 6-8 metres in southern Africa (Figure 2). It can also have papery yellow bark especially on the branchlets. Young branchlets are more or less pubescent. Leaves have with 4-12 pinnae pairs. Inflorescence axes are pubescent.

Variety *leiorhachis*

There are two growth forms in *A. senegal* var. *leiorhachis* which are strikingly different in the field. Both have glabrous inflorescence axes, often purplish. The more widespread form is found both in southern and eastern Africa, and is a dense bush with a small number of tall whippy stems that can reach 12 m or more (Figure 3). The other growth form of *A. senegal* var. *leiorhachis*

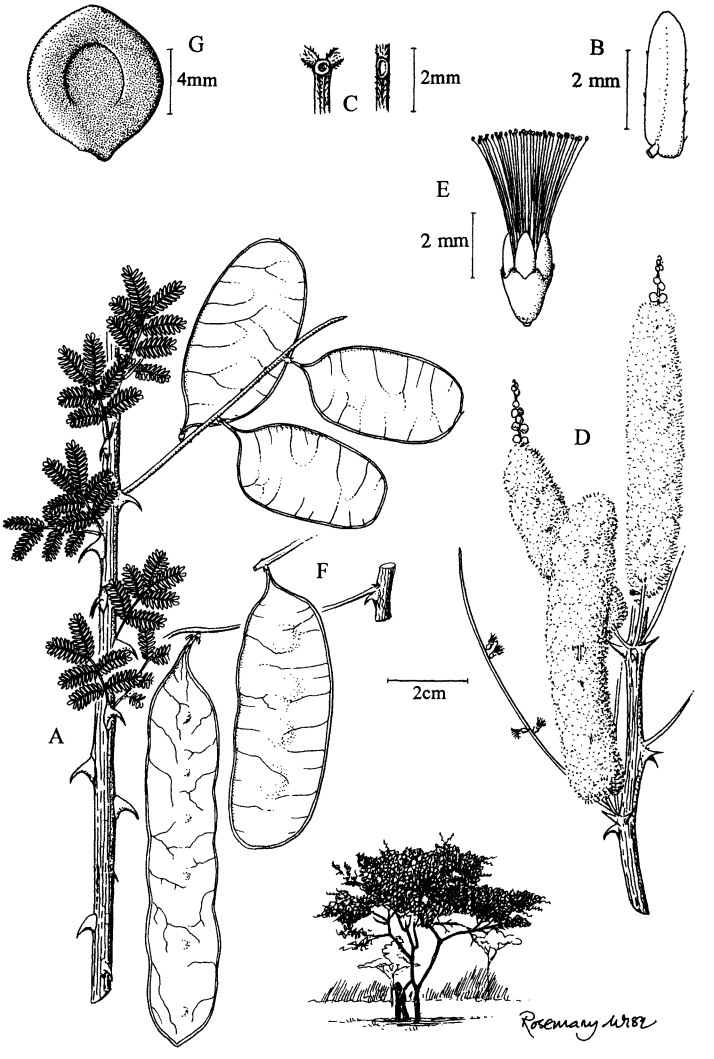


Figure 1. Botanical drawing of *A. senegal* var. *senegal*. It usually occurs as a small to medium sized tree. A – branchlet with leaves and pods (x1); B – leaflet (x10); C – petiolar gland on the right, rachis gland on the left (x4); D – branchlet and infolescences with flowers buds and open flowers (x1); E – flower (x8); F – pods (x1); G – seed (x4). Drawings by Rosemary Wise.

is very different, being a large tree with a rounder crown than the flattened crown of the normal *A. senegal* (Figure 4). It also has the peeling yellow bark and glabrous inflorescence of the whippy form. The whippy form has sparingly pubescent more or less straight greyish branchlets and rounded pods, whilst the tree form has glabrous more or less zigzag purplish-brown branchlets with pods tapering at both ends, and is distinct from the other varieties of *A. senegal* in having longer internodes and greater numbers of leaflet pairs.

Variation has been recorded between seedlings of *A. senegal* var. *leiorhachis* and *A. senegal* var. *rostrata* in southern Africa, the former always having its first leaf pinnate and the second leaf bipinnate with four jugae and in the latter the second leaf is bipinnate but with two jugae (Robbertse 1971).

Chemical variation

There exists a wide variation in gum chemistry within and between varieties; however to what extent this is due to genetic differences rather than the environment in which they grow remains to be evaluated. This can only be done through comparative field trials in which there is some control over environmental effects. For instance, Anderson and Wang Weiping (1992) found that gum arabic taken from *A. senegal* var. *senegal* in Uganda differed in several respects from typical Sudanese gum arabic.

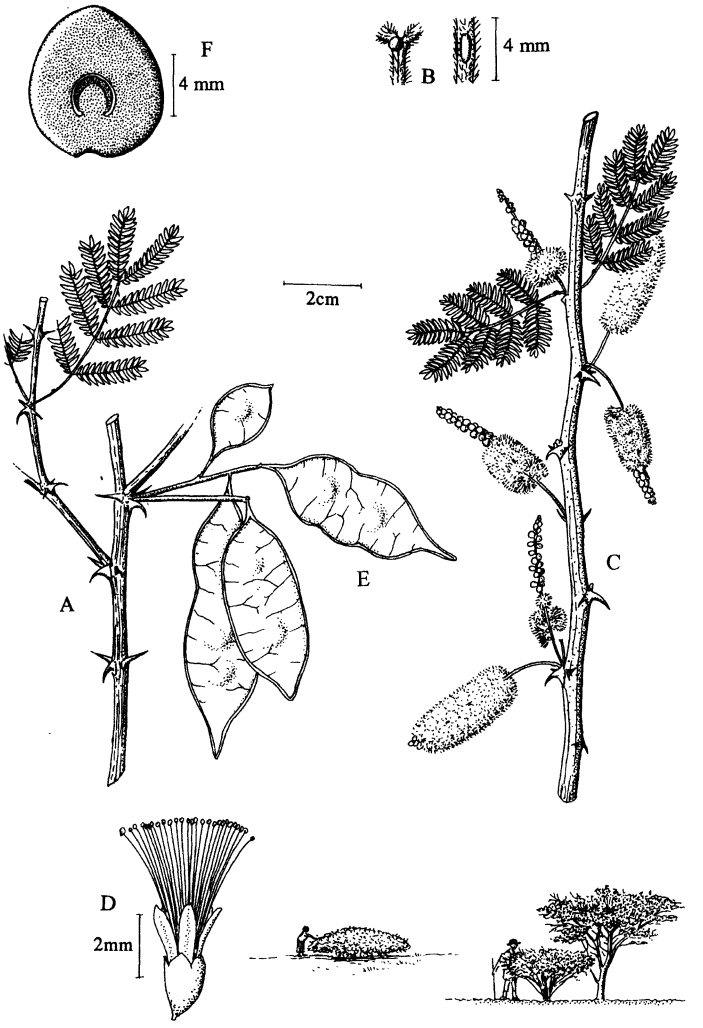


Figure 2. Botanical drawing of *A. senegal* var. *rostrata.* It can occur as a low bush or a small tree. A – branchlet with leaf (x1); B – petiolar gland on the right, rachis gland on the left (x4); C – branchlet and inflorescences with flower buds and open flowers (x1); D – flower (x8); E – pods (x1); F – seed (x8). Drawings by Rosemary Wise.

Differences in terms of fine structural features (13C NMR spectroscopy), amino acid composition, and high contents of aluminium and iron (but not of chromium and copper) were confirmed. Data for soil samples taken from beneath gum bearing trees indicate strong preferential uptake of potassium, calcium and magnesium; there is also a relationship between the acid leachable amounts of aluminium, barium, chromium, copper, iron, lead, titanium and zinc in a soil, and their content in the gum produced by the tree growing thereon. Chikamai *et al.* (1996) found that gum arabic from *A. senegal* var. *kerensis* in Kenya had properties that make it less marketable than that of *A. senegal* var. *senegal* from Sudan (higher viscosity and tending to gel at lower concentrations) and that it differs from the current specification of commercial gum arabic (see Section III) by having a higher specific rotation, nitrogen content and intrinsic viscosity (Chikamai 1994). Gums can vary considerably within a region and variety. For example, 67 individuals of var. *kerensis* in Northern Kenya had a specific optical rotation mean (alpha)-D varying from -34 to -37 degrees, with individual values of -40 degrees and average nitrogen content was 0.45%, with individual samples as high as 0.70% (Jurasek *et al.* 1994).

Molecular variation

Most studies have been undertaken in Senegal. Bergonzini and Joly (1992) evaluated genetic diversity of 11 populations in Senegal using 8 isoenzyme systems. The mean number of alleles per locus was 1.4, and the mean heterozygosity was 0.175. Chevallier *et al.* (1994) also assessed genetic diversity using isoenzymatic markers

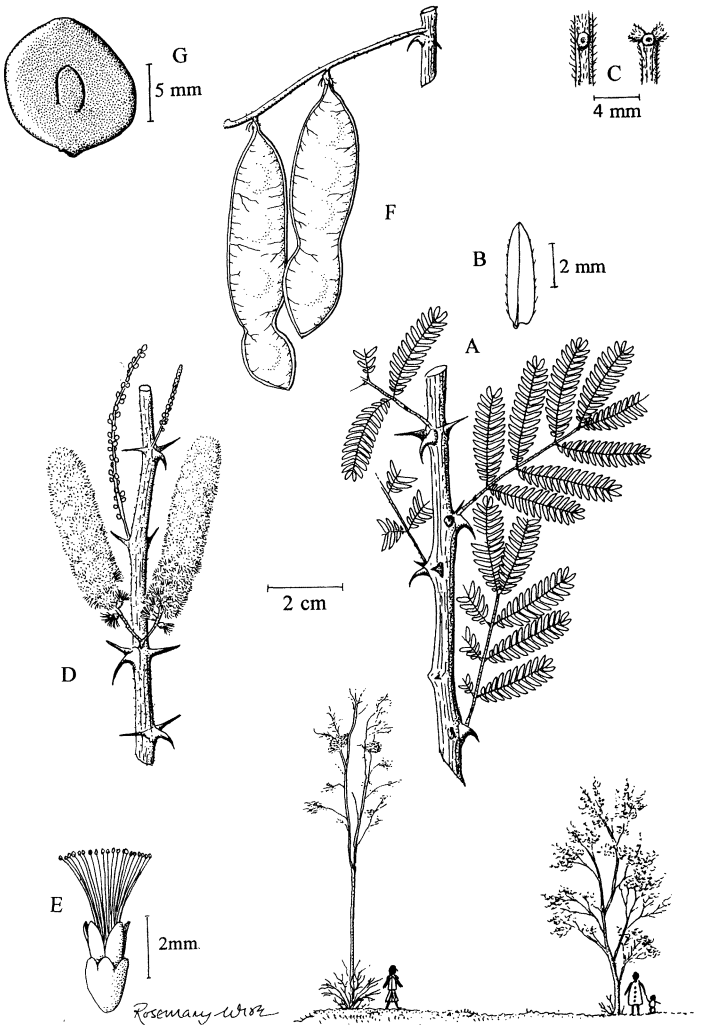


Figure 3. Botanical drawing of *A. senegal* var. *leiorhachis* – whippy form. This is the more widespread form with tall whip-like stems from a basal bush. A – branchlet with leaves (x1); B – leaflet (x6); C – petiolar gland on the right, rachis gland on the left (x3); D – branchlet and inflorescences with flower buds and open flowers (x1); E – flower (x4); F – pods (x1); G – seed (x3). Drawings by Rosemary Wise.

for 15 provenances collected in Senegal. A hypothesis for the mode of inheritance of each of 10 enzymatic systems was proposed. Polymorphism was weak with only 12 genes found to be polymorphic. They found a low genetic diversity (H = 0.175) between populations, and a wide variation within a population. What little difference between populations that was noted was found between populations from south eastern Senegal and those from the north. They also compared the genetic diversity of *A. senegal* with other related species in west Africa (*A. dudgeoni, A. laeta, A. mellifera* and *A. gourmaensis)* and found many similarities with *A. dudgeoni* (see related species section) which was previously known as variety of *A. senegal* (Berhaut 1975).

Chevallier and Borgel (1998) reported on a further study where the genetic diversity was assessed using isoenzymatic markers for 12 populations within Senegal. The mean percentage of polymorphic loci per population was 47%, the mean number of alleles per locus was 1.54 and there was a low genetic diversity (H = 0.17). Another study including populations from Mali, Mauritania, Sudan, Kenya and Pakistan found a clear separation between west and east Africa. Of the two light and dark grey "phenotypes" of *A. senegal* in Senegal, no notable difference in isoenzymes was found between them (Bergonzini and Joly 1992).

Bibliography: 121, 122, 189, 190, 520.

Sampling genetic variation for provenance testing

Most interest is in gum production from the plantations in Africa, although in India it is also grown for

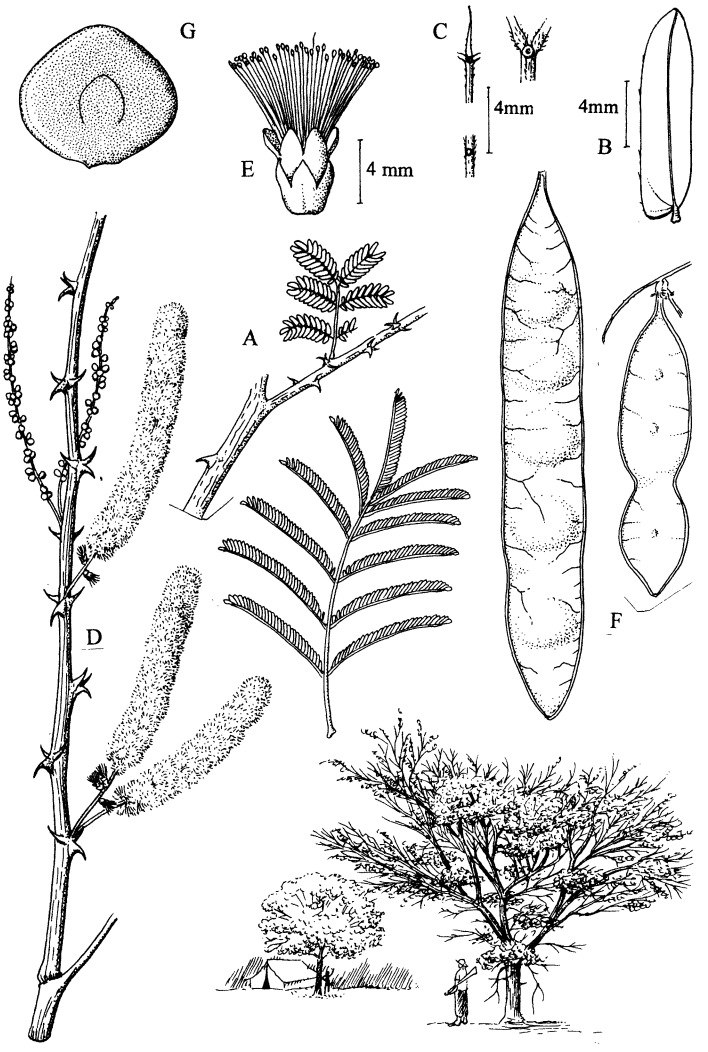


Figure 4. Botanical drawing of *A. senegal* var. *leiorhachis* – tree form. This form develops into a medium to large tree with a rounded crown. A – branchlet with leaf and larger leaf separated (x1); B – leaflet (x4); C – petiolar gland below, rachis gland above (x4); D – branchlet and inflorescences with flower buds and open flowers (x1); E – flower (x4); F – pods (x1); G – seed (x3). Drawings by Rosemary Wise.

sand dune stabilisation, and for fodder and fuel. The sampling strategy has been relatively simple, and most seed sown is from local provenances within the countries concerned.

Provenance trials have been established in many of the countries within the gum belt in Africa and in the Indian sub-continent, although not all appear to have been evaluated and the results published. In Niger, Saley (1988) reported on provenance trials started in 1987 at Ndouga with 11 provenances (6 from Niger) and found that the three exotic provenances (two Malian; Dialaka and Aite, and a Sudanian; Northern Kordofan) performed best in terms of survival and height growth (data not given). In Chad, Ali (1988) describes two research trials that were installed, one a 4 ha plantation in 1987 near the capital Ndjamena, and a second 2 ha plantation in 1988, with four provenances of *A. senegal* from Mali (Kayes) that were also inoculated with *Rhizobium* (IRANEX protocol). Sina (1988) reported on provenance trials undertaken in three areas (Djibo, Dori and Gonsé) of Burkina Faso using 14 provenances; after three years' growth there were no significant differences between them. However after 5 years, Raebild *et al.* (2003b) found highly significant differences in growth especially at Gonsé, where the local Burkina Faso provenance performed best producing around 2 t $ha^{-1}a^{-1}$ of above ground dry biomass. Gum yields were not measured. Studies from Senegal, both from the plants and from molecular studies (see above section), indicate that gum yields vary considerably between individual trees, and there is more variation within populations than between populations

(Chevallier *et al.*, 1994). Provenance trials have also been undertaken in Mali (Vassal 1985).

In Sudan, traditionally seed is collected from local populations for sowing. Field observations indicated that gum yields per tree varied enormously, not only from one tree to another, but also from one season to another. Individual trees were monitored in plantations at Um Ruwaba research station, and some trees consistently yielded more gum than others. Those that yielded over 500 g/season for more than three years, which was twice the average, were recorded as high-yielding. Seeds were collected from these high yielders, planted in separate plantations and then monitored. While initial results suggested higher yields from these selected progenies, cross-pollination between the selected progenies was not undertaken, and the genotype/environmental interactions were not examined. In 1994, the government tree seed centre had 14 local provenances of which most had 30 individual tree collections available for trials (Kananji 1994). Researchers have since looked at the possibilities of clonal propagation of high yielding trees, and at identifying the mechanisms of gummosis.

A number of early trials were based on relatively few collections. More diverse material was collected and tested in the FAO/IBPGR project for arid zone species, but again sampling was from relatively few sites (for assessment of the Burkina Faso sites see Raebild *et al.* 2003a, b). Care should be taken if species introductions are made with a small genetic base as inbreeding problems are likely to occur, as was found with *Acacia mangium* in Sabah, Malaysia (Sim 1984). More recently, range-wide collections have been undertaken by OFI and members of the African Acacia trials network co-ordinated by the FAO, and seed from these collections is available for trials (Fagg *et al.* 1997).

Initial evaluation of these new seed collections was carried out in screening trials and in the main provenance trials in Zimbabwe in the mid 1990s (Barnes *et al.* 1999). Five provenances of *A. senegal*, four of var. *senegal* and one of var. *leiorhachis* were used in the screening trials at seven sites (Guyu, Lucydale, and Cyrene with sandy loam soils, Mahiye with sandy clay soils, and Chesa Forest, Chesa FRS, Madlulani on fine grained sandy soils) in Zimbabwe. The initial results of the screening trials showed that the species did best at Guyu, a frost-free site on granite-derived soils. The next best sites were the harsh Kalahari Sands localities of Chesa Forest and Madlulani. At Guyu the seedlings flowered and produced fruits by 18 months, and the northern provenances of var. *senegal* exuded small quantities of gum by the second year, but the southern provenances from Tanzania of var. *senegal* (higher altitude) and var. *leiorhachis* from Kenya did not. These results indicated that the main trials should focus on the northern provenances of var. *senegal* only on granite and Kalahari Sand soils in frost-free localities.

Wide spacings and single tree plots were used in the main trial designs as the best compromise to avoid early competition and to provide enough replications to impose selection and management studies on the experiments. Sixteen provenances of var. *senegal* were included in the main trials, and second year assessments have shown that the Ethiopian provenance, Arba Nosa, is giving the best growth. By the third year, the northern provenances were producing gum from natural lesions in the stem without tapping, whereas the Tanzanian provenances were not producing gum although they had some of the best growth rates (Barnes *et al.* 1999). Gum yields from these northern provenances have varied considerably between sites. Preliminary data has shown that after eighteen months from planting, average weights per tree were 5 g at Chesa FRS, 11 g at Guyu and over 84 g at Mafanisa or Ntabazinduna (pers. comm. Zimbabwe Forestry Commission 2002). The latter site is at 1,350 m above sea level, mean annual rainfall 644 mm, on shallow granite-derived sands overlying intrusive granite parent rock.

Bibliography: 21, 107, 190, 306, 440, 617, 618, 664, 691, 692.

REPRODUCTIVE BIOLOGY

Breeding system

Acacia senegal is almost exclusively outcrossed, and pollination studies have shown that the species is self-incompatible (Obunga 1995; Tandon and Shivanna 2001). The numerous flowers produce an abundance of pollen, grouped into polyads of 16 pollen grains (Guinet 1969) and the cup-shaped non-papillate stigma generally only accommodates one polyad. While self pollen can be deposited on the stigma, self-incompatibility appears to operate inside the embryo sac, and incompatibility could either be a pre-fertilisation or post-fertilisation event (Obunga 1995). In Senegal, Diallo *et al.* (1997) found that by controlled pollination, the percentage of flowers setting fruit varied from 0.12% for pollination of flowers within the same inflorescence, 0.69% for pollination between flowers within the same tree and 1.44% for pollination of flowers between different trees. This was compared with 1.75% for natural pollination. Selfing clearly results in lower fruit set than outcrossing, demonstrating the importance of outcrossing, and the level of pod set reached in open pollination demonstrates that the level of outcrossing is sufficiently high to produce maximum pod set. Total pod and seed production appear to be resource limited; this is probably the reason for the low pod set found even when manipulating outcrossing (Tybirk 1993).

Flower and fruit phenology

In *A. senegal* the flowers have creamy white anthers, and are only hermaphrodite flowers on the inflorescence, with an infra-staminal nectary and opening during 1-3 days releasing some pollen together with nectar (Diallo *et al.* 1997; Tybirk 1993; Sinha 1971).

Acacia senegal flowers at a relatively young age, around three years in ideal conditions. Flowering varies between the taxa occurring either before or soon after the rains, and usually around the time of leaf flush or just before, on the previous season's growth. In variety *senegal,* flower initiation occurs just after leaf flush while in variety *leiorhachis* flowering occurs before leaf flush. Flowers are borne on spicate inflorescences and open along the axis starting from the base over 2-3 days, each flower opening for about 24 hours. The flowers show weak protogyny, with the styles protruding above the stamens in open flowers. In Mkomazi (Tanzania) mass flowering in the species (var. *senegal*) occurred in December and January, following the autumn rains (Stone *et al.* 1998).

In southern Africa (all countries south of Tanzania), variety *leiorhachis* is known to flower (August/ September) considerably earlier than var. *rostrata*, usually before the rains and before the leaves flush, while var. *rostrata* is often found flowering after leaf flush, from November to January; the pods ripen 3-4 months later. In western Africa the flowering peak occurs around July to September. In eastern Africa the pattern is more complicated because of the bimodal rainfall, with a greater frequency of flowering records from August/ September and January for variety *senegal*, June/August for variety *leiorhachis.* In Narok, Kenya, Obunga (1995) found that the flowering of *A. senegal* (probably var. *senegal*) occurred shortly after the rains, and leaf flush occurred around or just after flowering.

Pollination

Acacia senegal flowers are pollinated mainly by bees (Stone *et al.* 1998; Crane *et al.* 1984) but are also visited by a high diversity of other insects. In Senegal, Diallo *et al.* (1997) found species belonging to three main insect groups; Coleoptera, Hymenoptera and Lepidoptera. Bees of the genus *Xylocopa* and the wasps are the most important visitors both in frequency and quantity of pollen carried. Tybirk (1993) found one hundred and eighteen taxa of insects (Coleoptera, Diptera, Hymenoptera and Lepidoptera,) on four species of *Acacia* in Senegal and Kenya. The most important pollen vectors were bees from the families Megachilidae and Halictidae, and wasps from the families Eumenidae and Scoliidae. Beetles, butterflies and flies were secondary pollen vectors. Diversity and frequency of flower visitors to species with floral nectar (*A. senegal* and *Faidherbia albida*) were not clearly different from species without floral nectar (*A. tortilis* and *A. nilotica*). In India, a wide variety of insects visit the flowers of variety *senegal*, from five insect groups Lepidoptera (butterflies and moths), Hymenoptera (bees and wasps), Diptera (flies), Coleoptera (beetles) and Hemiptera. The giant Asian honey bee (*Apis dorsata*) was the most efficient pollinator and was found to carry on average 877 polyads per insect (Tandon and Shivanna 2001). Wasps preferentially forage for nectar and this combined with a low frequency of visits suggests they are of secondary importance as pollinators. Butterflies are also not effective pollinators, while carrying a small pollen load. Beetles while having large pollen loads are not considered legitimate pollinators as they are destructive, infrequent and exhibit low fidelity.

At the Mkomazi game reserve in Tanzania, mechanisms inhibiting interspecific pollen flow in communities including 10 Acacia species were studied (Stone *et al.* 1998). Partitioning between the *Acacia* species was achieved, in part, through separation of flowering in space and seasons, and through interspecific differences in pollinator guilds. Flowers in both sub-genera (*Acacia* and *Aculeiferum*) are typically protandrous and last a single day. In Mkomazi mass flowering in *A. senegal* occurred in December and January, following the autumn rains, when up to eight *Acacia* species were flowering concurrently, although slight scattered flowering could occur in other months. The flowers open in mid to late morning, and anther dehiscence followed immediately, giving peak availability during the middle of the day. The pattern of flower opening is correlated with decreasing relative humidity at the micro site. Nectar availability was greatest at the onset of dehiscence, and nectar foragers consistently made up a high proportion of all visits to this species. Honey bees were the most important visitors, followed by nymphalid, papilionid, and pierid butterflies, anthophorine and megachilid solitary bees, pepsid spider wasps and sunbirds (*Nectarinia hunteri* and *A. venusta*). Even the large nectar feeding butterflies, wasps and sunbirds were considered efficient pollen vectors (Stone *et al.* 1998).

In *A. senegal* populations in Senegal, the mean number of seeds per pod was three, the mean number of ovules/ovary 10.88, and the mean seed:ovule ratio 0.28. Pollination in *A. senegal* was high with 52% of the stigmas pollinated but even so there was a low seed:ovule ratio. Flower abortion due to competition in the inflorescence and seed predation are major factors that limit the survival of the seeds (Tybirk 1997).

Seed production and dispersal

Acacia senegal has dehiscent papery walled pods that separate on the plant into two halves with a small number of flattened seeds attached by thin thread like

funicles to them. Some seeds will detach themselves on the tree as the funicles dry out, whereas others remain attached and are dispersed with the pods. These are classified as hemi-legumes and are dispersed by wind possibly with secondary dispersal by ungulates (Tybirk 1991), although possible dispersal by ants cannot be ruled out. Strong winds, such as the harmattan, in the areas where the species occurs may carry the seeds and pod halves for relatively long distances, although documented evidence is lacking. The low seed numbers per pod was found to be typical of wind dispersed species, while ungulate dispersed species had much higher numbers and bird dispersed species between the two (Tybirk 1993). Thin seed coat (<300 µm thick) is also correlated with the wind dispersal syndrome, compared with ungulate dispersed *Acacia* species such as *A. nilotica* or *A. sieberiana* which have thicker coats (>450 µm thick).

Seeds are discus shaped and rather small, and on average 3-4.5 are produced per pod in var. *senegal*. The low mean number of seeds per pod, with a seed:ovule ratio of 0.28, is due to seed abortion (22-48%) and predation by insects. Most abortions occurred in the proximal end of the pods, indicating selective seed abortion (Tybirk 1993). Seed weights vary considerably over the natural range, in west Africa weighing 55-83g/1000 seeds or 12-18,000 seeds/kg (Tybirk 1991; Nongonierma 1976; Sina 1988). In Sudan 8-10,000 seeds/kg are commonly reported (Badi *et al.* 1989; Wunder 1966). In southern Africa, seed of var. *rostrata* appear to be heavier, weighing in at 100-140g/1000 seeds (Tietema 1992). Carr (1976) in South Africa has found seed averages of up to 6 seeds/pod in var. *leiorhachis* whereas var. *rostrata* has usually 2-3 seeds/pod. Average annual pod weights of 54 g per tree have been recorded from Senegal (Houérou 1980c), and total seed numbers per tree from seed collecting expeditions can be around 40-50 g or 500-1000 seeds, although in Senegal average seed numbers can be as high as 13,800 (Tybirk 1993). In Sudan this is not regular, and on average a good seed year occurs once in every five (Badi *et al.* 1989). Interestingly, gum yields per tree also appear to peak on 3-5 yearly cycles and further studies are needed to compare these two trends in individual trees. In India, poor fruit set is blamed on insufficient pollination (Tandon and Shivanna 2001).

On average 15-38% of stored seeds have been recorded infested in west Africa, primarily by bruchid beetles, although rates can be much higher (see insect section). In the field up to 2/3 of the seeds are damaged by beetles, millipedes and rodents before germination (Tybirk 1991; Nongonierma 1976).

Asexual reproduction

There are no reports of root suckering, although coppice regeneration is common in the gum gardens of Sudan (Badi *et al.* 1989; Jamal and Huntsinger 1993; NAS 1980), and has been tried in western Africa (Bellouard 1949) and India (Troup 1983). For further details see under Establishment, Management and Yield - Lopping and Coppice.

Bibliography: 90, 118, 177, 213, 223, 242, 305, 362, 363, 364, 365, 407, 427, 539, 552, 556, 562, 692, 697, 715, 737, 753, 763, 765, 766, 767, 768, 769, 778, 834.

ECOLOGY AND ENVIRONMENT

Climate

Given the very wide distribution of *A. senegal* from Africa to the Indian sub-continent, only generalizations can be made about the climate across the range. It principally occurs in the drier lowland tropical and sub-tropical regions, with regular and irregular unimodal, bimodal and trimodal rainfall regimes (Nicholson *et al.* 1988).

In the Sudanian and Sahelian regions of west Africa, *A. senegal* occurs in the tropical summer rainfall zone, with a single short rainy season of 3-4 months, and dry harmattan winds contributing to a long and severe dry season. Within this area lies the gum belt which stretches from Senegal to the Red Sea coast in Sudan, from which nearly all internationally traded gum comes. Annual rainfall in this region varies from around 150-200 mm in the north to 800 mm in the south, and in the absence of topographic features the rainfall isohyets run parallel to the latitudes. Ninety percent of the rain falls between June and September. Most of the rainfall is convective, derived from short heavy thunder storms. During the rest of the year the gum belt suffers from an acute water deficit, with potential evaporation exceeding rainfall for at least nine months of the year. In Sudan the annual deficit can vary from 1000 mm in the south to 1600 mm in the northern part of the belt. Rain failure is common which makes rainfed agriculture a risky venture. There are also cyclic changes in rainfall patterns, and at present a southward shift appears to be occurring whereby the northern edges of the gum belt are experiencing lower rainfall than in the past (Wata 1979). This is loosely attributed to desertification, and is not a new process. For instance, desertification has been recorded along the Mauritanian coast since the 18th century. The humidity in the gum belt is generally low on the plains with mean annual relative humidity varying from 25-40%, and with values dropping to 15-20% in the height of the dry season. This area is characterized by high and variable temperatures (annual maximum temperatures 20-36°C), with large daily extremes dropping to a minimum of 5-8°C, and reaching maximum temperatures of over 40°C. The species appears to be frost sensitive, as shown by frost damage in Zimbabwian trials (Barnes *et al.* 1996).

In the Somali-Masai region, rainfall is also arid to semi-arid, usually less than 500 mm, and mean monthly temperatures of 25-30°C, again free from frost. Most areas have bimodal rainfall, but this is very variable with frequent drought periods. In east and southern Africa, *A. senegal* is again more common on the drier lowland sites, but there are populations that occur much higher in Rwanda and reaching around 2000 m in the highlands of Kenya. Around the Lake Victoria region, there is more rainfall with averages over 1000 mm, and a dry season less severe than other regions. In the Zanzibar-Inhambane region rainfall is mostly 800-1200 mm with a well defined dry season, which is less severe since relative humidity is high with no month absolutely dry. Mean annual temperatures of 26°C are common north of the Zambesi. Frosts are unknown. In the Tongaland-Pondoland region rainfall is moderately high and more evenly distributed than the Zanzibar-Inhambane region, and the mean annual temperatures diminish from 22-17°C.

In India, maximum shade temperatures may rise to 48.3°C and absolute minimum ranges from -2.5 to -5°C. The mean daily temperatures vary from 37.5 to 45°C in May (summer) and 20 to 30°C in January (winter), and the mean minimum temperature in the coldest month (January) varies from 4.4 to 10°C. Annual rainfall is erratic and varies from 250 to 600 mm, with long periods in the year without rain (Troup 1983).

Climate has a major influence on gum production, and under high rainfall such as in the highlands of east Africa, little gum appears to be produced from trees of *Acacia senegal* var. *senegal*.

Soils

Acacia senegal var. *senegal* prefers sandy soils, such as fossil dunes in the Sahelian belt, but it will also grow on loamy sands, sandstone and on skeletal soils (lithosols). Generally soils are well drained although it also occurs on heavy clay soils in the east of Sudan. Most *Acacia* taxa are found to be growing in a wide variety of soils with a low mean exchangeable calcium content (0-5.2% in milliequivalents), and *A. senegal* var. *senegal* occurs on soils with 3.7 % in m.e. (Nongonierma 1977). In the Sahelian region, the best sites are reported to have a pH range of 5-8 (von Maydell 1986).

Acacia senegal is found across a wide range of soil types, from poor sandy soils to sandy clays, such as Affole in Mauritania, sandstone clays at Brakna in Mauritania, and Kayes in Mali, and lithosols over quartz such as in Assaba in Mauritania (Fall 1987). In Chad, *A. senegal* occurs on sandy soils, which have quartz with some elements of felspar, and are poor in organic matter and nitrogen. The levels of clay and alluvium never exceed 10% in the horizons, and the level of infiltration of water is very rapid. The pH is slightly acid to neutral on the surface but becomes more acidic deeper down. The total cations of these poor soils is around 2.5 meq% (Giffard 1973).

In Somalia it occurs on rocky limestone hills or on limestone overlain by alluvial gravels, and also along gypseous drainage lines (Hassan and Styles 1990). It develops into different statures in the three habitats, which are sometimes referred to as variants. The gypsum variant is a small slow growing tree with a 2-3 m diameter crown, a slender stem that divides about 1 m above ground. The alluvium variant, which is a medium sized tree and shrubby, is fast growing and particularly thorny. The limestone upland variant, which is the tree form of *A. circummarginata*, is a yellow barked tree to 5 m and its trunk can reach 30 cm diameter (Wieland 1985). In Kenya, variety *kerensis* can be found on shallow gravelly soils.

In India, *A. senegal* can occur on rocky hills of the Aravalli range which have poor shallow and stony soils, or on aeolian sands (Troup 1983; Sharma and Gupta, 1989a). The species dominates the rocky areas at Ajmer, Rajasthan, and the shallow topsoils there were found to be alkaline (pH 7.8-8.2) and predominantly sandy with a low cation exchange capacity (CEC) and poor nutrient content (Sharma 1988). In western Rajasthan, *Acacia senegal* var. *senegal* grew successfully on rocky areas, on semi-rocky and gravelly areas, on sandy soils but not on consolidated loam (Raheja 1965).

In southern Africa, *Acacia senegal* var. *rostrata* is found in tree and bush savannas of Botswana in sandveld regions on slightly alluvial or calcium-rich soils. In the hardveld it is associated with calcrete outcrops, but not in wet depressions (Timberlake 1980). In Zimbabwe, the var. *leiorhachis* grows as a distinctive spindly tree commonly on shallow basalt lithosols, especially found on stony ridges and gravely slopes, and more rarely on gneissic and shallow sandy soils. Variety *rostrata* grows as an obconical shrub only on calcareous soils (sometimes with calcium nodules) of alluvial origin associated with the Shashe, Limpopo and tributaries and Save Rivers (Timberlake *et al.* 1999).

The effect of the species on soil amelioration and increasing fertility is discussed in subsequent sections on soil amelioration and protection and effects on soil fertility.

Bibliography: 81, 106, 107, 305, 308, 343, 384, 505, 548, 553, 702, 754, 755, 763, 804, 816, 822.

Vegetation types and associates

Acacia senegal is widespread throughout the drier areas of Africa and is mentioned as being dominant or an associate in six major floristic zones or phytochoria (White 1983).

The following description is based on White's compilation for the vegetation map of Africa, and the authors quoted within, except where additional references are given. The Sudanian regional centre of endemism extends in a narrow band across West Africa from the coast of Senegal to the foothills of the Ethiopian highlands, and in most places where cultivation is possible the natural vegetation has been greatly modified. *A. senegal* is one of the species characteristic of the drier northern parts of the Sudanian woodland with *A. nilotica* subsp. *adstringens* and *A. macrostachya* (both Sudanian endemics). It also forms part of the *Anogeissus* woodland in the drier parts of Northern Nigeria. The gum belt occurs partly in the northern part of this phytochoria and the southern part of the adjacent Sahel regional transition zone. In central Sudan, *A. senegal* is one of the dominants in the short grass savanna on sandy and clay plains. It is more common on the western sandy plains of Kordofan and Darfur, where it can dominate along with *A. mellifera* (El Amin 1990). In the Kazgail area of Kordofan, it is the second most important tree species after *A. mellifera*, representing 10.6% of standing timber volume (El Deen 1991).

In the Sahel regional transition zone, on the southern fringes of the Sahara desert, *A. senegal* occurs in Sahel wooded grassland (widespread in the southern Sahel) often forming pure stands, such as on sandy soils with between 280-450 mm annual rainfall. It frequently follows cultivation and in places appears to be a secondary species. It is also found in the Sahel semi-desert grassland where rainfall is over 100 mm a^{-1}. In the Jebble Mara area of western Sudan, it forms part of a number of vegetation types on the Basement Complex peneplain, including as a dominant in the *A. senegal/Combretum glutinosum* communities on aeolian sands that are widespread in the Sahel zone. It is an important associate of the *A. mellifera/Commiphora africana* communities on brown clay soils. In Kordofan Province, it dominates *A. senegal* wooded grassland on aeolian sand (*qoz*), and due to the gum cultivation cycle it has increased in abundance (Noel *et al.* 1990). In this area, there is a gradual change in floristic composition from north to south, and in the driest northern parts *Acacia tortilis* is more abundant than *A. senegal*. In the semi-desert grassland on aeolian sand, with less than 250 mm a^{-1} rainfall, it is one of the tree species with *A. tortilis, Balanites aegyptica, Faidherbia albida* and *Maerua crassifolia* very thinly scattered in the sand dune areas and normally restricted to interdune hollows. In the *Acacia mellifera* frog-spawn pattern found in Kordofan, it occurs on the sparsely vegetated crescent dune areas with *A. tortilis* and *Leptadenia pyrotechnica* and the dominant grass *Aristida sieberiana*, while impenetrable thickets of *A. mellifera* are found on fluvio-lacustrine deposits in the intervening hollows.

The Somali-Masai regional centre of endemism, which includes most of the lowland areas of Ethiopia, Somalia, Kenya, Tanzania, South Eastern Sudan and North Eastern Uganda, deciduous bushland and thicket is the climax over most of the region. *A. senegal* is common in the *Acacia/Commiphora* deciduous wooded grassland characteristic of the Serengeti National Park, and specifically an important associate of the *Commiphora schimperi* dominated wooded grassland, on well-drained soils derived from granite or granitic gneiss on ridge tops and slopes. In Northern Kenya, it is scattered in semi-desert annual grassland on poorly developed shallow stony soils, and in semi-desert dwarf scrubland. It is one of the dominants in deciduous bushland on rocky gneiss-derived mountain slopes, and occurs as non-dominant bush (var. *kerensis*) in stunted deciduous bushland on gneiss derived sandy-silty soils. In northern Kenya, a survey by Chikamai *et al.* (1995) found that the most common associates of *A. senegal* were *A. tortilis* and *A. reficiens* on the plains and along the luggas, and the *Commiphora* species (with the exception of *C. africana*) were characteristic of the hills, although in frequency *A. senegal* was by far the most dominant species. *A. senegal* var. *kerensis* thrives under arid conditions, in Turkana at around 250 mm $a^{-1}$of rainfall and in Isiolo district at around 590 mm a^{-1}. In north western Somalia *A. senegal* occurs in the tree-*Acacia* open woodland formation (Gillett 1941). In south western Somalia, *Acacia senegal* var. *leiorhachis* was found in the *Commiphora boranensis* community and on limestone areas in the *Commiphora corrugata* community. *Acacia senegal* var. *senegal* was found to be on the alluvial plain, with *Grewia villosa*, on limestone hills in the *Commiphora corrugata* community and on the gypsum interplain with the *Acacia edgeworthii* community (Wieland and Werger 1985). In north eastern Ethiopia, *A. senegal* occurs between 900-1600 m above sea level in mesophyllic deciduous open woodland (Houerou and Corra 1980).

In the Lake Victoria regional mosaic, it is one of the *Acacia* species that form part of the secondary wooded grassland, and replaced the climax evergreen and semi-evergreen bushland. This in turn can be replaced by lianas that shade out the Acacias and allow the return of semi-evergreen thicket communities.

The Zanzibar-Inhambane regional mosaic, a coastal belt from southern Somalia to the mouth of the Limpopo River in Mozambique, has forest as the most widespread climax but this has been largely replaced by secondary wooded grassland and cultivation. *A. senegal* is found in the Zanzibar-Inhambane secondary grassland and wooded grassland which replaced the original climax forest.

In the Tongaland-Pondoland regional mosaic, the coastal region south from the Limpopo River to Port Elizabeth in South Africa, it occurs in evergreen and semi-evergreen bushland and thicket, in the northern area with *A. nilotica* ssp. *kraussiana* and a number of southern African *Acacia* species.

Bibliography: 81, 90, 194, 209, 281, 282, 345, 357, 387, 409, 463, 497, 503, 551, 554, 584, 621, 685, 687, 743, 796, 816, 824.

Rooting habits

Initial seedling growth is predominantly underground, with the seedling sending down a long tap-root (seedlings two months old had roots 5 ft long). The few lateral roots that develop in the earliest stages probably cease to function as the topsoil dries out (Sudan Forest Dept 1960; Tybirk 1991). Rhizotron studies of the seedling root systems of *A. senegal,* showed that like the majority of woody plants, it develops from an orthogravitropic tap root which elongates rapidly and indefinitely describing small oscillations around the vertical (Palma *et al.* 1994). Lateral roots appear in an acropetal sequence 8 days after germination, 6 cm below the soil level. Root studies of 2-year-old *Acacia senegal* plants in Sudan found two zones of lateral root proliferation from the tap root in the first 20 cm and around 80 cm depth (Khan 1965). In Niger, Saley (1988) also found that the species has a spreading root system in the upper horizon and tap roots down to 6 m deep.

In Rajasthan, India, high survival rates of *A. senegal* seedlings were found to be correlated with a low shoot to root ratio (Bhimaya and Kaul 1966). When 6-year-old planted trees were excavated, the majority of the roots developed within a metre of the surface in the upper half of the sandy layer, spreading laterally about 3 m. Deep tap-roots penetrated the hard pan to over 6m (Bhimaya and Kaul 1965). Twenty year old planted trees were also excavated there and are described in Muthana *et al.* (1984).

In Sudan, the mature tree can develop lateral roots up to 20 ft long on sandy soils as well as a deep tap root (Blunt 1926). On shallower soils, very extensive lateral roots to over 10 m radiating out in all directions can develop (see photograph reproduced in Wickens *et al.* 1995 and National Academy of Sciences 1979). Thomasset (1993) noted that lateral root systems may cover up to 500 m^2. The need to develop root systems that can tap into any water source or table has been shown by Ullmann (1985) who found that *Acacia* species in the Sahelian region have high transpiration rates despite accentuated drought conditions.

In an adult tree, the root system represents up to 40% by weight of the total biomass, while the above-ground biomass is equally distributed among the tree components: stem, main branches, and secondary branches (Poupon 1976). The root system develops quicker than the aerial parts in the seedlings (Poupon 1977).

Bibliography: 89, 130, 131, 140, 181, 290, 293, 428, 431, 457, 537, 538, 567, 605, 606, 664, 703, 730, 742, 765, 772, 792, 821.

Nitrogen fixation and mycorrhizas

Early investigations failed to find nodules on mature trees in Sudan (Anderson 1984) partly due to the difficulty in excavating around trees in the field, and only relatively recently have nodules from a *Rhizobium* strain been isolated from mature trees in Senegal. These are less common than the *Bradyrhizobium* strains in tropical soils, which associate with some *Acacia* species but not *A. senegal* (Lajudie *et al.* 1991). In Sudan, Deans *et al.* (1993) concluded that the inoculum potential of the soil in Sudan was high, but that nodulation in the field was inhibited by lack of water. In a separate study, nursery grown seedlings of *A. mellifera* and *A. senegal* only produced substantial numbers of nodules when peat was added to the Nile silt/sand medium, and improved aeration was thought to be the most likely reason for the stimulation of nodule production. Habish (1970) tested the effect of variation in soil moisture, temperature and pH on the growth and nodulation on five Sudanese Acacias including *A. senegal* grown in a sandy medium. Growth and nodulation increased to an optimum of 15% soil moisture. With a soil temperature of 35°C significantly more nodules were produced than at 30°C. Nodulation only occurred between pH 6.5-9.0 and the optimal range was pH 6.5-7.0. He suggested that alkaline soils (pH 8.5-9.0) in northern Sudan may tend to limit nodulation. An other soil factor recorded inhibiting nodulation, apart from high acidity/alkalinity and moisture, is available phosphorus (Colonna *et al.* 1993). Also in Sudan, the high salinity of irrigation water may inhibit nodule formation and/or nitrogen fixation, and Miettinen *et al.* (1992) recommended innoculation of an effective salt-tolerant *Rhizobium* strain for use at Um Hager nursery.

Reports of nodulation in seedlings are common. In Zimbabwe, both varieties of *A. senegal* (var. *leiorhachis* and var. *rostrata)* were found to nodulate (Corby 1974). The nodules produced on the roots of *Acacia senegal* belong to the Caesalpinioid nodule type (Corby 1988). In Senegal, *A. senegal* var. *senegal* seedlings when inoculated with both fast and slow growing strains of *Rhizobium* only nodulated with the fast growing strains in common with *A. raddiana* [*A. tortilis* ssp. *raddiana*] and *A. nilotica* ssp. *tomentosa* (Dreyfus and Dommergues 1981). The most effective *Rhizobium* strain (ORS 901) produced over a five-fold increase in fresh weight of two month old seedlings compared to the uninoculated control. Badji *et al.* (1988) also found that inoculating seedlings of *A. senegal* var. *senegal* with fast growing strains produced nodules, and showed average increases in shoot N content of 49% after five weeks compared with non-nodulated controls. In the Indian sub-continent, Jayasankar and Kumar (1992) found that 170 day old seedlings of *A. senegal* var. *senegal* readily nodulated and showed the fastest growth and the greatest number of nodules (mean of 15 nodules/plant) in a comparison of five *Acacia* species.

Mycorrhizal associations have also been found in the root systems of *A. senegal*, and the beneficial effects on seedling growth by inoculation have been investigated. Only vesicular arbuscular mycorrhizas (VAM) are

commonly found on *A. senegal* whereas both ecto and endo-mycorrhizas have been found in the Australian *Acacia* species (Reddell and Warren 1987).

Diem *et al.* (1981) suggested that VAM contribute not only to drought resistance of plants but also to the improvement of plant growth by increasing P uptake under water stressed conditions. In two month old seedlings of *A. senegal* grown under nursery conditions, 45% of the lateral roots were found to be infected by mycorrhizae, and 26% of the main roots. Mycorrhizal infection penetrated to the root cortex as well. The soils around Dakar, Senegal, had an abundance of mycorrhizal fungi in the genera *Glomus* and *Gigaspora* genera. In the same soils, Colonna *et al.* (1993) found that seedlings of *A. senegal* inoculated with an endomycorrhiza (*Glomus mosseae*), increased growth and mineral composition compared with uninoculated controls especially if additional phosphorus was also added.

As well as the beneficial effects of increased water and mineral uptake, VAM appear to protect plants against soil and root borne pathogens. In India, seedlings of *A. senegal* inoculated with a mixture of VAM fungi appeared to suppress or eliminate most of the pathogenic fungi in the rhizosphere compared with uninoculated plants (Mohan *et al.* 1996). Studies of soil/root samples of this species growing on sand dunes in the Indian Thar desert, found arbuscular mycorrhizas belonging to genera *Acaulospora, Glomus* and *Gigaspora* (Srivastava *et al.* 1997).

Bibliography: 21, 29, 79, 82, 91, 92, 98, 109, 117, 143, 166, 179, 200, 201, 205, 206, 228, 246, 256, 259, 263, 293, 333, 360, 376, 377, 385, 386, 428, 429, 430, 465, 466, 498, 517, 518, 524, 550, 611, 622, 629, 636, 646, 667, 711, 830, 837.

GROWTH HABIT AND GUMMOSIS

Life cycle

Like many pioneer Acacia species, *A. senegal* flowers and fruits profusely. In a good year, which may only occur one in every five, up to 13,800 seeds per tree are set (Tybirk 1993). These are mainly wind dispersed, with possibly some secondary ungulate or rodent dispersal, although their relatively thin seed coats are unlikely to provide a great deal of protection against the chewing action of ruminants. They are heavily predated by a wide range of herbivores, insects and rodents.

Given the large numbers of seeds produced, many authors have assumed that a viable seed bank exists in the soil awaiting the right conditions for germination. In Kenya, high numbers of seeds of *A. hockii, A. mellifera* and *A. seyal* (from 810 to 2439 seeds m^2) were found in the upper 3-5 cm of topsoil (Tybirk *et al.* 1994). However, in the Senegal Sahel even inside a fenced area with restricted grazing, Tybirk (1991) found no living seeds under the crowns of *A. senegal* and *A. seyal* whereas seed was found under *A. tortilis* and *A. nilotica*.

The seeds germinate and establish episodically, and the seedlings grow rapidly if not consumed by herbivores, insects and millipedes. The ground flora competition, and the shade cast by the flora reduce the vitality of the seedlings. The main factors affecting seedling mortality in Sudan are high soil temperatures and low soil moisture content in the dry season (El Din 1969). After the first dry season, these factors are less important but established seedlings can be completely destroyed by grass fires that are common, and browsing by goats and rodents can cause serious losses. Population structures tend to have an inverted J distribution (Poupon 1976; Bird and Shepherd 1989), with the majority of individuals having less than 10 cm circumference. Over the first 20 years of growth a large root system develops, while the aerial parts develop more slowly. At age 16-40 years, above-ground biomass increases more quickly than underground biomass, with its maximum mean annual increment at 30-40 yrs, coinciding with the maximum foliar production. The older the tree becomes, the greater the flower production, with maximum fruit production between 30 to 40 years (Poupon 1977). In Sudan, average life of trees is given as 25-30 years, based on the Kordofan gum gardens (Blunt 1926; National Academy of Sciences 1980).

Growth rates from trees in natural stands and plantations vary considerably. In the Rift Valley in southern Ethiopia, wood volume incremental rates of 5.4 and 5.9 $m^3ha^{-1}a^{-1}$ have been recorded from five year old trees at two sites, which occur at 1580-1650 m altitude and 625-690 mm of annual rainfall (Abebe 1994). Other figures commonly quoted are between 4 - 7 $m^3ha^{-1}a^{-1}$ (Webb *et al.* 1984).

More detailed assessments from plantation trees in Senegal, give average growth rates of 1.77 t $ha^{-1}a^{-1}$ dry biomass for 3-18 year old trees at 6 x 6 m spacing (Deans *et al.* 1999). The fastest growing provenances from trials at Gonse in Burkina Faso, yielded an average of 2 t $ha^{-1}a^{-1}$ dry biomass assessed five years after establishment (Raebild *et al.* 2003b). Slightly lower growth rates are given from a 16 year old plantation in India, where Grewal *et al.* (1996) recorded 26.9 t ha^{-1}. Height growth varies considerably between varieties and the environments where they are growing. Variety *senegal* can grow 1 m in three years and reach 1.5 - 2 m after five years in Sudan or Burkina Faso (Raebild et al. 2003a; 2003b; Jackson and Shawki 1950). However in Ethiopia trees reached an average height of 5.6 m after five years (Abebe 1994). For the shrub varieties such as var. *rostrata*

slower growth has been recorded, one planted tree reaching 3.6 m in 17 years in South Africa (Carr 1976).

Gummosis

Understanding the factors that induce gummosis is the key for any tree improvement programme. However, the exact causes and the mechanism of gum exudation or gummosis are still not clearly understood. It has long been known that wounding the bark, whether by natural (wind and insect damage) or artificial (tapping) means stimulates exudation. Anatomical studies have shown that "gum pockets" or lacunae in the phloem tissue will yield gum from up to a 10 cm radius around the wound, and the further from the wound, the smaller the lacunae in the phloem become (Ghosh and Purkayastha 1962). There appears to be a direct relationship between wounding and gummosis. However it is quite common for tapped trees to produce no gum at all. Clearly, other factors must also be involved.

One of the most popular views of the late nineteenth and early twentieth centuries explaining gummosis (and not just in *Acacia senegal*) was that parasitic microorganisms played an important part (Grieg-Smith 1902; Blunt 1926; Beijerinck 1884 and Martins in de Rochebrune 1899). Martins believed that gummosis could be attributed to the actions of parasites belonging to the genus *Loranthus*. However, the presence of gum on trees not attacked by these mistletoes invalidates the hypothesis. *Loranthus* spp. tend to attack ageing trees which are no longer very productive causing a final peak of production before death.

Both bacteria and fungi are commonly found in the gum. It was suggested that fungi may have an important role to play in inducing gum formation. Beijerinck (1884 cited in de Rochebrune 1899) found that a fungus related to *Coryneum* (observed in the Rosaceae), and later named *Pleospora gummipara*, is also found in gum arabic and believed that it was responsible for enzyme activities that induce gummosis. The existence of mycelial strands close to wounds has been observed by Mouret (1987). In an investigation of the microflora of gum arabic from Sudanese trees of varying ages, five genera of moulds were identified, namely *Aspergillus, Penicillium, Rhizopus, Gilocladium* and *Cladosporium* (Khalid *et al.* 1988). Absence of the moulds from some samples suggests that they probably do not induce gummosis. This supports the hypothesis of Frank (1884 cited in de Rochebrune 1899) that fungi do not have any role to play in gummosis. In fact it seems that fungi are secondary invaders that attack the tissues of the tree once it is wounded (Vassal and Mouret 1993).

Grieg-Smith (1902) isolated a bacterium from the gum of *Acacia binervata*, an Australian species. He believed that this bacterium (*Bacterium acacieae*) was the pathogenic agent responsible for the formation of gum. Blunt (1926) also believed that gummosis in *A. senegal* was due to bacterial infection resulting from wounding. He noted that any stress on the trees increases gum production, be it lack of moisture, poor exhausted soils or hot weather, and favoured the view that starch in the plant is converted into gum by the bacterial infection. Conversely, a tree in healthy condition with plentiful water does not produce abundant gum. Ghosh and Purkayastha (1962) also observed rod bacteria in the gum-producing tissue but did not attribute their presence as the main causal agent to gummosis. More recently, Khalid *et al.* (1988) studying many samples of Sudanese gum arabic found bacteria characterized as gram positive spore formers, gram positive non-spore formers, and gram negative rods, and that they were free from the pathogenic micro-organisms (salmonella and coliforms).

Generally speaking, the hypothesis that pathogens induce gum formation has not had much credence since the 1930s when Malcolm (1936) wrote as follows: "It has been said of *Acacia senegal*: 'the more sickly the tree, the better the yield of gum', and also that gum is only produced when the tree is in an unhealthy condition. Both these statements are now looked upon as erroneous, as almost every specimen of the same species will produce gum if tapped. It can hardly be maintained that all or even the majority are unhealthy when the *A. senegal* has survived and multiplied despite the perennial strains of drought and tapping." Malcolm came to the conclusion that gummosis was a normal metabolic process that was sensitive to stress in the form of wounding. Contradictions existed however. Why was it, for example that, as Blunt (1926) commented, a good year for rain and seed production was usually a poor year for gum production?

To attempt to answer this it is necessary to examine the possible effects of ecological and nutritional factors associated with site. It has long been known that gum exudation appears to be triggered in the dry season. Research conducted at M'Biddi Forest research centre in Senegal has confirmed Sudanese research that the best time to tap and get satisfactory gum production is from October to mid-November (Gum Research Station 1969/70; Dione 1988a; Sene 1988). It appears that very low atmospheric humidity triggers the necessary phenological response. Water stress appears to accelerate the onset of a physiological dormancy.

After tapping during this optimal stage it has been noted that trees did not respond in the same way. Variation appears to occur in relation to topographical location or microsite on the sand dunes (Dione and Vassal 1993; Gum Research Station 1978/79). It was in Sudan that the first experiments were carried out, during the 1978/79 season by the Gum Research Station. The main gum producing areas in western Sudan are in undulating country with gum gardens on sand dune crests, others on slopes and still others in depressions. The average gum yields per tree on the trees occuring on slopes was 252 g,

followed by 217 g for those on the dune crest or summit, while the trees occuring in the interdune hollows were the least productive with yields of 162 g/tree (Gum Research Station 1978/79). Similar results were found at the M'Biddi Forest research centre in Senegal from 1989/90, where from the bottom to the top of the dunes, there was observed decreasing rates of growth and survival, an accelerated defoliation and increasing mean gum yields per tree. In parallel there was noted a decrease in water storage from the hollows to the dune tops (Dione and Vassal 1993). Hence the trees on the dune summits had the highest gum yields (average yields from 250-460 g/tree) and a low variation in soil water levels, while the dune hollows (around 100 g/tree) had a variation eight times greater in soil water levels. The slopes had values intermediate between the two (Dione and Vassal 1998). The results in the following three years were less clear. However Saad (1981/2) in Kordofan Province, Sudan, found that the highest gum yields occurred in the depressions, and suggested that this could be due to increased fertility and moisture there. Similar results have been recorded from the M'Biddi region (Sylla Gaye 1989), and presumably this is also linked to the soil water relations in the experimental year.

There have been various anatomical studies on the site of gummosis. Ghosh and Purkayastha (1962) studied wood, twigs and branches of *A. senegal*, collected at different seasons of the year in India, and found that in the specimens showing spontaneous exudation of gum, the development of gum cysts is preceded by widespread changes, such as profuse development of parenchymatous tissue and disappearance of starch, in both xylem and phloem, as well as disintegration of the pith. Formation of cysts and the other changes occur only in localized areas of the stem.

Vassal and Mouret (1993) summarized work showing that gum lacunae arise from the large tanniferous cells of the sub-cambial phloem, which are progressively dislocated (by intercellular secretion), and broken down by lysis. These lacunae become enlarged tangentially and grow out radially after alteration and engulfment of fibre strata and phloem rays. Some of the xylem vessels are filled in with a gummy substance. Gum appears to be synthesized from starch grains, which were abundant in the xylem parenchyma.

Joseleau and Ullmann (1985) tested two hypotheses on the biosynthesis of gum; that it could result from the molecular rearrangement of cell wall hemicelluloses (especially arabinogalactans) or from a turnover of starch. Carbohydrate analysis of aqueous and alkaline extracts and the enzymic activity of gum producing and unproductive branches of *Acacia senegal* were compared. The nearly complete disappearance of starch in the gummiferous tissues together with the high level of amylase activity can be interpreted as strong evidence for the involvement of starch hydrolysis in the synthesis of gum arabic. Ullman (1983) citing the work of Seita *et al.* (1977), showed the effect on gummosis of hormone injections (Indol acetic acid, Kinetin) on *Sterculia urens*, the tree that produces gum Karaya. He believed that hormonal activity encourages the formation of enzymes such as amylase, which break down starch, the raw material for the formation of gum. This also agrees well with the use of applying etephon and 2,4-D which trigger gum formation, (see section on tapping and other factors which stimulate gum production), and also induce a-amylase synthesis and starch degradation. Gummosis seems to be directly related to starch metabolism in *A. senegal*.

Further studies showed that acidic polysaccharides, which were precipitated by hexadecyltrimethyl ammonium bromide, were abundant in the aqueous extracts from the inner bark and the cambial zone of the gum producing branch, and were absent from the non-gummiferous branch (Joseleau and Ullmann 1990). Neutral sugar and uronic acid analysis showed that the precipitated polysaccharides had the same composition as the gum produced by the same branch. These biochemical analyses (methylation analysis and 13C NMR spectroscopy) showed the presence of the gum only in the gum producing branch in the cambial zone; however, the presence of gum was not restricted only to the site of tapping and gum exudation but also occurred throughout the cambial zone of the branch. The same research was carried out on a one year old plant without any sign of the gum being found, indicating that gum production from the cambial zone requires a certain maturity of the tree. This is in agreement with the local knowledge that a tree needs to be at least five to seven years old to produce reasonable amounts of gum. Small quantities of gum have been found on planted seedlings of var. *senegal* in Zimbabwe in their second year (Barnes 2000).

From the different hypotheses above it can be said that the factors that induce gummosis are still not fully explained. It does seem that a link exists between water stress and the release of gum and that gummosis is directly related to starch metabolism. Biosynthesis of the gum must be in competition with the tree growth.

Bibliography: 108, 116, 140, 227, 249, 251, 252, 253, 311, 312, 323, 338, 255, 367, 368, 434, 435, 453, 492, 528, 529, 636, 659, 675, 736, 771, 780, 783, 784, 788.

WOOD PROPERTIES

Physical properties

In India, the wood of var. *senegal* is hard and heavy (865-913 kg m^{-3}) and takes a beautiful polish, with the sapwood being yellowish white and the heartwood nearly black and irregular (Troup 1983). In southern

Africa, the wood of var. *rostrata* is hard and heavy (air-dry 990 kg m^{-3}) with a light colour with no heartwood, and var. *leiorhachis* has similar properties but is slightly lighter, air-dry 930 kg m^{-3} (Smit 1999).

Robbertse *et al.* (1980) investigated the wood characters of 37 different *Acacia species* from southern Africa to find characters that could be used to distinguish between the species. They presented 10 wood characters for all the species and including the two varieties of *Acacia senegal* (vars. *rostrata* and *leiorhachis*) that occur in Southern Africa. The average values of the wood characters in var. *leiorhachis* and var. *rostrata* (with the mean value for the sub-genus Aculeiferum in brackets) were: ray width (no. of cells in widest part of ray) 3.8 and 4.2 (3.4); ray height (μm) 273 and 420 (296); number of rays (per mm-cross section) 6 and 5.9 (5.7); number of rays (per mm^2- in tangential section) 33 and 18.4 (27.6); parenchyma number of crystals cells per mm^2 in tangential section 7.9 and 12.2 (12.3); diameter of pores (μm) 96 and 89 (105); both had solitary and multiple pores; the number of pores (per mm^2) was 5.1 and 11.6 (9.8). Growth rings were noted in var. *rostrata* and not var. *leiorhachis* and var. *leiorhachis* had banded axial parenchyma whereas var. *rostrata* had confluent axial parenchyma.

El Amin (1972) studied the timber characteristics of the Sudanese Acacias including *A. senegal* var. *senegal*. *A. senegal* was found to have an aliform parenchyma type along with *A. laeta* and *A. asak*. The fibrous tissue is always more abundant than the parenchyma tissue. Pore number cm^{-2} is 14 and pore diameter 10 μ. The rays are of the multiseriate type, their width ranging from 1-4 cells wide, and the number of rays per square cm of the longitudinal tangential section is 41.

Growth rings

Anatomical studies have shown that in many tropical trees growth periodicity is seldom clearly and unambiguously defined, particularly in the wet areas. In the more arid areas, with very distinctive wet and dry seasons, there is a greater chance of finding a discernible growth pattern. Previous studies on *A. senegal* have noted distinct growth rings in the wood in Senegal (Poupon 1976), Sudan (Seif el Din 1981) and South Africa (van Wyk 1972) without experimentally verifying the observations. Poupon (1976) attempted to establish a relation between number of growth rings and girth at the butt, but failed to confirm experimentally that the growth rings were annual. Gourlay (1995) studied a number of African Acacia species of known age, and found a highly correlated relationship between narrow bands of marginal parenchyma in the wood and the annual rainfall of the site. These bands were filled longitudinally with long crystal chains, which were subsequently identified as calcium oxalate. While not directly working with *A. senegal* of known age, he found that wood samples of *A. senegal* from Sudan (Oxford xylarium no. 2398) and Tanzania (Oxford xylarium no. 13431) had similar crystal chains present (Gourlay 1992), indicating the potential for tree dating in this species.

Bibliography: 134, 170, 275, 286, 338, 350, 351, 399, 476, 487, 605, 644, 701, 756, 763, 778.

PREDATORS, DISEASES AND HARMFUL PHYSICAL AGENCIES

Insects

There are large numbers of insect pests that attack the seeds of *A. senegal* but relatively few of major economic importance attacking the trees - see reviews in Luna (1996), Jamal (1994), Booth and Wickens (1988) and Troup (1983). Larval stages of Coleoptera (bruchids), Hymenoptera and Lepidoptera can damage the seed (Southgate 1983). El Din (1969) for instance recorded seed losses of over 84% caused by insect species of which bruchids presumably predominate. Bruchid infestation can vary considerably between trees and tree populations, and infestation rates vary between different bruchid species (see Table 1).

There are also many parasites, mostly wasps belonging to the Hymenoptera family, that parasitize these bruchids. Luca (1965) recorded *Erytoma bruchocida* parasitizing *Bruchus baudoni* in seeds of *A. senegal,* but there are likely to be many more. Tybirk (1991) and Rasplus (1990) also list a number of parasites of these Bruchid species.

The buffalo treehopper (*Stictocephala bubalus*) can destroy up to 80% of the seed crops in south western Pakistan (Cheema and Quadir 1973). In Sudan large numbers of seed are eaten by insects and rodents. At the beginning of the rainy season, more seed and seedlings are eaten by insects and millipedes that appear during that period (El Din 1969; Gaye 1988).

In western Sudan, Jamal (1994) found that the most important insect pests on *A. senegal* were the buprestids (wood beetles) *Agrilus spp.*, *Chrysobothris sp.*, *Psiloptera sp.*, and *Sternocera castanea* L., the elaterids *Lanelater notodonta* Latr. and *Tetralobus cavifrons* Fairni. and the cerambycid *Acanthophorus confinis* Cast.

Cut worms have been recorded attacking seedlings in Sudan (Blunt 1926). In Indian plantations, termites are reputed to destroy seedlings (Luna 1996). In Senegal, Tybirk (1991) estimated that up to 66% of the seeds were damaged by beetles, millipedes and rodents before germination. Seedlings appear abundantly after rain, but suffer severely from damage from fungi, insects, rodents,

Table 1. Bruchid infestation rates in the seeds of *Acacia senegal.*

Bruchid species	Infestation rates	Reference
Bruchus silaceus Fahr	3-51%	1, 2
Bruchus subuniformis Pic	3-51%	1, 2
Bruchus centromaculatus All	3-51%	1, 2
Bruchus bilineatophygus Pic	6-43%	6, 7
Bruchidius petechialis Gyllenhal	27-77%	1, 3
Bruchidius albosparsus Gyllenhal	3-51%	1, 4
Bruchidius andrewesi Pic	13%	6, 7
Bruchidius cadenati Pic	3-51%	1
Bruchidius pennatae Decelle	6%	1
Bruchidius sahelicus Decelle	27-77%	1
Bruchidius uberatus Caill.	3-29%	1, 5
Bruchidius senegalensis Pic	25%	1
Bruchidius submaculatus Fahr.	6%	1, 4
Caryedon mauritanicus Decelle	13-77%	1
Caryedon pallidus Ol.	29-98%	1, 2
Caryedon sahelicus Decelle	29-98%	1
Caryedon longispinosa Decelle	19%	1
Caryedon gonagra Fab.	n.a.	6
Caryedon serratus Oliver	43%	7
Pachymerus pallidus Ol.	7%	1, 4
Tuberculubruchus natalensis Pic	7%	1

References: 1 Tybirk (1991), 2 Southgate (1975, 1983), 3 Van Tonder (1981, 1985), 4 Peake (1952), 5 Jamal (1994), 6 Vir and Parihar (1993), 7 Parihar and Singh (1998).

browsing ungulates and fire. Near El Obeid in Sudan, millipede damage to seedlings was controlled by applying Agrocide 3 BHC (Sudan, Forest Department 1961).

White ants or termites have been recorded attacking older trees in the Sudan (Blunt 1926) and Pakistan (Cheema and Quadir 1973). In the Thar desert region of India, four species of termites were recorded as serious pests of plantations of *A. senegal* and *A. tortilis* (Vir and Parihar 1993). Termites attacking the roots of seedlings in western Rajasthan were identified as *Microtermes mycophagus* Desn. and *Odontotermes latiguloides* Roonwal and Verma, and were most active in the dry season (Parihar and Singh 1998).

Long horn bettles and borers are also found on older trees, and their damage increases natural gum exudation. Injector insects known in Sudan as "Garraha" beetles are locally believed to have a positive relationship with gum production. Many farmers believe that the beetle pierces holes into the newly created tapping wounds and that gum comes only from these holes. Farmers are convinced that the presence of lots of these beetles bodes well for a good harvest, and that their absence will yield a poor harvest (Barbier *et al.* 1990). Matey (1975) gave a comprehensive account of the Coleoptera (and of their associated insects) boring in *A. senegal* in the Sahelian region. In South Africa, the larval borer *Titoceres jaspideus* (Cerambycidaie, Coleoptera) was recorded

(Plant Protection Research Institute 1970). In western Rajasthan, the most important pests found on *A. senegal* were the wood borers. The larvae of the Buprestid beetle *Acmaeodera aurifera* Laporte and Gory, can severely infest the shoots, boring beneath the bark with numerous galleries. The cerambycid *Derolus volvolus* mainly attacks the trunk, boring into the live wood. The larvae of the bostrychid *Sinoxylon anale* on the other hand attacked the weaker or dying plants turning the wood into fine dust (Parihar and Singh 1998).

The tree locust *Anacridium melanorhodon* is found principally on species of *Acacia*, *Balanites* and *Zizyphus* in the Sahelian zones. Damage to the trees, particularly on *Balanites* spp., *A. mellifera* and *A. senegal*, can be considerable in Sudan/Chad (Popov 1959) and Nigeria (Roberts 1969), with large areas defoliated overnight (Awouda 1973). In fact, locust defoliation was reported to be one of the causes of poor gum arabic harvests in Sudan for 1992 (Idriss pers. comm., 1993)[2]. Jackson and Peake (1955) also report sporadic defoliation by the tree locust *Anacridium wernerella* in Sudan. The tree locust (sari el lail) in Sudan appears to prefer *Acacia* species including *A. senegal* to other tree species and, when they defoliate the trees prematurely, the tree responds by flushing new leaves. In doing so they use up the stored reserves which would otherwise have been used to produce gum. Gum tappers know this by experience and refrain from tapping trees where locusts have swarmed (Barbier *et al.* 1990).

Grasshoppers have been recorded attacking seedling establishment in Sudan (Blunt 1926). The aak grasshopper *Poekilocerus pictus* Fabricius (Orthoptera: Pyrgomorphidae) was found to defoliate *A. senegal* in Rajasthan, India (Kumar and Ullah 1997). In western Rajasthan, the most common grasshopper causing defoliation of seedlings in the monsoon season was *Chrotogonus trachypterus* (Parihar and Singh 1998). They found that various species of curculionids also caused mild damage to the leaves of seedlings in the same area. On the trees the most common defoliator was the Chafer beetle, *Holotrichia consanguinea*, which inflicted damage only in the first few showers of the monsoon in western Rajasthan (Parihar and Singh 1998).

Gagne and Marohasy (1993) found plant-feeding gall midges (Diptera: Cecidomyiidae) on *A. senegal* var. *senegal*, while looking for biological control agents against *A. nilotica* in Kenya. In India, sap suckers were found attacking leaves, shoots and most importantly pods. The Corid bug, *Namausus sp.*, fed on young pods, affecting the seed crop, and more importantly the nymphs of dusky cotton bug, *Oxycarenus sp.*, hatched on immature pods and in sufficient numbers to wither them (Parihar and Singh 1998).

[2] Pers. Comm. Mr Idris Nour Idris, Planning Division, Forests National Corporation, Sudan, 1993.

In Rajasthan, India, nymphs and adults of the babul (*Acacia nilotica*) whitefly, *Acaudaleyrodes rachipora*, were observed infesting the leaves of *Acacia senegal* plantations (Sundararaj and Murugesan 1996). This pest was controlled by Neem (*Azadirachta indica*) seed oil at 0.5-0.1% concentrations (Sundararaj *et al.*1995). In a separate study in the same region, 37 pest species were recorded on *A. senegal*, although most of the pests were not a major problem. Exceptions were white grubs (Scarabaeidae) and termites (Isoptera) at the nursery stage, defoliators *Indarbela guadrinota [I. quadrinotata]* and *Beralade similis [Chilena similis]* and sap suckers (*Oxyrachis tarandus*) on plantation trees, borers on old/felled timber (Buprestidae and Bostrichidae), and bruchid species on pods and seeds (Vir and Parihar 1993). In a further study by Parihar and Singh (1998), the important injurious insects listed on *A. senegal* were *Oxycarenus sp.*, *Holotrichia sp.*, bruchids and *Acmaeodera aurifera*.

Bibliography: 83, 105, 140, 146, 186, 264, 283, 331, 335, 343, 423, 426, 447, 464, 484, 486, 499, 579, 580, 585, 598, 603, 614, 624, 637, 706, 707, 731, 732, 733, 734, 757, 758, 763, 765, 766, 767, 768, 769, 794, 795, 818.

Man and livestock

Human activity can greatly decrease the productivity of gum trees by overtapping or careless technique. This has been a particular problem in West Africa. Destruction of trees also occurs in fuelwood collection, fodder harvesting, bark stripping and cutting for charcoal. Bark is commonly used for thatching, rope and mat making. These activities are usually carried out in a reasonably moderate way but population pressure, and occasionally economic conditions, induce over-exploitation (Larson and Bromley 1991).

Nomads and their livestock are commonly blamed for much of the destruction of *A. senegal* forests (Blunt 1926; Perrot 1939; Gaye 1988; Giffard 1973; Wata 1979). Burning to improve pasture is a growing problem and the practice of debilitating trees by hacking off branches for animals to browse is also destructive.

Camels and goats are particularly fond of browsing *A. senegal* and damage can be particularly severe around water points and villages. Heavy browsing results in small stunted trees with few branches for tapping which makes them unproductive. Grazing by cows and sheep below the trees can be beneficial in reducing grass biomass and minimizing the risk of fire but will also damage regenerating seedlings. El Din and Obeid (1971b) found that simulated browsing of young seedlings of *A. senegal* caused serious mortality and a great reduction in dry-matter production and the numbers of lateral roots formed. Mortality was greatest when the plants were grazed at 2-7 weeks of age, before the prickles are well developed, and this critical stage appears to coincide with the formation of

the lateral roots. When over-grazing occurs and the soil is left bare, run-off is high, erosion takes place and trees can suffer from a lack of water infiltration into the soil even in the rainy season.

In combination with drought, over-grazing can effectively preclude the natural regeneration of the species. The result is an ageing tree population that is not being replaced. This has been noted in northern Mali in the region of Gao where *A. senegal* has virtually disappeared from the landscape (Coulibaly 1988), and in parts of Manga, Niger (Saley 1988).

Bibliography: 24, 105, 140, 197, 210, 211, 283, 290, 335, 343, 471, 491, 530, 539, 589, 664, 679, 762, 776, 804.

Fungi

Fungal diseases are not a major problem in *A. senegal*, and most records are from India and Pakistan. The rust fungi *Ravenelia acaciae-senegalae* Mundk. and Thirum. and *Ravenelia acacicola* Sanwal which form amphigenous pustules on the leaves of *A. senegal*, have been recorded in India (Bakshi and Sunjan Singh 1967; Gibson 1975). *Cladosporium herbarum* and *Fusarium* species were found on *A. senegal* in south western Pakistan (Cheema and Quadir 1973). Also listed from Pakistan are *Ascochyta sp.*, *Botryodiplodia theobromae*, and *Sphaeropsis sp.* (Boa and Lenné 1994). Lenné (1992) also reviewed the important diseases of woody legume genera including *Acacia* as well as giving brief sections on their control strategies.

The Heart Rot *Inonotus hispidus* (Bull. ex Fr.) Karst has been recorded in *A. senegal* in France (Gibson 1975). Wood of *A. senegal* can also be attacked by the parasitic fungi *Polyporus hispidus* (Lutz 1946). The mycorrhizal fungi, on the other hand, probably play an important beneficial role in the growth of the species and affording protection against soil and root borne pathogens, and these are discussed under nitrogen fixation and mycorrhizas.

Bibliography: 96, 142, 186, 208, 221, 340, 477, 487.

Nematodes

Like most tropical plants, the Acacias are attacked by many species of nematodes, although not severely. In Senegal, Prot (1986) tested seven legume tree species including *A. senegal* for susceptibility to infestation with four common root-knot nematodes *Dolichorhynchus elegans, Meloidogyne javanica, M. incognita* and *Scutellonema cavenessi. A. senegal* was resistant to the latter two species, and a poor host for the former two species, only maintaining the initial population inoculated. Another study in sahelian Senegal found nematodes of the genera *Helicotylenchus, Meloidogyne, Pratylenchus, Scutellonema* and *Tylenchorhynchus* in the rhizospheres of *Acacia tortilis, A. senegal, A. holosericea* and *Faidherbia albida* (Cadet *et al.* 1998). They also found that *F. albida* and *A. senegal* were in a group of species more resistant to gall nematodes (*Meloidogyne spp.*), and that resistance increases with tree age. These two species suffered little effect on their growth, and their rhizobial symbiosis was even stimulated by its presence, with a significantly greater total dry weight of nodules found in the seedlings of *A. senegal* under the highest inoculum treatment (Duponnois *et al.* 1999).

Drought

In relatively recent times, severe drought has struck the gum belt twice, in 1972/3 and in 1984/5. Drought not only affects production by physically destroying gum trees, it also creates enormous social, environmental and economic knock-on effects such as human and animal migration away from afflicted areas to more favourable but nonetheless fragile ecosystems.

In terms of the physical impact of drought on production, this can be seen most clearly in West Africa where estimates of as high as 80% loss of gum forests have been reported (Wate 1979; Coulibaly 1988) for Mauritania, Mali, Burkina Faso in particular, but also Chad, Niger and Senegal. These areas are characterized by very poor sandy soils (relic dunes) with virtually no water-retaining capacity. The traditional gum growing regions of Northern Kordofan and Darfur have the same aeolian sands (known as *qoz*) and have been similarly afflicted (Bunderson *et al.* 1990). The initial effects of drought on the trees are that they come into leaf later, with a reduced leaf production, and the leaves are retained for a shorter time. Fruit and seed production is usually very low or nil. In the Northern Ferlo region of Senegal, *A. senegal* proved less drought resistant with mortalities of 53% during the 1972/3 drought compared to *Balanites aegyptica* and *Commiphora africana* with 5.5% and 7.9% respectively (Poupon and Bille 1974). Many trees were killed during the drought by stress-induced insect attacks of *Cerambycidae* beetles and locusts. Termites also commonly attack the roots of trees during dry periods.

Drought also affects the availability of drinking water for gum tappers, which is perceived as the major constraint to gum tapping in both sandy and clay areas of the Sudanese gum belt (Barbier *et al.* 1990).

Fire

Fires are a natural disturbance in savannas, and consequently the species that grow there often adapt to infrequent burning especially at the end of the dry season. Adult trees of *A. senegal* var. *senegal* are generally

tolerant of burning (Pratt and Knight 1971), and their bark structure, with a thick bark and suberized cells, appears to be well adapted against excessive heat from sunlight and grass fires (El Din 1981b). In a study of savanna vegetation in the Akagera National Park, Rwanda, Bouxin (1975) found that *A. senegal* was one of the most resistant species to burning, based on its stem diameter distribution. Fire also affects the soil seed bank by breaking the seed coat and can promote germination (Tybirk *et al.* 1994), although of course hot grass fires can also increase seed mortality on the soil surface (El Din 1969).

Frequent seasonal fires started by man on the other hand can devastate the tree populations, especially if used when the trees are lopped for browse by pastoralists (Toupet 1984). In the Kenyan rangeland, intense fires kill the trees irrespective of height (Tchie and Gakahu 1989). Natural regeneration is severely affected by fire, and many foresters recommend fire and cattle exclusion to allow natural regeneration (Bellouard 1949; Blunt 1926; Boudet 1972; Fall 1987). Seedlings are particularly susceptible to fire (El Din 1969; Tybirk 1991), and a year's regeneration can be totally eliminated. In Sudan, the species is more susceptible to fire damage in the higher rainfall areas, above 400 mm/yr, because the grass cover is denser and taller. It also suffers in competition with more fire tolerant species such as *Acacia seyal*. Estimates of fire damage made by the Range and Pasture Administration range from 10% in the driest areas to 60% in the tall grass savanna (Barbier *et al.* 1990). Hence the need for firebreaks around gum populations and plantations where frequent burning takes place (Wata 1979).

Fire damage that does not destroy the trees can have a similar detrimental effect on gum production as a locust attack, in defoliating the trees and causing resumed vegetative growth thus drastically reducing gum production that year (Barbier *et al.* 1990).

Bibliography: 74, 105, 118, 140, 149, 153, 217, 235, 283, 308, 343, 402, 424, 447, 610, 656, 738, 762, 765, 769, 804.

PRODUCTS AND USES

Wood

Because of its relatively small dimensions, *A. senegal* is not commonly used as a source of timber. The dark heavy heartwood is used for cart-wheels, sugar cane crushers, Persian wheels, posts, weavers' shuttles and agricultural implements in India (Troup 1983), and in Africa it has also been recorded for making roofing poles, lining wells, timber framing of huts, and the lighter sapwood for tool handles (Wickens 1980). The wood is durable and said not to be attacked by white ants (Troup 1983). Wood colour varies considerably within the species and provenance (Burkill 1995), from white through veined black to black although this may in part be due to differences between sapwood and heartwood.

Wood is a secondary product after gum, and is usually harvested at the end of gum production cycle after 15-25 years. It is an important source of firewood and charcoal (National Academy of Sciences 1980), although often other related species such as *A. tortilis, A. mellifera* and *A. seyal* in Sudan (Wickens 1995), and *A. bussei* in Somalia are used first. Properties include a high calorific value and low smoke production. A head-load of fuelwood (weighing about 22.5 kg) is found equal to 72,000 kcal (Baumer 1983). In Niger, the calorific values measured for *A. senegal* var. *senegal* was 18.9 MJ/kg of dry matter (Lamers *et al.* 1994). It makes good quality charcoal, as recorded for example from French west Africa (Aubréville 1941), Somalia (Robinson 1988) and Sudan (Al Tahir 1987). In the Bay Region of Somalia, the estimated moisture content of the wood was 45% in stems over 15 cm diameter, and the conversion of wood (oven dried) to charcoal was estimated at 25-40% (Bird and Shepherd 1989).

The thorny branches, like many African Acacia species, are also lopped off to make livestock enclosures or zaribas (Blunt 1926).

Bibliography: 24, 80, 112, 134, 140, 146, 150, 170, 207, 402, 467, 488, 519, 539, 648, 755, 763, 819, 821.

Fodder

Acacia senegal is an important source of fodder where it is abundant, both for livestock and wild herbivores. The leaves and pods are very palatable to livestock (camels, goats and sheep), as reviewed by Le Houérou (1980), Booth and Wickens (1988), Baumer (1983). On average the leaves contain 10-13% digestible protein and 0.12-0.15% phosphorus, while the pods contain 15% digestible protein and 0.12-0.14% phosphorus, although green pods have higher recorded values of 1.07% phosphorus (IBPGR 1984). In Senegal, fodder hedges of *A. senegal* planted at 2.5 m spacing are recorded to produce 3 t ha^{-1} fresh biomass after 30 months (Cazet 1989). In Sudan, Wickens *et al.* (1995) recorded 2.5kg DW of dry litter/tree/yr from a 7 year old tree in Kordofan. However, livestock primarily exploit the tree as a browse species on the range; for further details see the larger section on Browse.

Gum

Gum is the major product of *A. senegal*, and its uses are treated in various sections of this volume. Historical uses

are described in section II, and modern day commercial uses in section III under food and drinks, pharmaceuticals/slimming aids and technical uses. Traditional medicinal and food uses of gum are described below, and the other indigenous uses which tend to be given a cursory mention in the literature are noted here. Observations also exist for West Africa from the accounts of French expeditions (*i.e.* Capt M Vincent 1860) and colonial foresters (Chevalier 1934). Burkill (1995) reviewed the uses in western Africa and Miller and Morris (1988) gave valuable details on traditional uses in Dhofar (Oman).

In Senegal, even today, a substantial local market exists for gum arabic as a starch for the laundering of ceremonial robes in particular (Giffard 1975). Laundries use gum arabic instead of the more common starches. It not only gives the clothes "body" as starch does, but also a lustrous finish that starch does not. Gum has traditionally also found use in pottery and house building to give added strength and viscosity to the raw materials and for decorative glazes. It is used to make hair preparations, and as a base to apply ochre and other decorative body paints. In Oman and throughout the Middle East, gum arabic has been traditionally mixed with oil and goat or sheep brain and used as a depilatory cream by both men and women. The gum in water produces an excellent glue, and in solution it is mixed with soot to prepare a black ink or with powdered Nubian sandstone to produce a red ink in the Jebel Marra region of Sudan (Burkill 1995).

Medicine and food

Gum arabic has been an important source of nutrition in the difficult environments of the Sahel, and is eaten throughout its range in Africa. In Mauritania nomads use it to make a confectionery called N'dadzalla (Vincent 1860, Giffard 1975), which is still enjoyed today. This consists of a mixture of grilled gum with butter and sugar. In India, the gum of *Acacia senegal* is dried, broken into small pieces and fried in fat to make puffs, which are supposed to be a very nutritious food; ground gum mixed with fried wheat flour and sugar is given to women after child birth (Caius and Radha 1941). Gum arabic is said to be rich in calcium, magnesium, potassium and other trace salts; it is reputed to be highly nutritious and the commonly quoted example is that the Moors can subsist on as little as 6 ounces (170 g) a day during the gum harvest (Grieve 1931; Miller and Morris, 1988). In fact gum arabic has an energy value 84% of that of starch, and can hold up to 16% moisture content (Anderson 1988a, 1993b).

The seeds of *A. senegal* are dried and used as a vegetable to form a dry preparation called Panchkuta (including seeds of *Capparis* and *Prosopis*) in Rajasthan, India (Sen and Bansal 1979). The seeds and fruits of *A. senegal* are especially noteworthy as they do not rot when made into a vegetable and keep for many days without any refrigeration. Germinating seeds of *A. senegal* have high concentrations of ascorbic acid (vitamin C) in the embryonic tissues (Tewari and Rathore 1973), and the processed seed meal has a high protein content of 37.2% (Banerji *et al.* 1988). The seeds contain a dark yellow seed oil, containing oleic and palmitic acids (Grindley 1945). Baboons eat the young fruits, young leaves, flower buds and blossom (Peters *et al.*1992). *Acacia senegal* is also an important honey bee plant, providing a light amber coloured honey with a mild aroma which granulates in two weeks (Crane *et al.* 1984; Wickens *et al.* 1995).

In traditional medicine most parts of the plant are used (Miller and Morris 1988; Chaudhri and Saleem 1962;. Saleem *et al.* 1998; Watt and Breyer-Brandwijk 1962). Wickens *et al.* (1995) listed a wide range of uses in local medicine, the gum being used in the treatment in four main areas: as an emollient (inflammation, angina - sometimes with the bark as well), a demulcent (opthalmia, whitlow, colds), a bechnic (diarrhoea, otitis, aphrodisiac) and a diuretic (haemorrage). The bark and leaves are used as an astringent, demulcent (colds and opthalmia) and a diuretic (haemorrage) and the leaves also in treating diarrhoea.

Medicinal uses of the gum are very important. In Mauritania, M'khatorat (1959) showed that gum arabic was viewed as a panacea for a great many complaints. He quotes a local prophet as saying: "Le remedé en toute choses etait dans la gomme". Traditional recipes include the mixing of gum with milk, senna, metal filings and camel hair for the treatment of migraines, boils and acne, fractured bones and respiratory complaints. Miller and Morris (1988) noted that in Oman gum arabic is left to dissolve in water overnight and is then drunk on an empty stomach in the morning as a remedy for chest pain. Eating gum was said to strengthen the muscles of the abdomen and make the stomach hard and flat. Consumed in large quantities it causes flatulence (because the gum is high in fibre) which is highly regarded for cleansing and purifying the entire digestive system. Gum arabic ground to a powder and mixed with fat or grease is used to anoint the body, to strengthen it and to serve as a tonic to protect against future disease. It is used in Senegal by the Tukulor medicinemen to treat the giraffe form of leprosy, and is applied on localized inflammations and nodular leprosy in Senegal and Nigeria. The Moor Arabs of the Sahara take an infusion as a strengthening medicine, against an indeterminate malady called igendi which is probably a symptom of vitamin deficiency (Burkill 1995). Gum is also used externally in the treatment of local inflammations such as burns and sore nipples, and internally in the inflammation of intestinal mucosa, and dysentery (Duke 1987; Booth and Wickens 1988).

The astringent properties of the bark and leaves are due to tannins, and as well as treating external wounds it

is also used to treat gastrointestinal disorders (Watt and Breyer-Brandwijk 1962; Saleem *et al.* 1988). The tannins are also sources of two flavanol compounds, (-)-epigallocatechin-7-gallate and (-)- epigallocatechin-5, 7-digallate commonly found in *Acacia* species and which were shown to have high molluscicidal activity against *Bulinus truncatus* and *Biomphalaria pfeifferi*, snails which transmit schistosomiasis in Sudan and Egypt (Ayoub 1985). In Kenya, a root decoction is slightly purgative and is drunk in the case of constipation or for stomach-ache, and is also used in the treatment of gonorrhoea. A decoction of the bark is drunk to treat diarrhoea and stomach disorders (Kokwaro 1976). In India, bark extracts are used in local medicines and analyses of the bark have found β-amyrin, β-sitosterol and β-D-sitosterol glucosides, erythrodiol and sucrose (Saharia and Sharma 1981).

Bibliography: 38, 48, 88, 101, 122, 146, 170, 172, 185, 266, 344, 356, 358, 458, 519, 522, 590, 661, 663, 673, 696, 705, 741, 793, 805, 820, 821.

Bark

Apart from the medicinal uses given above, bark extracts from *A. senegal* have high tannin contents which have the potential to replace commercial wattle (*Acacia mearnsii*) in tanning leather. However, they need to be mixed with weakly astringent bark extracts from *Acacia nilotica* to give a protein precipitating profile similar to that of wattle (Mugedo and Waterman 1992).

The bark of the roots is twisted into strong ropes (Lely 1925; Wickens 1980; Cossalter 1991), and commonly used for thatching, rope and mat making.

Soil amelioration and protection

Acacia senegal has value in desertification control through sand dune stabilisation (Cossalter 1991; Puri *et al.* 1973; Arbonnier 2000; Booth and Wickens 1988; Luna 1996; Zollner 1986) and wind breaks (Lamers *et al.* 1994), because of its extensive lateral root system. Overall fertility under tree cover improved on sand dunes in western Rajasthan (Sharma and Gupta, 1989a, 1989b). (See also sections on rooting habits, nodulation and mycorrhizas and effects on soil fertility.)

For the south Sahelian zone in west Africa, Lamers *et al.* (1994) evaluated seven species and concluded that for the establishment, growth and fodder value of wind-breaks, *A. senegal* and *Bauhinia rufescens* showed the greatest potential. Vidal Hall (1963) also noted that wind breaks of *A. senegal* would be beneficial on the wide flat clay plains in Kassala and the Blue Nile Provinces of Sudan where mechanized agriculture is undertaken, and which are relatively devoid of trees.

Blunt (1926) noted the benefits of *A. senegal* on sand dune fixation, where planted seedlings continued to grow through 70 cm of sand which had accumulated on top of them over 2 years. He also noted its importance in reclaiming exhausted soils (see Sudanese gum gardens below).

Cattle farmers recognize the beneficial effects that Acacia species have on the range through their influence on the species composition of the associated grasses. The development of palatable perennial grasses, such as *Cenchrus ciliaris* and *Panicum maximum*, in the understory of these trees species is dependent on the species' ability to provide shade, utilize water and nutrients at depth, fix nitrogen and improve soil structure and infiltration of rainfall (Acocks 1988; Barnes *et al.* 1996). In southern Africa, grass species such as *P. maximum* are dependent on bush, and if the trees are cleared the grass species will tend to be rapidly replaced by less valuable species. Bosch and van Wyk (1970) measured the density and frequency of *P. maximum* underneath and away from the crowns of *A. senegal* and found a strong association between the two species. Soil samples were then collected from under and away from the crowns, and the yields of *P. maximum* grown in them compared in greenhouse experiments. Much higher yields were harvested from the canopy soils than from those outside the crown area; for instance average *Panicum* yields of 5.26 g were recorded for the canopy soil compared to 0.74 g from open ground soil after 36 days growth. Soil analyses indicated that the surface canopy soils were richer in nutrients, and further experiments with additions of N, P and K to the open soils increased *Panicum* yields to those found under canopy soils. They concluded that the *Panicum*-tree association is largely due to soil enrichment by the trees.

Bibliography: 6, 76, 106, 140, 146, 208, 467, 486, 615, 682, 683, 792, 838.

ACACIA SENEGAL AND AGRICULTURE

Sudanese gum gardens

The gum gardens in Sudan evolved from the traditional bush-fallow system, where the staple cereals (millet and sorghum) when planted year after year in the same area exhausted the soil and allowed the parasitic *Striga* plant to build up populations with consequently declining cereal yields. Cultivation then moves on to a neighbouring fallow area, and *A. senegal* regenerates or is planted in the recently worked abandoned area. After a few years the abandoned area provides fodder and the trees are tapped for gum arabic.

Blunt (1926) described the gum gardens from Kordofan District, western Sudan. Trees are grown on fallow land (after 4-5 years of cropping) near the village (gum gardens). Gum gardens can have one tree/acre to over 200 trees/acre. All the community have the right to cultivate, and small taxes are paid to the Sheik and Omdah. Tapping depends on the quality of the agricultural harvest, and in a good harvest year much less tapping occurs as there is less need for income to buy food. Gum tapping occurs when the leaves of the trees are wilting and dropping, well into the dry season. Manual tapping only started around the 1890s; prior to that gum was collected from natural exudation. The tapping procedure, using a tradional axe, involves pulling a strip of bark from the upper trunk of the tree, and a new section of the bark is worked in the following year. The outer bark is broken horizontally by a shallow cut about 3-4 cm or two fingers wide, and the bark peeled one strip up and one strip down about 1 m in length. Trees from 6-7 years old can produce abundant gum but tapping too young will kill them. Gum droplets form generally between 2.0 and 7.5 cm in diameter, hardening on exposure to the atmosphere. Gum is collected 20-30 days after tapping if the weather is hot and dry but, if cold, exudation can take up to 60 days. Each season the tapping occurs in a different place, working around the trunk. A single tapper can tap around 100 trees per day. The gum production calendar fits well into the agricultural calendar of the traditional farmer, millet and sesame being harvested in October/ November around the time the first tapping occurs. There is also migrant labour from Northern Kordofan that tap the trees in the clay areas, return to their harvest in November and move back to the clay areas at the end of November for gum collecting.

Jackson and Shawki (1950) also described the gum arabic cycle from the sands close to the Nile north of Kosti in eastern Sudan. There are four periods which occur in the cycle, starting with the cultivation period where acacia scrub is cleared from the land leaving some stunted *Balanites aegyptica*. Crops (*Pennisetum typhoideum* and *Sorghum vulgare*) are sown from 4-10 years until the soil is exhausted and becomes infested with *Striga hermonthica*. Land is abandoned and the soil becomes colonized by *Cenchrus biflorus, Acacia seyal* and *A. senegal* which regenerate on freshly worked soil. In three years the acacias reach a metre in height and in eight years are ready for tapping. This second phase moves on to the dominant phase, where trees are tapped for gum from 6-10 years. Finally the cycle enters the deterioration phase, where trees tend to die simultaneously. They do not regenerate as densely growing grasses have colonised the site. Fire is more prevalent and eventually the cultivator moves in and starts the cycle again.

Earlier descriptions of the gum arabic cycle on the clay soils west of Kosti are given by Bond (1918). Traditionally it is a 24 year rotation, divided into 4 equal periods. The first is named Bildat, a 6 year cropping period until the soils are exhausted; then this is followed by Seraya and Shigl, a 6 year fallow period, where seed of *A. senegal* naturally regenerates and grows up; then this is followed by Geneina or gum garden where gum is harvested for 6 years and finally the fourth period is Bur, where gum yields deteriorate and clearance and cultivation begins.

In Senegal, the *sira* tapping system follows a 4 year tapping cycle. The main trunk and branches over 35-40 cm in diameter have long strips of bark removed over one quarter of the circumference in any one year. The next year another quarter circumference is stripped, and so on until the fifth year where tapping in back on the renewed bark (Burkill 1995).

Impacts on soil fertility

The traditional method of agriculture in many arid and semi-arid areas is based on a repeated cycle of cropping until declining yields make further cropping uneconomic and this is followed by a longer fallow period whereby soil fertilities are restored. The role played by trees in restoring soil fertility, especially those that fix nitrogen such as *A. senegal* and *Faidherbia albida,* are also percieved benefits in traditional societies. There are a number of studies that support increased macronutrients and organic matter in the soil under the tree canopies compared with the soils away from them (Abate *et al.* 1998; Bernhart–Reversat and Poupon 1980; Gerakis and Tsongaraks 1970; Deans *et al.* 1999). Hussein (1983) studied soil samples from *qoz* sands of an *A. senegal* forest east of El Obeid in Kordofan Province, Sudan. He sampled a young forest stand, an old forest stand and a nearby area cleared for cultivation and grazing.There was a higher accumulation of nitrogen and carbon in the older forest stand compared with the younger aged stand, and this was over twice that found in the adjacent arable area.

Nitrogen and organic matter have received the most attention. Bernhart–Reversat and Poupon (1980) studied nitrogen cycling via mineralization and plant uptake in a population of *Acacia senegal* in the Sahelian savanna of northern Senegal. They measured the nitrogen accumulation in different parts of the tree biomass, herbaceous biomass and in the soil, and found that the annual flow of nitrogen from under adult *Acacia* trees to the soil was about 12 g $m^{-2}a^{-1}$. This was comparable to some forest ecosystems. The savanna soils have low organic matter and N content, and these are concentrated in the first centimetres of soil. *In situ* N mineralization in the 0-10 cm layer was relatively high, ranging from 5 - 8% of total N per year, according to the relief (Bernhard-Reversat 1982). It occurred mainly from the beginning of the rainy season (July) to August, although rainfall occurred up to October. *In vitro* measurements showed that N mineralization was a function of the number of days

during which the soil was wet, for a given temperature and N content. Prediction of in situ mineralization on this basis was in good agreement with in situ data. N fluxes between the vegetation and soil were higher in soil-tree systems than in the open, but litter-fall and canopy weathering accounted for a small part in the N cycling, the major fluxes occurring via the herbaceous stratum, and this is then available to cattle.

Deans *et al.* (1999) also studied biomass and tissue nutrients of trees from 3- to 18-year-old plantations of *A. senegal* as well as the soil nutrients close to and away from the trees in northern Senegal, to provide quantitative information on the rate of nutrient enrichment in tree fallows. Tree biomass increased linearly with age and above and below biomass accumulation averaged 1,770 kg $ha^{-1}a^{-1}$ for trees at 6 x 6 m spacing. By 18 years of age, an average tree had accumulated 945, 38 and 420 g of N, P and K respectively. Soil organic matter, N, P and K concentrations were always greatest in the surface horizons close to the stems. However, unlike N and K, there was little evidence to show P concentrations increasing in the surface horizons. N and K increased in the surface soil by ca. 24 and 4 kg $ha^{-1}a^{-1}$ respectively, and soil organic matter increased by ca. 0.05% and 0.035% per year under the tree canopies and in open ground respectively. Felling the trees and harvesting all wood >2cm diameter at age 15 would remove ca. 60, 2.7 and 35 kg ha^{-1} of N, P and K respectively at 6 x 6m spacing. At the same age harvesting only a single year's production of leaves and fruits would remove 75%, 80% and 40% of those N, P and K amounts. It would appear that regular large scale fodder harvesting would remove much more from the site than harvesting the wood at the end of the tree rotation. This effect was more serious for K and P, because at 15 years there was more N in the surface soil than in the tree tissues.

In the Great Rift Valley in Ethiopia, Abate *et al.* (1998) found that in the surface soils organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and electrical conductivity were higher under all tree canopies including *A. senegal* than outside canopy soils. The beneficial effects on soil fertility were not however found at greater soil depths. On the other hand, Aggarwal (1976) found only slight increases in N and P and a decrease in K values in the surface soils under *A. senegal* in India, compared with bare soil. Zinc was the only micronutrient that increased under *A. senegal*, from 0.20 ppm to 0.74 ppm.

Bibliography: 1, 13, 85, 112, 123, 124, 125, 140, 144, 170, 228, 229, 336, 414, 415, 424, 427, 478, 479, 551, 554, 560, 698, 816.

Effects on crop yields

While the perceived benefits of the role played by trees such as *A. senegal* in restoring soil fertility is recognized in traditional societies and discussed above, relatively little reliable data exists on crop yield increases. The role of nitrogen fixation and mycorrhizas in the trees, and the leaf litter produced must all contribute to improving the fertility of the soil. Gerakis and Tsongaraks (1970) in western Sudan found that goz soils that had lain fallow for 12 years under *A. senegal,* provided noticeably better growth of the traditional crops sorghum, pearl millet, sesame and groundnut, than on soils nearby. Similar improvements were recorded for the grass species *Panicum maximum* under *A. senegal* in South Africa (Bosch and Van Wyk 1970).

Browse

Livestock exploit the tree as a browse species on the range, and in many cases such as in Sudan the cattle herders practise a transhumance system. There is little "cut and carry" undertaken by the pastoralists.

Proximate analyses

The nutritive value of fodder depends on a number of factors including palatability, intake, chemical composition, digestibility and toxicity due to secondary compounds. The standard measures of nutritive value derived from proximate analyses must be treated with caution and there is no substitute for *in vivo* digestibility studies which measure animal production, although the costs of such studies are very high (Robinson 1985). Nevertheless, the large number of proximate analyses assembled and reviewed for the rangeland species in sub-Saharan Africa (Houérou 1980d) give a tentative idea of the browse value of *Acacia senegal.* Other more direct evidence comes from the field in sub-Saharan Africa, where a pasture trial was tried with and without browse species. Restricting access to fodder trees by Fulani cattle in the Nigerian Sahel proved near fatal and the trial had to be stopped (Houérou 1980f).

A good fodder tree should have a relatively high crude protein content, which is maintained when alternative feed sources have low crude protein contents. The average crude protein value for browse species from west Africa was 12.5% (Houérou 1980d), the general acceptable level for maintenance of ruminants 9% or lactation and growth 15% compared to 3-4% for the herbage from tropical grasslands in the dry season (Robinson 1985). Analysis values of the leaves pods and seeds of *A. senegal* identify the species as an attractive fodder (Table 2), being particularly high in crude protein and calcium and low in crude fibre. The fruits and especially the seeds are particularly high in crude protein, and, as their seed coats are relatively thin in comparison to other *Acacia* species such as *A. nilotica*

Table 2. The proximate analysis values reported for *A. senegal* var. *senegal.*

			Fractions								
Material	**Origin**	**Refs**	**DM**	**CP**	**CF**	**EE**	**NFE**	**DP**	**NE**	**DP/FU**	**Ash**
New growth	Kenya	2	-	20.3	27.7	2.6	42.7	-	-	-	6.8
New growth	Kenya	2	-	20.5	27.7	2.2	41.3	-	-	-	8.3
Leaves green	West Africa	1	47.3	26.6	22.9	3.3	39.7	21.2	5.5	265	7.5
Leaves green	Chad	1	40.1	27.6	15.5	4.3	37.9	22.1	5.6	271	14.6
Leaves	Chad	1	40.1	27.7	15.5	2.8	37.9	22.2	5.6	272	14.6
Leaves dry	Senegal	1,3	88.5	18.2	11.2	6.7	55.5	13.4	-	-	8.4
Pods green	Uganda	2	-	22	39	1	30.9	-	-	-	7.1
Pods dry	Uganda	2	-	19.6	29.6	2.1	43.3	-	-	-	5.3
Pods dry	Niger	1	85	15.2	22.8	2.8	50.8	11	6.2	125	8.4
Pods	Niger	1	92.9	-	-	-	-	15.8	4.8	226	-
Pods dry	Niger	1,3	92.9	20.4	29.2	3.1	41	14.3	5.2	190	6.3
Pods dry	West Africa	1,3	95.1	11.1	28.7	1.2	53.4	6.8	5.4	87	5.5
Pods dry	Chad	1	85	15.2	22.8	2.8	50.7	10.6	6.1	117	8.4
Seeds	Senegal	1,3	86.6	40	13.7	5.8	35.4	33.6	7.6	305	5

DM, dry matter (% of fresh weight); CP, crude protein (% of DM); CF, crude fibre (% of DM); EE, crude fat (% of DM); NFE, nitrogen free extract (% of DM – estimated by difference); DP, digestible protein (% of DM); NE, net energy (MJ kg-1 dry matter); DP/FU, nutritonal ratio- digestible protein /feed units (1 FU = 6,9 MJ); Ash, ash residue (% of DM). Refs: 1, Houérou Le (1980d); 2, IBPGR (1984); Baumer (1983). -, information not available.

and *A. tortilis*, it is likely that many will be chewed and digested.

Tissue concentrations of silica and minerals

The mineral concentrations in the browse of *A. senegal* are relatively good (see Table 3), with low levels of silica compared with many browse species in tropical west Africa (Houérou Le 1980d). Phosphorus concentrations are adequate from browse in western Africa (0.1-0.3%) but with much higher levels found in eastern Africa (0.8-1.1%), which is thought to be due to differences in soil concentrations of this element between the two regions. Calcium levels are higher which in some cases increases the calcium/phosphorus ratio well over the optimum figure of 1-2 (Houérou Le 1980d). Concentrations of potassium and magnesium also appear satisfactory.

Most of the nutrients in the tree biomass are held in the leaves and fruits. At 15 years old, Deans *et al.* (1999) calculated that harvesting a single years' production of leaves and fruits would remove 75%, 80% and 40% of the total quantity of N, P and K in the trees. Hence fodder harvesting would remove much more from the site than harvesting the wood at the end of the tree rotation. This effect was more serious for K and P, because at 15 years there was more N in the surface soil than in the tree tissues.

Digestibility, energy and palatability

In terms of estimated net energy, values are high and usually above 5 MJ kg^{-1} dry matter which is classified as excellent fodder and well above the maintenance levels required by livestock (Houérou Le 1980d). The digestible protein levels are also high, well above the 5.3 figure for excellent forage quality. This affected the average nutritional ratio (DP/FU - digestible protein /feed units (1 FU = 6.9 MJ,) which was over 200, well above the average figure of 100 for west African browse species in general.

Table 3. Concentrations of silica and minerals reported for *A. senegal* var. *senegal.*

			Concentrations (% of dry matter)				
Material	**Origin**	**Refs**	**Si**	**P**	**Ca**	**Mg**	**K**
New growth	Kenya	2	-	0.2	1.4	-	-
New growth	**Kenya**	2	-	0.2	1.4	-	-
Leaves green	West Africa	1	-	0.2	1.5	-	-
Leaves	**Chad**	1	1.1	-	-	-	-
Leaves dry	Senegal	1,3	1.8	0.1	1.3	0.4	1
Pods green	**Uganda**	2	-	1.1	0.8	-	-
Pods dry	Uganda	2	-	0.8	1	-	-
Pods dry	**Niger**	1,3	0.3	0.2	1.3	-	-
Pods dry	West Africa	1,3	0.4	0.1	1.3	0.2	0.7
Seed	**Senegal**	1,3	0.03	0.3	0.7	0.3	1.3

Si, Silica; P, Phosphorus; Ca, Calcium; Mg, Magnesium; K, Potassium.
Refs: 1, Houérou Le (1980d); 2, IBPGR (1984); 3, Baumer (1983); -, information not available.

From the data collected in the Serengeti National Park, Tanzania, Pellew (1980) reported that *A. senegal* is a highly nutritious and productive browse plant and is strongly selected for in the diet of both giraffe and elephants. The plant is shown to have the highest crude protein levels of all the species, the flushing shoots having a mean crude protein content of 33.5% with a maximum recorded figure of 37.7%. This browse persists only for a few days and then the shoots harden off and lignify, and the crude protein levels drop to about 22% in older leaves. Dougall and Drysdale (1964) found similar crude protein levels (20-21%) for young leaves and twigs of the species from the Mara, Kenya. Productivity rates can be very high in *Acacia* browse, and Pellew (1980) records 1,725 kg $ha^{-1}a^{-1}$ of new shoots and leaves from the ridge-top *Acacia* regeneration thicket (of which *A. senegal* forms 17% in species composition).

In Darfur Province in western Sudan, Bourreil (1968) studied the browsing preferences of the different domesticated herbivores to a range of fodder species in areas dominated by the highly palatable grass genus *Aristida* (see Table 4). He found that camels were the preferential browsers of *A. senegal* plant and fruits, goats browsed the plant less and goats and sheep preferred the fruits when available, while sheep, donkeys, horses and cows did not browse the plant at all, although cows would browse the fruits a little.

In Niger, the species is described as a palatable browse species, although during the dry season the species is without leaves for as long as October to June (Dicko-Toure 1980). In northeastern Ethiopia the leaves are recorded as palatable in a survey of 82 browse species (Houérou Le and Corra 1980). Pods are also recorded as palatable and are eaten by livestock (IBPGR 1984), and are available in the dry season even after leaf fall when the nutritional value of the herb layer is very low. In Kenya, Stuth and Kamau (1990) found that browse in the dry season, particularly from *Acacia mellifera*, *Acacia senegal*, *Commiphora africana*, *Grewia bicolour* and *Solanum incanum* were abundant in the diets of goats from August to November. *A. senegal* pods were the major source of feed for goats in July and August. Crude protein concentration exceeded requirements of goats throughout the period of study. By giving goats simultaneous access to protein-rich, pod-producing areas and also high-energy grassland areas, pastoralists can diversify diet selection and stabilize nutrient intake. Cutting large *Acacia* trees for fuelwood and charcoal and tetse fly control was particularly detrimental to the nutritional ecology of goats and perhaps other browsing herbivores.

Bille (1980) found that the proportion of annual pod production per tree per year of *A. senegal* in Senegal (1.34 kg of dry matter) is about a third of the total leaf production (3.84 kg of dry matter). Dicko and Sikena (1992), stressed the nutritional value of browse species

Table 4. Forage preference for three tree species, five grass species and a herb in Darfur Province, Sudan. Coefficient of preferences indicates degree to which plants were browsed ranging from 5 for 'very browsed' to 0 for 'not browsed at all'. The second figure (in parenthesis) signifies that the animal consumes more of the plant when there is restricted choice (Bourreil 1968).

	Sheep	Goats	Cows	Donkeys	Horses	Camels
A. senegal plant	0	1	0	0	0	4
A. senegal fruit	3	3	1	0	0	4
Faidherbia albida plant	0	2 (3)	0	0	0	5
Faidherbia albida fruit	2	4	5	0 (1)	0	5
Calotropis procera	0	0	0	0	0	0
Aristida adscensionis	1 (2)	0	2 (3)	2 (3)	1 (3)	4
Aristida funiculata	1 (2)	0 (1)	2 (3)	2 (3)	1 (2)	3 (4)
Aristida pallida	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	1 (3)
Cenchrus ciliaris	3 (4)	3	5	4 (5)	5	4 (5)
Eragrostis aspera	2	1	2 (3)	2 (3)	2 (3)	1 (2)
Tribulus terrestris	3	3	1 (2)	1	0	2

such as *A. senegal*, with high crude protein and mineral contents contributing to a lack of photophobia or eye infections in those browsing species (camels and goats) compared to cattle in dryland western Africa. In a study on the anti-nutritional factors (total phenolics and proanthocyanidins) contained in a range of provenances of 6 browse species of *Acacia* and *Faidherbia* planted in southern Zimbabwe, Dube *et al.* (2001) found that *A. senegal* had the lowest concentrations of both factors in all the species tested.

Fall (1987) reported that *A. senegal* is a vital browse providing foliage from July to January in the Sahelian regions, and fallen pods from February to March. In Fété-Olé, Senegal, an estimated 5.6 kg of fodder per hectare was produced in 1973, split into 3.7 kg of leaves and 1.8 kg of flowers and fruits. In a study of forage production during 1971-77 in the same area, *A. senegal* produced a mean of 0.054 kg of fruits/tree/year (Houérou Le 1980c). Le Houérou (1980c, 1980d) in a review of 105 browse species from west Africa, considered *A. senegal* to be one of the main browse species in the Sahelian and Sudanian zones, and gave crude protein levels of 22%DM (13-29), high in Digestible Protein (mean DP = 17.1%), net energy (5.8 MJ) and a nutritional ratio (Digestible Protein/Forage Units) of 206 (mean for all Browse species = 100 or legumes = 145). He stressed the need for browse to supplement the grasses in the dry season, dry grass not being able to meet livestock requirements. For an adequate maintenance diet, a minimum of 20% browse is required.

Acacia senegal plantations established for gum production appear to offer limited browse production out of any fallow period. Forage output is low, the tree only being available for browse outside the gum collection period, in other words at the beginning of the rainy and dry seasons, giving only a marginal value to the forage as a supplementary source of feed supplies during drought periods. Browse production consisting of leaves from plantations in Senegal and Sudan can be estimated at 200 Forage Units (FU)/ha with a DP content of 200g/FU. Average estimates per tree was 1 kg a^{-1} of dried leaves with a feed value of 0.33 FU kg^{-1} (Montgolfier-Kouévi and Houérou Le 1980).

In Senegal, Kone (1988) reported that some projects have fenced off areas of *A. senegal* to protect the trees. This was not liked by the pastoralists at first, but later they realized that they could use the plots as fodder reserves (especially the herbaceous layer).

Bibliography: 112, 113, 114, 133, 152, 229, 244, 245, 258, 261, 308, 405, 406, 407, 408, 409, 410, 417, 461, 527, 587, 649, 717.

ESTABLISHMENT, MANAGEMENT AND YIELD

Natural regeneration

Most regeneration of *A. senegal* is natural throughout its range, although in any year the species may fail to regenerate if not all the environmental factors are favourable. Blunt (1926) noted that even in the gum gardens in western Sudan, most regeneration was natural with a small proportion sown by seed. The pioneering studies by El Din (1969) in his thesis and the following publications by him and Obeid in the early 1970s have shown that, although the species is still capable of regenerating naturally in many parts of the former gum belt of the Sudan, local land use practices have become unfavourable. This is attributed to changes in the distribution and density of the population and the consequent changes in the lengths of the cropping and bush-fallow stages of the usual agricultural cultivation cycle. A shortening of the bush fallow and lengthening of the cropping stage are inimical to the persistence and regeneration of *A. senegal* (Obeid and El Din 1970). The species behaves like a pioneer, rather than a major component of closed stable forest.

El Din (1969) found that in Sudan there are many factors affecting the regeneration and growth of the tree at different stages of its life cycle. At the fruit stage, there are heavy seed losses in the trees by many insect species (only about 16% were found to germinate). When the seeds fall on the ground, large numbers are eaten by insects and rodents. At the beginning of the rainy season, more seed is eaten by insects and millipedes than germinate during that period. Grass fires can also increase seed mortality. The amount of rainfall and its distribution and the soil type seem to have a direct impact on seed germination, it can germinate with rainfall as low as 250 mm a^{-1} on sands, but requires a minimum of 550 mm or more on heavy clays (Obeid and El Din 1971b). In the early seedling stages insects and millipedes are the chief causes of seedling mortality. The ground flora competition, and the shade cast by flora reduces the vitality of the seedlings. *A. senegal* does not appear to be shade tolerant whereas *A. mellifera* is more so, and can replace it on the clay soils where they both co-exist. On the other hand, Bird and Shepherd (1989) found the species more shade tolerant than *A. bussei* in the Bay rangelands of Somalia.

El Din (1969) concluded that the main factors affecting seedling mortality during October-May (dry season) are high soil temperatures and low soil moisture content. Seedlings that survive the hazards of the first dry season are then not affected by these variables. Losses are greater among seedlings in natural forest (only 1.3% survival) than in cultivated land (4.5% survival). Established seedlings can be completely destroyed by grass fires that are common, and browsing by goats and rodents can cause serious losses. Although moderate grazing can be beneficial to the development of the seedlings, heavy grazing can completely eliminate the species from the areas affected. This complex of factors seems to hinder regeneration and contribute to the disappearance of the species from many sites particularly the northern-most ones. Experimental evidence indicates that plantations can be raised by mixed cropping (taungya system), cultivating seedlings or direct sowing of seeds of *A. senegal* with the traditional crops (*Sorghum* and *Pennisetum spp.*, groundnuts, sesame and karkade) of the area. Tybirk (1991) found that seedlings of *A. senegal* appear abundantly after good rains in the Sahelian Senegal but also suffer severely from damage from fungi, insects, rodents, browsing ungulates and fire. Some grass or mulch cover seems optimal for establishment of seedlings and cultivation seems beneficial. He concluded that the pre-requisite of good regeneration (good seed crop, low seed predation and good rains occurring together) in the Sahel is rare.

As a pioneer, the rate of regeneration is often increased due to soil disturbance (Pratt 1964; Giffard 1973). Natural regeneration is significantly improved if protected against overgrazing, fire and indiscriminant lopping in cultivated fields and fenced areas (Depierre and Gillet 1971;Wata 1979; Baumer 1983; van den Bergh 1990). Obviously the importance of mature seed trees nearby is necessary, and in Senegal where tree stocking is less dense than in Sudan, reliance on natural regeneration has often proven unfeasible (Giffard 1975). Natural regeneration in the sandy soils of western Sudan has been recorded as episodic where different aged graduations in the same area are not common. By contrast natural regeneration in the clay plains of central and eastern Sudan is said to be more favourable. Average stocking of the trees in the gum gardens of western Sudan is around 45 trees/feddan (El Din 1969), whereas in the Demokeye Forest reserve near El Obeid average densities of 32 trees/feddan (1 feddan = 0.4 ha) have been recorded (Barbier *et al.* 1990).

Away from man's influence, the regeneration of the species in the Serengeti in Tanzania was found to be affected by fire (frequency and intensity) and browsing pressure by herbivores (Ruess and Halter 1990).

Bibliography: 105, 112, 134, 141, 238, 283, 284, 287, 289, 290, 343, 344, 554, 555, 608, 656, 765, 776, 804.

Enrichment

Given the poor regeneration in some areas, and the high costs of establishing plantations, enrichment planting has often been advocated within the gum belt (Giffard 1973; Awouda 1988). In Senegal, the density of the trees of *A. senegal* can be as low as seven trees per hectare

(Giffard 1975), and attempts have been made to enrich existing natural populations. Depierre (1969) described the broadcast sowing of 5 kg of seed per ha on recently cultivated land as giving reasonable results. However direct sowing by scattering seeds has not always proved feasible in Senegal (Giffard 1966, 1975), and planting seedlings is the more established method. In enrichment planting, the area around the seedlings needs to be cleared to reduce competition (Giffard 1973), and protection from grazing animals, fire and regular weeding. In Sudan, Awouda (1988) also advocated enrichment planting to fill gaps in the main gum producing areas of the gum belt between latitudes 12-13°N.

Direct sowing

Direct sowing of seeds, pre-treated or not, either broadcast or dug into the surface soil is a cheap method of establishing plantations provided large quantities of seed are available as mortality rates can be high. In dry and difficult areas only container-grown plants succeed; elsewhere the lower costs of bare-rooted planting or direct sowing are offset by the lower survival rate (Delwaulle 1979).

Seed can be directly drilled 1 cm deep. In Chad direct sowing has proved successful if the plantation is looked after in the first years after planting, and the costs of afforestation are estimated at 120 man days per hectare (Giffard 1973).

The 'gum-cycle' method used in the Sudan, where *A. senegal* and *A. laeta* regenerate naturally on areas of recently abandoned cultivation is not applicable in Senegal because the existing stands are too thinly stocked and too small. In Chad, a combination of direct sowing and 'taungya' has proved successful if tending in subsequent years has been adequate, but in Senegal, where this method would be too expensive, and planting is the accepted regeneration method (Giffard 1975).

In India, direct sowing can be successful, and on gravelly or rocky hilly sites plantations it is undertaken on the ridges of a ridge-and-trench contour system, with trenches 60 cm wide and 30 or 60 cm deep (Kaul and Chitnis 1964; Hocking 1993). In the driest regions of India such as Rajasthan, direct sowing is susceptible to die-back and nursery raised seedlings are recommended (Luna 1996). Also in India the failure to nodulate in so many of the species indicates the need for inoculation before sowing (Balasundaram 1987).

In drought years such as 1949, experiments in direct sowing were often unsuccessful (Bellouard 1949) but, in the same year in Niger, broadcast sowing of *Acacia senegal* followed by hoeing was found to be very successful even in a very dry year (136 mm of rain), whereas spot sowing was a failure (Nigerian Forest Service 1950).

Depierre (1969) gave results from experiments into establishing gum tree plantations in Northern Chad. Direct seeding of *Acacia senegal* with millet cultivation or broadcast seeding on abandoned cultivated fields were compared. The latter was recommended as being simpler and cheaper and preferred by farmers. Seeds broadcast at 4-5 kg ha^{-1} and enclosed by a thorn bush fence would expect a population of 1000 plants per hectare after 5 years. The value of gum production over 10 years was estimated to return 10 times the inital cost of establishment (15,000 FFr/ha).

In Sudan, there have been a number of sowing experiments carried out at the Umm Ruwaba research station comparing broadcast sowing with seed sown using a digging stick, with seed untreated or pre-treated with concentrated sulphuric acid (Sudan Forest Department 1956a). Seed was also sown at two dates, in May before the onset of the first rains and June during the rains. Germination was relatively low (9-22%) although sufficient for restocking the species in all treatments. In May untreated seed gave significantly better results than the treated seed, and the digging stick method was significantly better than broadcast sowing. In June there was no significant differences between pre-treatments, and again the digging stick proved a better sowing method. Results of experimental sowings of *Acacia senegal* at Sweilinga near El Fasher in 1954 obtained an 80% success rate. Seed pre-treated for 3 minutes with acid was sown on small mounds about 40 cm in diameter by 2 cm high.

In the Kordofan Province of Sudan, the most efficient method was found to be direct seeding, in the taungya method in the following way. After preliminary clearing, the soil is disc ploughed twice after the first rains. Seeds of *A. senegal* are planted in lines every 4 m, and the seeds sown in the lines every 8-15 cm, at the same time as sowing the agricultural crop (often sorghum). The final spacing of the trees is 4 x 4 m. Replanting in some lines may be necessary the year after. Weeding for two to three years is necessary close to the seedlings. Sowing with crops appears not to adversely affect production, as the roots of *A. senegal* penetrate well below the upper soil horizon in which sorghum develops (Vidal Hall 1963).

In the undulating sandy terrain in western Sudan, topography has an influence on establishment. El Hadi (1987) planted seeds from four different populations in two sites, one site being on an upper dune crest (sandy soil) and the other site on the lower slope of the same dune (sandy loam soil). Seedlings of all populations survived and grew better on the upper dune crest (sandy soil). Similar results were found in northern Senegal (Dione and Vassal 1993).

Bibliography: 85, 98, 105, 118, 235, 236, 237, 253, 293, 342, 343, 344, 402, 447, 448, 486, 549, 725, 792

Mechanized seeding

Mechanized seeding developed on the clay plains of central and eastern Sudan, where large scale mechanized rainfed agriculture was established (Awouda 1990). In central Sudan, plantations of *A. senegal* were established on abandoned cultivated lands where sorghum yields had declined due to loss of soil fertility. They were established by mechanised seeding at a seed rate of 15-25 kg ha^{-1}, on dark cracking clays. With disc harrowing and sowing during the rains, the plantations were successful, with weed growth not being too vigorous and the seeds being relatively cheap (El Houri Ahmed 1986). Similar techniques have been tried in northern Nigeria (Phillip 1975) and Chad (Giffard 1975).

In Kassala Province of eastern Sudan, there have been many research trials undertaken on the clay plains (Badi 1967). These plains are divided into two sections by the 450 mm isohyet which is approximately along latitude 14°30' N. In section A (above 450 mm mean annual rainfall) where crop production is possible, soil ploughing and mechanical seeding of *Acacia senegal* around Gedaref was successful. On these deep black cracking clays, it is essential to drill deep so that the seedling has deep root penetration to survive the dry season. The seedlings are thinned to 4 x 4 m spacing and sorghum (dura) drilled between them. Previous failures were due to sowing in shallow pits. Deeper ploughing with weeding and mulching allowed seedlings to reach over 60 cm after the second rainy season. Rats can be a problem but with clean weeding, kites could then control the rat population. In section B, which are brown non cracking clays (with less than 450 mm annual rainfall) such as Hawata, the best results were achieved by planting in 35 cm deep contour furrows, prepared from a tractor and ridger.

On the other hand, Khan (1965) found that direct spot seeding was more successful than furrow planting at Hawata. Of the eight different soil working techniques were tried, the most efficient and economical was the 'Pit Method', where 30 cm^3 of top soil was dug out, broken up and refilled into the pits. Pits were spaced 4 m x 4 m. To ensure success with direct seeding, the earliest sowing should be done in July. Nursery stock was better left to the end of July. There was also a need for three to four weedings to reduce excessive competition from grasses.

Techniques for direct mechanized sowing on the drier *qoz* soils of northern Kordofan have proved to be much less successful, largely because of problems of moisture conservation. Micro-catchments are essential but even so, survival is poor.

Bibliography: 86, 89, 90, 295, 343, 344, 457, 595.

Raising seedlings

Seed can be planted in the nursery, preferably in long plastic tubes (30 cm), 2-4 seeds per tube, thinned to one seedling after 4-6 weeks. There is a rapid tap root growth, and frequent root pruning is required. After 4 to 6 months they are ready to be planted out, the spacing depending on the end use. In sandy soils in Sudan minimum spacing is 4 x 4 m or 10 x 10 m with agriculture intercropping (beans, groundnuts and millet). On clay soils, mechanical preparation by sub-soiling is preferable, but this method is costly and therefore planting in hand-dug 'pit method' has proved most cost-effective . Pits are dug every 4 x 4 m and 30 cm^3 of topsoil is dug out, broken up and refilled (Khan 1965).

In India, the plants can be sown by planting out one-year-old nursery stock. Nursery-raised seedlings are often planted in 30 cm^3 pits which are half filled with soil and half made to heap on the lower side of the slope. Height growth is slow, on average 40-45 cm a^{-1}, and seedlings are suceptible to attack by white ants (Luna 1996).

The best results in Senegal are achieved with planting nursery raised plants, although there needs to be a good source of water (1m^3/10,000 seedlings/day), windbreaks and barbed wire fences around the nursery. Three to four seedlings per polythene sac (30 x 10 cm) are sown, with germination starting around the fifth day. Estimated time in the nursery is 100-115 days (Giffard 1973). Ground preparation is very important if successful planting is to be achieved. Deep ploughing is widely recommended (Giffard 1975). This makes the most of available water, reduces loss by run off and evapo-transpiration, improves the aeration of the soil and increases the volume of exploitable soil for the roots in the weeks which follow planting.

In Senegal, seedling planting has also been tried when plants are "en motte" (in soil brickettes). Initial growth is much faster for nursery raised stock than in direct seeding so it is possible to gain a year in time between planting and first harvest when seedlings are used. It takes 100 to 120 days from the sowing date to the time when the seedlings are ready to plant. Seedlings must not be planted too young because they will not be able to develop a tap root in time before the rains stop which will render them very prone to drought. Seedlings which are too old become pot bound.

There have been some trials using water-absorbing polmers to aid establishment and early growth of *A. senegal* in arid soils (Callaghan *et al.* 1986; 1988; Ahmed 1989). A polyacrylamide and a polyvinylalcohol were tested in the Sudan, with both polymers significantly increasing survival rates in two nursery experiments. However, it is unlikely that their application will be justified economically.

Bibliography: 15, 42, 91, 92, 140, 148, 174, 175, 181, 228, 268, 283, 295, 342, 343, 344, 457, 486.

Vegetative propagation

There have been a number of research studies on rooting cuttings from different aged trees of *A. senegal*, but while rooting has been successful the cuttings have retained the physiological characteristics of mature trees, with slow shoot growth and plagiotrophism. Propagation by this method has not been used to any extent in the field.

Research into vegetative propagation has aimed to bulk up trees with higher gum yields. In Mali, cuttings from five-year-old plants rooted best when the IBA hormone at 2% was added (N'Diaye *et al.* 1993a), and Cheema and Quadir (1973) also sucessfully rooted cuttings in Pakistan. In a series of studies undertaken in Senegal, successful rooting of eight node cuttings from four-year-old trees (Badji *et al.* 1991), and branch fragments from 13-year-old trees was achieved (Danthu *et al.* 1992). In the latter study, the most responsive planting stock was taken from cuttings 15 cm long (with 12 to 15 nodes) and a diameter of 10±6 mm (wood 2-4 years old). Rooting was optimal when the cuttings had no leaves and were collected in the rainy season (June-October). However they retained the slow shoot growth of the mature trees, and further studies aim to investigate a process of rejuvenation.

In Mali, grafting and micrografting have been successfully tried on seedlings, but again the clonal material has not proved viable (N'Diaye *et al.* 1993b; Palma *et al.* 1996, 1997). In India, Kathu and Tewari (1973) described the development of roots from callus cultured *in vitro* from excised cotyledons of *Acacia senegal*.

Bibliography: 93, 94, 95, 186, 221, 443, 542, 543, 567, 570, 571.

Planting out

Planting out practices include soil preparation, plant spacing and density, watering and irrigation, fertilization and general maintenance (Houérou Le 1980a). Plantations tend not to be irrigated but are planted out at the beginning of the rains. Plantations in Africa are primarily for gum production, while those in India have been for fodder and fuelwood and sand dune stabilisation. In Africa too early tapping or lopping of the trees before 4-8 years can adversely affect future production (Houérou Le 1980a).

For planting in Senegal, the land needs to be cleared of vegetation, and the best method found was to dig 60 x 60 x 60 cm holes spaced every 4 to 5 m apart (the recommendation is 5 x 5 m for easy vehicle access). Giffard (1973) estimated planting 3-4,000 trees daily. It is important to weed the plantation, protect against livestock, and apply insecticides against termites although the Acacias are not very susceptible to them. For seedling establishment, competition from the grass (*Pennisetum cenchroides* Rich.) was recorded by Blunt (1926) as one of the major limiting factors. The competition with other plants can be for moisture, light and nutrients. Other spacing trials in Senegal have shown an optimum spacing of 6 x 6 m with thinning after six years (Dione 1988a). Lindley and Deans (1992) found a range of final spacing from 7-10 m in agroforestry plantations ranging from 3-17 years old in Senegal.

For transplanting into extremely arid regions in India, half-filled pits 60 x 60 x 60 cm have been found suitable for establishment (Kaul and Chitnis 1964). In the hot arid zone of Jodhpur, Western Rajasthan, India, which has an annual rainfall of 320 mm, trials were established at 5 x 5 m spacing (Raina 1984). On sloping hillsides in northern India, closer spacing of 3 x 3 m was tested on staggered contour trenches (Grewal *et al.* 1996). In Jodhpur, Ahiya *et al.* (1985) recorded a planting density of 1,517 trees per hectare in a 12 year old forage plantation.

In western Sudan, the recommended spacing from the Umm Ruaba research station on the goz soils is 4 x 4 m. The actual density of trees in the gum gardens is around 45/feddan, and if the 4 x 4 m spacing is followed the density would increase to 250 trees/feddan (Vidal Hall 1963). Nursery grown seedlings which are planted out produce gum a year earlier than direct sown plants.

Because the west African soils are poor in nutrients, some experiments have looked at supplementation with fertilizers when planting out. Baumer (1983) recommended 150 g of NPK at the bottom of each planting pit to increase growth and drought resistance of the seedlings. Because of the high cost of fertilizers and the capacity for nitrogen fixation by the seedlings, only phosphorus applications to the soil have been investigated in more detail. In the northern Senegalese soils, Dering *et al.* (1978) found that the low phosphorus adsorption capacity of the soil indicated that phosphorus applications should not exceed 83 kg ha^{-1}, and recommended the use of slow-acting granulated triple superphosphate. Colonna *et al.* (1993) found that as little as 30 ppm of additional phosphorus increased growth and nodulation of seedlings of *A. senegal*, through increased macro nutrient uptake. Increased seedling growth over four years was also recorded in India with use of phosphorus or phosphorus plus nitrogen applied to the planting pits (Dutta *et al.* 1997).

Bibliography: 14, 105, 112, 140, 200, 229, 239, 249, 268, 342, 343, 354, 405, 447, 478, 620, 792, 836.

Windbreaks and hedgerows

The field experiments, at the ICRISAT Sahelian Center at Sadore, southwestern Niger, analysed the effects of

windbreaks of five native tree species (*Acacia nilotica* subsp. *adstringens*, *A. senegal*, *Azadirachta indica*, *Bauhinia rufescens*, *Faidherbia albida*), one exotic tree species (*Acacia holosericea*) and a grass (*Andropogon gayanus*) on the growth of pearl millet (*Pennisetum glaucum*) sown to the west of each windbreak. The tree windbreaks were in a staggered two-row configuration at 3 x 1.5 m spacing established in 1988, and were pruned to 2 m tall and 1 m sideways before each rainy season. Windbreaks were 30 m apart (Mayus 1998). Lamers *et al.* (1994) concluded that, for the establishment, growth and fodder value of windbreaks, *A. senegal* and *B. rufescens* showed the greatest potential. In Rajasthan India, 3 x 5 m spacing was used for a number of species including *A. senegal* for stabilizing sand dunes (Sharma and Gupta 1989b).

As a thorny security barrier or hedgerow species, both varieties of *A. senegal* (vars. *rostrata* and *leiorhachis*) are recommended for the hot and dry regions of southern Africa (Henderson 1987). Variety *rostrata* makes an excellent framework plant, being sturdy, multi-stemmed and low-branching with fine foliage casting little shade. It reaches an average height of 2-3 m and a maximum of 9 m, and will grow on stony, deep sand, clay, brack and calcrete soils. Variety *leiorhachis* on the other hand could be a potential tall filler, giving rise to a very sparse and slender crown, and reaches an average height of 5-8 m with a maximum of 17 m, and appears to grow only on stony or calcrete soils.

Bush encroachment

Lely (1925) noted that the species can form dense thickets around Sokoto in northern Nigeria, and Pratt (1964, 1971) detailed methods for clearing thickets of this species in northern Kenya. Various herbicides have had a limited success by ground spraying (Anon 1956). Mechanically flattening the trees doubled the natural rate of regeneration but, combined with arboricidal treatment, burning and grazing by goats proved a better control method (Ivens 1958; Pratt and Knight 1971). *A. senegal* var. *rostrata* has been included in the National Weed List in South Africa having the undesirable characteristics of being competitive (for space, light, water, nutriment), a thorny (plant), and obstructing access. It is also a declared invader (Wells *et al.* 1986). A number of herbicides were tried by aerial spraying to control thornbush invasion of pasture in Mozambique, and Picloram was found to be effective against *A. senegal* (Almeida 1974). Both in South Africa and Australia there are policies to eradicate it (National Academy of Sciences 1980). It is these competitive properties that make it so resilient in establishing in semi-arid areas.

Bibliography: 23, 73, 202, 421, 476, 539, 608, 609, 610, 813.

Tapping and other factors which stimulate gum production

In Sudan, the established method of tapping using a small axe appears to be the best. In some areas there is an alternative method in which the local hoe, similar to the Dutch hoe, is used to scrape the bark instead of tearing off a strip. Use of short handled rubber tapping tools proved unsuccessful (Sudan Forest Dept. 1960). Muthana (1988) also described a new gum tapping tool, the "Sunki" or "Sonky", which is in the form of a bayonet which is pushed under the bark on branches having more than 2.5 cm diameter. The tapper then has to move about 90 degrees, facing the strip of bark to be removed. The blade is pulled back causing a wound about 2.5 cm wide and up to 1 m long. The "sonky" is widely used in the White Nile, North Kordofan and South Darfur, whereas the small axe is more commonly used in Blue Nile, South Kordofan and North Darfur (Barbier *et al.* 1990).

The best time for tapping appears to be around mid to end of October when leaf shedding occurs, and there is a change in the colour of the inner bark. This is the early tapping, while there is also a late tapping period from December to March. It should be noted that this date depends on the prevailing season's environmental conditions, and can vary in wetter or drier years. The first gum exudation takes place a few weeks after tapping and is favoured by hot weather. Cold weather will reduce the gum yield significantly. The gum is collected in a series of pickings and peak production is obtained from the two to three pickings afterwards. In northern Nigeria, gum yields were higher from the late tapping (April) than the early tapping (December), and trees tapped early during the dry warm season and late during the dry cold season produced darker gum arabic (Oleghe and Akinnifesi 1992).

The age that the trees are first tapped varies, and in the gum gardens of Kordofan and Darfur it usually starts around 4 years. This is also the case in the natural stands on the clay plains, while trees produced from coppice regeneration can start as early as 3-4 years. There have been reports that the yield and quality of the gum depends on whether the gum is exuded from the main stem, main branches, mid-crown or upper branches. Gum exuded by the mid-crown branches is reported to be best in terms of quantity and quality, while gum from the main trunk tended to produce darker coloured nodules. The gum chemistry from the main trunk also appears to be different from the mid-crown (Anderson and Dea 1968). There appears to be an inverse relationship between gum yield and pod yield, with more gum produced in trees that failed to produce pods or seeds (Saad 1981/82). There is also a linear relationship between the numbers of branches tapped and the gum yield. The greatest yields occurred when six branches were tapped, but this is usually only done in an old gum garden destined to be felled, and more commonly two branches/tree/season are recommended. Overtapping can

be destructive (Ballal 1986 cited in Barbier *et al.* 1990). Healthy trees produce more gum than diseased ones, and hot dry weather promotes exudation while cold weather can significantly retard the process (El Din 1981b). He also reported that four to six pickings can be made on sandy soils in one season whereas only three to four pickings on trees growing on the clay soils.

As gum yield is associated with leaf fall, spraying the trees with an artificial defoliant was tried at the Gum research station near El Obeid during 1968 and 1969 to see if it produced a similar effect. Gramoxone was sprayed at different concentrations, and sprays at 10 millilitres/tree gave a higher gum yield than either the control or at higher doses. While this hastened the gum productive season, it has not been adopted to any extent (GRD, Annual report 1968/69 cited in Barbier *et al.* 1990).

A number of chemical solutions have also been investigated to stimulate gum production. In India, extensive stands of *A. senegal* (both wild and planted) occur in Gujarat and Rajasthan, but the trees exude little or no gum naturally. Ethephon solution was introduced into holes bored into the bark of various *A. senegal* trees to induce gum production. Little or no gum was produced by control trees (holes bored but no ethephon added), and the most gum exudation (806-950 g/tree) occurred in the 960 mg concentration treatment. Exudation started 4-8 days after treatment (Bhatt and Mohan Ram 1990; Khan and Harsh 1994). Misra and Singh (1985) also studied the effects of applying acid, alkali and mud solutions to blazes produced by tapping the bark, to stimulate gum exudation in natural stands of *A. nilotica* in Uttar Pradesh, India. Greater gum exudation was obtained with the alkali (NaOH) solutions, and in a second experiment the optimal concentration of NaOH was found to be N/20. It is suggested that tapping at breast height should be done in the summer and the gum collected at the end of the rainy season (September/October) provided the blaze is protected from rain with a tin shade. From Sudanese research, gum tapped from the main trunk is of rather poor quality. Hocking (1993) reported for gum production in India, transverse blazes 4 cm wide and 1.3 cm deep are cut every 26 cm apart on the branches in the summer and then sprayed with a solution of 50% sulphuric acid.

In Senegal, various hormone treatments were sprayed on the trees of *A. senegal* (Netragone 600, Rhodia 600, Netrazol double and Tropotone) to increase exudation without success (Giffard 1973). Other experiments were tried there by spraying *A. senegal* with various formulations of 2,4-D, 2,4,5-T, and MCPA, which showed that all exercised a temporarily depressing effect on gum yield. In the case of one formulation, however (200 g of 2,4,5-T + 400 g of 2,4-D in 1 litre water), the depressing effect slowly wore off, and at the end of the season gum yield of treated trees was double that of controls (Service des Eaux et Forêts 1960). Note that these formulations were used at higher concentrations to eliminate the trees from pasturelands (see Bush encroachment).

Bibliography: 53, 105, 128, 286, 343, 402, 454, 521, 534, 559, 659, 678, 728.

Lopping and coppice

While the species is considered an important browse species in the Sahelian and Sudanian zones (Houérou Le 1980c), the pastoralist is often blamed for large mortalities of its populations through over-lopping and overgrazing (Toupet 1984; Wata 1979; Delwaulle 1975). This is also the case in the Indian subcontinent (Verma 1972). Excessive lopping and half cutting the branches so that they hang down and are accessible to the goats, can lead to disease and premature death of the trees (Perrot 1939).

On the other hand, coppicing has long been practised in the gum garden cycle in western Sudan (Troup 1983; Badi *et al.* 1989; Jamal and Huntsinger 1993), the same tree sometimes coppiced more than once. In a coppicing experiment carried out in 1978/79 by the gum research officer at Kordofan, Sudan, a total of 1,744 eighteen year old trees were felled, and 808 coppiced (Barbier *et al.* 1990). Coppice growth rates in Kordofan gum gardens reach 1.2 m high after 3-4 years, and 3-4 m after 10 years. On clay soils of Kassala region, plantation seedlings grew 1.4 m in 7 years.

In French west Africa, experiments in cutting down the trees which have ceased to yield gum, led to the conclusion that coppice regrowth occurs only in trees of 12-13 cm. in diameter or less and the larger trees do not coppice (Bellouard 1949). However in India it has been managed on a coppice rotation of 30-40 years. Troup (1983) gives figures from the Ajmer-Merwara Forest Division, where on coppice rotation of 30 years 82% of the stools gave coppice shoots, and on a 40 year rotation 92% gave coppice shoots.

Bibliography: 90, 105, 118, 232, 405, 407, 427, 589, 762, 763, 791, 804.

II. HISTORICAL SURVEY OF GUM ARABIC: ANCIENT TRADE AND USES

Gum arabic is a truly ancient article of international commerce. Although many of its present uses involve complex technological processing, some have changed little since the first recorded use of gum arabic in the mixing of inks and paints in ancient Egypt. The traditional uses for which gum arabic earned its reputation amongst the ancients and the peoples of the Sahel, the Arabian Peninsula, and India, can still be found in these areas today. This section provides an outline of the development of the trade in gum arabic from antiquity until the 1960s.

GUM ARABIC IN ANCIENT EGYPT AND THE CLASSICAL WORLD

The oldest recorded finds confirming the use of gum arabic, or gum acacia as it is referred to, date from the first Egyptian Dynasty (3400 B.C.). Petrie (1902) noted the use of carbon mixed with gum and water to make ink. He found "dozens of pottery jars with ink inscriptions" at Abydos which he confirmed were painted with this mixture. This type of ink is still used today. Inks and pigments consisted of very fine powders of malachite, azurite, ochre, none of which will adhere to a surface without some sort of binder. These tempera colours used either egg white, gelatin or, most usually, gum which was recognized as the most effective binder giving the best results (Lucas 1963). Inscriptions from the 18th Dynasty refer to gum as "Komme" or "Komi". Medical texts have proved to be valuable sources of information on gum at this time. Charpentier (1981) recorded in his major work on botanical inscriptions the following referring to 'Komme' (see Figure 5).

Spurrell (in Petrie 1902) found gum, which he stated was gum acacia, used as an adhesive for paint in the 4th Dynasty (ca. 2600 B.C.) and again in the 18th Dynasty (1580 to 1314 B.C.). Spurrell also stated that "Several pots of paint were found to have a thick layer of gum overlying the colour which had settled at the bottom. These had not been exposed and the gum answered all the usual tests. Gum was also used for the painting of Akhenaten and the little princesses. It was used also on part of the painted pavement."

Inks and paints in the time of the Pharoahs were similar to the watercolours available today, especially those produced for children, which have to be non-toxic and contain gum arabic. Lucas (1962) remarked that inks and paints were used in the same way as modern watercolours. "The pen was dipped in water and rubbed on the ink which was often stored in a palette form."

Gum arabic was commonly used as an adhesive though not to the same extent as gelatin. It was however the only adhesive to be used in the glueing together of small pieces of papyrus for making writing "paper" and also for linen. Only animal glues were used for heavy jobs, such as glueing wood in joinery. One of the better known uses of gum arabic by the ancient Egyptians was in the mummification process. According to Herodotus (in Lucas 1962) gum was used to fasten together the linen bandages in which mummies were wrapped after embalming. Reutter (undated) identified gum on bandages in the 18th Dynasty (1580 - 1314 B.C.) and Lucas confirmed this for the 20th Dynasty (1200 - 1085 B.C.). Smith (undated, quoted in Lucas) noted "a sheet of cloth saturated with some gum like substance was placed in front of the face" of the mummy of Amenhopte III (18th Dynasty) and Smith also mentions "gum saturated bandages".

Naville (1894) in his work on the Temple of Deir-el-Bahari found pots containing "nitre" (probably natron the soda used for desiccating the body), gum and straw for stuffing the body. Gum it seems was used not only in the bandaging but also mixed with spices to pour over the prepared mummy. Carter, whilst exploring the

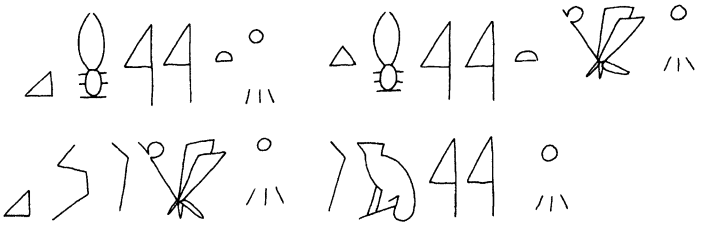


Figure 5. Four 18th Dynasty hieroglyphs depicting gum acacia.

tomb of Tutankhamun, found the "embalmers cache". The equipment used and the body parts removed during the mummification process could not be buried together with the king but nor could they be thrown away because they had been in contact with the king's body. It was therefore common practice to bury these materials some distance from the tomb (Hepper 1990). These finds have given valuable information on the materials and methods used in mummification and it appears that gum arabic played an important part.

Although gum arabic, being largely odourless, was never used to the same degree as the perfumed gums and resins such as myrrh and frankincense in the perfume and cosmetic industry of ancient Egypt, it was a key ingredient in certain notable products such as *kohl* eye make-up, rouge powders and face creams. Eye paints were very important in ancient Egypt and indeed *kohl* is still widely used today and has even been marketed in the west as the make-up of the ancients. *Kohl* consisted usually of galena (lead sulphide) mixed with gum and water to create a smooth paste that could be easily applied. Manganese oxide, brown ochre, malachite and other copper ores were also used for making eye paints always mixed with gum and water. Samples of rouge and lip colours made from ochre mixed with gum have survived until the present (Manniche 1989).

Pre-occupation with wrinkling and dry skin was just as strong in ancient Egypt as it is today and gum was an important ingredient of anti-wrinkle moisturising face creams which were applied after cleansing the face (Manniche 1989). Gum was also mixed with beeswax to give shine and lustre to the hair. Body hair in ancient Egypt was removed by both men and women and gum formed a key ingredient of depilatory preparations.

Although unscented, gum arabic was already known for its ability to "fix" flavours and scents without altering them. Its ability to create emulsions with oil was also important in the perfume industry and in the making of salves.

Gum arabic was a common part of the Egyptian *materia medica*. It was, and still is, an essential ingredient in the binding of drugs (which were usually to be found in a powdered form) into an edible or spreadable form. There are a great many examples of medicinal remedies that include gum and for a fuller account of this fascinating subject, Manniche (1989) has compiled an ancient Egyptian herbal. A few examples are given below:

1) Gum used in dentistry for the treatment of toothache and gum disease. Cinnamon, honey, oil and gum are mixed together with a little water and are taken as a masticatory. Cinnamon in large doses is known to give a numbing effect rather like cloves. The gum formed a "chewing gum" base for longer lasting contact in the mouth.

2) Gum used to treat eye disorders. The Copts used acacia flowers, leaves and gum in their preparation of eye ointments. A common recipe included opium, gum, acacia leaves (not specified as to which species) and copper ground in equal parts. When mixed with a little water the gum dissolves and forms an ointment that will slowly dissolve in the eye. The opium probably had the greatest effect although copper is commonly mentioned as an important ingredient in the treatment of eye disorders.

3) Bone fractures were commonly treated using various unknown herbs and acacia leaves. Gum was an essential ingredient in the wrapping of the bandages to provide a "caste" by giving some support to the fractured bone.

4) Gynaecology was probably more developed in ancient Egypt than it was right up until the Middle Ages in the Arab world and later in Europe. Gum arabic was used in combination with astringent herbs, applied as a tampon and used to treat excessive bleeding after giving birth and to treat infections of the uterus. Gum arabic was also eaten by lactating mothers because of its high calcium content. In India and many Sahelian areas this is still practised today. Breast feeding mothers applied gum arabic to painful nipples as a soothing salve. This is also commonly practised today.

It is well documented that Egypt traded with the land of Punt (now widely accepted as referring to present day Somalia) by sea and with the land of Cush (the Nile valley) by river and land. Egyptian and later Greek ships are known to have traded along the Red Sea coast. This linked the Egyptians to the Asian trade routes which brought spices to Oman and Yemen. Cinnamon is thought to have entered Egypt by this route. Very little information exists for the trade in gum arabic specifically but it is known that caravans operated between Cush and further south to Aswan (Philae). Gum, ivory, gold, carnelian, incense, slaves and hides were regularly traded. Pliny, writing in 1 AD stated that in his day the best gum came from Egypt. Although Lucas believed that gum producing acacias were plentiful in Egypt at the time, and that gum probably was produced locally, the best water soluble gum came from the land of the upper Nile. In other words, Pliny was referring to gum that was exported by Egypt to Greece and Rome but which originated in "Sudan" (in Lucas 1962).

In the 19th Dynasty, Sethos I boasted of his conquests on behalf of the god Anrium:

"I turn my face to the east, I work a wonder for you... I gather all the countries of Punt, all their tribute of gum and myrrh and cinnamon and all the sweet wood of God's land." (Quoted in Manniche 1989).

THE COLLAPSE OF EGYPT AND THE MIDDLE AGES

The Egyptian style of civilization continued long after the collapse of Egypt under the foreign invasion of Assyrians, Persians, Greeks, Romans and finally Arabs until the invasion of Cush by the Christian king of Axum. From the 4th Century to the 14th Century the Nile Valley came under the control of the Christian Kingdoms of Nubia. During this long period for which information is severely lacking it can only be assumed that trade between the region and Egypt ended because it is known that frequent fighting took place between Nubia and the new Moslem State first under the Fatimids and then the Mamluks before the Turkish Ottoman Empire took hold at the end of the 14th Century. Trade must have continued through the Red Sea where Greek traders exported gum arabic to southern Europe.

Although the Arab Moslem invasion first took place in 620 A.D., it was not until the 14th Century that the Christian kingdoms of the upper Nile collapsed under the Islamic pressure from the north (and from an increasingly proselytised local population). The Arabs took control of the Red Sea trade routes, ousting the Greeks and cutting off all trade (which was very profitable) between the Nile Kingdoms, Asia and Yemen. Information on the fate of the trade in gum arabic from the Nile at this time is unavailable but it is likely that gum found its way into the markets of the Arab world where small amounts were probably re-exported to Europe.

Meanwhile, the spread of Islam had a profound effect on and was effected by the growth of trans-Saharan trade routes, which were developing amongst rumours of "Wangara", the legendary land of gold south of the desert. Travellers such as Leo Africanus and Ibn Battuta inspired many traders to make the journey across the desert to the famous savanna kingdoms (see Figure 6). These empires and city States stretched from west to east in a zone corresponding roughly with the "Gum Belt" so it can be assumed that gum was an item of trade once excursions across the Sahara began. These States were well placed to benefit from a north-south trade which cut across the west-east ecological zones characteristic of western Africa and so were able to engage in the trade of forest and savanna zone goods which began to enjoy considerable demand in Europe. The trade goods could be divided as follows:

Essential goods:	Going North - Slaves and gold
	Going South - Swords, salt and cowries
Luxury goods:	Going North - Cloth, pepper, ivory, gum, leather, kola and, later in the19th Century, ostrich feathers.
	Going South - Copper, textiles, glass beads and fancy goods.

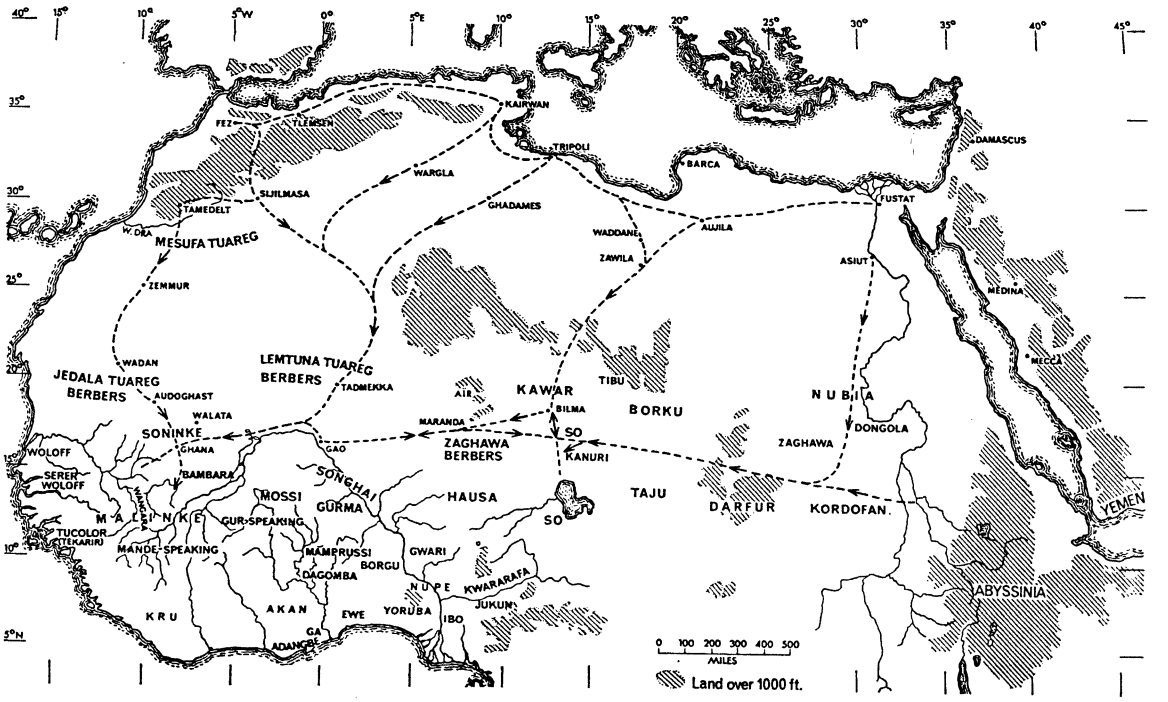


Figure 6. Trans-Saharan caravan routes from the first millennium A.D. onwards (from Hogben and Kirk-Greene 1969). Gum trade north of particular importance during the Middle Ages.

The Middle Ages were a truly golden age for trade and civilization in the savanna States, particularly those of West Africa. Richard Jobson (quoted in Bovill, 1962) writing much later in the 18th Century said of this time: "The golden trade of the Moores in Barbary was the first incourager and beginning of this businesse (referring to the slave trade)". During this period gum was traded across the Sahara mostly to entrepots in Morocco and Libya (Fez, Carthage and Tripoli) from where it was traded throughout the Mediterranean.

Literature directly related to gum arabic in the Middle Ages is very scarce. It is however known that, through contact with the Middle East during the crusades, the growth of medical ideas and the translation in the 15th and 16th centuries of Arab scientific works did involve an increased trade in "exotic" natural products into northern Europe. Giffard (1975) cited the case of King Philip V of Valois (France), in the 14th Century, placing an import tax on gum arabic. This would imply that the product was deemed sufficient in value and quantity to make this worthwhile.

Uses of gum arabic in the Medieval world seem to have changed very little since the time of the Pharoahs. In paints and inks, which for the most part remained in the tempera form, gum was still used as a base for mixing pigments (Singer *et al.* 1956). Medicines during the Middle Ages in Europe tended to consist almost entirely of simply ground plant substances with some minor physical treatment such as heating or mixing with water. Rubin (1974) noted that there was very little change in English medicine from Anglo-Saxon to Norman times. It seems that medicine was not very far advanced in England, certainly in comparison to other parts of Europe and the Arab world in particular, right up until the end of the 15th Century. It is unlikely that gum arabic was widely used in northern Europe during the early Medieval period; however, Rubin (1974) mentioned that King Alfred (9th Century) was in communication with the "east". King Alfred is known to have suffered from a long term respiratory complaint and, unaided by his English physicians, he looked further afield for help. Prescriptions are believed to have been sent to Alfred from the Patriarch of Jerusalem, Elias. The ingredients sent have been described as different "balsams" which probably included gum arabic because this gum was a major ingredient in the blending of cough mixtures and other remedies for respiratory problems. Other than this particular incident, gums seem to have been unknown in England until the 15th and 16th Centuries.

The use of gum was better known in France where recipes very similar to those of ancient Egypt were used in the preparation of ointments to treat eye disorders. The recipes included honey, seawater or wine, rainwater, herbs and gum (Rubin 1974).

In the 13th and 14th Centuries the Arab influences in science and medicine began to reach even northern Europe and with this a greater interest in the cause of disease rather than just the symptoms. However, Thorndike (1963) demonstrated that even at the height of the Renaissance in Italy medicine remained inextricably linked to superstition and magic and that little had changed in the treatment of illness since ancient Egypt, Greece and Rome.

Gum was used in Italy during this time. Thorndike (1963) gives an example from the medical recipes of Bistichius, a minor physician of the 1400s. A recipe including gum "oft tested in many and the greatest emergencies" is given:

"Take a pound of turpentine; of frankincense, 2 ounces; of aloes, lemon, one ounce; of mastix, gariofle, galange, cinnamon, musk, cubebs, one ounce each; of gum six ounces; of ardent water four times distilled, one pound. Ground all of them that can be ground and mix together and put in an alembic and seal it so no vapour can get out and place it in a furnace for the purpose, namely a distillery, and distill it with a slow fire. The first water will be clear as spring water, the next will begin to show colour and to thicken and it will float on the other water and they will not mix. But the third water will be denser and thick like honey (i.e. the gum will have dissolved). If you put a drop of the mixture into tepid milk it coagulates." Similarly, John of Arezzo, another physician of this period (1460s) who worked under the patronage of the de Medici's, extols the virtues of "traditionally" used medicines; frankincense, cinnamon, gum, saffron, amber, citrus, figs, mace, musk, pistachio, silver, gold, tamarind, honey and coriander. Many items of eastern origin are clearly found in this list. It seems that there was very little innovation of ideas in medicine at this time, physicians tending to rely on what had gone before: "For in these matters I would not presume to advance anything of my own. Since the richest treasures have been found rather by the opinion of the ancients than by reason, it is better for anyone to acquiesce rather than to attempt something new" (Thorndike 1963).

There do not yet appear to be any other important uses for gum in Europe at this time other than for paints and medicine. The breakthrough into the textile market had not yet taken place in Europe where urine was still the major ingredient in the finishing of cloth. It is likely however that gum for sizing cloth was already practised in the Arab world.

THE 16TH CENTURY ONWARDS

In the east, the Sultanate of Funj, which was in its prime in the 1500s brought a period of political stability and

economic prosperity to the Nile Valley. At this time, slave trading, cattle keeping and gum tree husbandry were the most important economic activities (Ewald 1990). Sennar became a major market centre being the nexus of the principle trade routes. The Funj Sultanate continued to control the trade in the specialized markets of Sennar right up until the 1760s when the sultanate finally collapsed. It had been a very long period of stability during which the trade in gum with the Ottoman Empire in Egypt and with the Red Sea ports flourished. Gum was, by the 17th Century, being regularly exported to Europe through the Ottoman Empire (hence it obtained the name of Turkey Gum). Gum traded through this channel tended to make its way to the Adriatic port of Trieste which was up until the end of the 19th Century the "gum capital" of Europe (Daly 1986). Gum from the Nile Valley which was exported to India via the Red Sea ports also entered the European markets in the 18th century and later under the name "East Indian Gum" (Caius and Radha 1941).

Eighteenth Century Kordofan (the main gum producing area) on the collapse of the Funj Sultanate became a centre of conflict and political fragmentation (Ewald 1990). Commerce, however, managed to continue through the development of trading diasporas of merchants who needed protection during the unsettled times. Gradually, settlers from the Donghala region to the north settled in Kordofan and brought new agricultural skills with them. A market began to develop at El Obeid and the gum trade was once again organized as one of the major items of commerce after slaves. Gum was traded to Shendi, the major trading centre north of Khartoum where it was then transported mainly north, by caravan but also to some extent by river, to Egypt. Figures are not available for exports but, although gum was an important article of trade, it is unlikely that the quantities exported ever amounted to more than a few hundred tonnes at this time. The very long distances which had to be covered precluded an expansion in exports of the level found in West Africa in the 17th and 18th Centuries.

Much more information is available for the gum trade from West Africa because by the end of the 15th Century European interest in this area was considerable and so records are available. The reasons for the interest in West Africa are attributed mainly to the knowledge of the existence of considerable gold producing areas and the desire to have more control over trade. By this time, much of the Mediterranean trade was in the hands of the Moslem Arabs. A genuine desire to have Christian control (and of course cut out the Arab middlemen) was at the heart of much of the interest of Europeans in West Africa at this time. This interest was most obviously taken up by the Portuguese under their King Henry the Navigator. By the mid 1400s, Portuguese ships were establishing trading posts along the Atlantic coast. From here, gum was much more important than it had ever been across the Sahara because the producing region was close to the Senegal River and within access to the sea. Ship transport could handle the bulk much more easily than the caravan trade. This access and transport factor is at the heart of the advantage that West Africa had over the Nile region until the nineteenth Century steamers began to operate on the Nile and later when the railway reached the gum producing areas.

There can be no doubt that the prime motivation for European trading activity on the West African coast was the search for gold and not gum but in so doing the gum trade became very important. As early as 1531 the coastline from southern Mauritania to the mouth of the Senegal River was called "the gum coast" (Bovill 1963). Arguin became the major centre of the trade in the late 16th Century. The Portuguese, however, lost their position in the gum trade when their attention turned to the trade in slaves which began to take off at this time. The Portuguese effectively left the trades in products such as ivory, gum and gold to the French, British, Dutch and Danes who began to vie for influence along the coast. The 17th Century witnessed the start of the period of fort building and trade wars which are so characteristic of the history of this region.

The history of West Africa is perhaps over-dominated by the issue of slavery to the exclusion of other important economic activities which took place. The trade in gum is one such activity. Even during the peak of the slave trade (early 18th Century), some areas along the West African coast continued to conduct an important trade in other commodities (Hopkins 1973). The Senegambia region is one of the best examples of trade in commodities other than slaves. Gum was the major export of this region throughout the 17th and 18th Centuries, outstripping the trade in slaves in terms of profitability.

In the 17th and 18th Centuries a substantial trade in gum arabic took place from the desert ports of Arguin, Jiwa and Portendick on the Mauritanian coast (Figure 7). The British and the French were the main shippers of gum even though the industries in France and Britain were using very little of it (Webb 1985). Most gum was destined for re-export but information on destinations is lacking. Traders were attracted by the considerable profits that could be made in the gum trade. The prices for gum on the European markets were much higher than the prices paid to the desert suppliers. These large profits help to explain the "gum wars" which were fought betweentrading groups along the Mauritanian coast. The figures below, although sparse, give some idea of the disparity (a trend which continued well into the 20th Century):

Table 5. Showing gum prices paid to suppliers and at European markets (£ sterling per metric tonne).

Date	Price at London or Bordeaux	Price to desert supplier	Price to negociant*
1710	88		
1718		3.4	
1723		5.45	
1776		23.31	
1783		44.6	
1786	137		
1788		30.4	
1803	170		52-60
1810		60	95

* *negociant* is a French merchant based in St Louis. Sources: Curtin (1975) and Webb (1985).



Figure 7. Gum coast of West Africa. Section of a map printed in 1744 showing the Senegambia region (and Mauritanian coast), which was a major exporter of gum throughout the 17th and 18th Centuries. Note references to *woods produce much gum* and *gum forest* (Bowen 1744).

Export figures for the period are difficult to come by but Curtin (1975) gave the following:

Table 6. Exports of gum arabic in the 17th and 18th Centuries.

Date	Gum arabic exports/metric tonnes
1687	200
1693	294
1718	2200
1750	1028
1784	339
1793-7	339 (average)

The last two figures for the later 18th Century show a major drop in exports. This reflects the deterioration of the trade from the Mauritanian ports. By this time the trade had all but ended at Arguin the northernmost port and was much reduced at Portendick. This was due to desertification and a lack of potable water which deterred traders from carrying their gum to sell on the coast.

From the early 19th Century onwards the trade shifted further south to the mouth of the Senegal River. Before examining this trade, for which much information is available, it is worth noting briefly the knowledge pertaining to gum arabic in Europe (Britain in particular) at this time.

In 1792 Sibly wrote his "Herbal of Foreign Plants" as a supplement to Culpeper's earlier "British Herbal". Sibly appears to have confused *Mimosa nilotica* for what is today known as *Acacia senegal*, and what he termed *Mimosa senegal* with what is now called *Acacia seyal*. He said:

"Gum arabic of a pale yellowish colour is the most esteemed (i.e. that from *Acacia senegal*), on the contrary, those pieces which are rough, of a roundish figure, and of brown or reddish hue and found to be less pure, are said to be produced from a different species of *Mimosa* - *Mimosa senegal* - but the Arabian and Egyptian gum is commonly intermixed with pieces of this kind, similar to that which comes from the coast of Africa near the river Senegal."

Silby described the mucilageous, glutinous quality of gum arabic as making it "preferred to all other gums and mucilaginous substances, as a demulcent in coughs, hoarseness, and other catarrhal affections, in order to obtund irritating acrimonious humours and to supply the loss of abraded mucus. It has been very generally employed in cases of ardor urinae and strangury; but it is the opinion of Dr Cullen that even this mucilage, as an internal demulcent, can be of no service, beyond the alimentary canal."

In France at the end of the 17th Century, gum arabic was attributed with many curative powers. Father Labat (cited in Delcourt 1952) commented:

"Les médecins prétendent qu'elle (the gum) est pectorale, anodine et rafraîchissante, qu'elle est propre a guérir le rhume après qu'on lui ait donné une teinture de réglisse ou de sucre d'orge qu'elle est specifique pour arrêter les flux de sang, les dysentries et même les hemorrages les plus obstinées."

THE 19TH CENTURY

The move of the gum trade southward to the River Senegal coincided with the decline of the slave trade in the 1790s and the rise of "legitimate" commerce. St Louis was a French port, although it suffered from periodic British occupation, which grew rapidly as a result of the gum trade. The population grew from 6,000 in 1817 to 13,000 by 1830 largely due to the migration of Wolof people to the town to work in the gum trade. Between 1818 and 1837 commercial activity increased from 2 million to 12 million Francs (Bouet-Willaumez 1848). By the end of the 1830s, 3,000 people were directly involved in the gum trade and 30 or more *negociants* had established themselves in St Louis. Giffard (1965) said of the history of the region: "durant trois siècles, l'histoire de Mauritanie et du Senegal a été l'histoire de la gomme". One of the reasons for the great success of the gum trade in St Louis was that the French made an exception in their commercial policy by allowing gum arabic to be the only product which could be exported from St Louis on non-French ships (although this soon ended).

The Senegal River was the trade artery for the region; supplemented by other minor trade routes which crisscrossed the ecological zones from the desert to the sea. Detailed descriptions of the way in which the gum trade operated can be found in Crowder (1968), Meillassoux (1971) and Webb (1985). Here only a brief summary will be given.

The trade was hierarchically organized with the *negociants*, the French merchant traders, at the top of the commercial ladder. The *negociants* either represented French trading houses or owned their own. They were few in number but powerful, and they held the monopoly on the importation of the blue cloth from India called *guinee*, which became the unit of currency in the gum trade. The merchandising of the *guinee* and other trade goods was undertaken by the *marchands détaillants*, and below them the *licencies* who were the small scale shop keepers (Webb 1985).

Up the river was a commercial hierarchy of river traders and their workers. At the top were the *traitants*, African traders who owned their own boats and worked up and down the river. Much rivalry existed between members of this group. Only the wealthiest could afford to by-pass the *negociants* and trade directly with France. Most had to enter into a special trading relationship with the *negociants*. West African trade in general depended on a system of trust. Credit was the basis upon which the gum trade succeeded (and failed as will be shown) and, as Newbury (1971) discussed, this system was in operation even before the use of the *guinee* as the common unit of currency. For example, tobacco was sold with a credit period of 3 months, iron bars with a credit period of 5 months and flour, 4 months. In the 1830s Newbury (1971) cited a figure of 25 to 30 kg of gum as being the repayment value per piece of *guinee*. Problems however arose by the 1840s when an increased number of traders became involved and competition forced down the value of the *guinee*. In addition, cheaper imports of inferior quality *guinee* also forced the price down. Credit was a great risk, particularly when prices were not stable. A *guinee* valued at 25kg of gum on "purchase" was not guaranteed to be worth the same on repayment. Traders and *negociants* were at risk depending on which way the price swung. Certainly African middlemen were making money so long as the price remained stable. An observer noted in 1841 (Newbury 1971), that the trader bought *guinee* at 16.5kg of gum on credit and sold it to the Moors for 24 - 30 kg of gum making a profit of up to 6 kg after costs.

Credit defaulters were always a threat to the *negociants* during periods of inflationary prices. One English trader (in Meillassoux 1971) commented:

"With the utmost confidence a fellow nearly naked will ask you for 3 or 4 or even 5 thousand pounds' worth of goods on credit, and individuals are often trusted to that amount. I have trusted more than one man goods, the returns of which were worth between 2 and 3 thousand pounds".

The official gum trading season was called the *grande traité*. Between January and July the *zawaya* gum producers (nomadic herdspeople of West Africa) bought their gum to the river where three designated markets existed (two of them in Trarza territory). The negotiations between gum producer and river trader were a lengthy process, the river trader acting as the host and trying to offer the best hospitality to the gum sellers in order to secure the fastest sale and the best price. "Opportunities for chicanery were rife" (Webb 1985).

The gum sellers enjoyed a powerful position because if they felt aggrieved towards the French trading network the British were only too willing to step in and buy their gum. This became very important over the mid-19th Century as French relations with the Trarza empire deteriorated. The Trarza could take their gum to sell at Portendick although this was a hazardous journey. In the 1834 Franco-Trarza war, Trarza gum was carried to Portendick and it is believed that the British introduced guns to the Trarza warriors. An international incident arose when a French blockade of Portendick seized British vessels laden with gum.

The gum trade was extremely unstable from the 1840s onwards. Competition was so great that the French authorities declared a minimum floor price for the *guinee* in the gum markets. However, the erratic supply of the *guinee* and the import of cheaper quality *guinee*, meant that prices fluctuated enormously with the result that the African *traitant* could no longer operate profitably. The 1850s marked the decline of African trading hegemony and the start of colonial rule under General Faidherbe, after whom the genus *Faidherbia* was named. Until the arrival of Faidherbe there was very little French activity away from the river. His arrival, coinciding as it did with yet another trading dispute with the Trarza, saw the beginning of his campaign to protect French trading interests. Faidherbe was convinced that the gum trade in particular was in need of protection and so pushed northward into Trarza. Interestingly enough, by this time (1860s) the interest of traders had mostly shifted southwards to groundnut cultivation as Sudan began to enter the international market for gum. Other than during the period 1885 to 1896 when the Mahdia disrupted supplies from Sudan and Senegal enjoyed a period of unrivalled prosperity, Senegal lost the gum trade to Sudan and after 1896 never managed to recover it. Many gum traders were bankrupt by 1900 and attention shifted to groundnuts, which became the most important produce of the region during the colonial period. The *A. senegal* resource in the meantime had been over-exploited during the brief boom and then slipped into decline until colonial efforts to restore it began in earnest in the 1930s.

The occupation of Kordofan and Darfur in 1820 by the Mamluk Bey of Egypt, Mohammed 'Ali, on behalf of the Ottoman Empire, marked the start of what can be viewed as the modern period of gum arabic production in the Sudan. It has already been said that prior to this period, gum exports to Europe were relatively minor and that in the 17th, 18th and early 19th Centuries, West Africa was the main supplier. Sudan had continued to supply the Arab world and the trade to India had continued. However, under the *Turkiyya* period from 1821 to the Mahdia in 1885, Egyptian rule brought a period of stability and improved communications which greatly encouraged the production and trade of gum arabic. More encouraging perhaps was that the new regime, like the British who followed, demanded taxes paid in cash. The result was an increase in economic activity, particularly in the agricultural sector. Land grabbing, alienation and wage labour was also a feature of this period.

Under the *Turkiyya* northerners from Donghola moved into Kordofan and brought with them techniques in irrigated agriculture. They settled in the gum belt. Improved communications helped markets to develop and El Obeid became a prosperous garrison town and trade centre (Ewald 1990). Relations were normalized with Darfur which further encouraged trade and prosperity. Slaves, gum, ostrich feathers, ivory and hides were traded at El Obeid in specialized market places. Imported goods from Europe such as swords, spices, sugar, coffee, rice and soap were exchanged. The Dongholawi people who had come from the north became the controllers of trade and a wealthy merchant class developed.

Mohammed 'Ali placed monopolies on all traded items except slaves. This was so that production, which was very slave dependent, could continue. Gum, gold and feathers were particularly valuable sources of revenue from the Bey's monopolies. The gum trade thrived under the *Turkiyya*. As early as 1827-8, 1,270 tonnes of gum were exported, already matching exports from West Africa. By 1843, under pressure from Europe, state monopolies were formally ended. Direct trade could now take place between the representatives of the European merchant houses and the suppliers. Chambers of commerce opened in the major trading centres (1862 in Khartoum), and steamers operating along the Nile and the Red Sea Coast greatly facilitated the movement of goods (1868 onwards). Trade flourished during this period and not just by the river. Daly (1986) estimated some 40,000 camels were involved in caravan trading with Egypt in the 1870s. Suakin on the Red Sea, for so long a minor port, became an international centre of commerce and by 1880 a large percentage of the £(Egyptian) 250,000 exports per year were accounted for by gum. In 1881 alone Britain imported 3,620 tonnes of gum valued at £180,085. It was fortunate for Sudan that a period of stability and trade stimulus came at a time of expanding demand in Europe's fast industrializing nations. Traditional uses for gum arabic in pharmaceuticals continued but the big growth was in the confectionery and textile industries.

This period of prosperity was brought to an abrupt end by the *Mahdia* (Islamic uprising) in 1885. Most of the infrastructure, developed under the *Turkiyya,* collapsed. A period of instability followed with major economic dislocation during which Sudan was effectively cut off from the outside world. It was not until the 1890s that government officials were persuaded of the benefits to the treasury of continuing to encourage production and trade of gum (Blunt 1926). Gum production therefore did recover slightly towards the end of the *Mahdia* but the market was temporarily lost to French West Africa. The following figures reflect the disastrous effect of the *Mahdia* on gum exports:

Table 7. Showing gum exports from Sudan during the *Mahdia.*

Date	Gum exports/tonnes
1881	7,543
1885	1,146
1890	7
1895	160
1899	1,890

Source: Daly (1986), Blunt (1926).

In the latter part of the 19 th Century, gum arabic was added to the ivory and benniseed trade by the Royal Niger Company, who traded along the Benue River, as far north as Adamawa Province (Hogben and Kirk-Greene 1969).

THE 20TH CENTURY

In 1896 the reconquest of Sudan by Egypt and Britain took place. A system of tax based on the traditional *ushur* (equivalent to the tythe of Mediaeval Europe) was immediately put in place on all rainfed crops to stimulate production. Royalties were an important source of government revenue. They were collected on gum, ivory and ostrich feathers but gum was the most important. An ordinance in 1899 fixed a royalty of 20% *ad valorem* on gum from Kordofan. This royalty was subsequently based loosely on the size of harvest and the market price. This meant that government revenue also fluctuated but the trend seems to have been up. In addition, an export duty of 1% was placed on all traded goods, most of which still passed through Egypt until Port Sudan opened in 1906.

The British encouraged and invested in the expansion of gum production but also in cotton growing which was to become the major export of the Sudan after 1920. Gum, however, was the major export of the Anglo-Egyptian Sudan until then. Gum prices were steadily increasing from 122 piastres per 100 kg in 1904 to 234 piastres per 100 kg in 1910. Until 1913 the principal gum trading market was at Omdurman, this being due to its transport links along the Nile. The internal trade in gum was carried out by a series of middlemen traders who operated between the gum producing areas and the merchants at the major markets. These traders would go out to the producers with scales to buy gum. "The trader would put his leg on one side of the scales, the gum being placed on the other scale. A leg was considered to weigh 10 *rottles* (100 rottles = 1 kantar) and with pressure

could be made to equal 100 *rottles* or more "(Blunt 1926). Many of these traders were "minor merchants dabbling in a highly speculative trade" (Daly 1986). The result of this trading system was that the producer received a tiny fraction of the value of the gum. Higher up the hierarchy, the representatives of the trading houses at the Omdurman market were making the biggest profits. Even here, however, trading conditions were difficult with uncertainty about demand, transport availability and loan repayments adding considerable risks to the whole enterprise.

The development of the railways in Sudan therefore had a major impact on all aspects of the gum trade. The opening of the Nile to Red Sea railway allowed considerable economies to be made over the longer journey to Egypt. Once the railhead reached El Obeid, in the heart of the gum producing belt, transport costs and time were cut enormously, risks were therefore minimized and most importantly, commercial intelligence was for the first time accessible to all those involved in the trade, not just the final exporters. Figure 8 shows the dramatic increase of exports from Sudan around 1912 when the railway reached El Obeid.

As early as 1902 annual production reached 10,000 tonnes which far outstripped anything ever produced in West Africa. By 1912 nearly 20,000 tonnes was exported. Gum therefore brought considerable revenue to government coffers. Twenty percent of Sudan's revenue was derived from gum royalties and export duties alone. In 1902 gum accounted for 75% of all export earnings. Even after 1920 when cotton took over as the most important export, gum regularly accounted for between 20 and 30% of the value of exports. Gum kept the Sudanese economy afloat when the bottom fell out of the cotton market in 1931.

A pre-war peak in production was achieved in 1938 (24,000 t). Soon afterwards, exports dropped because war interrupted supply routes. Gum could only be exported through British territory, which involved very long journeys through Kenya although occasionally gum was exported through French West Africa. Exports were reserved only for British industry, no exports to neutrals being allowed.

Production recovered quickly after the war and by the early 1950s had reached 38,000 tonnes. By 1957, 46,000 tonnes were being exported from Sudan to Western Europe and North America emerging from post World War Two austerity. Exports reached their peak in the late 1960s but have never matched this since (see Section III for recent trends).

In 1912 a gum market under government supervision was opened at El Obeid thus eliminating many of the middlemen previously engaged in transporting the gum to Omdurman. Each firm had several brokers or buyers who haggled with producers over prices per kantar (1 Kantar = 100 rottles = 44.93 kg). The result was an improvement in the percentage paid to pickers. An increase of six times that paid in 1903 was suggested by Daly (1986). However, it was still the brokers and big merchants who benefited the most. Price mark-ups remained considerable but speculative elements of the trade were much reduced therefore diminishing their exposure to risk.

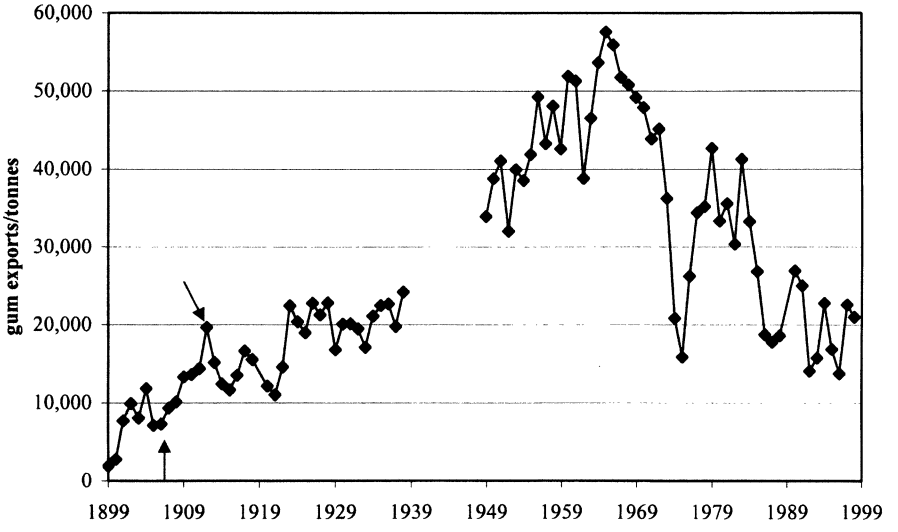


Figure 8. Gum arabic exports from Sudan 1899 to 1998. The first arrow (1906) indicates when the Nile to Red Sea railway was opened, and the second (1912) when the Nile to El Obeid railway was opened. Figures were unavailable from 1939 to 1948. Sources: Aubréville (1950); Blunt (1926); Daly (1986); Gum Arabic Company and Barbier *et al.* (1990).

For this period, Daly (1986) claimed that there was no local demand for gum arabic. It is assumed that Daly meant no local industries had developed requiring the use of gum arabic but that traditional local demand still existed. It is noteworthy that the writers on the subject of gum arabic in the Sudan during the colonial period do not mention any of the local uses or demand for gum arabic. The emphasis is solely on the export trade.

Although the condominium agreement between Egypt and Britain in 1898 opened up Sudan to free trade and foreign capitalists, in fact very little foreign investment took place. Investors who did come did not stay realizing that Sudan was "no El Dorado" (Daly 1986). A telling report written in 1915 described a situation which still exists today and is at the core of why even now there is virtually no significant internal industrial market for gum arabic:

"In the absence....both of minerals of industrial value and indigenous fuel supplies, no prospects for the early establishment of manufacturers can be entertained, and the Sudan is consequently destined to stand or fall by agriculture" (Sawer 1915).

A major landmark in the colonial gum trade occurred in 1922 when the brokerage system of marketing at El Obeid and other markets was replaced by an open auction supervised by the government. The gum was auctioned by a government clerk and the merchants had to bid for a price per *kantar*. The producer was under no pressure to sell if not satisfied with the price offered. The merchants then took the gum away for sorting and grading before export. Blunt (1926) gave a detailed description of the way in which this system operated. The auction system was supposed to be fairer towards the producer and as Howes (1949) stated:

"With the present marketing system the Arabs (sellers) are assured of fair play and of getting good and fair value for their gum." In practice it was possible for buyers' rings to develop whereby the merchants attempted to keep the price down. After government investigation into rumours of this practice in 1948 it was in fact found that this rarely occurred and healthy competition was the norm (Anon 1954). This system remained more or less unchanged until the nationalization of the gum industry in 1969.

Significant events occurred on independence in Sudan which have had bearing on the gum arabic trade. The first and most obvious development was the founding of the Gum Arabic Company (GAC) in 1969 which replaced all other exporters of gum arabic. The company became the sole organization authorized to export gum from Sudan. The effects of this monopoly are considered in Section III (supply factors). The second less obvious development was the outbreak of hostilities (long expected) between the Christian/animist negro south and the Moslem Arab population of the north. On independence the south tried to secede. The problem erupted into full scale war in 1983, and remains a major drain on the already impoverished resources of Sudan.

After the brief boom in the gum trade at the end of the nineteenth century, gum was overshadowed by groundnut production in Afrique Occidental Francaise (AOF) and was from the turn of the century onwards largely of secondary importance. Trade from this area had slackened off, the *A. senegal* stands were degraded and local people were exploiting them for other purposes (i.e. for fodder and fuel) but gum was still regionally important, being the only product of exportable value coming from the Sahelian zone.

By the early 1900s France's vast West African Empire was virtually in place and this encompassed significant areas with the potential to produce gum arabic. Logistical problems in terms of transport and socio-economic conditions, however, meant that the region was never able to compete with Sudan.

The Senegalese boom in the 1890s had captured the imagination of administrators and exporters who were keen to establish plantations of *A. senegal*. No plantations were established at this stage but production did increase once the Joloff and Ferlo regions were brought under European control in the 1890s. The royal town of Yang-Yang became an important new centre for gum trading and the administrator was keen to promote tapping techniques to increase production. By the 1920s however, panic had set in. Moor and Peulh collectors were over-tapping the trees and killing them. The administration responded by imposing bans on tapping (i.e. in 1923 in Mauritania). Tapping is discussed at length in section I.

In the 1920s and 1930s Sudan was producing most of the world's gum arabic, and the French administration, fearing that this situation would become permanent, sent missions of foresters to Senegal and Mauritania to try and find ways of expanding production. In doing so they attempted to emulate British efforts in the Sudan that had been used to increase production there. The investigating commission of 1927 recommended increased government intervention in gum arabic production and marketing (Freudenberg 1988). An overall plan was envisaged which would consist of:

1) The extension of the zone of gum harvesting.

2) Protection of existing groves.

3) Correct tapping techniques.

4) Reform of the "reprehensible" commercial behaviour currently employed.

5) Search for ways to assure gum arabic quality control.

French colonial administrators implemented these guidelines virtually to the letter over the ensuing period of colonial rule and in fact this formed the basis of forest policy towards *Acacia senegal* after independence. The result was the creation of State owned forests or "Forêts classées" which proved to be very important in protecting forest from the expansion of groundnut cultivation. Colonial administrators believed that the key to increasing production was to provide roads and wells for the collectors and to enforce vigorously the forest codes against abusive tapping.

In order to improve the trading system, the following regulations were put in place:

Exploitation - Opening and closing dates were set from the 20th of December to the 20th of July each year. Outside these dates, no authorised sale of gum could take place. Places for buying and selling were fixed and transactions were only permitted in these places. Market days and minimum prices were set according to the region and the quality of the gum.

Sorting - All stones, pieces of bark and other contaminants had to be removed and new sacks guaranteed to remain intact during transportation. The wrapping and cleanliness of the gum was subject to strict control for all exported produce.

Quality - Quality control was necessary to make the product competitive on the international market. Gum had to be either *gomme dur* from *A. senegal* or *gomme friable* from *A. seyal*. No mixing was supposed to take place and the product had to be traded dry.

Exporting - This was strictly regulated during the colonial period requiring a permit obtainable through the Forest Department. The black market through Mauritania was siphoning profits from Senegal. In order to qualify for a permit one had to be Senegalese, in possession of a trader's license and listed on the register of approved traders held by the Minister of Trade (Dabo 1988).

With these regulations in place the colonial government rationalised to some extent the trade from Senegal.

Productive regions of AOF during the colonial period were; Trarza, Brakna, Assaba and Aioun el Atrouss in Mauritania, Ferlo in Senegal, Nioro and the Niger bend in Mali, Manga and Zinder in Niger. Senegal and Mauritania however produced more than 80% of the gum exported from AOF. Collection and trading of gum in the rest of AOF tended to be in a much more haphazard, opportunistic way. Nomadic pastoralists collected naturally exuded gum when they happened to find it. No market structure as in Sudan existed. What little that was produced, found itself lumped together with Senegalese and Mauritanian gum as exported from AOF (see Table 8 for exports from AOF). Chad did not become a producer until 1964 because transport did not make it worthwhile.

France imported virtually all of the gum produced in AOF (and still does today) through Bordeaux, the centre of the Francophone gum trade, (London being the centre of the Anglophone gum trade). Until the 1940s France was the biggest single importer of gum arabic (8,000 tonnes) followed by Britain (6,000 tonnes) and the USA (4,500 tonnes).

Confectionery was still the biggest market followed by paper making and textiles. The AOF was unable to meet all the needs of France and so gum was also imported from Sudan. This is still the case today although French companies are involved in trying stimulate greater production from AOF to break the Sudanese monopoly.

The AOF gum arabic trade, in spite of the efforts of colonial administrators, was never able to compete with that of Sudan. The human population in the gum areas was largely nomadic, harvesting on an *ad hoc* basis from trees exuding naturally. When tapping did take place it was often done badly. As long as international demand had remained relatively small, as in the 18th and 19th Centuries, production from West Africa had been able to keep up but once the major markets of the 20th Century expanded they demanded a quantity and quality that AOF could not supply given the socio-economic nature of the producing areas.

The 20th Century saw the development of other producing areas. Nigeria's history of gum trading is much more recent than those of the two main producing areas. Most of the gum comes from dense stands of *A. senegal* in Bornu Province, northern Nigeria. Some gum from this area had found its way into the caravan trade of the 19th Century and was sold in Bordeaux and Trieste as Senegalese gum but Bornu was not considered an important gum producing area until the 1900s.

The existence of gum in Nigeria aroused considerable interest in British industrial circles. Increased competition for Sudan could only be a good thing for the buyer. The Niger Company took interest in the idea and started buying gum from Adamawa Province (south of Bornu) towards the end of the 19th Century. Inexperience, however, led to the export of poor quality, unsorted gum which fetched a poor price and gave a poor reputation. Undeterred, the Colonial Office appointed WR Dunstan of the Imperial Institute to undertake a fact finding mission to Bordeaux, Trieste and Tripoli, the centres of the gum trade, to learn techniques of sorting and grading with the aim of doing the same thing in Nigeria. The Resident of Bornu, H R Palmer, wrote:

Table 8. Gum exports from Afrique Occidental Francaise 1901 to 1960.

Date	Tonnes exported	Date	Tonnes exported
1901-5	2,600 (averages)	1943	2,043
1906-10	3,340 (averages)	1944	1,556
1911-15	2,750 (averages)	1945	5,862
1916-20	3,367 (averages)	1946	6,509
1921-25	4,089 (averages)	1947	7,452
1930-36	5,490 (averages)	1948	4,210
1931	6,172	1949	3,743
1932	4,200	1950	4,481
1933	2,746	1951	4,902
1934	4,024	1952	5,036
1935	5,220	1953	4,960
1936	5,423	1954	5,100
1937	6,656	1955	5,300
1938	5,556	1956	5,700
1939	4,946	1957	5,700
1940	-	1958	5,300
1941	-	1959	5,300
1942	3,600	1960	5,700

Source: Giffard (1975); Perrot (1946); Michon (1968); Edmonds (1965); – figures unavailable.

"It appears to me that given transport and a certain amount of instruction in preparation, there is no reason why Bornu should not rival Kordofan."

In 1925 J H Farquhar, a Senior Conservator of Forests, attempted to develop the Nigerian gum trade. His efforts failed because the colonial government was unable to station an organizing Forest Officer on the spot. Missions were sent to Sudan to try and learn from there. H W Weir, stationed at Maiduguri, was the man responsible for bringing Nigeria into gum production. As a result of his efforts some British firms showed an interest in Nigerian gum. However, Weir soon found that "the natives are much more prosperous than the Sudani and to pick gum pays them less than most of their other interests...so that they have to be attracted to the industry. So far the price offered at Maiduguri (by the Niger Company) has been low and I understand they have not bought much" (Weir 1930).

MacDonald (1941) complained that the local population were not clamouring to take up gum production:

"The requirements of these people, whose pursuits are mainly agricultural and pastoral, are few, and so long as they can obtain sufficient money to pay their tax they do not welcome any innovation which calls for unaccustomed expenditure of energy during the rest period of the dry season" (MacDonald, 1941).

In 1933 an English Company, Messrs B Seebohn Rowntree, applied to the Nigerian government for a concession to exploit gum in Bornu. A collection station was set up at Nguru and agents of the company embarked upon an "extension" programme to persuade local chiefs to participate in gum collection. Rowntree's had hoped that through this awareness campaign producers would come and sell exclusively to them. In fact this was not

Table 9. Exports of gum arabic from Nigeria.

Date	Tonnes exported	Date	Tonnes exported
1897	10.5	1940	340.2
1900	7.2	1944	1,020.0
1908	68.1	1948	1,260.0
1910	449.0	1951	1,500.0
1915	589.7	1955	2,300.0
1920	90.7	1956	2,000.0
1923	13.6	1957	2,700.0
1925	340.2	1958	3,700.0
1933	272.2	1959	4,300.0
1935	362.8	1960	4,300.0

Sources: Egboh (1985) and Edmonds (1965).

the case and producers sold in the open market to the highest bidder. The European buyers did their best to create monopoly buyers' rings to keep the prices down but because gum was very much a secondary activity here, the producers had the option of not participating.

Rowntree's then applied for a full concession to have the exclusive rights to all gum produced from a given area. It appears that this was the only concession of its kind in any of the Anglophone gum producing countries. Information is unavailable for the Francophone regions although it seems likely that French firms were similarly involved. Rowntree's concession was granted for an initial period of 25 years. It covered four areas of gum forests within which Rowntree's had the exclusive rights to all gum produced, would pay no tax for the first 5 years and was guaranteed stable rail freight prices.

Exploitation by private firms was at the heart of the gum trade in Nigeria. This was a very different situation to that in the Sudan and as a result the trade never grew up significantly. Instead of producing more gum at giveaway prices, producers preferred to engage in the production of more rewarding goods such as skins and hides (Egboh 1985). This reaction to low producer prices has become a feature of the Sudanese trade in recent years.

The war provided a stimulus to gum production in Nigeria for a brief time, and by 1955 up to 1,500 tonnes were being exported (Edmonds 1965). Nigeria's share of the world market has been steady at around 4% but after the 1973/4 drought and the more recent drought, interest has grown in the potential of Nigeria as an alternative source of supply to Sudan. However, quality remains a problem and there is very little official interest or organization in internal marketing although the extension of the railway to reach Maiduguri in 1965 did help.

Gum was produced in Australia, India, South Africa and Tanganyika at this time, but for the most part this was not of *Acacia senegal* origin and so will not be considered here, except for the case of Tanganyika, now Tanzania.

Malcolm (1936) had great hopes for the expansion of the gum trade in Tanganyika but, unlike the Sudan, the trees were very scattered, the human population was unskilled in tapping techniques and more interested in other activities. What gum there was tended to be of very mixed quality and was shipped to India for use in the textile market there. Since 1960, even this market has declined as starches replace gum in textile manufacture and as Indian gums have become available.

III. MODERN TRADE IN GUM ARABIC: WORLD SUPPLY AND DEMAND

DESCRIPTION AND USES

Recent definition

Since the biggest consumer of gum arabic is the food and drinks industry its definition as a permitted food additive by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) is particularly important. The specification has changed a number of times in recent years (see Table 22 in subsequent section on specifications). In 1998 the latest JECFA specification was published (FAO 1998). It explicitly included *A. seyal* gum in the definition, along with *A. senegal*, and made no reference to other species of *Acacia*:

> Gum arabic is a dried exudate obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or *Acacia seyal* (fam. Leguminosae).

This specification was discussed in March 1999 at the 31st Session of the Codex Committee on Food Additives and Contaminants (CCFAC); some minor amendments were made and it was placed in Category II (*i.e.* to be accepted unless further data were forthcoming) for consideration by the Codex Commission for adoption as a Codex Advisory Specification. The specification, as amended by the CCFAC, was adopted by the Codex Alimentarius Commission at its 23rd Session (28 June-3 July 1999).

The consequence of this latest change to the definition of gum arabic is that *A. seyal* (talha) is now officially recognised as a source of gum arabic, in addition to *A. senegal*. Irrespective of the fact that, in practice, talha has always been regarded as gum arabic, and has been utilised accordingly, this fact is now legitimised. This may, in time, lead to an increase in talha consumption, to the benefit of producer countries in Africa who have an *A. seyal* resource.

In Sudan, the term gum arabic is used in a wider context to include these two types of gum which are produced and marketed, but which are, nevertheless, clearly separated in both national statistics and trade: 'hashab' (from *A. senegal*) and 'talha' (from *A. seyal*). Statistical data originating in Sudan and shown in Tables 10, 11 and 12 separate gum hashab and gum talha. Figures relating to Sudan in other statistical tables are assumed to combine both types of gum arabic (hashab and talha).

In a still wider sense, gum arabic is often taken to mean the gum from any *Acacia* species (and is sometimes referred to as 'Acacia gum'). 'Gum arabic' from Zimbabwe, for example, is referred to as such but is derived from *A. karroo*. In practice, therefore, although most internationally traded gum arabic comes from *A. senegal*, the term 'gum arabic' cannot be taken as implying a particular botanical source. In a few cases, so-called gum arabic may not even have been collected from *Acacia* species, but may originate from *Albizia, Combretum* or some other unrelated genus.

Description

The description of gum arabic as given in the 1998 JECFA specification (amended 1999) is thus:

> Gum arabic (*A. senegal*) is a pale white to orange-brown solid, which breaks with a glassy fracture. The best grades are in the form of whole, spheroidal tears of varying size with a matte surface texture. When ground, the pieces are paler and have a glassy appearance.
>
> Gum arabic derived from *A. seyal* is more brittle than the hard tears of gum arabic derived from *A. senegal*.
>
> Gum arabic is also available commercially in the form of white to yellowish-white flakes, granules, powder, roller-dried, or spray-dried material.

Trade names

Gum arabic has been marketed under a large number of trade names; for instance Glicksman and Sand (1973) listed 76 of which the 36 specifically come from *A. senegal* and are listed below from their area of origin. The others come from other African Acacia species such as *A. karroo*, *A. nilotica* and *A. seyal*.

Adad (Somalia), Aden (east Africa), Berbera, Blanche gomme, Blonde gomme (west Africa), East India (India domestic), East Indian (India imported from Africa), Falli (Nigeria), Gedda (Africa), Geddaref (Sudan, Egypt), Gomme blanche, Gomme blonde, Gomme de galam, Gomme de poder, Gomme de Tombouctou, Gomme du bas du fleuve, Gomme du haut du fleuve, Gomme fabrique, Gomme friable (French west Africa), Hashab, Hashab geneina, Hashab wadi (Sudan), Jeddah (Morocco), Khartoum (Sudan), Khor (India), Kolkol

(Nigeria), Kordofan (Sudan), Kumta (India), Sandra Beida, Salabreda (west Africa), Savakin, Suakim (east Africa near Red Sea), Senegal (west Africa), Sudan, Verek (Sudan), White (west Africa).

In addition Burkhill (1995) listed: Somali gum, Ghezirah gum, pricked Turkey gum, and white senaar.

End-uses of gum arabic

Gum arabic is a complex, slightly acidic polysaccharide. The precise chemical and molecular structure differs according to the origin (both genotype and environment) of the gum, and these differences are reflected in some of the analytical properties of the gum. As a result, the functional properties and uses to which gum arabic can be put (and its commercial value) are also very dependent on its origin.

Gum arabic is very soluble in water and forms solutions over a wide range of concentrations without becoming highly viscous. The combination of high solubility in water and low viscosity confers on gum arabic its highly valued emulsifying, stabilising, thickening and suspending properties. Its modern uses fall into three main areas: food and drinks, pharmaceutical and cosmetic, and technical.

Food and drinks

The main uses of both *A. senegal* and *A. seyal* gums are in the food industry. Confectionery is the biggest end-use application for gum arabic because it is often used as an ingredient rather than simply an additive. Confectionery use is greater in Europe than in the United States but there are marked regional variations – Scandinavia, Italy and Switzerland are big markets in Europe for example. Hashab (*Acacia senegal* gum), rather than talha (*Acacia seyal* gum), is preferred for high gum formulations and some brands contain up to 50% hashab. For coating purposes, talha is often used.

The role of gum arabic in confectionery products is usually either to prevent crystallisation of sugar or to act as an emulsifier. In candy and other products such as chocolate-coated peanuts it is used to give an improved glaze and a harder coat. In chewing gum and toffees it gives improved chewiness.

The quality and technical performance of gum arabic from *A. senegal* makes it the material of choice in most cases, although the gum from *A. seyal* has a significant price advantage. Where the darker solutions of talha (*A. seyal* gum) do not pose a problem, this gum is increasingly being used as a food additive in parts of Asia (especially India and Pakistan) and elsewhere.

Gum arabic is used to stabilise oil-in-water emulsions where, for example, citrus oils are employed as the flavour component. In flavour encapsulation it prevents evaporation and protects the flavour oil from oxidation and absorption of water. In snacks such as dry-roast nuts it gives improved flavour adhesion and texture. In dairy products it is used to improve texture and creaminess (mouthfeel) and as stabilisers for ice cream and sterilised cream. In bakery it is used to provide a glaze and a neutral film to prevent oxidisation.

Consumption is also high in the soft drinks industry, both carbonated and non-carbonated, but especially cola-type drinks, where it acts either as a vehicle for flavouring or as an emulsion stabiliser (cloudy emulsion). In the United States the soft drinks industry, particularly that part of it involving cola and other carbonated drinks, is the biggest consumer of gum arabic (mostly hashab-type). In wines it gives improved clarity or wine fining and, in beers, improved foam stability.

Gum arabic is widely used in processing meat products. It improves brine retention in ham, improves texture, moisture and flavour retention in poultry products and freeze-thaw stability in processed meats. It is used in gelling and water and fat stabilization in canned meat and frankfurters and in pet foods. It retains moisture, and provides soluble fibre and crispness in batter and bread-making. In salad dressings and mayonnaise its function is fat retention, heat stabilization and emulsifying.

It is even added to dried foods, such as instant noodles, pastas and mashed vegetables, to give body and smoothness when reconstituted, and to cereals and snacks to improve texture and extend shelf life.

Pharmaceuticals and slimming aids

Traditional pharmaceutical use of gum arabic has declined. One reason is that the trend to providing certain drugs in the form of capsules rather than tablets has diminished the gum's use as a binder and excipient.

However, it still finds some use in compressed tablet manufacture, where it functions as a binding agent or as a coating prior to sugar coating, and it is also used as a suspending and emulsifying agent, sometimes in combination with other gums. It is the main ingredient in diabetic confectionery and medicated cough drops as a gelling agent and is used to encapsulate oil-soluble vitamins. In lotions and protective creams it provides improved spreadability, in face powder cakes it acts as a binding agent, and in syrups it helps suspension.

One area that is increasing in Europe (though static in the United States) is the use of gum arabic-containing slimming aids such as SlimFast® and Fibregum®, although they contain talha (*Acacia seyal* gum) rather than hashab (*Acacia senegal* gum). They are promoted as high fibre/low calorie products and consumer interest in them reflects the growing public awareness of health issues in foods.

Technical uses

The major non-food/pharmaceutical application of gum arabic is in the printing industry where it is used to form a protective coating on offset lithographic plates; as a base for photosensitive chemicals; for encapsulation in carbonless paper; and in fountain solutions where it serves to increase hydrophilicity and repel ink from areas of the paper where it is not required, so giving a sharp print. Although the use of disposable lithographic plates has led to some decrease in the use of gum arabic as a protective agent, cheaper prices for hashab (*Acacia senegal*) in recent years have encouraged some newspapers in the United States to switch from the use of celluloses in fountain solutions to gum arabic.

Other technical uses include ceramics and porcelain (such as spark plugs and isolators), where gum arabic acts as a glaze binder, certain types of inks, firing paste for matches, fireworks and explosives, foundry moulds, as a binder for artists' water paints and pastels (including children's paints), as a suspending agent in agricultural sprays (pesticides, insecticides and fertilizers) and as a carrier in co-spray drying. It is used in the process of ore flotation, and in cement and concrete sand helping water absorption. Use in textiles, paints and adhesives (including the traditional office glue and postage stamps) has declined considerably over the years and now accounts for only very small quantities of gum arabic.

SUPPLY – PRODUCTION & EXPORT

Sudan

Sudan is the world's biggest producer of gum arabic, and since very little is consumed domestically it is also the main source of gum in international trade. Sudanese production data are given in Table 10 (5-year annual averages since 1960) and Table 11 (yearly figures for the crop years 1990-97). In both cases, gum hashab is distinguished from gum talha. It is more accurate to describe the figures as purchases rather than production figures, since more gum may have been produced than is shown but not sold on to the GAC (Gum Arabic Company). However, for convenience the term 'production' is used.

The data in Table 10 show a drop in production by more than half in the last decade compared to that in the 1960s (when it averaged over 48,000 tonnes/year). Annual production figures for the years 1990-98 are shown in Table 11. Although they are termed 'production', the figures actually refer to purchases of collected gum made by the Gum Arabic Co.

The more detailed data in Table 11 show an all-time low of 7,600 tonnes in 1992. Since then, production of the two types of gum arabic increased to over 48,700 tonnes in 1995, the highest level for twenty years, and then fell in 1996 and 1997. Total production of gum arabic was only slightly lower in 1998 than in 1997 but this disguises a sharp fall in hashab (from around 17,700 tonnes to 12,500 tonnes) which was almost balanced by an increase in talha production (from almost nil to 4,600 tonnes). The reason for the sharp increase in production in 1995 was largely a result of the prevailing high price (as a result of favourable exchange rate of the Sudanese currency against the US dollar, which led to attractive prices being obtained by collectors for the gum), which encouraged the farmer to go out and collect gum. Conversely, the fall in price in 1996 discouraged collection and led to decreasing production levels thereafter. The levels of production of both types of gum arabic in the peak years illustrate that production in the other years is not constrained by the size of the resource (the trees) – if economic factors (prices) are favourable to the collector then he will make efforts to collect gum. It may also indicate that export markets are sufficient to absorb the increased production in these peak years but, equally, high production levels could be used to accumulate buffer stocks as a safeguard against low levels of production in subsequent years.

Table 10. Gum arabic: production in Sudan (5-year annual averages), 1960-94 (tonnes).

	1960-64	65-69	70-74	75-79	80-84	85-89	90-94
Annual average	46550	50576	35073	37408	31079	23721	18358
Of which:							
Gum hashab	44299	47434	30910	36026	26721	19777	15038
	95%	94%	88%	96%	86%	83%	82%
Gum talha	2251	3142	4163	1382	4358	3944	3320
	5%	6%	12%	4%	14%	17%	18%

Source: Gum Arabic Co., Sudan

Table 11. Gum arabic: volume of production in Sudan, 1990-98[a] (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total	25733	12351	7616	12865	33458	48758	31725	17759	17118
Of which:									
Gum hashab	22408	11756	7439	11410	22409	39303	30291	17746	12479
	87%	*95%*	*98%*	*89%*	*67%*	*81%*	*95%*	*100%*	*73%*
Gum talha	3325	595	177	1455	11049	9455	1434	13	4639
	13%	*5%*	*2%*	*11%*	*33%*	*19%*	*5%*	~	*27%*

Source: Gum Arabic Co., Sudan
Note: [a] 1990 indicates 1989/90 crop season, etc.

Table 12. Gum arabic: Volume and value of exports from Sudan, 1990-98 (tonnes, millions US$).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total	26912	24978	14068	15730	22735	16847	13722	22548	20989
FOB value	54.7	50.8	23.5	40.0	76.1	49.9	24.3	26.1	20.4
Of which:									
Gum hashab	22960	21543	8198	9925	18339	11564	8377	15576	16107
	(85%)	(86%)	(58%)	(63%)	(81%)	(69%)	(61%)	(69%)	(77%)
FOB value	51.8	48.6	20.1	36.0	72.4	46.8	21.6	23.0	17.9
	(95%)	(96%)	(86%)	(90%)	(95%)	(94%)	(89%)	(88%)	(88%)
Gum talha	3952	3435	5870	5805	4396	5283	5345	6972	4882
	(15%)	(14%)	(42%)	(37%)	(19%)	(31%)	(39%)	(31%)	(23%)
FOB value	2.9	2.2	3.4	4.0	3.7	3.1	2.7	3.1	2.5
	(5%)	(4%)	(14%)	(10%)	(5%)	(6%)	(11%)	(12%)	(12%)

Source: Gum Arabic Co., Sudan.

The proportion of gum talha in Sudanese production of gum arabic has been around 5-15% (Tables 10 and 11). However, in recent years it has become more erratic, varying from less than 200 tonnes (2%) in 1992 and almost nothing in 1997 to over 11,000 tonnes (33%) in 1994 (Table 11).

Kordofan has traditionally been the most important producing region for gum hashab in Sudan and during the mid to late1980s it usually accounted for around 55-60% of total production. Since 1991, however, its contribution to total production has fluctuated widely; in 1992, for example, it was approximately 75% while in 1994 it was about 25%. Central State has been the other major producing state, with Darfur, Eastern and Upper Nile States (in that order) making up the balance of production.

Sudan is also the only country for which accurate export statistics are available. Exports in volume and value terms for the period 1990-98 are shown in Table 12, where gum hashab is separated from gum talha.

Total exports for the 9-year period averaged 19,800 tonnes/year although there was a series of peaks and troughs, with peaks in 1990 (26,900 tonnes), 1994 (22,700 tonnes) and 1997 (22,500 tonnes). The pattern of change was largely a result of fluctuations in exports of hashab (*Acacia senegal* gum); levels of exports of talha (*Acacia seyal* gum) were smaller than those of hashab and less variable. Year-by-year comparisons with production data are difficult because of the uncertainty in the level of carry-over stocks from one year to the next. For example, exports of gum talha in 1997 are reported to have exceeded 6,000 tonnes although nominal 'production', as noted in Table 11, was negligible (13 tonnes).

One important feature of Table 12 is a consequence of the much higher average unit value of hashab compared to

talha. This means that the domination of total gum arabic exports by hashab in volume terms is even greater in terms of value. Even for those years in which talha exports represented around 40% of the total volume (1992 and 1996) they only accounted for 11-14% of total value. More normally in the earlier years, talha exports were worth 4-6% of the total value. In 1997 and 1998 the lower prices for hashab meant that talha increased its share of the value to 12%. FOB export prices for different grades of gum arabic are discussed later (Grades and Prices).

Other African producers

The European Union, collectively, is by far the biggest market for gum arabic (though much of this is processed and re-exported). Outside of this, India, Japan and the United States are important markets. South Korea, the Philippines, Taiwan, China, Indonesia, Australia and South Africa are all modest importers. Malaysia and Thailand import lesser amounts. For all these countries, imports include gum arabic shipped directly from primary producers (as well as that from secondary sources). By summing all such imports for a given year for each of the primary producers, a reasonable estimate is obtained for the exports of that producer. There will be some year-to-year error caused by exports at the end of one year not being recorded as imports in the destination country until the beginning of the following year, but these would be expected to be small.

Using import data for the countries/region referred to above, levels of imputed exports of African producers for the period 1991-97 are shown in Table 13. There are a few missing years for a few of the minor importers but the effect on the summation process for the primary producer is relatively small.

The year-on-year figures extracted from the Indian data are also somewhat in error because they are based on the financial year April-March rather than the calendar year. Nevertheless, the data from the EU, the US and Japan, as well as some other countries, are complete, and in most other countries only one or two years' data are missing. Some other countries, such as Argentina, Brazil and Mexico, import several hundred tonnes of gum arabic annually but this is mostly from the EU and US and not direct from primary producers.

Using the data in Table 13, total exports of gum arabic from Africa averaged 37,200 tonnes per year over the seven-year period. In the four years 1994-97, total African exports averaged almost 42,000 tonnes annually. Since most African producers are only very small users of it, this figure also represents approximate worldwide consumption of gum arabic.

For the three biggest exporters, Sudan, Nigeria and Chad, average imputed exports were 18,300, 10,700 and 5,000 tonnes/year, respectively. Although Nigeria has long been recognised as being the second biggest producer/exporter after Sudan, levels of Nigerian exports have probably been under-estimated in the past.

In Nigeria, the main gum-producing States (in decreasing order of production) are Yobe, Borno, Sokoto, Jigawa and Kano. Smaller amounts are produced in Bauchi and Adamawa States. The domestic market for gum arabic is believed to be small compared to the level of exports, but not insignificant. Most of the gum used domestically is almost certainly the lower priced grade 2 (mainly from *A. seyal*) and grade 3 gums (see section on Grades and Prices), which are produced in smaller quantities than grade 1 (from *A. senegal*).

Chad is the next most important producer after Sudan and Nigeria. Traditionally it has been collected in the east of the country, particularly in the Prefectures of Ouaddai and Biltine adjoining the Darfur province of Sudan. Production during the 1960s and 1970s peaked at something over 1,000 tonnes in the late 1960s and ceased completely in 1979 due to the war, and resumed again in 1985. The most obvious trend in Table 13 is the year-on-year increase in exports from Chad, from just over 1,000 tonnes in 1990 to around 8,300 tonnes in 1997. (Owing to the absence of Indian import data for 1998, total imputed exports for that year are not shown in Table 13. However, imputed exports for Chad – which has only appeared once in Indian import statistics since 1991 – were almost 13,000 tonnes in 1998.) The emergence of Chad as a significant supplier is considered by some in the industry to have safeguarded the position of gum arabic as a raw material and prevented further movement of end-users away from it to alternatives.

Apart from genuine producers, Table 13 also includes several countries where there is no indigenous production (such as Egypt and Morocco) and those such as Cameroon, the Central African Republic, Ethiopia/Eritrea and Somalia where some or all of the gum may originate from Sudan or Chad. While, in the past, smuggled gum from Sudan has undoubtedly been exported from Chad, the trade view is that this is now far less than it used to be and the bulk of Chadian exports appears to represent legitimate production. Outside of Sudan, Nigeria and Chad, Senegal and Mali are the most prominent of the genuine producers, with Niger and, to a lesser extent, Mauritania, being modest exporters. Ethiopia is known to produce some gum arabic from its own resources and it may be that the more usual levels of exports shown in Table 13 (20-70 tonnes) are a reflection of domestic production, while the higher levels estimated for 1994 and 1997 have their origins elsewhere. The latter may be true for much of the Eritrean exports.

Tanzania is an unexpectedly significant exporter (most going to India), but trade opinion is that some of this may

Table 13. Gum arabic: volume of imputed exports from Africa, and sources, 1991-97 (tonnes).

	1991	1992	1993	1994	1995	1996	1997
Total	36 411	29 864	26 568	41 062	40 092	43 892	42 893
Of which from:							
Sudan	24 851	16 154	12 946	21 852	18 406	17 108	17 050
Nigeria	8 087	8 718	7 631	10 971	11 831	15 929	11 971
Chad	2 193	2 441	3 597	4 515	6 781	7 366	8 365
Cameroon	75	573	842	1 022	161	560	349
Senegal	273	245	450	396	785	295	460
Mali	75	32	77	249	316	228	502
Central Afr. Rep.	74	79	33	121	126	651	991
Niger	20	155	205	252	111	229	172
Mauritania	32	48	55	167	258	256	193
Ivory Coast	-	-	26	50	16	20	21
Guinea Bissau	-	20	-	-	-	-	-
Togo	-	-	-	-	29	-	-
Burkina Faso	-	-	-	-	-	-	1
Somalia	38	49	5	139	31	28	39
Ethiopia	20	43	37	237	68	53	690
Eritrea	-	-	-	-	266	492	712
Djibouti	-	-	-	7	40	-	-
Tanzania	215	872	472	784	622	429	1 256
Kenya	18	133	183	234	201	111	19
South Africa	-	-	-	48	44	135	-
Egypt	440	282	9	15	-	-	92
Morocco	-	-	-	3	-	2	10
Western Sahara	-	20	-	-	-	-	-

Source: Import statistics for the EU, USA, Japan, India, Sri Lanka, China, Taiwan, South Korea, Thailand, Malaysia, Philippines, Indonesia and South Africa.

be *Combretum* or some other non-*Acacia* gum. Since 1985 Kenya has also had an organised collection of gum for export, from the arid or semi-arid northern regions, particularly just north of Isiolo in central Kenya. Further areas of gum-yielding Acacias are found to the north in Marsabit, to the northwest in Turkana, and south of Turkana in West Pokot. At least one NGO and three private companies have been involved in commercial production. No official production data are available but total production has probably never been greater than about 300 tonnes/year; in the early years it was considerably less than this.

SUPPLY – PRODUCTION CONSTRAINTS

There are a large number of factors which affect gum production and supply throughout the gum belt, which have been blamed for the supply shortages. These can be broken into the physical (climate, soil, topography) and biotic (man, animals and pests) affecting the trees, which are dealt with in Section I. They have a direct bearing on production, with drought and insects having played a major role in disrupting the supply of gum arabic, and in affecting the socio-economic status of producers. These are important but must not be over-stressed. Socio-economic factors (income, credit, producer prices, smuggling, migration, tenure, ethnicity, agriculture, war and instability) and institutional factors (policy, transport, water, extension, services, marketing, research & development) can be equally important in affecting production and supply (Awouda 1973, 1989). These are briefly discussed below, concentrating upon events in the Sudan.

Socio-economic factors

The socio-economic factors affecting supply cover a wide spectrum of issues including farm income and credit, gum prices, labour and migration, ethnicity, tenure and social instability which all interact to affect the production and supply of gum arabic. It is therefore difficult to deal with each factor separately.

Income

Income, credit and pricing policies are probably the most important factors in Sudan. Farmers in much of the gum belt suffer from very low incomes. Gum production therefore, cannot be viewed in isolation but as part of the wider land use issues with which farmers and rural people have to deal.

In much of the *qoz* region of western Sudan (relic dunes), where agricultural incomes can be very low, there has been increased pressure to migrate away from farms during the dry season in search of off-farm employment. This coincides with the gum picking season. Hashab production starts when the agricultural season is over in the rainfed sector. Harvesting in the irrigated sector however begins at that time too. When harvests in the rainfed sector are poor, migration to work on the cotton farms of the irrigated sector is substantial and the gum harvest is neglected. A good agricultural harvest is the pre-requisite for gum production. Migration is much reduced following a good harvest.

Cotton picking on the large scale irrigated schemes of Gezira for example employs much seasonal labour because picking is done by hand. Government propaganda is partly to blame for this seasonal migration, as it encouraged people from Kordofan (a poor area where labour is cheap), to work in the cotton fields. This migration has become so important that whole villages "move" during the dry season leaving gum gardens and collection unattended. Labour has therefore become a constraint in gum production in these areas.

There can be no doubt that this trend has been exacerbated by deteriorating climatic and environmental conditions in the gum belt and by a lack of price incentive to farmers to stay on their land in the dry season to collect gum. This is inextricably linked to the problem of obtaining badly needed cash at the beginning of the dry season and the lack of adequate credit facilities (see below).

The idea that the cost of producing gum is just the opportunity cost of leisure (Beshai 1984) and that the trade-off is between earning money and inconvenience (the marginal rate of substitution between income and leisure) seems absurd given the situation described above. This is perhaps a more accurate description of the situation encountered in parts of West Africa where nomadic people still tap trees in the traditional way (Kone 1988).

Credit

Rural credit is critical to the continued stable production of gum arabic from the Sudan. In Sudan, a traditional credit system called "sheil" (which applies to many crops) has been in operation since the 19 th Century. The farmer effectively mortgages his/her gum crop to the merchant buyer at interest rates of as high as 50 to 60%. The producer is paid in advance (at prices usually well below the floor price set by the GAC) before the harvest. This system was effectively the only credit available to gum producers well into the 1980s, and was widely used up until the 1985 drought after which merchants and money lenders lost interest in the system because of the reduced productivity of gum trees. Farmers having difficulty repaying were forced out of production or to sell their gum gardens to the sheil creditors (pers. comm. Idris 1993).

No official sources of credit were open to the gum producer. The Agricultural Bank of Sudan does give credit for other crops, and in the early 1990s increased credit to cover gum production. A more appropriate credit system would allow farmers to borrow for all farming activities rather than specific crops. All sorts of private informal credit systems exist in the clay regions of central province.

Little information exists on the subject of credit for West Africa. It is much less likely to be a key issue because most gum collection comes from natural forests and does not form part of the farm rotation. Dione (1988) described a system that appears to have changed little from the 19th Century "trust" system that operated along the Senegal River (see section II). Collectors of gum,

approached by middlemen buyers, take the cash equivalent to what they can collect (and what their trees are capable of producing). In this system, the collector has the money in advance to buy the provisions required for the tapping season. As in the 19th Century, the drawback of this otherwise sound system, is that price fluctuations occur during the period between advance payment and delivery of gum which can cause financial loss to either side (as well as a lot of disagreement).

Producer prices

The prices paid to producers or collectors for their gum has probably been the most discussed factor affecting supply in recent times (Beshai 1984; Barbier 1990b; Larson and Bromley 1991). Larson and Bromley believed that domestic pricing policies are at the heart of the collapse of gum production in the 1970-1980s in Sudan and that valuable lessons could have been learnt from past British experience in Nigeria, and indeed from Senegal during the boom of 1893.

There is some evidence, although it all pre-dates the 1984/5 drought (Beshai 1984; Bateson and El Tohami 1986) that the response of producers to a change in price is high (in other words there is high supply elasticity). A price increase appears to result in increased tapping and collection. If producer price rises result in increased production then this might appear to be the best way of securing supply. Larson and Bromley (1991) however, argued that in the Sudan price rises led to over-tapping and destruction of the resource in the 1973/4 drought during a period of high producer prices. During periods of drought and food shortage, it is common for trees to be cut for charcoal making in order to have money to buy food. Prices cannot go on being increased indefinitely to give producer incentives to increase production. International markets will not accept indefinite price rises. Farmers are quick to respond to price rises but are also aware of their transitory nature and this, Bromley and Larson argue, is a root cause of the demise of gum production.

If price increases are permanent, all future returns from the gum trees are higher and the value of the stand is enhanced. Permanent price increases are unlikely and so a transitory price rise is viewed as a short term opportunity to capitalize on a resource whose intrinsic value has not increased. The price increases offered to producers in 1973/4 aimed to increase production during a difficult period of drought. Farmers were used to long periods of constantly low prices (see Table 14) and so understandably regarded the price rise as temporary. Massive exploitation took place at a time when drought was already taking its toll on the gum belt. Drought alone therefore, cannot be blamed for the loss of trees in the 1970s.

Table 14 shows the producer prices at the time of the two droughts. It is worth noting the periods of fixed pricing just after the two major droughts - from 1975 to 1979 and from 1987 to 1990. If one compares yearly producer prices with yearly production, it is common to find that the current year's production is influenced by the previous year's price. This is largely because the GAC fixes the season's floor price too late for producers to react in the same year (Bateson *et al.* 1988). In 1986/7 the producer price was so high (to encourage production following drought) that international prices had to follow suit. This put off international customers.

In West Africa producer prices have reflected the same trends as in Sudan with an increase in 1974 at the time of the drought and a dramatic rise after the 1984 drought. The large price increase in 1986 was probably to encourage producers to capitalize upon the Sudanese predicament of under-supply. Unfortunately reliable figures have not been obtainable for producer prices from West Africa, but, like the international price, is generally lower than that in Sudan because the quality of West African gum has until now been poorer, often mixed with other gums.

In much of FWA, producer prices appear to be strongly influenced by the activities of the French trading company IRANEX (Colloides Naturels International) which dominates the region. Even though State monopolies exist in Chad and Niger for example, prices are largely determined by this company. Until recently it got away with offering very low prices for exports (in Mali for example) which in turn affect the producer price that the government Societé can offer. Prices well below those set by the Sudanese for export forced monopolies or private firms within FWA producing countries to offer low producer prices.

Unsurprisingly, lack of interest in gum production has been a major feature in West Africa, experienced by the British in Nigeria in the early 20th Century (Egboh 1985) and today in Mali (Saley 1988). Most countries now have a pre-season price set in the same way as in Sudan by the GAC.

It is not known whether price rises are an incentive enough to farmers to plant trees but it appears not. Increasing production through increased tapping is not sustainable. Trees need to be replaced especially because *A. senegal* is only productive for about 15 years. For constant assured production and supply, planting trees is necessary. Barbier (1990b) showed that the poorest farmers have very high personal discount rates which make them unable to consider the potential returns of tree planting, however good they may be, because they will not mature for 5 years or so. Tree planting for those with such a short time horizon is not considered an option but by not planting they are adding to their worsening situation.

From the discussion above, it can be seen that price has a very powerful effect on production. However, it not only affects production but also encourages smuggling. Some

Table 14. Producer prices in relation to export prices in Sudan.

Date	Price to Producer (LS/t)	GAC Price to Buyer (LS/t)	Export Price (US$/t)
1970/71	100.2	134.7	236.5
1971/72	100.2	135.9	237.0
1972/73	102.5	142.5	255.0
1973/74	184.6	241.4	1,625.0
1974/75	340.0	430.5	2,400.0
1975/76	200.3	286.9	1,250.0
1976/77	200.3	286.9	1,250.0
1977/78	200.3	86.9	1,250.0
1978/79	250.4	356.2	1,380.0
1979/80	278.2	398.5	1,450.0
1980/81	356.2	500.8	1,450.0
1981/82	422.9	589.0	1,450.0
1982/83	613.3	844.4	1,250.0
1983/84	890.4	1,255.5	1,600.0
1984/85	1,157.5	1,558.2	1,900.0
1985/86	2,047.9	2,801.4	4,950.0
1986/87	6,678.0	8,458.8	3,495.0
1987/88	8,904.0	11,130.0	2,800.0
1988/89	8,904.0	11,463.0	2,300.0
1989/90	8,904.0	12,243.0	2,300.0
1990/91	9,571.8	12,465.0	2,500.0
1991/92	29,383.2	41,403.6	2,930.0
1992/93*	100,170.0	127,995.0	3,200.0
1993*	180,000.0	247,500.0	7,000.0

Source: The Gum Arabic Company, 1990 (Awouda pers. comm.)
LS = Sudanese Pound * Devaluations of LS.

Sudanese sources believe that as much as 30% of annual production was smuggled through Central African Republic and Cameroon in the post-1985 drought period when producer prices were not favourable in Sudan. Smuggling in West Africa is very common and makes it very difficult to place much faith in the production figures of individual countries published.

Competition from other crops

Experience from Nigeria in the early part of the 20th Century (see Section II) has indicated that low prices turn farmers away from gum production to more profitable activities. This has more recently been observed in Sudan (Anderson 1985; Barbier *et al.* 1990; Larson and Bromley

1991). Increasingly, gum is having to compete with other forms of agriculture. In Sudan, government policy to encourage the production of oil seeds (sesame in particular) and the promotion of mechanized farming have both led to increased areas of hashab forest being cleared for agriculture, especially in the clay regions of Central Province. The high returns from sorghum in 1975, 1976 and 1980 persuaded many hashab growers to change their crop (Barbier *et al.* 1990). More recently there appears to be a trend moving back to *A. senegal* in the clay regions. Traditionally productive areas in Northern Kordofan and Darfur are becoming less productive whilst production from the clay regions is increasing.

Under British rule gum production was encouraged as a cash crop (to pay taxes in cash) but on independence government policy encouraged the growing of other cash crops. Import substitution was adopted as official economic policy (Daly 1986) and industries using indigenous oils were established requiring extensive cultivation and production of sesame and groundnut. Gum was increasingly abandoned in favour of other cash crops with more immediate returns and better producer prices. The consequences have been serious - shortening fallows, loss of tree cover, soil impoverishment and environmental degradation.

The situation was very similar in West Africa where natural forests of *A. senegal* were cleared to make room for the cultivation of groundnuts and millet. This was particularly the case in Nigeria. In largely nomadic areas this policy had little impact except for encroachment by settled agriculturalists.

Population and settlement growth

Shortening fallows are often viewed as symptomatic of population pressure. The traditional gum garden bush fallow system has all but died out in parts of provinces of Northern Kordofan and Darfur largely because of population concentration rather than overall population numbers. National population growth in Sudan is 2.8% but regionally it can be as high as 3.6%, such as in Darfur (Economist Intelligence Report 1993).

Sedenterization of nomadic peoples was government policy in many West African states and has resulted in similar problems of resource degradation largely through changes in livestock migration and increased livestock numbers.

In both Sudan and West Africa colonial policy to provide wells in gum producing areas was continued after independence. The controversy has been over whether lack of drinking water limits production or whether poorly spaced wells attract degradation around them. Both arguments seem to be true. Water provision continues to be a major issue as yet unresolved.

One effect of the increase in water points, as well as improved veterinary medicine, has been the increase in livestock numbers. Nomads and farmers traditionally invest in animals as live "banks". The increase in livestock numbers places increased pressure on already degraded ecosystems. The 1987 Livestock Census for the gum belt region in Sudan, quoted in Barbier *et al.* (1990), gave the following population figures: cattle 12 million head (3.5% growth rate), sheep 12.5 million head (6.0% growth rate), goats 8.5 million head (3.6% growth rate) and camels 2.2 million head (1.6% growth rate). In Sudan, Senegal, Mali and Mauritania, the north-south transhumance of pastoralists is being affected by the degradation of the northern edge of the gum belt. Livestock are having to shift southward placing a greater burden on those areas considered more favourable (Wata 1979).

Conflicting land uses competing for resources are becoming more and more common as human populations increase and settle, livestock numbers grow and agriculture mechanizes. In both Sudan and West Africa, what were once relatively compatible land use systems have in more recent years given rise to conflict. In West Africa this is further complicated by traditional ethnic animosity between pastoralists and settled farmers, such as the nomadic Peul and the settled Wolof in Senegal (Dione 1988c).

In Sudan, the Native Administration which used to be so effective in dealing with local land use conflicts and performed many local resource conservation services (such as controlling grazing and burning) was disbanded in the early 1980s. This has been a major reason for the increase in land use disputes.

Tenure

Tenure issues appear to be much more of a problem in West Africa than they are in Sudan. Most authors (Dione 1988c; Kone 1988; Coulibaly 1988; Fall 1987) agree that tenure is one of the key issues holding back the development of gum arabic in FWA countries. Customary rights prevail in much of West Africa's Sahelian zone under systems of State appropriated common property resources (*i.e.* traditional users have usufruct rights). In natural forests the lack of clear laws regarding "ownership" of trees and rights to tap gives rise to many problems. Exploitative attitudes very similar to those of the 19th Century prevail with a disregard for the protection of trees over which ownership cannot be assured.

In Senegal, where community plantations have been strongly encouraged, problems exist over who actually owns them because clearly defined tenurial legislation does not exist (Dione 1988c). Ethnic conflicts over rights to tap natural trees and plantations are common between nomads (traditionally the tappers) and settled farmers. Private property all too quickly becomes a public good

(Freudenberger 1988). The situation in Senegal clearly demonstrates the dangers of the commercialization of what was a common property resource. Development projects attempting to encourage community planting are finding it difficult to convince communities that (a) the plantations that they are planting do not belong to the State and (b) that the trees are the property of the community alone. This has proved very difficult and trees are frequently "robbed" of their gum (Kone 1988) by nomadic people who feel alienated or have found fenced plantations blocking their grazing routes. Clearly, the uncertainties of rights and ownership do not create a conducive environment for increasing production.

Until recently, tenure was not considered to be a constraint on production in the more settled gum producing communities of Sudan. Under traditional systems the sheikh (traditional leader of the village) is the allocator of land. The act of clearing the land allocated and cultivating it is enough to confer ownership. Abandoned land (*i.e.* unused for more than 2 years) reverts to the village. Ownership rights include trees and anything planted (El Din 1987). More recent developments include share-cropping whereby landless people cultivate land belonging to those with a surplus.

Trees which grow wild on unallocated land are community property administered by the sheikh who keeps the land in trust for the village. Access to the village hashab land is in theory open to all but in practice is often exploited by the sheikh to support his office.

These traditional tenure systems have recently come under increasing pressure from human and livestock populations, particularly in the communal areas which are degenerating into open access. Ownership of hashab trees has become very inequitable as appropriation by wealthier members of society takes place and the number of landless increase. This has no direct effect on overall production but results in the impoverishment of regions and communities within the gum belt (Barbier *et al.* 1990).

No definite government policy exists for hashab land tenure (but there is for mechanized farming). This has exacerbated encroachment by mechanized farmers and nomadic herders into areas with no clearly recognized tenurial systems in place. Big land use changes are therefore being experienced in the Sudanese gum belt because land can be taken over with no guarantee by the buyer to continue hashab growing. More land is therefore going out of hashab production (Idris pers. comm. 1993). Hashab rights are being abused as *de facto* cultivation rights (Adam 1981).

Unrest

Unrest within producing and neighbouring countries can have a significant effect on the production of gum arabic. War in Chad, for example, effectively cut off all gum production between 1973 and the mid 1980s. Burkina Faso, Mali, Mauritania, Niger, Nigeria, Senegal, and Sudan have all experienced disruption in supply to some degree as a result of internal political instability.

The fact that gum production takes place in border regions, in difficult drought prone environments, means that forests also come under considerable pressure from the influx of refugees escaping neighbouring conflicts, oppression or environmental disaster.

Institutional factors

Policy

There is no clear government policy on gum arabic in any of the producing countries in the gum belt. This may not be surprising in West Africa where gum arabic contributes little to the national economy in terms of foreign exchange (although locally and environmentally it is deserving of a clearly defined policy). Coulibaly (1988) stated that the government of Mali has shown total disinterest in developing a national policy for gum arabic. In the Sudan, where gum arabic is so important to the national economy and the livelihood of more than a million people it is surprising that no comprehensive policy exists (Barbier *et al.* 1990; Awouda in Rathgeb 1989). Broad directives do exist for the rainfed sector generally and a Forestry Act passed in 1989 does make some attempt to outline the need to prevent further deterioration of the gum belt.

On independence, most producing countries nationalised their gum "industry" (in the Sudan the GAC is not quite a State organization). The notable exceptions were Senegal and Nigeria where gum trading remains in private hands today. In the other countries, state companies manage the gum trade, setting prices and attempting to promote gum cultivation.

Internal marketing

Sudan

In Sudan, internal marketing is probably as efficient as it can be, with the auction system described in Section II remaining largely unchanged. One of the greatest strengths of the Sudanese gum arabic industry is the consistency it offers end-users in terms of both quality and price at the point of export. This is due, in large measure, to the fact that production of gum arabic is actively controlled from beginning to end by a single body, the Gum Arabic Company (GAC). GAC was established in 1969 as the sole organisation responsible for exporting gum arabic from Sudan. It is a public limited company owned partly by the government but mainly by the private sector (individuals and producers' associations).

GAC's activities begin at the start of each gum collection season, usually around September/October, when it

announces the export price (FOB Port Sudan) to be set for the coming year. The level at which it is to be set is decided as a result of market intelligence gained through a network of overseas agents and other sources, which enables estimates to be made of likely demand for gum arabic, and the anticipated availability of gum from the resource. Using the export price (in US$) and the appropriate exchange rate as a starting point, the total estimated costs (at Port Sudan) of cleaning, handling and preparing the gum for export are deducted to give a Port Sudan procurement price. From this are deducted the costs of up-country cleaning, handling and transport to Port Sudan, as well as merchants' profits, to arrive at the basic floor price which is set for the gum auctions at origin.

At the up-country markets the collectors, or small village traders to whom they have sold gum, bring sacks of gum for auction and sale to the highest bidder. The bidders are other, larger traders who, if successful, clean and sort the gum and then sell it on to the GAC. The GAC, in turn, re-clean and grade the gum at their warehouses in Port Sudan and prepare it for export. If the bidding at auction does not reach the guaranteed floor price, then the GAC intervenes to buy the gum themselves.

In 1994 the Gum Development Corporation (GDC) was set up to coordinate and enhance the production and marketing of gum arabic within the country, *i.e.* up to the point of export, at which time the GAC assumes responsibility.

At the resource level, the parastatal Forests National Corporation (FNC) is responsible for all aspects of the management of the forest reserves in Sudan. Apart from the planting programme involving gum-yielding Acacias, in which FNC is directly involved, great emphasis is placed on extension work in the gum belt. Information on the new season's price for gum arabic, the time when the trees will be ready for tapping, the best tapping technique and tools to be used, and ways of cleaning and storing the gum are disseminated to the people through radio programmes, leaflets, posters, demonstrations and other forms of personal contact. FNC also maintains statistical data on gum arabic plantations and production, implements measures to control pests which affect gum production (such as locusts), and identifies and plans appropriate research in collaboration with research organisations.

Producer associations exist in all of the gum-producing regions and were set up to assist the producers, and to give them a voice in discussions and decision-making processes further downstream. In the past, there has been some criticism that the associations have not, in practice, been effective in serving the interests of the producers, and some efforts are being made to change this.

In summary, there are in place institutions with well-defined roles and objectives covering all aspects of gum arabic production, from planting and conserving the trees and promoting and optimising production to processing and marketing the cleaned product.

Nigeria

In marked contrast to Sudan, gum arabic production in Nigeria is highly fragmented, with a plethora of producers and traders all competing to do business and with no coordinating body to ensure consistency of production methodologies or product quality. Lack of Forestry Department funds has meant that there has been little or no extension advice offered to collectors, although this may change with a recent decision to lend federal government support to the promotion of gum arabic production. There is a Nigerian Gum Arabic Association, with branches in each State and whose members include producers and traders, but it is not clear whether its role extends beyond that of simply serving as a forum for discussion and airing grievances.

Traders in the gum-producing States purchase gum from collectors or smaller merchants and clean and sort it in their warehouses. Some of the larger traders have agents in villages who purchase on their behalf and to whom they pay a commission. After cleaning and sorting, the grades of gum intended for export are either sold to exporters in Lagos, or exported by the same company that undertakes the cleaning. Gum from Maiduguri is also sent by rail to Jos where it is sorted by the representatives of the few export houses (dominated by the United Africa Company).

Kenya

In Kenya, organised collection of gum arabic for export is a recent development, begun by an NGO a decade ago but now undertaken by a number of individual companies. SALTLICK (Semi Arid Lands Training and Livestock Improvement Centres of Kenya) works to benefit the pastoralists of Kenya's arid and semi-arid lands. A major thrust of their work is long-term security against drought and decreasing the level of dependence of the pastoralists on their livestock is seen as an important step in achieving this aim. Gum arabic collection was identified as having the potential to provide an alternative source of income for the pastoralists since it can be collected from the trees during the course of their normal herding activities. SALTLICK purchases gum either directly from the pastoralists or from intermediate traders to whom the pastoralists have sold it. The main collection centre, where cleaning and bagging for export takes place, is at Isiolo but there are several other centres in the main collection areas. Two or three private trading companies are based in Nairobi but have networks of agents in the gum collection areas who purchase gum from local people on their behalf.

Other producers

For the most part, marketing of gum arabic elsewhere in Africa, as in Nigeria and Kenya, is in the hands of private

traders. In Senegal it is also well established and relatively efficient (Dione 1988c). There is a hierarchical system of middle men and merchants through whose hands the gum passes in going from the collector to the exporter. At the point of export there are usually only a handful of companies involved - in Chad, three companies control 75% of the export market - but they remain competitive. No single, well-oiled organisation exists as in Sudan. In many of the Francophone countries, attempts were made to organise the production and sale of gum through state-controlled organisations in the years following independence, but these usually collapsed through inefficiency and the poor economic state of the countries. As elsewhere in the world, the 'free market' philosophy gained credence. For instance, one major French buying company dominates the trade in many Francophone countries, sending envoys to engage in direct contact with producers. It is largely for this reason that other consuming countries deal so little directly with FWA and instead import through France. In Ethiopia, production and marketing of gum arabic is undertaken by a parastatal, the Natural Gum Processing and Marketing Enterprise, but here, too, it is planned that its functions will be taken over eventually by the private sector.

Government support, where funds permit, is usually focused on the forest resource. International backing has been forthcoming through programmes aimed at combating desertification and promoting rural development. Recognition of the economic value of non-timber forest products such as gum arabic, and the wider role that such activities can play in reducing the loss of forest cover and consequent land degradation, should strengthen moves in this direction.

Transport

Until recently, transport was not considered to be a constraint to production and supply in Sudan. Producers in the past have been prepared to travel enormous distances in order to sell their gum (Blunt 1926). That is no longer necessary now that markets are well distributed through the gum belt. The problem is rather one of bulk transport. As in many other countries in the developing world infrastructure, particularly roads and transport systems, are decaying. One British importer stated this as a major constraint on supply (commercial pers. comm. 1993).

In Senegal the river remains a cheap and effective means of transport but in other West African countries enormous distances have to be covered over land in order to ship gum abroad. Transport in these landlocked countries can be a major constraint.

Water

Water has already been mentioned as a problem in the gum belt. Studies in Sudan (Barbier *et al.* 1990) showed that the buying of drinking water from itinerant traders at excessively high prices (LS 1 - 3 for a 4 gallon tin) is a major drain on the cash earnings of rural people in the *qoz* region especially. Tanker deliveries of water or drilling wells have been successful but are very costly for local government.

Water remains a major constraint, particularly in the drier less accessible regions of the gum belt where some of the better tracts of *A. senegal* are to be found. This is especially so in Mali and Burkina Faso.

Extension and development aid

Services for agricultural extension are woefully lacking in most of the gum belt. Government forest departments are notoriously under-funded and short-staffed throughout Africa. In Sudan the Gum Arabic Company is involved in giving extension advice, promoting new tapping techniques and also providing the nearest thing to social welfare assistance that a country such as Sudan could provide. The GAC has been relatively successful in its efforts to create "gum awareness" but follow-up has been a problem.

The State-run Societé's which operate in Niger, Chad, Mauritania, Burkina Faso and Mali are much less able to meet the extension needs required to popularize gum production. Coulibaly (1988), Dione (1988c) and others have said that lack of awareness of the potential value of gum arabic is preventing the participation of rural people in gum production. Development projects that are directly concerned with *A. senegal* and gum production are to be found throughout the gum belt. These attempt to create awareness of the productive potential of the trees where awareness does not already exist, encourage the planting of trees for future production and promote the diverse benefits the trees afford.

Extension services are generally dependent upon the external projects. This is potentially a problem in Sudan where, due to political problems, many donor countries have withdrawn their support.

Gum oriented development projects can be traced to the late 1960s even though they did not proliferate until the 1980s. In keeping with development thinking in forestry generally, they followed three principle schools of thought:

1) In the 1970s attention focused on government plantations, often mechanized, as the solution to increasing supply.

2) In the early 1980s the community development era began and projects concentrated upon community gum plantations.

3) The present focus of attention is much more on natural forest management wherever this is appropriate

and in terms of working with farmers, a more holistic approach to the farming system as a whole is being taken incorporating agriculture and pastoralism. The erratic nature of the international trade precludes the implementation of forestry programmes designed with the primary intention of promoting the export of gum arabic.

It is difficult to assess the degree to which development projects have affected or are likely to affect gum supply. It appears from studies by Dione (1988c) and Freudenberger (1988) that the plantation approach has not been successful and that certainly in West Africa many of the community style projects were ill conceived without an adequate understanding of the complex tenurial and ethnic issues. In Sudan development projects have perhaps been a little more successful, dealing as they do mostly with settled agriculturalists already used to the production of gum.

Research

Three types of research can be identified in the French and English literature:

1) Field research to improve methods of tapping and establishment. Techniques to reduce production costs.

2) Tissue culture techniques to produce high yielding and drought resistant strains (difficult without certainty of the actual cause of gum exudation).

3) Industrial research to expand future markets, discover new uses to combat substitutes.

The obvious omission is the study of farm level economics and systems. An exception is the Western Sudan Agricultural Research Project, Darfur, which studies farming systems in each of the main ecological zones of the region (Bunderson *et al.* 1990).

Creation of a security of supply system

In Sudan it was hoped that supply irregularity might be combated by providing a triple security system consisting of buffer stocks of gum (at least 20,000 tonnes), reserves of untapped trees and an improved tree stock in reserve. Unfortunately the 1992/3 supply crisis implied that the back-up system did not always work. In 2000, large buffer stocks of over 30,000 tonnes were held by GAC.

International marketing

International marketing and the effect that this has on demand will clearly have an influence on production. The GAC in Sudan and IRANEX (Colloides Naturels International) from France are largely responsible in recent times for trying to promote the sale of gum arabic abroad. The consumer end of the trade is exceptionally secretive and because of this, studies providing quantitative information on likely supply needs are virtually unobtainable to anyone outside the trade, and indeed outside the companies involved.

From the above examination of factors affecting the production and supply of gum arabic, it is unsurprising that fluctuations in output occur (or that West Africa is well behind the Sudan in terms of production). This is particularly important in the case of Sudan which, being the main producer, takes the full brunt of consumer displeasure (*i.e.* consumers turn to substitutes) when supply is down. West Africa instead is in a much freer position to take advantage of Sudan's misfortunes and indeed has done so. Irregularity of supply has been one of the major causes of the decline in the trade after the late 1960s.

DEMAND: INTERNATIONAL AND DOMESTIC MARKETS

Domestic markets in producer countries

In most cases there are few, if any, reliable data on levels of consumption of gum arabic in the producer countries. It appears, however, that domestic markets are generally small but occasionally may be quite significant. Gum that is used is invariably the lower grades or 'waste' left over from cleaning and sorting gum destined for export.

In Chad, for example, it is estimated that about 500 tonnes of 'waste' gum are sold in N'Djamena alone, mainly for use in building (rough-casting of houses made from clay and straw or for mixing with whitewash to paint the walls of the house), with much smaller amounts used in traditional medicine. In Sudan, domestic markets are very small but include use in mixing with sand for plastering, in solution for priming walls prior to painting, in inks for Koranic writing after mixing with soot, as office glues and in cosmetics when mixed with henna. Similar uses are found in Nigeria, with additional use in pharmaceuticals and starching caps worn by the Moslem community. In Senegal, up to 200 tonnes are used in local food and pharmaceutical industries. In Kenya, there are miscellaneous markets for non-export grade gum in Nairobi, and local people near one of the gum collection and cleaning centres use gum arabic dust as a binder for briquetting sawdust for fuel use.

Historical international markets

The use of gum arabic has a very long history but in modern times production and trade has been dominated

by Sudan. Levels of supply from Sudan are therefore a good indicator of consumption.

A more detailed discussion of production levels in Sudan has been given (Supply production & export), but towards the end of the 1960s total gum arabic production (hashab + talha) was in excess of 60,000 tonnes/year; supplies of gum arabic from other countries meant that total world usage was around 70,000 tonnes. Events in the 1970s and 1980s led to fluctuations in both the supply and price of gum arabic and, as a consequence, to changes in demand. The severe Sahelian drought of 1973/74 resulted in a world shortage of gum arabic and high prices which, in turn, accelerated the replacement of gum arabic by substitutes such as modified starches. A low point of approximately 20,000 tonnes of Sudanese exports was reached in 1975, which recovered to around 40,000 tonnes during 1979. A further drought in 1982-84, combined with political and civil unrest, saw levels of exports fall to below 20,000 tonnes in some years in the mid/late 1980s and early 1990s.

Demand for gum arabic has therefore been constrained at times by the supply, and under these circumstances end-users who switch to alternatives do not always revert to gum arabic when supply problems are eased. It is unlikely, therefore, that the traditional markets for gum arabic in Europe and the United States will reach the heights that they once did, although the superior properties of gum arabic (especially good quality material from *A. senegal*) will ensure that it retains substantial markets if availability is assured and prices are favourable. Likely future trends in the light of the recent changes in definition of food-grade gum arabic are discussed later. Consumption in Asia may well increase.

International markets

The European Union, North America (mainly the USA) and the Indian sub-continent (mainly India) are the biggest markets for gum arabic. Asia (mainly Japan) is the next most important region. An examination of trade statistics for the period 1991-97 enables one to estimate the average share of total consumption for these four regions as approximately 40%, 20%, 20% and 9%, respectively, *i.e.* accounting for around 90% of world consumption. It is important to remember that trade statistics for gum arabic do not distinguish between the different types, *A. senegal* and *A. seyal* gums.

European Union

The European Union is the biggest regional market for gum arabic and imports into it, with sources, are given in Table 15 for the period 1990-98.

Excluding the most recent EU members, Austria, Finland and Sweden a cyclical pattern is evident. Troughs of around 27,600 tonnes (1990), 26,500 tonnes (1993) and 28,200 tonnes (1996) have alternated with peaks of 32,100 tonnes (1991), 34,600 tonnes (1994) and 36,400 tonnes (1998). Average imports have amounted to approximately 30,800 tonnes/year. If the full EU membership is taken into account, the additional imports for the years 1995-98 amount to an annual average of 1,800 tonnes, most of which goes into Sweden and Finland.

Sudan, Nigeria and Chad are the three biggest sources of gum, with imports from these countries averaging 12,800, 4,700 and 4,200 tonnes/year, respectively. Imports from Sudan in 1998 were the biggest during the whole period and almost twice the level of those reported in 1997. However, the most striking feature of Table 15 is the steady rise in imports from Chad: except for 1996, when there was a slight fall from the previous year, there has been an increase every year since 1990. The average annual increase is 31% and Chad has now displaced Nigeria as the second most important source of gum arabic for the EU after Sudan.

Within the EU, France, the UK and Germany are the major re-exporters into other EU countries. Imports from the United States have averaged just under 700 tonnes/year since 1990.

Table 15 also shows total imports into each of the EU countries. France is by far the biggest importer, with an upward trend from 1990 to 1998. The last two years have seen particularly large increases in imports, from 13,00 tonnes in 1996 to almost 21,00 tonnes in 1998. The UK has consistently been the second most important destination, although since 1993 imports have been significantly lower than in the three years 1990-92. Germany and Italy have been the next most important importing countries, with Sweden also accounting for significant quantities for the last three years for which data are available.

A breakdown into destinations of imports within the EU for the three largest exporters of gum arabic, Sudan, Nigeria and Chad, is given in Tables 16, 17 and 18, respectively, for 1990-98. France is the biggest importer of Sudanese gum arabic (Table 16). Levels of imports were fairly even from 1990 to 1997 and averaged 5,400 tonnes/year. The steep increase in imports in 1998 pushed the 9-year average up to almost 6,000 tonnes/year.

France, the UK and Germany are the only three major importers of Nigerian gum arabic (Table 17). The UK has traditionally been the main market for Nigerian gum but since 1995 this position has been shared with France and Germany. French imports in 1998 were almost as much as those from the UK and Germany combined.

Table 15. Gum arabic. volume of imports into the European Union, and sources and destinations, 1990-98 (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total[a]	27636	32106	29947	26533	34621	28610	28194	33453	36433
Total[b]	27636	32106	29947	26533	34621	29495	30451	35221	38730
Of which from[c]:									
Sudan	14400	17098	10198	9305	13922	10752	10834	9801	18535
Nigeria	4385	3568	7244	4759	5526	3683	4314	5506	3214
Chad	1059	2153	2423	3527	4152	5453	4941	6777	7245
Cameroon	302	75	573	842	1022	81	560	349	374
Senegal	276	273	245	450	396	785	295	460	96
Mali	69	75	32	77	249	298	228	502	352
Central Afr. Rep.	-	74	79	33	121	126	639	991	147
Niger	-	20	155	169	241	110	220	170	100
Mauritania	-	32	48	55	167	258	256	193	18
Ivory Coast	-	-	-	26	50	16	20	-	20
Burkina Faso	-	-	-	-	-	-	-	1	13
Somalia	82	38	49	1	100	14	12	10	7
Ethiopia	68	20	43	27	225	68	15	540	54
Eritrea	-	-	-	-	-	250	432	472	150
Djibouti	-	-	-	-	-	40	-	-	-
Tanzania	27	118	161	176	223	80	120	40	34
Kenya	-	18	121	103	200	161	89	19	13
Zimbabwe	20	-	-	-	-	-	-	-	-
Egypt	-	406	272	9	15	-	-	92	-
Iran	112	52	78	197	81	182	18	59	95
India	587	435	469	369	146	195	236	503	204
France	1994	2104	3005	2629	2734	3199	2968	3868	3568
UK	1698	1855	2514	1774	1351	1308	1504	1949	1253
Germany	670	997	1348	1179	1459	1291	1141	1450	997
Netherlands	1043	1296	185	87	115	99	101	111	133
Belgium/Lux.	106	61	75	91	145	60	138	71	477
Italy	44	108	16	13	176	13	31	44	112

(continued)

Table 15. (continued)

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Spain	4	9	19	18	405	20	11	40	17
USA	432	978	317	163	906	609	892	842	875
Others[d]	258	243	278	454	494	344	436	361	627
Of which to:									
France	7140	10289	10205	11004	13133	10912	13201	16854	20956
UK	8654	8516	9858	6495	6738	6431	5641	6623	6635
Germany	3335	3756	4710	3472	5006	5025	3111	3832	3606
Italy	3941	5036	2070	3188	5965	2917	2454	1879	1967
Denmark	1224	1044	1011	904	1199	700	717	677	676
Belgium/Lux.	832	903	695	704	1341	981	957	1536	1086
Netherlands	1392	1435	551	228	456	298	293	357	289
Ireland	681	757	499	235	411	877	1390	1168	669
Spain	308	261	244	208	273	303	302	365	328
Greece	81	70	71	66	53	133	69	78	98
Portugal	48	39	33	29	46	33	59	84	123
Sweden	[e]nm	nm	nm	nm	nm	350	1781	1365	1731
Finland	nm	nm	nm	nm	nm	510	335	294	427
Austria	nm	nm	nm	nm	nm	25	142	109	139

Source: *Eurostat*

Notes: [a] To give a self-consistent 9-year series, data are given for the 12 EU countries, *i.e.* excluding the most recent members Sweden, Finland and Austria (who joined the EU in January 1995).

[b] Data are given for the full EU membership, *i.e.* 12 countries 1990-94, 15 countries 1995-98.

[c] Data for individual source countries refer to imports into the full EU membership.

[d] Includes occasional large quantities from e.g. Saudi Arabia (102 tonnes, 1991), Cambodia (203 tonnes, 1993; misclassification?), Iceland (343 tonnes, 1994), Philippines (117 tonnes, 1995), Switzerland (81 tonnes, 1996), Sweden (361 tonnes, 1998), Grenada (120 tonnes, 1998).

[e] nm = not member [of the EU].

Table 16. Gum arabic: volume of imports into the European Union[a] from Sudan, and destinations, 1990-98 (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total	14400	17098	10198	9305	13922	10752	10834	9801	18535
Of which to:									
France	5023	7074	5219	5118	5193	4525	5344	5556	10702
UK	3053	2521	2118	1168	1304	1326	1028	1522	3156
Germany	1388	1804	1027	478	1500	1500	570	468	1783
Italy	2675	3431	1007	1935	5023	2155	1688	663	636
Denmark	755	727	591	440	456	346	200	-	190
Belgium/Lux.	360	280	80	120	400	280	140	223	525
Netherlands	1000	1140	100	-	20	20	20	30	-
Spain	96	90	56	46	26	40	2	19	-
Greece	50	31	-	-	-	-	-	10	-
Portugal	-	-	-	-	-	-	-	-	-
Ireland	-	-	-	-	-	-	-	-	-
Sweden	[b]nm	nm	nm	nm	nm	300	1762	1310	1543
Finland	nm	nm	nm	nm	nm	260	80	-	-
Austria	nm	nm	nm	nm	nm	-	-	-	-

Source: *Eurostat*
Notes: [a] Data are given for the full EU membership, *i.e.* 12 countries 1990-94, 15 countries 1995-98.
[b] nm = not member [of the EU].

Table 17. Gum arabic: volume of imports into the European Union[a] from Nigeria, and destinations, 1990-98 (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total	4385	3568	7244	4759	5526	3683	4314	5506	3214
Of which to:									
France	403	167	1256	1152	1425	797	1120	2302	1577
UK	2862	2411	3244	2315	2168	1357	2048	1542	907
Germany	1119	990	2734	1237	1902	1525	1106	1581	729
Italy	-	-	-	38	-	-	-	-	-
Denmark	-	-	-	-	10	-	-	-	-
Belgium/Lux.	-	-	-	12	21	-	40	81	-
Netherlands	-	-	7	5	-	4	-	-	1
Spain	1	-	-	-	-	-	-	-	-
Greece	-	-	3	-	-	-	-	-	-
Portugal	-	-	-	-	-	-	-	-	-
Ireland	-	-	-	-	-	-	-	-	-
Sweden	[b]nm	nm	nm	nm	nm	-	-	-	-
Finland	nm	nm	nm	nm	nm	-	-	-	-
Austria	nm	nm	nm	nm	nm	-	-	-	-

Source: *Eurostat*
Notes: [a] Data are given for the full EU membership, *i.e.* 12 countries 1990-94, 15 countries 1995-98.
[b] nm = not member [of the EU].

Table 18. Gum arabic: volume of imports into the European Union[a] from Chad, and destinations, 1990-98 (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total	1059	2153	2423	3527	4152	5453	4941	6777	7245
Of which to:									
France	840	1463	1878	2819	3517	3459	3978	5033	5925
UK	219	690	545	-	245	1000	744	1440	1040
Germany	-	-	-	689	380	992	120	180	280
Italy	-	-	-	-	-	-	38	36	-
Denmark	-	-	-	-	-	-	60	-	-
Belgium/Lux.	-	-	-	-	-	-	-	87	-
Netherlands	-	-	-	-	1	-	-	-	-
Spain	-	-	-	1	9	2	-	-	-
Greece	-	-	-	18	-	-	-	-	-
Portugal	-	-	-	-	-	-	-	-	-
Ireland	-	-	-	-	-	-	-	-	-
Sweden	[b]nm	nm	nm	nm	nm	-	1	1	-
Finland	nm	nm	nm	nm	nm	-	-	-	-
Austria	nm	nm	nm	nm	nm	-	-	-	-

Source: *Eurostat*
Notes: [a] Data are given for the full EU membership, *i.e.* 12 countries 1990-94, 15 countries 1995-98.
[b] nm = not member [of the EU].

Historically, France has been the major importer of gum arabic from Chad (Table 18) and imports have risen steadily since 1990, in line with the general rise in Chadian exports. The UK is also a significant importer, although there have been ups and downs in the levels of imports. Germany is the only other importer of any note and began sourcing Chad in 1993; again, levels of imports have been variable.

United States

Outside the EU, the United States is the largest market for gum arabic. Imports for 1990-98, and their sources, are given in Table 19. Levels of imports declined from 1990 to 1993, recovered in 1994, dropped in 1995 (to a low of 5,500 tonnes) and then rose in successive years to an all-time high for the period of almost 15,300 tonnes in 1998. Average imports for 1990-98 were approximately 9,300 tonnes/year.

Imports from Sudan, traditionally the major source of gum arabic for the United States, averaged 3,900 tonnes/year. Nigeria has been a modest supplier (averaging just over 400 tonnes/year) but, as was seen in the case of the European Union (Table 15), the most significant observation is the rise of Chad as a major source of gum. From just 18 tonnes in 1992, imports from Chad have increased rapidly and in 1998 amounted to over 5,600 tonnes, more than twice the figure for Sudan. This is a reflection of the desire of US companies, in common with others, to broaden their raw material supply base and not be reliant on a single source of gum arabic.

In terms of processed/re-exported gum, France has always been the major supplier to the United States. Imports from France increased from 1,800 tonnes in 1990 to 5,300 tonnes in 1998 (an average of 3,100 tonnes/year); the increases in 1997 and 1998 were particularly large.

The total annual value of imports over the period 1990-98 (Table 19) varied between US$16.4 million in 1990 and a high of US$38.5 million in 1994. Recent

Table 19. Gum arabic: Volume, value and unit value of imports into the United States, and sources, 1990-98 (tonnes, '000 US$, US$/kg).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total volume	9304	8273	5802	5508	10456	8372	10061	10869	15288
Total value	16421	20011	18185	17088	38536	29024	25833	20670	23627
(Unit value)	(1.76)	(2.42)	(3.13)	(3.10)	(3.69)	(3.47)	(2.57)	(1.90)	(1.55)
Of which from:									
Sudan	7127	5440	2471	1800	5367	3346	3300	3564	2537
Nigeria	16	-	143	81	1061	597	680	636	569
Chad	-	-	18	60	363	1317	2425	1577	5641
Egypt	-	34	10	-	-	-	-	-	60
Western Sahara	-	-	20	-	-	-	-	-	-
Kenya	-	-	-	80	34	-	22	-	-
Somalia	-	-	-	4	-	-	-	-	2
Djibouti	-	-	-	-	7	-	-	-	-
Cameroon	-	-	-	-	-	80	-	-	-
Mali	-	-	-	-	-	18	-	-	-
Eritrea	-	-	-	-	-	-	60	240	200
Ivory Coast	8	-	-	-	-	-	-	21	-
India	125	-	18	2	102	2	2	19	20
Pakistan	-	-	-	-	1	-	-	-	-
France	1796	2511	2430	2699	2951	2557	3190	4479	5326
UK	21	278	678	740	525	335	324	282	244
Germany	1	2	12	5	22	107	9	4	15
Netherlands	1	1	1	3	4	9	7	10	8
Belgium	20	-	-	-	5	-	-	1	-
Italy	-	-	-	-	13	-	1	18	5
Switzerland	-	4	-	-	-	4	-	-	-
Ireland	-	-	-	2	-	-	-	-	-
Croatia	-	-	-	20	-	-	-	-	-
Greece	-	-	-	5	-	-	-	-	-
Turkey	-	-	-	-	-	-	2	3	1
Soviet Union for.	180	-	-	-	-	-	-	-	-

(continued)

Table 19. (continued)

	1990	1991	1992	1993	1994	1995	1996	1997	1998
UAE	-	1	-	-	-	-	-	-	-
Saudi Arabia	-	-	-	5	-	-	-	-	-
Jordan	-	-	1	-	-	-	~	-	1
Japan	1	1	-	1	-	-	-	-	-
Philippines	5	-	-	-	-	-	-	-	-
Indonesia	-	-	-	-	-	-	39	11	91
China	-	-	-	-	-	-	-	-	126
Australia	-	-	-	-	-	-	-	-	440
Mexico	3	-	-	-	-	-	-	-	2
Brazil	-	1	-	1	-	-	-	-	-
Ecuador	-	-	-	-	-	-	-	4	-

Source: National statistics

reductions at source in the export price of gum arabic have meant that although imports in 1998 were an all-time high, and 46% higher than in 1994, the total value of those imports was 38% less than in 1994. The variation in average unit value illustrates this.

India

Imports of gum arabic into India are large and are briefly discussed here. Recorded imports into India, and sources, for the period 1991/92-1997/98 are shown in Table 20.

The imports from Iran and Indonesia may not be genuine gum arabic but these are small compared to the summation of all other imports.

The volumes involved are large and show a marked increase after 1994/95, rising from an average of approximately 4,700 tonnes/year in the first four years of data to 11,400 tonnes/year in the last three years; the annual average for the whole period is 7,600 tonnes. For the years 1995/96 and 1996/97, levels of imports were greater than those into the United States. Nigeria is the major source of Indian imports – by a large margin – over the other two main sources, Sudan and Tanzania. Imports from Nigeria averaged 5,300 tonnes/year over the seven years compared to 1,400 tonnes/year and 500 tonnes/year for Sudan and Tanzania, respectively. Trade opinion is that imports of gum arabic into India are largely of talha (*Acacia seyal* or, talha-like gum) and calculation of average unit values (not shown) supports this view.

Japan

Imports into Japan, and sources, for the period 1990-98 are shown in Table 21.

Japanese imports are quite substantial and averaged just under 1,900 tonnes/year during 1990-98. Sudan has always been the major supplier of gum arabic to Japan, almost exclusively so in terms of primary producers. Imports from Sudan averaged 1,500 tonnes annually.

Other Asian markets

Elsewhere in Asia, South Korea and Taiwan are modest importers of gum arabic. South Korean imports averaged just over 400 tonnes annually for the period 1993-98 and Sudan was the principal source of unprocessed gum. Imports into Taiwan for the same period averaged 250 tonnes/year and, again, Sudan was the main source. The Philippines import around 300 tonnes/year but most of it appears to be processed gum from Europe and the USA. The People's Republic of China, too, imports mainly processed gum.

Table 20. Gum arabic: volume of imports into India, and sources, 1991/92-1997/98[a] (tonnes).

	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98
Total	5153	4048	3906	5822	11922	12921	9391
Of which from:							
Nigeria	4504	1323	2740	4293	7434	10917	5805
Sudan	240	1820	757	686	3020	1305	2010
Tanzania	97	711	284	543	499	294	1216
Chad	40	-	-	-	-	-	-
Somalia	-	-	-	39	17	16	29
South Africa	-	-	-	48	44	126	-
Togo	-	-	-	-	29	-	-
Ethiopia	-	-	-	-	-	-	150
Morocco	-	-	-	-	-	-	10
Yemen Rep.	-	-	-	1	-	-	-
Pakistan	-	-	-	64	-	12	6
Nepal	-	-	-	-	-	-	18
France	-	4	-	-	22	8	-
Germany	-	-	-	-	219	-	-
Netherlands	-	-	-	-	62	120	-
UK	-	-	-	-	-	40	-
USA	2	1	8	-	138	-	80
Iran	138	189	117	134	155	83	15
UAE	-	-	-	-	121	-	-
Saudi Arabia	-	-	-	-	120	-	-
Kuwait	-	-	-	-	-	-	1
Indonesia	80	-	-	15	22	-	31
Vietnam	51	-	-	-	-	-	-
Singapore	1	-	-	-	-	-	-
Japan	-	-	-	-	20	-	-
Malaysia	-	-	-	-	-	-	20

Source: National statistics
Notes: [a] Year runs Apr.-Mar.

Table 21. Gum arabic: volume of imports into Japan, and sources, 1990-98 (tonnes).

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Total	2735	2022	2019	1219	1805	1435	1798	1880	2017
Of which from:									
Sudan	2702	1983	1644	741	1447	1055	1141	1369	1539
Guinea Bissau	-	-	20	-	-	-	-	-	-
Kenya	-	-	12	-	-	-	-	-	-
Nigeria	-	-	-	20	-	-	-	-	-
Eritrea	-	-	-	-	-	16	-	-	-
Chad	-	-	-	-	-	-	-	11	1
Cameroon	-	-	-	-	-	-	-	-	40
India	-	-	-	20	-	-	80	-	19
France	20	12	60	145	200	178	88	118	283
UK	8	20	176	245	110	38	51	22	48
Germany	-	-	-	-	10	1	64	110	31
Belgium	-	-	5	-	-	-	-	-	-
Ireland	-	-	-	-	-	-	-	-	2
USA	5	7	62	43	38	147	373	248	54
Uruguay	-	-	-	-	-	-	-	2	-
Russia	-	-	40	-	-	-	-	-	-
Ukraine	-	-	-	-	-	-	1	-	-
China	-	-	-	5	-	-	-	-	-

Source: National statistics

DEMAND TRENDS: FACTORS AFFECTING TRADE

World demand for gum arabic has fallen in two distinctive stages since its peak in the late 1960s at 60,000 tonnes to around 20,000 tonnes or less in the early 1990s (Anderson 1993; Barbier *et al.* 1990). The first fall occurred after the 1973/4 Sahelian drought and the second after the 1984 Sahelian drought. The monopolistic position of Sudan in the international market has diminished falling from over 80% in the 1960s to 65% or less today. The main causes for the decline in demand for gum during the 1970-1980s can be summarised as follows: 1) Supply shortages; 2) Export pricing policy; 3) Quality and specifications; 4) Substitutes. While these factors are by no means mutually exclusive, for example in periods of short supply it is common not only for prices to go up but for quality to go down, but these will be discussed separately for clarity.

Supply shortages

In the previous section, the problems of supply were discussed at length. Supply shortage is one of the major causes of consumer frustration with the gum arabic trade. Major disruptions have occurred twice within ten years and a third in 1992. The first two supply crises were drought induced, the most recent, a combination of drought and locust attack. The 1984 shortage was particularly damaging to the trade, coming as it did with no warnings of impending scarcity. Those trading organizations with

good market intelligence and the fortune to have stockpiled reserves in their warehouses did very well out of the shortage but many other companies went bust. The result has been that only a small number of powerful companies remain in the trade, competing vigorously for the shrinking market.

The first drought and shortage of 1973/4 was overcome largely by increasing producer prices to encourage exploitation but this was at the expense of future supply. This drought decimated the *Acacia senegal* populations of West Africa which rendered this region insignificant throughout the 1970s in world production terms.

The 1984 drought was much more severely felt, particularly in Sudan, because the tree stock was already degraded. Consuming industries had been able to accommodate the supply irregularities and high prices of 1974/5 because recovery was anticipated. When massive interruptions of supply and very high prices occurred for a second time, combined with the outbreak of civil war in Sudan (1983), consumer confidence in the market was extremely low. Companies which had already been investigating the new techniques available using modified starch products were forced to look for more stable supplies, not to mention cheaper ones of known quality (see substitutes).

More recently, the increasing trend of exports from Chad and Nigeria, has helped to safeguard and stabilize the position of gum Arabic as a raw material in international markets.

Quality and specifications

Gum arabic for food use has now more than ever had to comply with much stricter safety specifications. This factor, although perhaps not as significant as price in putting off consumers, has had an impact on demand and the general conduct of the trade. Importers have had to become much more discerning in identifying the purity of consignments ensuring that they comply with international specifications. Processing the gum, such as spray drying, ensures sterilization but increases cost, making it less competitive with starch substitutes.

It is particularly noticeable that at times of shortage and high price, the quality of gum deteriorates. This is because unscrupulous traders are known to blend inferior gum talha (*Acacia seyal*) with gum arabic to make limited stocks go further and to make handsome profits. Skillful blending can still meet the JECFA specifications for optical rotation by mixing 8% gum talha with gum arabic. Even a small amount of adulterant gum can reduce cost to the trader and by selling at gum arabic prices substantial profits can be made by those trading in large quantities. Anderson (1993a, 1993b, 1992) has written extensively on the problems of this practice and the limitations of the JECFA specifications in controlling it. There is a sufficiently large loophole to allow all sorts of gums with similar optical rotations, which have not undergone the rigorous toxicological testing, to slip through into food products. Toxicological testing can take up to 5 years or more and can cost up to a million US dollars.

Adulteration of gum consignments is not only dangerous from a health point of view, it can also lead to economic loss because the mixed gum does not perform as it should in its applications. Adulterated gum will not have the same performance as gum arabic. For these two reasons many companies are having to install their own laboratories to ensure that they are getting what they ordered. This is particularly important for importers who are deemed to be the manufacturer of everything they import. They are liable in law should they deal in contaminated gum arabic (Barbier *et al.* 1990; Anderson 1989b; 1993a).

Detection of adulterant gum

Given the increase of gum production and export from areas which traditionally included adulterant gums (*Combretum* gums, and other species of *Acacia*) various chemical assays have been developed to test and identify the gum samples prior to processing. An array of chemical techniques is required to identify *A. senegal* gum from other gum species within the genus *Acacia.* The gum arabic samples used are characterised by optical rotation, molecular mass distribution, determination of arabinose, galactose, rhamnose and glucuronic acid contents and estimation of protein content (Anderson 1977; Chikamai *et al.* 1995; Duvallet *et al.* 1993; Idris *et al.* 1998; Jurasek *et al.* 1994; Menzies 1992; Menzies *et al.* 1996; Mocak *et al.* 1998 to cite just a few).

Another innovative technique being developed is the potential use of immunoassays. The advantage of these techniques is that only a very small quantity of gum is needed, the tests can be quick and very accurate. The first generation of gum immunoassays employed antibodies present in antisera (polyclonal antibodies) raised by intramuscular injection of the gum into animals (commonly rabbits or mice), and purification of the antisera by affinity chromatography on EAH-Sepharose to yield relatively specific anti-gum antisera. Menzies (1992) used purified antisera to develop an indirect competitive enzyme linked immunosorbent assay (cELISA). The specificity of the assay was investigated by assessing the extent of cross reaction with commercial gum arabic samples, authentic *Acacia* gums from different species, other *non-Acacia* gum exudates, degraded samples of *A. senegal* gum and by hapten inhibition experiments. It was found that their cELISA could detect *A. senegal* gum and commercial samples of gum arabic but some cross reaction occurred with gums from other *Acacia* species notably gum tahla (*A. seyal*). Later he found that

the monoclonal antibody MAC 207 which recognizes arabinose residues present in AGPs and arabinogalactans (AGs), could be used in a quick dot-blot format to screen for the presence of gum tahla in consigments of gum arabic (Menzies *et al.* 1996). This finding is consistent with the observed higher levels of arabinose present in the gum tahla samples relative to the gum arabic samples.

Dewey and co-workers at Oxford, raised monoclonal antibodies that specifically recognized gum from *Acacia senegal* (Dewey *et al.* 1997), *A. seyal* (Thurston *et al.* 1998). and one that recognized both *A. seyal* and *Combretum* gum (Thurston *et al.* 1998). Using these antibodies they developed ELISAs for the detection of possible adulterant gums (*A. seyal* and *Combretum* gum) in commercial gum arabic. They also demonstrated the suitability of these antibodies to be used for the detection and quantification of gums used in food production by testing their ability to detect gums autoclaved in buffers even as low as pH 2.1 (Thurston *et al.*, 1999). The limit of detection of *A. seyal* in mixtures with *A. senegal* using the monoclonal antibody SY-HH3 in plate trapped antigen ELISAs was 0.5% and the limit of detection of *Combretum* gum in competition ELISAs was 0.1%. The sensitivity of these immunoassays to detect *A. seyal* or *Combretum* gum in mixtures is 10 to 100 times greater than any of the procedures currently in use. They have since used one of these antibodies, SY-HH3, in collaboration with colleagues at CSL, York, UK to develop a 3 minute, user friendly, lateral flow device for the rapid detection of *A. seyal* in mixtures with other gums (see Plate 29). It should be noted that the most recent JEFCA specifications for gum arabic in food use include both *A. senegal* and *A. seyal* in the definition (FAO/WHO 1999); however the two sources of gum can have different applications in the world trade and command different prices.

Quality control

The principles of quality control are more or less universal but the manner in which it is carried out in Sudan is different to other countries and so is described separately.

Sudan

The intrinsically high quality of Sudanese gum arabic (hashab), combined with an efficient, long-established system of collection and post-harvest handling, means that the problems of quality control are not nearly so great in Sudan as they are for some other countries. A well-organised extension service ensures that the people who tap the trees and collect the gum do it in the correct manner (no mixing of gum from different botanical sources; picking the gum from the tree rather than off the ground; placing it in baskets rather than closed bags) and these aspects play an important part in determining the quality of the gum which arrives at the market for auction. Traders who clean and sort the gum before selling it on to the GAC know that they will be penalised if, during the re-cleaning, the gum is found to be below the expected quality.

At present, little cleaning or sorting is undertaken by the producer (collector) of the gum. Since he is paid at the auction according to the weight of gum rather than on quality criteria (within limits, since his gum would not be accepted for auction if it were grossly contaminated), there is no great incentive for him to spend time cleaning and sorting it. Some degree of cleaning and sorting may be undertaken by small village traders to whom the producer sells his gum, but it is usually undertaken by the large traders after it has been sold at auction and prior to them selling it to the GAC. If the GAC intervenes to buy the gum at auction because it has not reached the floor price, then the company undertakes the cleaning and sorting at its own warehouses in the regional centres in the gum belt.

Cleaning and sorting is done by hand, usually by women, who sort it on the ground into piles of whole tears and smaller pieces, separating any excessively dark gum and removing pieces of bark and other foreign matter. The sorted gum is sold on to the GAC and bagged and transported to its warehouses at Port Sudan. Unlike some other countries, separation of mixtures of gum from different botanical sources (such as *A. senegal* and *A. seyal*) is not necessary because it is kept quite separate during its collection.

On arrival at the GAC depot at Port Sudan, every consignment of gum hashab is re-cleaned, sorted and graded in preparation for export. Until 1991 this operation was carried out manually. Since then, it has been mechanised using a system of conveyor belts and shaking and sieving machines. The traders' bags of cleaned gum are upturned onto an inclined moving belt which takes the gum up to the shakers and sieves; a man is present at the start of the belt to remove any very large lumps. After separation of the dust and under-sized pieces by sieving, the remaining lumps of gum pass on a belt between lines of women who give them a final inspection - any remaining foreign matter (such as stones) or dark coloured pieces are removed by hand. At the end of the conveyor belt the gum is bagged and weighed ready for export or it is transferred to a kibbling machine for further processing (see Value-added processing).

Since 1992, when a purpose-built laboratory was established, a more rigorous system of quality control and certification has been put in place at the GAC's cleaning and processing facility at Port Sudan. Firstly, all gum which arrives at Port Sudan is sampled and analysed for optical rotation. This is sufficient to identify any gum talha in admixture with gum hashab. The bags of up-country gum are each labelled with a number which identifies the trader, so any problem brought to light by the quality control measures can be discussed and resolved with the trader concerned. A second sample is periodically taken

for analysis during mechanical cleaning. Finally, during bagging a sample is taken for analysis: loss on drying, optical rotation, acid-insoluble matter and total ash are determined and the details are recorded on a Certificate of Analysis. This is presented with each batch of kibbled, HPS (Hand Picked Selected) or cleaned gum that is exported. A sample of each export batch is kept for reference for one season.

Other producers

Procedures for quality control are far less stringent or formalised in other countries and depend very much on the inclination of the particular trader. Such quality control as exists rests largely on visual inspection: firstly, when the initial transactions are made between collector and agent, agent and trader, and secondly during cleaning and sorting which is done manually. After arrival at the trader's warehouse, sacks of gum are emptied on to the floor for cleaning and sorting, usually by groups of women. Foreign matter is removed by hand and sometimes by 'winnowing'. Pieces of bark are removed from lumps of gum with a knife. Large piles of cleaned gum are formed and these are then bagged for export, either in 50 kg jute or woven polypropylene bags or smaller, 25 kg ones. Larger (80 kg) bags are becoming less popular. In a few cases, optical rotation is measured as a means of checking the absence of dextro-rotatory gums such as *A. seyal* in batches of supposed *A. senegal*.

In Kenya, the sacks of gum which arrive at SALTLICK's Isiolo base are first upturned over a wire mesh on a table to separate dust and small pieces of gum from the larger lumps. Batches of the sieved gum are then taken and sorted on the floor. Any dark pieces of gum which are adhering to paler pieces are broken off and removed.

Quality criteria

For genuine gum arabic the most obvious visual indicators of good quality are cleanliness, *i.e.* freedom from foreign matter such as bits of bark, sand or dirt and paleness of colour. Food and pharmaceutical uses demand these and limits on things such as insoluble matter and ash generally appear in relevant specifications.

Whatever the changing face of specifications may be (see Specifications), the facts in the real world are somewhat clearer. The quality of gum arabic as received by the importer is very dependent on the source, both botanical and geographical. Gum arabic (hashab) from Sudan is the highest quality and sets the standard by which other 'gum arabics' are judged. Not only does Sudanese gum come from one species (*A. senegal*) which intrinsically produces a high quality exudate with superior technical performance, but the collection, cleaning, sorting and handling of it up to the point of export ensures that that quality is maintained. Within Sudan, gum arabic from the Kordofan region has the highest reputation, and traders and end-users in importing countries often refer to 'Kordofan gum' when indicating their preferences.

Nigerian gum arabic, on the other hand, has a reputation for very variable quality. Some gum is comparable to the best Sudanese quality but much of it is poorer. A major problem for importers and end-users is the inconsistent, and often heterogeneous, nature of the consignments: gum of varying degrees of cleanliness and colour is present, which reflects the less rigorous methods of harvesting and post-harvest treatment practised in Nigeria compared with Sudan. One aspect, in particular, which adversely affects the quality is the mixing of different types of gum, *i.e.* gum collected from different species of *Acacia*.

Gum talha from Sudan (produced from *A. seyal*) is intrinsically a poorer quality gum than hashab - it has inferior emulsifying properties and even light-coloured samples of whole gum sometimes form dark solutions in water due to the presence of tannins and other impurities. It is more friable than hashab and is rarely found in large lumps in export consignments.

Good solubility is a very important functional property but this does not just refer to absence of particulate foreign matter. Incomplete solubility can be due to the presence of other gums, which only form gels, or to the intrinsic nature of the gum arabic. Kenyan gum from *A. senegal* var. *kerensis*, for example, has been found by end-users to be somewhat variable and not always very good in terms of solubility. On the other hand, the viscosity of Kenyan gum is higher than that from *A. senegal* var. *senegal* and it is claimed to have better emulsifying and stabilising properties.

Food grade gum arabic has limits on heavy metals and/or arsenic and lead and this may occasionally cause problems. Ugandan sources of gum arabic from *A. senegal*, for example, although not yet exploited commercially in a big way, have been found to have unusually high heavy metal content and this has been attributed to the soils where the trees grow (Anderson and Wang Weiping 1992).

Grades

Sudan

There are four grades of gum hashab (*Acacia senegal* gum): HPS (Hand Picked Selected), Cleaned (occasionally called Clear Amber Sorts), Siftings and Dust. The first two are the main ones to enter international trade. Cleaned gum has accounted for around 80% of hashab exports in the past. The names of the grades arise from the way in which the gum is cleaned and sorted. Small amounts of 'Natural' gum (*i.e.* gum which has not been cleaned or sorted) used to be available but there is now very little demand for this. Kibbled gum (gum in powdered state) has recently been produced and this is discussed in more detail below (Value-added processing).

Gum talha (*Acacia seyal* gum) from Sudan has traditionally only been sold as one grade but from 1995 it was being cleaned and graded to form three grades, Super, Standard Clean and Siftings.

Nigeria

Nigerian gum arabic is sorted into three grades. The top grade (Grade 1) is gum produced from *A. senegal*, and although comparable to Sudanese Cleaned gum it was being discounted in price by US$ 400-500/tonne in 1995. Grade 2 is gum produced from other species of *Acacia* (such as *A. seyal* and *A. sieberana*). Grade 3 gum is much darker and very mixed in quality - it may consist of gum from species other than *Acacia* (such as *Combretum* and *Albizia*).

Other producers

Gum arabic from Chad is generally cleaned but not graded. Hard gum ('kittir', from *A. senegal* and/or *A. laeta*) is separated from flaky gum ('talha'). This applies to most of the countries in Francophone West Africa. In Niger there is also a product called 'clean sifted Niger gum', which is a mixture of 60% flaky gum and 40% hard gum. Most gum from Kenya is exported as a single ('cleaned') grade.

Specifications

Food-use specifications

The current definition of gum arabic as stated in the most recent JECFA specification (1998, amended 1999) has been given earlier (see Definition and Description). As noted earlier, a JECFA specification exists for gum arabic intended for use as a food additive. JECFA meets regularly to discuss specifications for food additives and the one for gum arabic has undergone a number of revisions over the years. In order to better appreciate the changes which have taken place, and the basis of the cause for concern by some, it is instructive to look at earlier specifications as well as the present one. Limits for various physico-chemical data, taken from specifications published in 1978, 1990, 1997 and 1998, are shown in Table 22. In addition, optical rotation is now described as levorotatory for aqueous solutions of gum from *A. senegal* and dextrorotatory for solutions of gum from *A. seyal*. Solubility is given as 1 g dissolving in 2 ml of water; insoluble in ethanol. Tests for starch, dextrin and tannin-bearing gums (as described) should be negative.

Microbiological criteria are given as:

Salmonella spp.:	negative per test
Escherichia coli:	negative in 1 g

It can be seen that limits for loss on drying, acid-insoluble matter and total ash have not changed over the 20-year period. Limits for heavy metals, lead and arsenic remained the same until 1997, when a limit for heavy metals was omitted and the one for lead was halved and, in 1998, it was further reduced.

Of particular interest are the parameters for optical rotation and nitrogen. Gum arabic from *A. senegal* differs from that from *A. seyal* and some other *Acacia* (e.g. *A. karroo*) and non-*Acacia* gums in that solutions of it in water are levorotatory (*i.e.* have a negative optical

Table 22. Gum arabic: summary of data given in JECFA specifications, 1978-98.

	1978	1990	1997	1998
Loss on drying	max 15%	max 15%	max 15%	max 15%
Acid-insoluble matter	max 1%	max 1%	max 1%	max 1%
Total ash	max 4%	max 4%	max 4%	max 4%
Acid-insoluble ash	max 0.5%	max 0.5%	max 0.5%	max 0.5%
Heavy metals	max 40 mg/kg	max 40 mg/kg	-	-
Lead	max 10 mg/kg	max 10 mg/kg	max 5 mg/kg	max 2 mg/kg
Arsenic	max 3 mg/kg	max 3 mg/kg	max 3 mg/kg	max 3 mg/kg
Nitrogen	-	0.27 to 0.39%	-	-
Optical rotation	sl. levorotatory	α_D = -26 to -34	*A. senegal:* levorotatory *A. seyal:* dextrorotatory	*A. senegal:* levoratory *A. seyal:* dextrorotatory

rotation) rather than dextrorotatory (positive optical rotation). Since the test article which was submitted to toxicological testing - and accepted as safe as a food additive in 1983 - was gum obtained from *A. senegal*, it was decided to amend the then existing JECFA specification (1986) to reflect this. The changes appeared in the 1990 specification which differed in three respects from the earlier ones.

Firstly, the definition changed subtly but significantly. The 1978 and 1986 specifications defined gum arabic as the "dried exudation obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or related species of *Acacia* (fam. Leguminosae)". Additional wording in all the specifications refers to the chemical nature of gum arabic and its hydrolysis products. In 1990 it changed to the "dried exudation obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or **closely** related species" (FAO 1990). The other two changes were the addition of numerical limits for nitrogen and optical rotation, limits which applied most closely to *A. senegal* and excluded most (but not all) other gums. Most notably it excluded gum from *A. seyal*. By tightening up the specification in these ways it was also seen as attempting to eliminate users' complaints that gum of unacceptable quality, originating from botanical sources other than that specified, was being supplied by some traders.

The 1995 specification retained essentially the same definition as the 1990 one - the words "closely related species" were only followed by "of *Acacia* (fam. Leguminosae)" - but the references to nitrogen and optical rotation were dropped. Those who wished to keep *A. seyal* gum (and other non-*A. senegal* gums) excluded from the specification pinned their hopes on the term 'closely related species' since, botanically, it is accepted that *A. seyal* is not closely related to *A. senegal*. However, the JECFA report which commented on these changes controversially contested that not only did the revised specification adequately reflect the material that was tested toxicologically but that *A. seyal* was closely related to *A. senegal* (WHO 1995).

The 1997 specification retains the words "closely related species of *Acacia* (fam. Leguminosae)" but adds two further sentences: "*A. seyal* is a closely related species" and "Gum arabic from *A. seyal* is sometimes referred to as gum talha". The first of these statements is contentious and as long as there remains ambiguity in what is meant by 'closely related' there will continue to be arguments. Its proponents (e.g. Jurasek *et al.* 1993) claim that the term 'closely related' is to be taken in a chemical sense rather than a botanical one. The specification's reference to optical rotation now relates to two specified types of gum arabic and states the simple facts that *A. senegal* solutions are levorotatory and *A. seyal* solutions are dextrorotatory.

The JECFA specification published in 1998 explicitly included *A. seyal* gum in the definition, along with *A. senegal* (FAO/WHO 1998), and made no reference to other species of *Acacia*. The question as to whether the present (1997) specification is likely to bring about any changes in the market for gum arabic is discussed in the concluding remarks section.

US food specification

In the United States, a Food Chemicals Codex specification exists. The latest edition (1996) defines "Acacia, Gum arabic" as "A dried gummy exudation obtained from the stems and branches of *Acacia senegal* (L.) Willd. or of related species of *Acacia* (fam. Leguminosae)". There is no mention of *A. seyal* and there remains the ambiguity as to what is meant by 'related species'.

The specification describes identification and purity tests and gives limits for the following:

Loss on drying	max 15.0%
Insoluble matter	max 1.0%
Total ash	max 4.0%
Acid-insoluble ash	max 0.5%
Heavy metals (as lead)	max 0.002%
Lead	max 5 mg/kg
Arsenic	max 3 mg/kg

The limits on heavy metals and lead represent a reduction by half in the values given in the previous specification (1981) but it is still higher than the JECFA (1998) specifications with a maximum of 2 mg/kg for lead.

Pharmacopoeia specifications

For pharmaceutical use, gum arabic appears in many pharmacopoeias, including the European and British Pharmacopoeias. The most recent edition of the British Pharmacopoeia (2002) defines "Acacia" as "the air-hardened, gummy exudate flowing naturally from or obtained by incision of the trunk and branches of *Acacia senegal* (L.) Willdenow and other species of *Acacia* of African origin". The definition of the European Pharmacopoeia (1997) is identical, as is most of the rest of the specification. Identification and purity tests are described and limits given for the following:

Loss on drying	max 15.0%
Insoluble matter	max 0.5%
Ash	max 4.0%
Microbial contamination	1.0 g free from *Escherichia coli*

The limit on microbial contamination is now worded as in the European Pharmacopoeia specification: "Total viable aerobic count not more than 10^4 microorganisms per gram, determined by plate count."

It should be noted that although the definition allows gum from "other species of *Acacia* of African origin", a solution of the gum is to be laevorotatory. Gums such as

those from *A. seyal* and *A. karroo* would not, therefore, be permitted.

Specifications for "Powdered Acacia" and "Spray-dried Acacia" are also given in the BP and for "Acacia, Spray-dried" in the EP.

Prices

It has already been said that producer pricing has had a major effect on production and supply. Similarly pricing of exports is a crucial factor in causing the demise of the gum arabic trade. Just as the quality of Sudanese gum arabic is used as a yardstick for judging the quality of gum arabic from other sources, so the FOB export price at Port Sudan is used as a benchmark by exporters in other countries for setting the price for their gum arabic. Prices of gum, particularly *A. senegal*, from sources other than Sudan are invariably discounted with respect to the official Sudanese price. In Sudan, the official price is announced by the Gum Arabic Company in October of one year and normally applies for the whole of the next 12 months.

During the 1960s, export prices were fairly constant at around $500 - 600 per tonne. By the 1970s prices were still stable but in 1973, under increasing pressure from central government to maximize foreign currency earnings, and because drought had reduced export earnings from the agricultural sector, (agriculture makes up virtually all of Sudan's exports), the first of the major price rises occurred. From $600 per tonne in 1972, prices were raised to $4,000 in 1974. The effect on the demand for gum arabic was dramatic. In 1971 39,000 tonnes were exported and in 1975 this was down to 15,000. Even though there was drought, supply was considerably higher than this figure (46,000) because high producer prices had encouraged over-exploitation. This was the first major pricing policy error by the GAC and it inevitably alienated customers.

To a point, the gum arabic price elasticity of demand was inelastic (*i.e.* demand did not decrease when prices increased). The initial price rise from $600 in 1972 to $2400 in 1973 did not deter the consumer significantly and exports were at 32,000 tonnes. However, when prices doubled once more, price elasticity suddenly increased. It is worthy of note that two other trades in natural gums, tragacanth from Iran and karaya from India both collapsed in the 1970s as a result of fixed non-competitive prices being set (Anderson 1993a). The GAC must have realized that not only was demand becoming increasingly elastic but also that many alternatives to gum arabic were becoming available. Reports from the 1960's onwards (Edmonds 1963, FAO 1973) already discussed the threat to gum arabic from substitutes and yet the GAC persisted with a pricing policy that drove consumers in search of more competitive substitutes. In fact Awouda (then of the GAC), warned in 1976 that although at that time demand was still relatively inelastic, this was changing and he concluded that prices could not go on increasing indefinitely (Awouda 1976).

In 1983 the International Trade Centre (ITC) report which in every other respect expressed optimism regarding future prospects for the gum trade (pre-1984 drought), already showed concern over the shift towards substitutes:

"formulas were reshuffled, technologies were changed, the balance tipped in the favour of substitute products or lines of products containing gum arabic were dropped altogether" (ITC Geneva 1983). These substitutes are mainly from the starch industry, (see below for a further discussion of substitutes).

The GAC realized the problem and reduced the prices in 1978 to $1,200 per tonne. Naturally, consumers were cautious about putting their trust once more into this product. Some had already invested in new technology, so as to avoid having to rely on unstable supplies and prices. The early 1980s did see the restoration of confidence but this was short lived. Drought and political unrest reduced production and caused prices to rise again, (as high as $4,950 at the beginning of 1986). The decline of both the gum belt and the gum trade was well underway. The international gum market was, it seems, irreversibly changed. Quantitative estimates of demand in relation to price are lacking for the period after the effects of the drought but it seems unlikely that price reductions (unless very significant and competitive with starches) would bring about a notable increase in demand. Modified starches are sold at between $1,100 and $2,400 per tonne as against gum arabic with a base price of around $2,800.

Larson and Bromley (1991) strongly believed that domestic pricing policies for production and export were the root causes of the fall in demand, and there are many within the trade who are of the same opinion (commercial pers. comm. 1993). During the 1980s and early 1990s gum prices have been unacceptably high for the confectionery industry who are the main users. The result has been a steady increase in the use of substitutes to the point where up to 90% of all gum used in confectionery, some 36,000 tonnes, has been replaced (Anderson 1993a; Rathgeb 1989; Heitmen 1988). High export prices are made even worse by the setting of high export taxes. This is a major stumbling block in attempts to make prices more competitive. In Sudan export tax can be as high as 50%. Although government assurances were sought by the GAC in 1989 to lower export taxes, it appears that the taxes remain largely intact.

More recently, prices for the two main grades of hashab (*A. senegal* gum) for the six seasons 1994/95-1999/2000 are indicated below (US$/tonne, FOB Port Sudan):

Hashab gum	1994/95	1995/96	1996/97	1997/98	1998/99	1999/2000
			Price (US$/tonne)			
HPS	4,850	2,600	2,600	1,600	1,800	1,775
Cleaned	4,200	2,200	1,800	1,200	1,395	1,250

Note: one UK industry source has stated that the 1995/96 price for Cleaned gum was US$ 3500, rather than US$ 2200. Its figures for 1994/95, 1996/97 and 1997/98 agree with those shown.

The Cleaned grade comprises the bulk of exports. Its price rose to US$4,200/tonne in 1994/95 and then fell in stages to US$1,200/tonne in 1997/98. In 1998/99 it increased to US$1,395/tonne and finally fell to US$1,250/tonne for the 1999/2000 season. The sharp fall in price in 1995/96 (and subsequently) was an attempt to attract new customers following near record production the previous year. In 1995, when Cleaned was fetching US$ 4,200, the price of Dust was US$ 2,760 per tonne. The sharp fall in price announced by the GAC at the beginning of the 1995/96 season is said by some to have been a response to the low prices being offered by Nigeria in 1995, and by others to have been a unilateral decision aimed at squeezing their competitors. Whatever the reason, the official Sudanese prices were held for the next year before falling further at the start of last season (current prices). Prices have fallen by more than half over the five years.

The price of talha (*A. seyal* gum) is always much lower than that of hashab. Gum talha from Sudan has traditionally only been sold as one grade but from 1995 it was being cleaned and graded to form three grades, Super, Standard Clean and Siftings. Export prices are shown below (US$/tonne, FOB Port Sudan):

Talha gum	1995/96	1996/97	1997/98	1999/2000
		Price (US$/tonne)		
Super	900-950	600-700	600-650	
Standard Clean	850	550	560	760
Siftings	400	275	245	

A marked drop in the price of all three grades in 1996/97 was followed by a small increase in the price of Standard Clean, the main grade, and a further small decline in the price of Siftings (current prices). In practice, there may be some deviation from these prices and the current price of Standard Clean is often greater than indicated what is seen in 1999/2000 price.

It is not possible to generalise about the magnitude of the price change at each stage in the chain from collector to exporter. The GAC in Sudan has all the cost information it requires to put into the complex formula for calculating the floor and export prices of gum arabic but such information is not publicly available and, in any case, would have no relevance outside Sudan. Elsewhere, where there is rarely a single body which buys gum or sets the price, each middle man and trader has his own costs and mark-ups. At the producer level, the collector may not always be paid in cash but in kind, particularly (in Sudan) of water.

Reliable information is notoriously difficult to acquire and very location-specific. It also becomes out-dated very quickly. However, the local price paid for gum is very dependent on the export price and the appropriate exchange rate. In Kenya for example, the price paid in 1994 by one group to collectors was KSh 85/kg. The 1995 price was KSh 50/kg. A second trader in Kenya paid KSh 80-120/kg to its agents for gum in 1994 (and received US$3,200/tonne FOB Mombasa for gum destined for France). The poor exchange rate of the Kenyan shilling against the US$ discouraged this trader from buying or selling gum in 1995. One Kenyan company has stated that at current prices it is not accepting less than US$ 1,400/tonne for export grade *A. senegal* gum. Siftings and dark coloured gum removed during cleaning are sold locally.

It is not possible to cite reliable year-by-year prices for Nigeria. Prices per tonne of the two main export grades in early 1994, (when Sudanese Cleaned gum was US$ 4,000/tonne), were US$ 3,500 (Grade 1) and US$ 600-700 (Grade 2). Current prices (2000) for Grade 1 are around US$ 1,400/tonne (*i.e.* discounted by US$ 400 compared to Sudanese Cleaned gum hashab) but this will vary amongst traders and is negotiable.

With the exception of Nigeria, gum buying in West Africa has been dominated almost exclusively by one major French organization IRANEX and its subsidiary Colloides Naturels International. This organization is the largest gum trading company in the world and takes

virtually all of the gum produced in FWA as well as such large consignments from Sudan that are eligible for special pricing. This organization has done much in recent years to improve the commercialization of gum production in FWA (Francophone West Africa) through organizations such as AIDGUM (a non profit organization, L'Association International pour le Developpement des Gomes Naturelles, which it funds). There attention has turned to developing this region as an alternative supplier of gum to Sudan since the mid 1980's when IRANEX was temporarily expelled from Sudan for having been implicated in the purchase of smuggled gum from Sudan into the Cameroon and Central African Republic. This trading Company appears to exploit much of the region (except Senegal with its already well established trading system) as a large concession.

The activities of this company are extremely secretive and because it has the virtual monopoly on the region it is very difficult to ascertain the demand trends for the region. The feeling within the trade appears to be that the trend is towards increasing the share of world production from this region. For the most part, the gum producing countries of West Africa are reasonably stable (with the possible recent exception of Nigeria) and this is also in their favour.

In general terms West Africa demonstrates a similar overall trend to that in Sudan. After an indifferent period from the 1970s to mid 1980s, exports from the region are improving at the expense of Sudan. When supplies from Sudan are short, the international market is turning increasingly to West Africa and other regions (*i.e.* Kenya and Tanzania) for an alternative supply. The shortage in 1993 has been aided significantly by exports of more that 5,000 tonnes from West Africa. West African producers because of their generally informal methods of gum production are able to respond quickly to changes in demand. The international price paid for gum arabic from West Africa is usually below that of Sudanese gum. This is an attractive feature when supply shortages from Sudan result in enormous price increases.

The quality of gum from West Africa is less constant or reliable than that from Sudan. It is often charged that West African collectors do not distinguish between the different *Acacia* gums nor between *Combretum* gums and that this is why prices are lower. Coulibaly (1988), citing the example of Mali, claimed that the dominant foreign buyer in the region deliberately criticized the quality of Malian gum in order to buy it at lower prices. While their may be some truth in this assertion, it is widely recognized that West African gum, if not inferior, has different chemical properties to the gums of Sudan (commercial pers. comm. 1993). Sudan is the only country at present with an internationally recognized grading system but it is common to find any number of gums sold under "meaningless" trade names originating from trees other than *Acacia senegal* (Anderson 1993b). Examples of these are; Nigerian Number 2, white Mali gum, and East African gum. These gums are however rarely confused with gum arabic because it is apparent from their much lower prices that they cannot be the genuine article and this is usually sufficient warning to potential buyers. This does not of course rule out the blending of some of these gums with gum arabic as discussed above.

In Nigeria, a steady demand is more or less assured for the country's annual production, continuing as it does its traditional links with British importers and the Manufacturer Rowntrees Mackintosh (Nestlé).

Value-added processing

When imported into the consumer countries most gum arabic is further processed into kibbled and powdered forms. An important benefit for the processor (and therefore, ultimately, the end-user) of reducing gum arabic to a powdered state is that it enables gums from different sources to be blended. This not only allows mixtures of gums to be made that possess the properties required for a particular application but, where appropriate, enables poorer quality or lower priced gum to be blended with the better, but more highly priced, *A. senegal*-type gum, with minimum loss of functionality. In a similar manner, gum arabic is blended with cheaper materials such as modified starches and other substitutes.

Kibbling

Kibbling entails passing whole or large lumps of gum through a hammer mill and then screening it to produce smaller granules of more uniform size. These pieces are more easily dissolved in water, and under more reproducible conditions, than the raw gum and so are preferred by the end-user.

As an extension to its mechanised cleaning process, Sudan recently installed machinery to produce kibbled gum arabic. In so doing, it became the first (and only) producer country to gain added value in this way. Production began during the 1993/94 season, when approximately 2,500 tonnes of kibbled gum were produced. Initially, kibbled gum was sold at a premium to all other grades but it is now priced between the top HPS grade and Cleaned. Prices are given below (price per tonne FOB Port Sudan, provided by the Gum Arabic Company) although one UK importer of gum arabic claims that relatively little kibbled gum has been produced since the first year's production:

1994/95	1995/96	1996/97	1997/98
US$ 5000	US$ 4000	US$ 2400	US$ 2000

In the case of Sudan, although it began production of kibbled hashab in 1993/94, sales of it since then have

simply drawn on stocks produced in that year. Most kibbled gum arabic (*A. senegal*) is kibbled by processors in the importing countries. The same is true of spray-dried gum although Sudan, for example, still aspires, one day, to producing spray-dried gum itself. A rather less demanding form of value-added processing is the production of mechanically powdered gum arabic and Sudan has plans to undertake this in the near future.

On a very much smaller scale, at least two producers in Kenya have used small mills to produce granules of gum arabic for the local pharmaceutical industry. Simple technology developed by Kenya Forestry Research Institute (KEFRI) has also been used by women's groups to briquette sawdust using gum arabic dust, thus enabling it to be sold in a more convenient form for fuel.

Spray drying

Powdered gum may be produced from kibbled gum but it may also be produced by a process known as spray drying. This furnishes a high-quality, free-flowing powder with even better solubility characteristics than kibbled gum. The gum is dissolved in water, filtered and/or centrifuged to remove impurities and the solution, after pasteurisation to remove microbial contamination, is sprayed into a stream of hot air to promote evaporation of the water. By altering atomising conditions, powder can be produced with varying particle sizes and bulk densities, according to the end-user's requirements. Spray drying is an energy-intensive process and this, together with the high capital cost of the equipment and the requirements for large quantities of pure water, makes it something that most gum arabic producers could not consider. The difficulty of handling large volumes of aqueous solutions of gum in a producer country - where ambient temperatures are high - without suffering unacceptable increases in the microbiological load adds further to the problem.

Added value

In the UK the cost of processing adds, very approximately, the following amounts to the price per tonne of raw gum at each stage of the processing (US$):

	Raw gum	Kibbled	Powdered	Spray dried
Added value (US$/tonne)	x	x + 250-500	x + 250-500	x + 500

Substitutes

If one considers the combination of supply irregularity, uncompetitive prices and the inconvenience of having to deal with an unscrupulous market in terms of quality, it is hardly surprising that many end users are turning to substitutes even though they admire the performance of gum arabic. As Anderson (1993a) stated:

"Modified starches are attractive alternatives because they are of modern technological origin, cost effective, standardized in quality from batch to batch, homogeneous, free from foreign matter and sterile as a result of the manufacturing process that led to their production."

Ever since the supply problems caused by droughts in the early 1970s, gum arabic has suffered intense competition from substitutes such as modified starches, maltodextrins and celluloses, particularly the starches. This has been especially true in the food industry. Rowntree Fruit Gums is often cited as an example of a product which used to contain a high proportion of gum arabic, but gradually switched from this to the use of blends containing modified starches. The most well known substitutes are given in Table 23. Gum arabic is also facing increased competition from other natural gums such as guar and locust bean gum. Guar gum for example is now most commonly used in dairy products such as ice creams having been found to perform more satisfactorily than gum arabic. In addition, these gums come from developed countries with greater assurance of regular supply.

Despite the unrelenting competition from substitutes, gum arabic is still regarded by many as having technical advantages which make it difficult to replace completely in many applications. Even in the past, when shortages of supply and high prices of Sudanese gum made it propitious to change, many end-users resisted. In confectionery, for example, starches do not retain the flavour in some products as well as gum arabic and, when gums are made with starch, they are liable to give rise to some split gums. Consumer acceptance is paramount and, for some in the confectionery industry, the inferior 'quality' of a starch-based product has been a strong enough reason not to change. In cola-type soft drinks, use of substitutes can adversely affect shelf life.

Apart from substitution by starches and celluloses, end-users may choose to switch from using, say, only top quality Sudanese *Acacia senegal* gum to blends of it with cheaper gums such as talha (*Acacia seyal* gum) or some other Acacia gum, or even non-Acacia gums. By altering the composition of the blend a wide range of functional properties is possible.

In recent years, the price advantage of the starches has been eroded by lower prices for gum arabic and this appears to have stemmed any further movement away

Table 23. Permitted food hydrocolloids.

Class	Origin	Source	Examples
		tree exudate	gum arabic gum karaya gum tragacanth
	Vegetable	seed galacto-mannans	guar gum locust bean gum
		marine algae	agar-agar alginates
Natural		carrageenans	
		citrus and other fruits	pectin modified pectin
	Animal	skin and bones	gelatin (*)
Bio-synthetic	Fermentation process	various micro-organisms	xanthan gum (others in production)
Chemically modified or processed	Various chemical reactions	cellulose from various trees	methylcellulose carboxymethyl cellulose (CMC) etc.
		starches from various plants	modified starches (a wide range)
Synthesised by the chemical industry	Various chemical reactions	natural oil or gas	polyvinyls polyacrylates polyethylene oxides etc.

Source: Flowerman (1985) * less popular since the BSE scare

from gum arabic. The renewed interest in gum arabic in the United States as a constituent of fountain solutions, referred to in technical uses above, is a further positive sign that gum arabic is making some headway in the fight against substitutes.

CONCLUDING REMARKS

The quality of the gum arabic which reaches the international market is dependent on two things: the intrinsic quality as determined by the species (or variety) of *Acacia* from which the gum is collected – which is a reflection of the chemistry of the gum – and the quality which is determined by its treatment and handling subsequent to exudation from the tree. At the varietal level, gum from *A. senegal* var. *senegal* (the variety found and planted in Sudan) is different in composition to the gum from *A. senegal* var. *kerensis* (found in Kenya) – the latter has inferior solubility characteristics compared with gum from the Sudanese variety. *A. seyal* var. *seyal* and *A. seyal* var. *fistula*, on the other hand, produce gums which are very similar in composition (and therefore intrinsic quality). In the case of Sudanese *A. senegal*, a recent study (Karamalla *et al.* 1998) of more than 800 authenticated samples demonstrated a relative consistency in most parameters which were analysed, despite being collected from a wide variety of soils and sites within Sudan. *A. senegal* gum has intrinsically superior characteristics to that from *A. seyal* and this is reflected in their relative prices. This is not to say that *A. seyal* gum does not command a sizeable market – there is general agreement within the trade that demand for talha has increased in recent years and up to half of all consumption of gum arabic could be talha-type gum.

Sudan enjoys a deserved reputation for delivering high quality hashab (*Acacia senegal* gum) to its customers and is the only country with whom most importers are willing to contract to buy gum on the basis of a Letter of Credit (and not insist on payment after receipt and inspection of goods). Moreover, it holds significant stocks of hashab as a buffer to guard against possible

years of low production. However, improved collection and cleaning practices in Chad have led to good quality kitir (*A. senegal* gum) becoming available in quantity and this has resulted in growing confidence on the part of importers to purchase gum from this source, as evidenced by trade statistics. These two countries, together with Nigeria, will continue to be the major sources of *A. senegal* (and *A. seyal*) gum for the foreseeable future.

THE FUTURE

Gum arabic is a truly ancient article of trade, dating back to the first Egyptian Dynasty (3400 BC). Europe imported gum in medieval times, and international trade increased dramatically in the first half of the twentieth century with increasing demand from the confectionery industry. Gum arabic is harvested principally from the tree species *Acacia senegal* and *A. seyal*, however, the superior properties of gum from the former means that it has dominated international trade. It offers a wide number of benefits to the people who live in the semi-arid zones of sub-Saharan Africa and the Indian subcontinent. This is particularly so in Sudan where gum production is an integral part of many of the rain-fed farming systems. Gum has provided an important source of cash income for the subsistence farming population and, for many thousands of families, the income from it has become crucial especially during years of poor agricultural harvests. Apart from the commercial benefits, the trees also provide invaluable environmental benefits. They produce browse and fuelwood as well as ameliorating and protecting the soil. Although not always perceived as such, possibly their greatest benefit in these drought stricken regions is to halt long term decline in soil productivity.

The world's demand for gum arabic is sensitive to many factors including price, quality and supply. The severe Sahelian drought of 1973/74 resulted in a world shortage of gum arabic and high prices which, in turn, accelerated the replacement of gum arabic by substitutes such as modified starches. Increasing supplies from Sudan and other countries such as Chad and Nigeria have helped to increase the African exports to over 40,000 tonnes in the final years of the 20th Century. It appears that the pessimism about falling markets for gum arabic in the 1980s and 1990s may not hold due to the more recent strengthening demand from the natural products sector.

A synthesis of the extensive literature on the species, followed by a historical and modern account of the gum arabic trade is presented in this book. Gum arabic still has an important international market, and most research undertaken on the species has been to increase production and marketing of this valuable product. However, from the large bibliography presented, it is evident that there still remain many gaps in our current knowledge of the species.

Areas for future research should include the following.

Ecophysiological studies on the mechanisms of gummosis. It is known that there is a link between water stress, starch metabolism and gum production but the processes are poorly understood and, until they are, selection and management to increase gum yield will be limited in their achievements.

Long-term provenance and progeny tests over a wide range of environments. Large variations have been observed in gum production from individual trees and it is important to quantify and partition the variance into environmental and genetic effects and to assess the importance of genotype-environment interaction.

Test Acacia senegal var. senegal outside its native range. Trials of *A. senegal* var. *senegal* in Zimbabwe indicate that the species grows very well and produces gum in frost-free sites well outside its area of natural occurrence in Africa; test objectives should include an assessment of the invasive potential of the species.

Resolve taxonomic inconsistencies within the species. The status of sub-taxa within the species is disputed; resolution of these problems and a study of the natural hybrids with other *Acacia* species could have the potential for introducing useful characters from other taxa.

Farming systems research. There is need for a better understanding of the growth and soil amelioration cycles of the species on very nutrient poor sandy soils.

Marketing and price structure. Marketing and price structure is vital to any successful venture.

PLATES

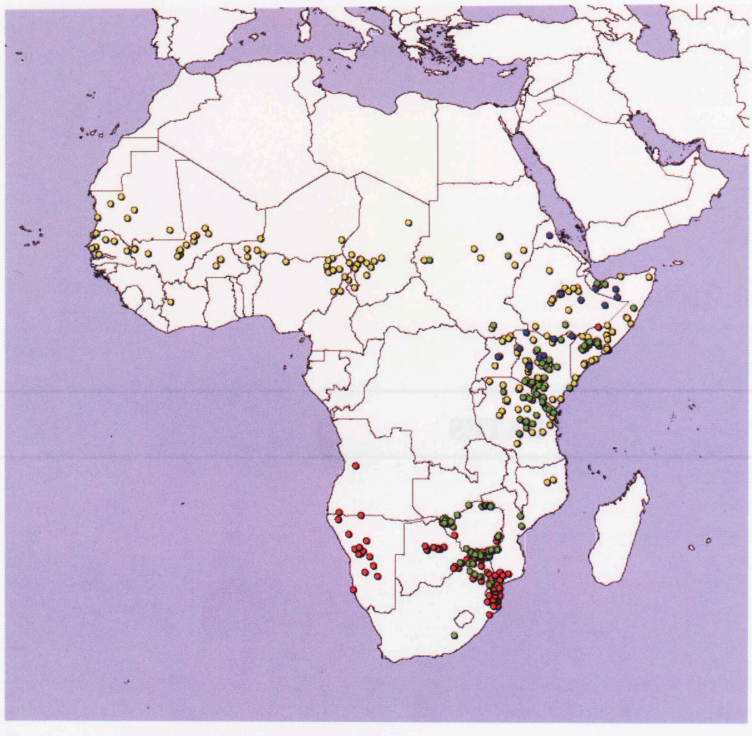


Plate 1. Natural distribution of *Acacia senegal* in Africa, based on herbarium vouchers. Three of the varieties are restricted to the African continent, while the typical variety *senegal* (yellow dots), from which most gum arabic is produced, also occurs in Oman, Iran, Pakistan and Northern India. Variety *rostrata* (red dots) has a mainly southern African distribution, however specimens with rostrate pods have been found in the Horn of Africa. Variety *leiorhachis* (green dots) occurs both in southern and eastern Africa and in the Horn. Variety *kerensis* (blue dots) is centred on the Horn. The disjunction between the east and southern African distributions of the species appears true inland; however there should be a greater occurrence in lowland coastal areas of southern Tanzania and northern Mozambique (Chris Fagg).

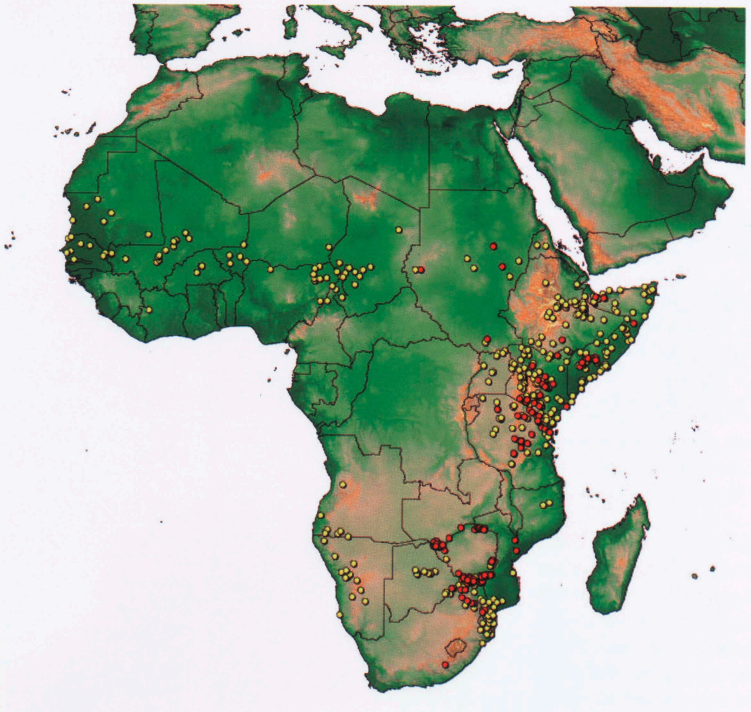


Plate 2. The natural distribution plotted on a relief map of Africa. *Acacia senegal* (vars. *senegal*, *rostrata* and *kerensis* are treated as one in yellow) and var. *leiorhachis* (in red) that is treated by some authors as separate species. There appear to be large gaps in Sudan and across western Africa, however this is due in part to under representation of herbarium vouchers in the larger herbaria (Chris Fagg).



Plate 3. Plantation of *A. senegal* on cracking clay vertisols at Abu Gmein, 70 km southeast of Damazine in Blue Nile State, Sudan. In the foreground is a naturally occurring mature tree surrounded by the six year old plantation, established in 1995 (Justin Mathews).



Plate 4. Another view of the same six year plantation at Abu Gmein, with dense vigorous growth producing almost thicket conditions. Taken on 20 Oct 2001 at 11° 21 N 34° 27 E (Justin Mathews).



Plate 5. A clearing in an otherwise dense virtually monospecific stand of *A. senegal* on clay vertisols, at Khordonia, 15 km northeast of Damazine, Blue Nile State, Sudan (11°51.40N 34° 15.60E). Taken in the dry season during October 2001.Tree bears a medium crop of green pods. (Justin Mathews)



Plate 6. The same stand of *A. senegal* at Khordonia taken during the rainy season during July 2001. Also visible are $1m^2$ collection trays used in sampling insects in the canopies using a knock-down insecticide. (Justin Mathews)



Plate 7. A four year old commercial plantation of *A. senegal* on sandy Qoz soils. Established by direct seeding, 15 km west of Rahad, Kordofan Province, Sudan, at 12°54 N 30°34 E with a mean annual rainfall ca. 380mm. In an area of shrubby wooded grassland previously occupied by amongst others *A. mellifera*, *Adansonia digitata*, *Boscia senegalensis* and some *A. senegal* (Justin Mathews).

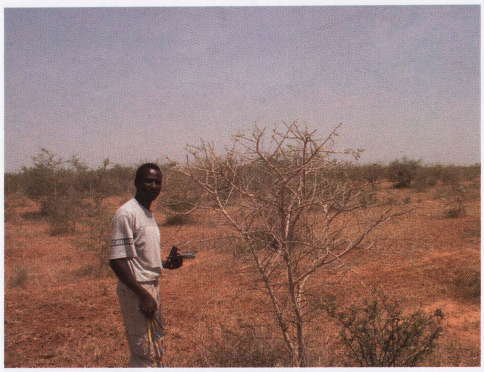


Plate 8. 90% Defoliation of *A. senegal* caused by combination of locust and camel herbivory. Photograph taken from the same plantation 15 km west of Rahad in Plate 7 (Justin Mathews).



Plate 10. Sudanese Gum garden on sandy qoz soils NW of Rahad, Kordofan underplanted with 'dura' millet (*Pennisetum* sp.). As well as scattered trees of *A. senegal*, there are *Boscia senegalensis* (left of central tree) and *Calotropis procera* (right of central tree). Photo taken in July 2001, at 12°58.40N 30°36.30E (Justin Mathews).

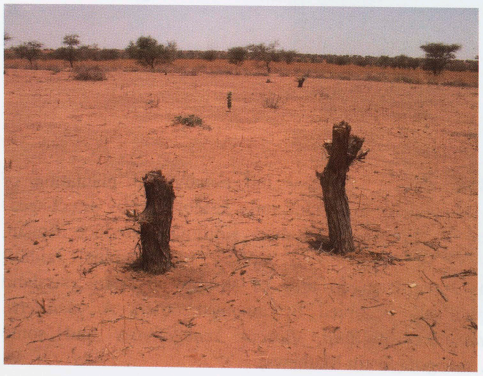




Plate 9. Solitary locust (*Anacridium melanorhodon*) defoliating a tree of *A. senegal* from the same plantation. Locust swarms can cause considerable damage to the gum harvest, defoliating large areas overnight, the tree responding by flushing new leaves using up stored reserves that would otherwise produce gum (Justin Mathews).



Plate 11. Tears of gum arabic forming on untapped branches of a 4 year old tree of *A. senegal.* From a commercial plantation, 15km west of Rahad, Kordofan at 12° 54 N 34° 41E the photo was taken in July 2001 (Justin Mathews).

Plate 12. Coppiced stumps of *A. senegal* at the Damokia research forest, 30 km east of El Obeid, Kordofan Sudan. Foliage is used as browse for sheep and goats, branches for fencing and timber mainly for fuelwood. Soil cleared of grasses in preparation for sowing dura (sorghum), groundnuts, and kharkade (Justin Mathews).

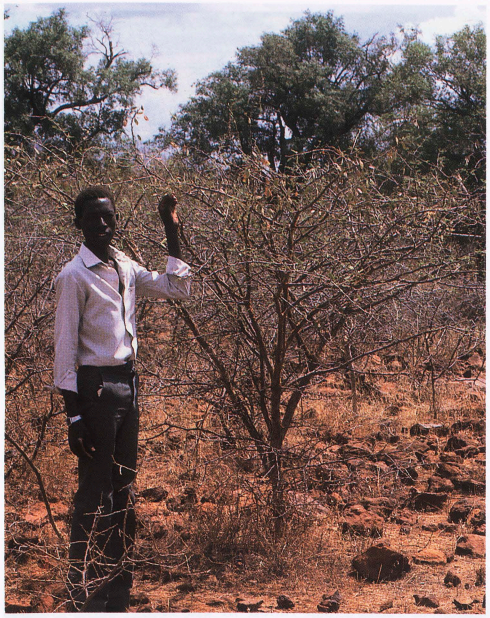


Plate 13. Bush habit of *Acacia senegal* var. *kerensis* near lake Baringo, in Northern Kenya. This variety thrives under arid conditions and produces gum in commercial quantities, whereas var. *senegal* in Kenya grows in the more humid highlands and does not yield much gum (Chris Fagg).

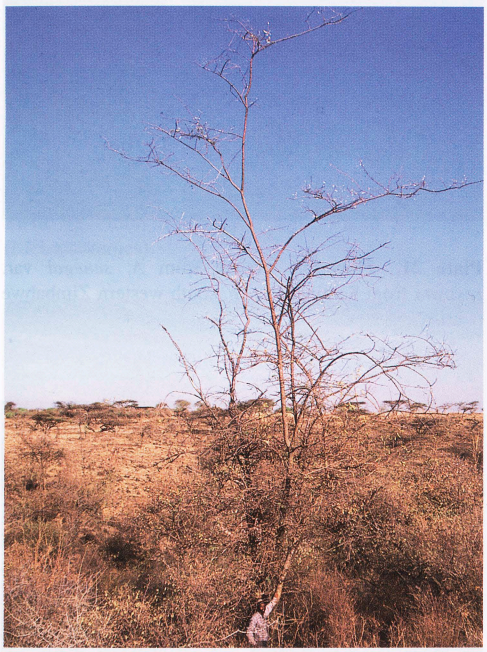


Plate 14. Tall whip-like stems of *A. senegal* var. *leiorhachis* from Northern Kenya, a few kilometres before Isiolo. This variety forms a dense low bush, but flowers and fruits higher up on the straggly leaders out of reach of herbivores. However it does not produce appreciable gum (Chris Fagg).

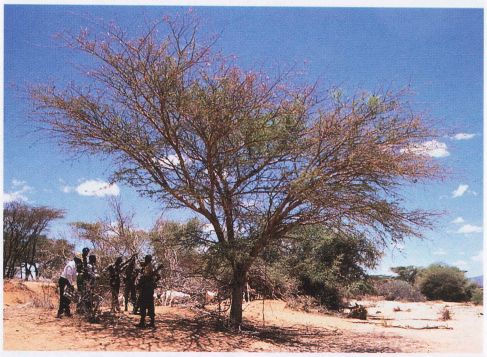


Plate 15. Tree form of *A. senegal* var. *leiorhachis* in the arid areas of northern Kenya. Around Isiolo district it occurs along luggas or dry river beds and does not produce appreciable gum although very small amounts were collected off the pods by the senior author (Chris Fagg).

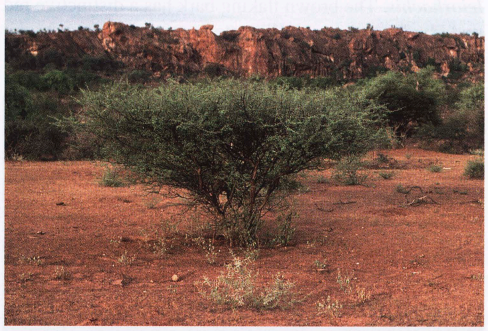


Plate 16. The multi stemmed obconical shrub of *A. senegal* var. *rostrata* from Sentinel Ranch. This ranch borders the Limpopo River in south western Zimbabwe. In south Africa it can also form a small tree (Chris Fagg).



Plate 17. Tree habit of *A. senegal* var. *senegal* growing in northern India. This fruiting tree was planted in a field near Jodhpur, Rajasthan, and it occurs naturally in the region (Colin Hughes).



Plate 18. Bark and slash characters in *A. senegal* var. *leiorhachis.* The brown flaking bark has a distinctive red underbark on the whip-like stems of a tree near Isiolo, northern Kenya (Chris Fagg).



Plate 20. *A. senegal* var. *leiorhachis* flowering near Tuli in southern Zimbabwe. Photo taken July 1996 (Richard Barnes).



Plate 22. Young green pods produced on plants of *A. senegal* var. *senegal* under two years from planting. From a provenance trial planted in December 1996 at Guyu, southern Zimbabwe, taken in November 1998. (Richard Barnes)



Plate 19. Bark and slash characters in *A. senegal* var. *senegal.* The brown bark on the trunk has a creamy white underbark covered by a thin green layer. This photo was taken at Arba Nosa ranch in the Ethiopian highlands (Chris Fagg).



Plate 21. Flowering branch from *A. senegal* var. *rostrata* from Sentinel Ranch, south western Zimbabwe (Chris Fagg).



Plate 23. Papery walled pods of *A. senegal* var. *rostrata* open when mature and dehisce their seeds. Photo taken in Namaqaland in Northern Namibia (Chris Fagg).



Plate 24. Provenance trial of *A. senegal* var. *senegal* at Guyu in southern Zimbabwe. A single tree plot design, planted in December 1996, showing rapid growth 23 months after planting out. Alt. 700 m; MAR 350mm; MAT 20°C. Photo taken in November 1998 (Richard Barnes).



Plate 26. *A. senegal* var. *senegal* provenance trial neat the Mbembezi River in southwestern Zimbabwe. Provenance trial EV 173C, planted Jan 1997, 1050 masl; MAR 625 mm; MAT 21.1 degC; Photo May 1998 (Richard Barnes).



Plate 28. Seedlings of six provenances of *Acacia senegal* six months from sowing. From left to right: var. *leiorhachis* Oltepesi, Kenya, var. *senegal* Fallatu forest, Sudan, var. *senegal* Mtandika, Tanzania; var. *senegal* Guetale, Cameroun; var. *senegal* Chetmari, Niger; var. *rostrata* Benfer, Zimbabwe. Seedlings used in Zimbabwe provenance trials (Richard Barnes).



Plate 25. Gum nodules from natural lesions in the stems of *A. senegal* var. *senegal* 23 months after planting out. Only the Northern African provenances were producing gum in this arid site (350 mm a^{-1}) at Guyu in southern Zimbabwe. Photo taken in November 1998 (Richard Barnes).



Plate 27 Provenance trial of *A. senegal* var. *senegal* near Mbembezi River, southwestern Zimbabwe. Planted in January 1997, photo taken in May 1998, Site at 1050 m asl; MAR 625 mm; MAT 21.1 degC (Richard Barnes).



Plate 29. Competitive Lateral flow device (cLFD) that specifically recognizes solutions of gum from *Acacia senegal* and not from *A. tortilis*. (In cLFD tests the appearance of two bands indicates a negative result and the appearance of only one band indicates a positive result). Depending on the antibody used such devices can also be made to detect gum from *A. seyal* or *Combretum* gums in admixtures with other gums. Developed by Dewey and co-workers (Oxford University, UK) in collaboration with Danks *et al* (Central Science Laboratories, York, UK).



Plate 30. Natural hybrid. Close to the Nairobi to Namanga road, *A. laeta* (tree on left) is a hybrid species of *A. mellifera* ssp. *mellifera* (bush in foreground) and *A. senegal* var. *senegal* (tree on right). As well as intermediate in form between the two parents, the numbers and sizes of the leaflets are intermediate between the two parents, and on closer inspection both 2 prickles (only found on *A. mellifera*) and 3 prickles (only found on *A. senegal*) can be encountered on *A. laeta* (Chris Fagg).

APPENDICES

APPENDIX 1. Common names for the taxa of *Acacia senegal* from herbarium specimens.

Common	Language	Species	Gazetteer	Region	Country
Adaad	Somali	*Acacia senegal* var. *kerensis*	Danot	Harerge	Ethiopia
Adad	Somali	*Acacia senegal*	Beled Weyne	Hiiraan	Somalia
Adad	Somali	*Acacia senegal* var. *kerensis*	Wajir	Wajir	Kenya
Adad	Somali	*Acacia senegal* var. *kerensis*	Erigavo	Sanaag	Somalia
Adad	Somali	*Acacia senegal* var. *kerensis*	Bohodleh	Unknown	Somalia
Adad	Somali	*Acacia senegal* var. *kerensis*	Wudwud	Unknown	Somalia
Adad	Somali	*Acacia senegal* var. *senegal*	Isiolo	Isiolo	Kenya
Adad geri	Somali	*Acacia senegal* var. *leiorhachis*	Garissa	Garissa	Kenya
Adad jerni, Adad geri	Somali	*Acacia senegal* var. *leiorhachis*	Dolondole	Bay	Somalia
Ashaat		*Acacia senegal* var. *senegal*	Fort Lamy	Chari Baguirmi	Chad
Burega	Tarme	*Acacia senegal* var. *leiorhachis*		Unknown	Tanzania
Cadaad	Somali	*Acacia senegal*	Balcad nature reserve	Shabeellaha Dhexe	Somalia
Cadaad	Somali	*Acacia senegal* var. *leiorhachis*		Bay	Somalia
Cadaad-geri	Somali	*Acacia senegal* var. *leiorhachis*		Bay	Somalia
Calincahtu	Tete	*Acacia senegal* var. *leiorhachis*	Chicoa	Tete	Mozambique
Chaleven		*Acacia senegal*	Hindhugan	Unknown	Somalia
Chemanayan	Pokot	*Acacia senegal* var. *senegal*	Chemolingot	Baringo	Kenya
Chemanga		*Acacia senegal* var. *senegal*	Scimo	Baringo	Kenya
Chemangayan	Pokot	*Acacia senegal*	Chemaneayan	Rift valley	Kenya
Chemangayan	Pokot	*Acacia senegal* var. *senegal*	Cheptapokwa, Chemolingot, Nginyang	Baringo	Kenya
Chemanka	Tugen	*Acacia senegal* var. *senegal*	Lorkortakim/ Saima	Baringo	Kenya
Danyukit	Pokot	*Acacia senegal* var. *senegal*	Makany	Turkana	Kenya
Derecess		*Acacia senegal*	Lewa downs	Samburu	Kenya
Duuo ka weyn		*Acacia senegal* var. *kerensis*	Hargeisa	Woqooyi Galbeed	Somalia
Ekodokodwoi		*Acacia senegal*	Emonayabem	Unknown	Uganda

(continued)

APPENDIX 1. (continued)

Common	Language	Species	Gazetteer	Region	Country
Ekonoit	Turkana	*Acacia senegal* var. *kerensis*	Lokitaung, Kaiya Ejom, Lokonai mt., Lake Rudolf	Turkana	Kenya
Entangoringoroi	Masai	*Acacia senegal* var. *leiorhachis*	Olekejo	Kajiado	Kenya
Far yer	Somali	*Acacia senegal* var. *leiorhachis*	Wajir	Wajir	Kenya
Ferix	Somali	*Acacia senegal* var. *leiorhachis*	Dandu	Maralal	Kenya
Golole	Boran	*Acacia senegal* var. *senegal*	Kiboko Camp	Meru	Kenya
Gommier blanc	French	*Acacia senegal* var. *senegal*		Unknown	Senegal
Guerasa	Baguirmi	*Acacia senegal* var. *senegal*	Dol	Chari Baguirmi	Chad
Gum acacia	English	*Acacia senegal*	Marigat	Baringo	Kenya
Haddado		*Acacia senegal*	Ilanto	Eastern	Kenya
Hedado	*Boran*	*Acacia senegal*	Belesa kulal	Maralal	Kenya
Hidado	Boran	*Acacia senegal*	Laga Chiratoni	Maralal	Kenya
Hluktu	Tindija	*Acacia senegal* var. *leiorhachis*	Rontumabe	Mbulu	Tanzania
Idado	Boran	*Acacia senegal* var. *senegal*	Kinu Sogo	Northern Frontier	Kenya
Khor		*Acacia senegal* var. *senegal*		Punjab	India
Kikwata		*Acacia senegal*	Kinango	Kwale	Kenya
Kol Kol		*Acacia senegal var. senegal*	Geidam	Bornu	Nigeria
Lderikesi	Samburu	*Acacia senegal*	Barsaloi	Samburu	Kenya
Lyadulele	Kii-Arusha	*Acacia senegal* var. *senegal*	Olmotonyi	Masai	Tanzania
Mesar jibis		*Acacia senegal* var. *kerensis*		Unknown	Somalia
Mgunga		*Acacia senegal* var. *senegal*	Kwale	Kwale	Kenya
Mongolli	Kikamba	*Acacia senegal*	Ukamba Reserve	Machakos	Kenya
Mongolli	Kamba	*Acacia senegal* var. *leiorhachis*	Thitani	Central	Kenya
Mugagauko	Tindija	*Acacia senegal* var. *leiorhachis*	Munguli	Mwanza	Tanzania
Munkhondo	Muquilenqe	*Acacia senegal*	Vite-Viele	Mocamedes	Angola
N'aonde	Muquilen	*Acacia senegal*	Vite-Viele	Mocamedes	Angola
Ngolpelwo	Tugen	*Acacia senegal* var. *senegal*	Endorois-Baringo	Baringo	Kenya

(continued)

APPENDIX 1. (continued)

Common	Language	Species	Gazetteer	Region	Country
Oiti-orok		*Acacia senegal*	Naivasha	Nakuru	Kenya
Olkiloreti	Masai	*Acacia senegal* var. *senegal*	Ngamuriak	Unknown	Tanzania
Ruchena		*Acacia senegal* var. *leiorhachis*	Magoe	Tete	Mozambique
Sabansa	Somali	*Acacia senegal* var. *senegal*	Dandu	Maralal	Kenya
Tambooli		*Acacia senegal* var. *kerensis*	Scillave	Harerge	Ethiopia
Upe	Karasuh	*Acacia senegal* var. *leiorhachis*	Pcholoio Forest Reserve	Northern	Uganda
Verak	Oloff	*Acacia senegal* var. *senegal*	Ross Bethio	Saint Louis	Senegal
Verede	*Oloff*	*Acacia senegal var. senegal*	Ross Bethio	Saint Louis	Senegal
Verek	Wolof	*Acacia senegal* var. *senegal*	Diourbel	Diourbel	Senegal
Wait a bit	*English*	*Acacia senegal*	Buchuma	Taita	Kenya

APPENDIX 2. Herbarium specimen list for *Acacia senegal* (L.) Willd.

Acacia senegal (L.) Willd. **sensu lato**

ANGOLA. **Huila, Donguena** (19 Nov 1964), *Brito Teixeira & Andrade 7837A, (SRGH);* **Humbe** (8 Feb 1956), *Torre AR 8693, (LISC);* **Mocamedes, Dois Irmaos** (23 Dec 1955), *Torre AR 8276, (LISC);* **Oncocua** (18 Jan 1956), *Torre AR 8464, (LISC);* **Vite-Viele** (6 Mar 1956), *Teixeira JB 741, (LISC);*

ETHIOPIA. **Gamo Gofa,** (30 Aug 1972), *Aweke G 507, (ETH);* **Harerge,** *5° 58'N 44° 46'E* (16 Apr 1956), *Simmons 5207, 7° 40'N 43° 40'E* (7 Nov 1976), *Corra M JD 1, (ILCA); 8° 50'N 42° 40'E* (10 Nov 1976), *Corra M JBK 7, (ILCA);* (22 Sep 1962), *Burger W 2135, (ETH); 9° 31'N 41° 25'E* (24 Aug 1961), *Burger W 675a, (ETH);* (10 Nov 1976), *Corra M JBK 9A, (ETH);* (6 Nov 1976), *Le Houerou HN 08, (ILCA); 9° 16'N 42° 52'E* (5 Nov 1976), *Le Houerou HN 03, (ILCA); 8° 00'N 42° 48'E* (11 Nov 1976), *Corra M JBK 10D, (EA, ILCA); 9° 19'N 42° 34'E* (6 Nov 1976), *Le Houerou HN 06 11 76 05B, (EA, ILCA); 9° 14'N 42° 48'E* (3 Nov 1976), *Boulos L 10580, (EA); 9° 21'N 42° 33'E* (21 Oct 1976), *Boulos L 10120, (EA); 9° 16'N 42° 38'E* (6 Nov 1976), *Le Houerou HN 06 11 76 08, (EA); 9° 29'N 42° 48'E* (16 Dec 1976), *Corra M JF 28D, (EA, ILCA); 7° 47'N 42° 48'E* (7 Nov 1976), *Corra M JD 1B, (EA); 8° 55'N 42° 48'E* (4 Nov 1976), *Corra M JJR XB, (EA); 8° 40'N 42° 48'E* (10 Nov 1976), *Corra M JBK 7B, (EA); 8° 03'N 42° 04'E* (26 Dec 1976), *Corra M JGL 3C, (EA); 8° 38'N 42° 48'E* (10 Nov 1976), *Corra M JBK 8D, (EA, ILCA); 0° 00' 42° 52'E* (5 Nov 1976), *Le Houerou HN 05 11 76 03B, (EA); 8° 50'N 42° 48'E* (25 Dec 1976), *Corra M JBR 8D, (EA);* **Biko plateau** *9° 00'N 43° 00'E* (10 Nov 1976), *Corra M JKB 8, (ILCA);* **Borale valley** *8° 40'N 43° 00'E* (25 Dec 1976), *Corra M JBR 8, (ILCA);* **Borale valley** *8° 58'N 42° 48'E* (29 Oct 1976), *Corra M JBR 4B, (EA, ILCA);* **Chalaka** (13 Dec 1977), *Boulos L & Getahun A 11797, (EA);* **Fafan valley** *9° 20'N 42° 30'E* (16 Dec 1976), *Corra M JF 28, (ILCA);* **Fafan valley** *9° 06'N 42° 48'E* (21 Oct 1976), *Corra M JF 3D, (EA, ILCA);* **Galalcha plateau** *8° 10'N 42° 10'E* (26 Dec 1976), *Corra M JGL 3, (ILCA);* **Jerer valley** *9° 16'N 42° 52'E* (5 Nov 1976), *Le Houerou HN 05 11 76 03, (ILCA);* **Khala** *8° 10'N 43° 00'E* (4 Nov 1976), *Corra M JJR X, (ILCA);* **Shewa,** *8° 10'N 38° 50'E* (6 Jun 1968), *Desta Hundessa 19, (EA);* (3 Jun 1978), *Mesfin T & Sebesebe D 308, (ETH);* (1 Apr 1965), *De Wilde W 6202, (ETH);* (19 Apr 1972), *Ash JW 1588, (ETH);* (3 Jun 1978), *Mesfin T & Sebesebe D 309, (ETH);* (25 Apr 1957), *Mooney HF 7072, (ETH);* (13 Jul 1963), *Beals E 259, (ETH);* (23 Dec 1964), *Beals E 935, (ETH);* (24 Jan 1964), *Brehme Beshaw sn, (ETH); 9° 05'N 40° 00'E* (26 Sep 1976), *Boulos L 9407, (EA);* **Alem tena** *7° 40'N 39° 20'E* (24 Dec 1980), *Kahurananga J & Abdul Kadir A 3725, (ILCA);* **Awash reserve waterfalls** *8° 50'N 40° 50'E* (26 Sep 1976), *Boulos L 9384, (ILCA);* **Robi valley** *10° 00'N 39° 55'E* (31 Sep 1959), *Mooney HF 8123, (EA, ETH);* **Zwai** (20 Jun 1981), *Kahurananga J & Abdul Kadir A 3264, (ILCA);* **Sidamo,** (22 Dec 1981), *Mesfin T & Tewolde BGE 2623, (ETH);* **Chebi Hill Sordu** *4° 46'N 37° 42'E* (23 Sep 1980), *Kahurananga J 2943, (ILCA);* **Southern,** *5° 32'N 38° 04'E* (23 Dec 1952), *Gillett JB 14763, (EA);* **Welo,** (22 Jul 1965), *De Wilde W 7346, (ETH);* (2 Nov 1979), *Sebsebe D 195, (ETH);*

KENYA. **Baringo, Baringo** (8 Oct 1985), *Birnie A 373, (EA);* **Chemolingot** *0° 58'N 35° 57'E* (6 Sep 1976), *Timberlake JR 684, (EA);* **Chemolingot bore-hole** *0° 58'N 35° 57'E* (24 Sep 1976), *Timberlake JR 888, (EA);* **Kinayang** *0° 56'N 36° 01'E* (16 Nov 1964), *Leippert H 5299, (EA);* **Lake Baringo,Roberts Camp** (1900), *Burney D s.n., (EA);* **Loruk** (17 Oct 1983), *Euphorbia Project 6, (EA);* **Loruk/Kinyang** (30 Oct 1983), *Mather AD 3, (EA);* **Marigat** (19 May 1987), *Tybirk K 7a, (EA);* **Marigat** (20 May 1987), *Tybirk K 8a, (EA);* **Nakuru** (12 May 1989), *Muasya J & Safary 076, (EA);* **Nginyang** (6 Jun 1973), *Udall R 14, (EA);* **Central,** *1° 32'S 37° 15'E* (4 Feb 1990), *Fagg CW 528, (FHO); 0° 06'N 38° 12'E* (11 Jan 1980), *Lambrecht FL s.no., (EA);* **Ikulha** (16 Apr 1958), *Trapnell CG 2402, (K);* **Coast,** (27 Jan 1990), *Fagg CW 515, (FHO);* **Eastern, Ilanto** (Jul 1976), *Sato S 85, (EA);* **Masalani** (14 Mar 1975), *Bunderson WT 6, (EA);* **Garissa,** (27 Jan 1958), *Verdcourt B 2105, (EA);* **Isiolo,** *0° 34'N 38° 19'E* (26 Apr 1978), *Gilbert MG & Thulin M 1072, (EA, K);* **Garba Tula rd.** (3 Jun 1970), *Gillett JB & Newbould JB 19155, (EA);* **Lochongale** (3 Jun 1977), *Gillett JB 21352, (EA);* **Mado Gashe** *0° 44'N 39° 12'E* (5 Jun 1970), *Gillett JB & Newbould JB 19179, (EA);* **Ngare Ndare** (Jan 1985), *Schultka W 146, (EA);* **Kajiado, Bissel/Namanga** (7 Aug 1986), *Dekker G 27, (EA);* **Kajiado** (30 Jan 1952), *Trapnell CG 2204, (EA);* **Magadi** (2 Aug 1965), *Gillett JB 16795, (EA);* **Ngong** (6 Mar 1938), *Bally PRO 7134, (EA);* **Ngong Hill** (Feb 1939), *Bally PRO 8867, (EA);* **Olorgesailie** (27 Aug 1987), *Bennun LA C, (EA);* **Kericho, Londiani** (10 Oct 1956), *Elliott 289, (EA);* **Kilifi, Galana Ranch** (8 Jun 1978), *Bally PRO 17101, (EA);* **Kitui, Katse** (7 Apr 1979), *Porter PW 24, (EA);* **Kitui** *1° 06'S 37° 45'E* (29 Sep 1987), *Beentje HJ 3345, (EA);* **Kitui Reserve** (16 Mar 1953), *Trump EC 53, (EA);* **Nuu** (3 Oct 1982), *Kuchar P 14889, (EA);* **Kwale, Kinango** (9 Sep 1958), *Moomaw JC 829, (EA);* **Shimba Forest** (20 Jul 1967), *Mulwa PCW 38, (EA);* **Machakos,** (23 Aug 1940), *Greenway PJ 6010, (EA);* **Kamburu** (31 Aug 1974), *Kokwaro JO 3615, (EA);* **Masalani** *2° 18'S 38° 07'E* (19 Aug 1980), *Sharland P 44, (EA);* **Ukamba Reserve** (Dec 1931), *Gibbons GR 6743, (EA);* **Mandera, Elwak** *2° 46'N 40° 56'E* (30 Apr 1978), *Gilbert MG & Thulin M 1257 A, (EA);* **Maralal, Belesa kulal** (27 Jul 1977), *Field CR ALPK 243, (EA);* **Kinu-Sogo** *3° 25'N 36° 35'E* (8 Aug 1980), *Hussein A 54, (EA);* **Koobi fora** (13 Jul 1970), *Nesbit Evans EM 90, (EA);* **Koobi fora** *4° 00'N 36° 30'E* (8 Aug 1974),

Jackson G 27, (EA); **Laga Chiratoni** (11 Aug 1980), *Legesse A 106, (EA);* **Lua-Mt.Kulal(S)** (19 Nov 1976), *Herlocker D 198, (EA);* **Marsabit** (20 Jul 1958), *Adamson T 240, (EA);* **Meru,** (8 Sep 1973), *Adamson T 106, (EA);* **Meru Game Reserve(muguongo)** (14 Jun 1963), *Mathenge SG 158, (EA);* **Meru National Park** *0° 06'N 38° 12'E* (Jan 1980), *Lambrecht FL 11, (EA);* **Meru National Park** *0° 09'N 38° 11'E* (1 Aug 1980), *Hamilton PH 716, (EA);* **Rainkombe Hill** (9 Jul 1977), *Hamilton PH 67, (EA);* **Nairobi, Nairobi National Park** (25 Apr 1982), *Mathenge SG 144, (EA);* **Nairobi National Park** (6 Feb 1953), *Bally PRO 6608, (EA);* **Nakuru, Naivasha** *1° 09'S 36° 21'E* (9 Jun 1963), *Glover PE 3837, (EA);* **Naivasha** *1° 09'S 36° 21'E* (3 Feb 1964), *Glover PE & Oledonet 4108, (EA);* **Njoro** (12 Mar 1971), *Nightingale JM 10, (EA);* **Njoro** (10 Jul 1955), *Sanart 3, (EA);* **Narok, Barkitabu** (2 Oct 1978), *Gordon HO s.n., (EA);* **Ewaso Nyiro** (11 Jan 1981), *Kuchar P 13856, (EA);* **Northern Frontier,** (1 Aug 1938), *Pole Evans IB & Erens J 1601, (K, SRGH); 2° 46'N 40° 56'E* (30 Apr 1978), *Gilbert MG & Thulin M 1257A, (EA);* **Yabello junction** *3° 25'N 39° 12'E* (30 Apr 1952), *Gillett JB 12973, (K);* **Rift valley,** (1900), *Fagg & Evans 1,* **Chemaneayan** (10 Feb 1978), *Caufield 108, (EA);* **Samburu, Barsaloi** (15 Jan 1983), *Shikano K 6, (EA);* **Morijo_Baragoi** *1° 23'N 36° 38'E* (19 Feb 1979), *Bamps 6611, (EA);* **Rhino sanctuary lewa downs** (Nov 1985), *Cally 11, (EA);* **Samburu Game Reserve** (10 Sep 1970), *Owen R 151, (EA);* **Taita, Bachuma area** (5 Aug 1965), *Williams GR 834, (EA);* **Buchuma** (10 May 1989), *Chepkwony & Esilaba 46, (EA);* **Kamaguru** (17 May 1983), *Mungai GM Mutangah JG & Rucina SM 226, (EA);* **Kamor Jila** *1° 21'S 39° 55'E* (19 Dec 1964), *Gillett JB 16431, (EA);* **Kora Game Reserve** (7 Dec 1984), *Mungai GM & Rucina SM 278, (EA);* **Kora Game Reserve** (5 Nov 1983), *Mutangah J & Muasya J 201, (EA);* **Kora Game Reserve** (18 Aug 1983), *Mutangah JG 12, (EA);* **Kora Game Reserve** (16 May 1983), *Mungai GM et al 176, (EA);* **Kora Game Reserve** (26 May 1977), *Gillett JB 21099, (EA);* **Kora Game Reserve** *1° 29'S 38° 42'E* (25 May 1977), *Gillett JB 21098, (EA);* **Kora camp I** (22 Jul 1976), *Tana River Expedition 14, (EA);* **Lake Chala** (1 Apr 1985), *Burney DA & Burney LP 210, (EA);* **Mt. Kassigau** *3° 52'S 38° 38'E* (1 May 1975), *Friis I & Hansen OJ 2661, (EA);* **National primate reserve** (13 Mar 1990), *Luke Q Kabuye CH & Robertson SA 272, (EA);* **Ndara Ranch** (10 May 1989), *Muasya & Safary 65, (EA);* **Ndara Ranch** (10 May 1989), *Muasya & Safary 64, (EA);* **Sala** *3° 05'S 39° 10'E* (12 Nov 1969), *Hucks MB 1185, (EA);* **Tana River** (13 Jun 1963), *Mathenge SG 121, (EA);* **Tana River** (5 Feb 1959), *Moomaw JC 147, (EA);* **Tsavo N. Park** (1965), *Hucks HP 321, (EA);* **Voi** (10 Mar 1965), *Leippert H 5643, (EA);* **Turkana,** *4° 17'N 35° 44'E* (2 Nov 1977), *Carter S & Stannard B 139,* **Kangatet** (25 Jun 1968), *Hemming CF 3072, (EA);* **Kobi Fora Research area** (16 Jun 1900), *Glesne C 17, (EA);* **Lake Rudolf** (24 Jun 1965), *Modha ML 24, (EA);* **Lodwar** *2° 52'N 35° 41'E* (23 Aug 1986), *Beentje HJ 2989, (EA);* **Lodwar** (Jun 1968), *Carr CJ 131, (EA);* **Lodwar** (Jun 1968), *Carr CJ 121, (EA);* **Lokichar** (5 Apr 1954), *Hemming CF 256, (EA);* **Lokitaung** (Jun 1968), *Carr CJ 130, (EA);* **Lokitaung** *4° 17'N 35° 44'E* (2 Nov 1977), *Carter S & Stannard B 138, (EA);* **Unknown,** *0° 15'S 38° 55'E* (17 May 1983), *Mungai GM 226/83, (EA); 0° 58'N 35° 57'E* (24 Sep 1976), *Timberlake JR 876, (EA);* **Iderikesi** (27 Jul 1977), *Ichikawa 713, (EA);* **Mtembur** (11 Mar 1973), *Robel B 109, (EA);* **Wajir, Wajir** *1° 59'N 40° 19'E* (29 Apr 1978), *Gilbert MG & Thulin M 1171, (EA);* **West Pokot, Akeriamet** *1° 45'N 35° 29'E* (19 Aug 1986), *Beentje HJ 2970, (EA);* **Suam river- Kongelai** (10 Oct 1985), *Birnie A 421B, (EA);*

NAMIBIA. Namibrand, Farm Nudis (15 Mar 1955), *Seydel R 437, (SRGH);*

RWANDA. Mutara, Biumba (1900), *Troupin G 3248, (EA);*

SAUDI ARABIA. Dscheddam (25 Nov 1833), *Schimper MW 865, (P);*

SENEGAL. Tambacounda, Kidira *14° 28'N 12° 13'W* (14 Dec 1930), *Trochain J 1145, (P);*

SOMALIA. Bari, *10° 48'N 50° 26'E* (27 Sep 1987), *Hassan AS 194, (FHO); 9° 40'N 50° 20'E* (26 Sep 1987), *Fagg CW & Styles BT 42, (FHO); 10° 48'N 50° 26'E* (27 Sep 1987), *Fagg CW & Styles BT 47, (FHO);* **Bay,** *2° 48'N 43° 14'E* (30 May 1987), *Hassan AS 34, (FHO); 3° 11'N 43° 14'E* (28 Aug 1987), *Hassan AS 128, (FHO); 2° 56'N 44° 16'E* (29 Aug 1987), *Hassan AS 129, (FHO); 2° 56'N 44° 16'E* (29 Aug 1987), *Hassan AS 130, (FHO); 2° 56'N 44° 16'E* (13 Oct 1987), *Hassan AS 224, (FHO); 2° 56'N 44° 16'E* (13 Oct 1987), *Hassan AS 225, (FHO);* **Awdiinlie** *3° 08'N 43° 12'E* (18 Sep 1987), *Fagg CW & Styles BT 6, (EA, FHO, K);* **Gedo,** *3° 50'N 42° 30'E* (23 May 1987), *Hassan AS 15, (FHO); 3° 50'N 42° 30'E* (23 May 1987), *Hassan AS 17, (FHO); 2° 25'N 42° 22'E* (27 May 1987), *Hassan AS 32, (FHO);* **Hiiraan,** *4° 22'N 46° 06'E* (29 Jun 1987), *Hassan AS 76, (FHO); 3° 58'N 45° 24'E* (8 Jul 1987), *Hassan AS 98, (FHO); 3° 56'N 45° 23'E* (8 Jul 1987), *Hassan AS 99, (FHO); 5° 06'N 45° 30'E* (4 Oct 1987), *Hassan AS 215, (FHO); 3° 28'N 45° 30'E* (2 Nov 1987), *Hassan AS 227, (FHO); 4° 22'N 46° 05'E* (3 Nov 1987), *Hassan AS 234, (FHO); 5° 06'N 45° 30'E* (4 Oct 1987), *Fagg CW & Styles BT 86, (FHO);* **Beled Weyne** (30 Oct 1952), *Hemming CF CFH 96, (EA);* **Jubbada Dhexe,** *0° 40'N 42° 46'E* (13 Jun 1987), *Hassan AS 50, (FHO); 0° 30'N 42° 40'E* (26 Jul 1987), *Hassan AS 102, (FHO); 0° 29'N 42° 40'E* (12 Sep 1987), *Hassan AS 168, (FHO);* **Jubbada hoose,** *1° 05'S 41° 38'E* (8 Jun 1987), *Hassan AS 44, (FHO);* **Mudug,** *5° 20'N 48° 16'E* (2 Jul 1987), *Hassan AS 82, (FHO); 5° 20'N 48° 16'E* (2 Jul 1987), *Hassan AS 83, (FHO); 5° 20'N 48° 17'E* (2 Jul 1987), *Hassan AS 84, (FHO); 6° 03'N 47° 45'E* (2 Jul 1987), *Hassan AS 88, (FHO); 5° 58'N 47° 53'E* (6 Nov 1987), *Hassan AS 239, (FHO); 6° 43'N 47° 26'E* (4 Oct 1987), *Fagg*

CW & Styles BT 82, (FHO); **Nugaal,** *8° 23'N 48° 30'E* (22 Sep 1987), *Fagg CW & Styles BT 19, (FHO); 7° 40'N 47° 50'E* (3 Oct 1987), *Fagg CW & Styles BT 78, (FHO);* **Shabeellaha Dhexe,** *3° 28'N 45° 30'E* (21 Jun 1987), *Hassan AS 55, (FHO); 2° 33'N 45° 25'E* (22 Jun 1987), *Hassan AS 58, (FHO); 2° 33'N 45° 25'E* (9 Aug 1987), *Hassan AS 110, (FHO); 2° 20'N 45° 25'E* (9 Aug 1987), *Hassan AS 114, (FHO); 2° 11'N 45° 33'E* (20 Aug 1987), *Hassan AS 116, (FHO); 2° 13'N 45° 37'E* (20 Aug 1987), *Hassan AS 118, (FHO);* (6 Sep 1987), *Hassan AS 141, (FHO); 2° 20'N 45° 25'E* (6 Sep 1987), *Hassan AS 144, (FHO); 2° 20'N 45° 25'E* (6 Sep 1987), *Hassan AS 146, (FHO); 2° 20'N 45° 25'E* (6 Sep 1987), *Hassan AS 147, (FHO); 2° 42'N 44° 26'E* (13 Oct 1987), *Hassan AS 221, (FHO); 2° 42'N 44° 26'E* (13 Oct 1987), *Hassan AS 222, (FHO);* **Balcad nature reserve** *2° 20'N 45° 25'E* (6 Sep 1987), *Hassan AS 145, (EA, FHO);* **Shabeellaha Hoose,** *1° 07'N 44° 03'E* (14 Jun 1987), *Hassan AS 51, (FHO); 2° 06'N 45° 07'E* (25 Jul 1987), *Hassan AS 100, (FHO); 0° 56'N 43° 36'E* (9 Sep 1987), *Hassan AS 156, (FHO); 1° 43'N 44° 46'E* (20 Sep 1987), *Fagg CW & Styles BT 17, (EA, FHO, K, MOG);* **Togdheer,** *8° 45'N 46° 25'E* (17 Jun 1979), *Hansen OJ & Heemstra H 6173, (EA);* **Unknown,** (26 Jun 1981), *Beckett JJ s.n., (EA); 9° 22'N 44° 08'E* (26 Jun 1981), *Beckett JJ 1173, (EA); 3° 08'N 43° 42'E* (12 Mar 1982), *Beckett JJ 1752, 3° 15'N 44° 19'E* (11 Mar 1982), *Beckett JJ & White R 1743, (EA); 9° 57'N 45° 16'E* (25 Jun 1981), *Gillett JB & Watson RM 23634, (EA); 0° 13'S 42° 35'E* (26 Jun 1983), *Gillett JB Hemming CF & Watson RM 24926, (EA); 10° 07'N 43° 00'E* (19 Aug 1966), *Wood AJ 6, (EA);* **Hindhugan** *6° 30'N 47° 45'E* (30 Nov 1961), *Paskin MWJ H103, (EA);* **Woqooyi Galbeed,** *9° 36'N 44° 04'E* (27 Apr 1987), *Hassan AS 12, (FHO); 9° 52'N 44° 31'E* (28 Apr 1987), *Hassan AS 13, (FHO);*

SUDAN. Ilemi Triangle, Kamattia (27 May 1953), *Padwa JH 219, (SRGH);* **Shoa,** (31 Aug 1959), *Mooney HF s.n., (EA);*

TANZANIA. Central, *6° 29'S 35° 48'E* (21 Nov 1988), *Fagg CW 429, (FHO);* **Coast,** *6° 40'S 38° 36'E* (23 Nov 1988), *Fagg CW 434, (FHO); 6° 40'S 38° 36'E* (23 Nov 1988), *Fagg CW 438, (FHO);* **East Musma,** *21° 08'S 34° 50'E* (9 Feb 1954), *Brooks AC sn., (K);* **Kondoa, Kondoa** (1900), *Burtt BD 1010, (EA);* **Korogwe, Kisarake** (8 Jun 1971), *Semsei SR 4242, (EA);* **Lake,** (29 Mar 1961), *Greenway PJ 9729, (EA);* **Pangani, Mkwaja Ranch** *5° 44'S 38° 51'E* (Sep 1976), *Kloetzli 398, (EA);* **Southern Highlands,** *8° 50'S 34° 42'E* (10 Nov 1988), *Fagg CW 399, (FHO);* **Mtandika** *7° 32'S 36° 26'E* (8 Nov 1991), *Fagg CW 554, (FHO);* **Tanga,** *5° 23'S 38° 32'E* (16 Nov 1988), *Fagg CW 410, (FHO);* **Unknown,** *5° 15'S 39° 04'E* (25 Nov 1954), *Faulkner HG 1526, (K); 2° 18'S 34° 50'E* (2 Mar 1965), *Leippert H 5600,*

UGANDA. Northern, *2° 36'N 34° 41'E* (12 Jun 1970), *Katende AB & Lye K K435, (EA);* **Unknown,** *2° 10'N 31° 24'E* (16 Sep 1969), *Lye KA 3980, (EA);* **Emonayabem** (13 Jun 1957), *Dyson-Hudson 183, (K);*

ZAMBIA. Western, Sesheke (17 Jun 1969), *Mutimushi JM 3756, (NDO);*

Acacia senegal (L.) Willd. var. ***kerensis*** Schweinf.

ETHIOPIA. Harerge, Danot *7° 30'N 45° 10'E* (3 Apr 1956), *Simmons 515, (EA);* **Scillave** (16 Apr 1956), *Simmons 207, (EA);* **Unknown, Metahara** *8° 52'N 39° 55'E* (Apr 1968), *Findlay DC 13954, (EA);*

KENYA. Baringo, Lake Hannington (19 Jan 1969), *Faden RB & Napper D 69/058, (EA);* **Isiolo,** *0° 34'N 38° 05'E* (26 Apr 1978), *Gilbert MG & Thulin M 1057, (EA);* **Kilifi, Lali Hills** (8 Apr 1970), *King JM 15, (EA);* **Machakos, Kwamololo** (1958), *Thomas DB 669, (EA, K);* **Mandera, Ramu** *3° 53'N 41° 14'E* (2 May 1978), *Gilbert MG & Thulin M 1352, (EA, K);* **Maralal, Moyale** (1 Jan 1972), *Bally PRO & Smith AR 14898, (EA);* **Northern Frontier,** (27 Jan 1958), *Verdcourt B 2105, (K);* **Taita, Buchuma Res. Station** (5 May 1971), *Nganga SK 37, (EA);* **Turkana, Kaiya Ejom** *2° 25'N 34° 55'E* (29 Jan 1965), *Newbould JB 6826, (EA);* **Lokitaung** (Feb 1943), *Dale IR 306, (EA);* **Lokitaung** (16 Mar 1934), *Lake Rudolf Expedition 48, (EA);* **Lokonai Mt.** (23 Aug 1968), *Mwangangi OM & Gwynne 1203, (EA);* **Lokori** (19 May 1970), *Mathew B 6300, (EA);* **Loriu Plateau** (5 Aug 1968), *Mwangangi OM & Gwynne 1067, (EA);* **Wajir, Laisamis** *1° 35'N 37° 48'E* (18 Sep 1944), *Adamson J 133970, (EA);* **Wajir** (Jan 1955), *Hemming CF 459, (EA, K);*

SOMALIA. Nugaal, Las Anod (19 Oct 1952), *Hemming CF 95, (EA);* **Sanaag, Erigavo** (20 Oct 1960), *Hemming CF 2041, (EA);* **Unknown,** *3° 08'N 43° 42'E* (12 Mar 1982), *Beckett JJ & White R 1752, (EA); 9° 24'N 46° 28'E* (4 Mar 1981), *Beckett JJ 922, (EA);* **Awarch** (27 Jun 1958), *Lawrie JJ 1439, (EA);* **Bohodleh** (7 Dec 1959), *Ashall C 11908, (EA);* **Eil** (4 Jan 1973), *Bally PRO & Melville JR 15541, (EA);* **Wudwud** (24 Sep 1952), *Hemming CF 76, (EA);* **Woqooyi Galbeed, Hargeisa** (22 Jul 1952), *Lawrie JJ 24, (EA);* **Hargeisa** *9° 30'N 44° 03'E* (25 Aug 1966), *Wood AJ 8, (EA);*

TANZANIA. Kilimanjaro, Lake Chala *3° 19'S 37° 42'E* (21 Jan 1936), *Greenway PJ 4438, (EA);* **Lake Chala** *3° 19'S 37° 42'E* (20 Oct 1968), *Bigger M 2232, (EA);*

UGANDA. Mengo, Buruli *1° 25'N 32° 20'E* (Nov 1932), *Eggeling WJ 706, (K);*

Acacia senegal (L.) Willd. var. ***leiorhachis*** Brenan

BOTSWANA. Central, Ngwapa Hill (6 1962), *Yalala AM 189, (K, SRGH);* **Seleka ranch** *23° 00'S 27° 50'E* (24 Aug 1978), *Hansen OJ 3440, (K);* **South East, Seleka ranch** (1 Nov 1978), *Timberlake & Kabelo 1834, (SRGH);* **Unknown, Molatatan** (20 Dec 1976), *Mott PJ 1068, (K, PRE, SRGH);*

ETHIOPIA. Gabredarre (2 Jul 1958), *Hemming CF 1512, (EA, K);*

KENYA. Central, Makindu (Feb 1905), *Linton A 108, (K);* **Thitani** *1° 03'S 37° 55'E* (9 Jun 1973), *Okwaro HW 21/A, (EA);* **Kima** *1° 57'S 37° 15'E* (2 Mar 1930), *Napier ER 1262, (EA);* **Coast,** *3° 25'S 37° 48'E* (7 Sep 1992), *Fagg CW 597, (EA, FHO);* **Takwa** (4 Nov 1957), *Greenway PJ SN, (EA);* **Kora Game reserve** *0° 05'S 38° 30'E* (22 Jul 1983), *Cunningham van Someren GR 982, (EA);* **Garissa, Garissa** *0° 14'N 39° 25'E* (6 Jun 1970), *Gillett JB & Newbould JB 19198, (EA);* **Isiolo, Merti** *1° 03'N 38° 30'E* (Feb 1959), *Pratt DJ 447, (EA, K);* **Kajiado,** *1° 49'S 36° 20'E* (8 Oct 1987), *Fagg CW & Styles BT 95, (EA, FHO, K);* **Magadi** (20 Sep 1962), *Glover PE & Samuel 3269, (EA, K);* **Magadi** (10 Apr 1956), *Greenway PJ 8995, (EA);* **Ngong** (15 Jan 1945), *Van Someren VGL 9498, (EA);* **Olekejo** (16 Jun 1962), *Greenway PJ & Samuel 2800, (EA);* **Olorgesaile** (Oct 1955), *Milne Redhead E & Taylor P 7135, (EA, K);* **Kitui, Thitani** (19 Jun 1973), *Okwaro HW 21, (EA);* **Yatta plateue** (Aug 1937), *Gardner HM 3694, (EA, K);* **Machakos, Mua Hills** (30 May 1958), *Verdcourt Paulo & Kirrika 2169, (EA, K);* **Maralal, Balesa Kulal** (5 Jul 1977), *Herlocker D 453-A, (EA, K);* **Dandu** *3° 26'N 39° 54'E* (14 May 1952), *Gillett JB 13186, (EA, K);* **Ol Doinyo Mara mt.** *2° 15'N 37° 02'E* (1 Aug 1977), *Herlocker D 501, (EA);* **Wq Logo** (18 Mar 1977), *Herlocker D 472, (EA);* **Masai,** *1° 52'S 36° 16'E* (20 Dec 1989), *Fagg CW 505, (FHO);* **Olekemunke** (16 Jun 1962), *Glover Gwynne & Samuel 2800, (K);* **Nairobi, Nairobi** (28 Dec 1958), *Greenway PJ 9548, (EA, K);* **Northern Frontier, Archer's Post** *0° 39'N 37° 41'E* (1900), *Pratt DJ 190, (EA);* **Ilanto** (Jul 1976), *Sato S 104, (EA);* **Mt. Hilal** (Jun 1958), *Adamson T S.N., (EA);* **Samburu, Archer's Post** (Jan 1958), *Sato S 190, (EA);* **Turkana, South Horr** *2° 06'N 36° 54'E* (Jan 1982), *Brown JM EA 16603, (EA);* **Unknown, longido** (1 Nov 1955), *Milne Redhead E & Taylor P 7157, (EA, K);* **Barkitabu** *1° 29'S 35° 34'E* (2 Oct 1978), *Oriana GH S.N., (EA);* **Leopard Rock** *0° 14'N 38° 12'E* (10 Sep 1963), *Verdcourt B 3745, (EA, K);* **Wajir, Wajir** (Jan 1955), *Hemming CF 433, (EA, K);*

MOZAMBIQUE. Manica, Pande (26 Jun 1949), *Pedro & Pedrogao 7777, (LMA);* **Tete,** (4 May 1972), *De Aguiar Macedo JM 5266, (LISC, LMU, SRGH);* (26 May 1966), *Neves Rosa F 350, (LISJC);* **Chicoa** (25 Jun 1949), *Andrada 1641, (LISC);* **Chicoa** (19 Feb 1970), *Torre AR & Correia MF 18060, (LISC);* **Foz** (10 May 1972), *Pereira A & Correia MF 2497, (LISC, LMU, SRGH);* **Magoe** (9 Mar 1970), *Torre AR & Correia MF 18230, (K, LISC);* **Mutarara** (1 Dec 1971), *Haffern JK 131, (SRGH);* **Tete** *18° 38'S 35° 13'E* (6 Mar 1972), *De Aguiar Macedo JM 5001, (LISC);*

NAMIBIA. Namibrand, Otjosondu (3 Nov 1966), *Seydel R 4454, (SRGH);* **Outjo, Etosha National Park** (22 Nov 1972), *Le Roux PJ 463, (PRE);*

SOMALIA. Bay, *3° 08'N 43° 10'E* (26 May 1987), *Hassan AS 25, (FHO, MOG);* *3° 06'N 43° 06'E* (26 May 1987), *Hassan AS 26, (FHO, MOG);* *3° 06'N 43° 06'E* (26 May 1987), *Hassan AS 28, (FHO, MOG);* **Awdiinlie** *3° 10'N 43° 14'E* (18 Sep 1987), *Fagg CW & Styles BT 5, (EA, FHO, K);* **Dolondole** *3° 16'N 44° 08'E* (15 Mar 1982), *Beckett JJ & White R 1778, (EA);* **Unknown,** *2° 25'N 42° 51'E* (18 Jun 1983), *Gillett JB & Hemming CF 24710, (EA);* (26 Feb 1945), *Glover PE & Gilliland HB 873, (EA);* **Duwi** (21 Oct 1932), *Gillett JB 4396, (EA);*

SOUTH AFRICA. Cape, Keiskammahoek *31° 37'S 27° 07'E* (30 Sep 1976), *Stirton CH 6283, (PRE);* **Transvaal,** *25° 22'S 31° 37'E* (31 Aug 1977), *MacMurtry D 2183, (PRE);* *24° 22'S 29° 37'E* (2 Dec 1981), *Van Wyk AE 5233, (PRE);* **Burgersfort** *24° 37'S 30° 22'E* (20 Nov 1951), *Codd LEW 6679, (PRE);* **Chuniespoort** *24° 22'S 29° 37'E* (20 Aug 1946), *Codd LEW 1701, (PRE);* **Chuniespoort district** *24° 00'S 29° 00'E* (26 Mar 1984), *Michael Tsas P PNBG 28166, (PRE);* **Dongola area** (17 Aug 1948), *Codd LEW 4325, (PRE);* **Dongola bot. res.** (14 Jul 1940), *Verdoorn IC 2070, (PRE);* **Dongola reserve** *22° 22'S 29° 37'E* (13 Oct 1948), *Verdoorn IC 2326, (PRE);* **Hartjiesfontein** *22° 22'S 29° 37'E* (16 Mar 1948), *Verdoorn IC 2294, (PRE);* **Lydenburg** (22 Nov 1959), *Acocks JPH 20934, (K, PRE);* **Malelane** *25° 37'S 31° 22'E* (22 Aug 1965), *Leach LC 13109, (PRE);* **Malelane** *25° 37'S 31° 22'E* (Aug 1917), *Pole Evans IB PRE 15768, (PRE);* **Masekwas poort** *22° 00'S 29° 00'E* (24 Aug 1967), *De Winter B 8776, (PRE);* **Messina** *22° 22'S 30° 07'E* (Sep 1927), *Pole Evans IB 2038, (PRE);* **Messina** *22° 22'S 30° 07'E* (18 Oct 1932), *Pole Evans IB 35258, (PRE);* **Messina** (2 Sep 1967), *Biegel HM 2265, (PRE, SRGH);* **Musekwa tribal area** (12 Oct 1979), *Du Toit GJ 273, (PRE);* **Noord transvaal** (2 Feb 1968), *Grobbelaar N 607, (PRE);* **Olifants bridge** (18 Aug 1946), *Codd LEW 1667, (PRE);* **Potgietersrust district** (25 Feb 1936), *Irvine LF 80, (PRE);* **Sekukuniland** (5 Jan 1939), *Barnard & Mogg 787, (PRE);* **Steelpoort** *24° 37'S 30° 07'E* (1980), *Fourie SP 393, (PRE);* **Vanetzi valley** (4 Jul 1946), *Gerstner JJ 6199, (PRE);* **Vivo** (26 Apr 1948), *Codd LEW 4049, (PRE);* **Vivo** *23° 07'S 29° 22'E* (25 Sep 1972), *Mogg AOD 36898, (PRE);* **Vivo** *23° 07'S 29° 22'E* (18 Oct 1967), *Robbertse PJ 207, (PRE);* **Vivo** *23° 07'S 28° 52'E* (29 Jan 1968), *Strey RG 7985, (PRE);* **Vivo p.o.** (16 Aug 1948),

Codd LEW 4320, (PRE); **Vivo p.o.** (11 Oct 1948), *Codd LEW 4440, (K, PRE);* **Waterpoort** (Sep 1918), *Rogers FA TM 18758, (PRE);* **Zoutpansberg** (Aug 1916), *Breyer HG TM 16063, (PRE);* **Gorge camp** (30 Oct 1950), *Codd LEW 6190, (PRE, SRGH);* **Zoutpansberg, Dongola** (15 Mar 1948), *Verdoorn IC 2266, (PRE, SRGH);* **Hartjiesfontein** (6 Mar 1948), *Verdoorn IC 2293, (PRE, SRGH);* **Messina Bot. reserve** (Oct 1932), *Pole Evans IB 3528, (FHO);*

SUDAN. Equatoria, Mongalla *5° 10'N 31° 48'E* (18 Sep 1948), *Jackson JAD 344, (FHO);* **Unknown, Galol** (18 Oct 1966), *Sahni KC 404, (FHO);*

TANZANIA. Central, *6° 00'S 35° 00'E* (22 May 1978), *Ruffo 1353, (K);* **Dodoma, Ikowa Dam** *6° 11'S 35° 45'E* (29 Jul 1970), *Thulin M & Mhoro B 530, (EA, K);* **Iringa, Iringa** (Feb 1966), *Procter J 3066, (EA);* **Msembe** (1 Dec 1970), *Greenway PJ & Kanuri 14687, (EA);* **Msembe** (25 Aug 1969), *Greenway PJ 14219, (EA);* **Msembe** (13 Mar 1967), *Kololo A 43, (EA);* **Ruaha** *7° 43'S 34° 55'E* (6 Aug 1970), *Thulin M & Mhoro B 607, (EA, K);* **Ruaha National Park** (6 Aug 1970), *Procter J 607, (EA);* **Ruaha National Park** (7 May 1972), *Bjornstad A 1622, (EA);* **Lake, Ukiriguru** *2° 43'S 33° 01'E* (2 Sep 1964), *Kadeha A 8240, (EA);* **Mbulu, Rontumabe** (14 Aug 1967), *Woodburn JC 52, (EA);* **Morogoro, Dakawa** (14 Sep 1959), *Pocs T 6033, (EA);* **Mpwapwa, Mpwapwa** (2 Jun 1929), *Hornby Mrs 140, (EA);* **Mpwapwa** (15 Jun 1938), *Hornby & Hornby 140, (EA);* **Mwanza, Munguli** (23 Jun 1967), *Woodburn JC 40, (EA);* **Northern,** *3° 31'S 36° 08'E* (18 Nov 1988), *Fagg CW 419, (FHO);* *3° 23'S 37° 33'E* (25 Jan 1936), *Greenway PJ 4505, (FHO, K);* *3° 00'S 37° 00'E* (1900), *McCoy Hill 24, (EA, K);* **Pare, Lembemi** *3° 56'S 37° 41'E* (29 Jan 1966), *Leippert H 6202, (EA, K);* **Tanga,** *4° 41'S 38° 06'E* (17 Nov 1988), *Fagg CW 412, (FHO);* **Same** *4° 04'S 37° 44'E* (7 Feb 1930), *Greenway PJ 2192, (EA, FHO, K);* **Unknown,** *2° 44'S 36° 42'E* (1 Nov 1955), *Milne Redhead E & Taylor P 7157A, (K, SRGH);* (25 Jul 1954), *Faulkner HG 1474, (K);* (23 Sep 1966), *Kodesha AK 4602, (EA);* **Chichoroni** (1 Jun 1967), *Robinette NJ 891, (EA);* **Kiberaschi** (1900), *Burtt 4910, (EA);* **Mina** (13 May 1961), *Akiley 81, (EA, K);* **Ngomeni** (25 Aug 1944), *Greenway PJ 7033, (EA, FHO);* **Ruaha valley** *7° 00'S 35° 44'E* (19 Aug 1951), *Trapnell CG 2157, (EA, K);* **Tangata** (29 Jul 1915), *Zimmermann 7007, (EA);* **Tochokwe** (1 Aug 1915), *Zimmermann 7006, (EA);* **Same** (27 Jan 1935), *Davis RM 994, (EA);* **Usambara,** *4° 50'S 38° 30'E* (1900), *Holbt 3167, (K);* *4° 50'S 38° 30'E* (1900), *Holbt 3870, (K);*

UGANDA. Northern, Pcholoio Forest Reserve (31 Apr 1959), *Lang Brown 119, (EA, K);*

ZAMBIA. Hwange, Victoria Falls (Dec 1906), *Allen CEF 399, (K);* **Southern, Lusitu** *16° 08'S 28° 50'E* (22 May 1961), *Fanshawe DB 6602, (K, NDO);* **Victoria Falls** *17° 55'S 25° 51'E* (Apr 1906), *Allen 399, (K);* **Sinazongwe** *17° 20'S 27° 28'E* (16 Mar 1964), *Bainbridge WR 838, (K, NDO, SRGH);* *17° 49'S 25° 45'E* (20 Jun 1992), *Fagg CW 577, (FHO, SRGH);* **Katombora** *17° 40'S 26° 00'E* (21 Jun 1956), *Gilges W 634, (K, SRGH);* *17° 49'S 25° 45'E* (4 Dec 1989), *Fagg CW 498, (FHO, SRGH);*

ZIMBABWE. Beitbridge, *21° 54'S 29° 53'E* (12 Jul 1988), *Barnes RD 525, 21° 42'S 29° 53'E* (2 Sep 1967), *Biegel HM 2267, (SRGH);* **Beitbridge** *22° 11'S 29° 59'E* (8 Aug 1970), *Cleghorn WB 2116, (K, SRGH);* **Beitbridge** (31 Aug 1958), *West O 3716, (K, SRGH);* **Beitbridge** *21° 59'S 29° 56'E* (19 Aug 1967), *Biegel HM 2216, (SRGH);* **Beitbridge** (3 May 1967), *Kennan TCD MRSH 4274, (MRSH);* **Giraffe dam** (Nov 1960), *Davies RM 2821, (SRGH);* **Tuli police camp** *21° 55'S 29° 16'E* (2 May 1959), *Drummond RB 6060, (SRGH);* **Machuchuta** *21° 51'S 29° 21'E* (20 Aug 1964), *West O 4934, (SRGH);* **Guruve, Dande mission** (15 May 1962), *Wild H 5755, (K, SRGH);* **Hwange,** (26 Dec 1952), *Lovemore DF 348, (SRGH);* **Matetsi river** (Sep 1969), *Davies RM 2810, (K, SRGH);* **Matetsi safari office** (9 Oct 1978), *Gonde P 220, (SRGH);* **Wankie game reserve** (Jul 1956), *Davison E SN, (SRGH);* **Matobo, Noel Nickel** *21° 18'S 28° 35'E* (10 Jun 1968), *Wild H 7738, (SRGH);* **Mwenezi, Chikombedzi** *21° 38'S 31° 15'E* (4 May 1961), *Drummond RB & Rutherford Smith ROB 7659, (SRGH);* **Lundi escarpment** *21° 21'S 32° 21'E* (1900), *Mowbray RM 113, (SRGH);*

Acacia senegal (L.) Willd. var. ***rostrata*** Brenan

ANGOLA. Cunene, Curoca (15 Mar 1973), *Menezes A Barroso et Sousa 4732, (SRGH);* **Huila, Onepolo** (8 Nov 1969), *Azancot De Menezes 3159, (SRGH);* **Mocamedes, Caracul** (9 Jun 1967), *Menezes A Henriques C et Brites M 2862, (SRGH);* **Mocamedes** (5 Jan 1956), *Torre AR 8376, (SRGH);*

BOTSWANA. Central, *23° 25'S 27° 11'E* (3 Sep 1988), *Barnes RD 528, 22° 17'S 29° 08'E* (1 Jul 1962), *Yalala AM 196, (SRGH);* **Orapa** *21° 07'S 25° 52'E* (30 Dec 1972), *Thompson MF 1680, (K, PRE);* **Orapa** *21° 18'S 25° 22'E* (11 Jun 1974), *Allen A 139, (SRGH);* **Orapa** *21° 22'S 25° 22'E* (11 May 1974), *Allen AM 112, (PRE);* **Orapa** *21° 22'S 25° 22'E* (11 May 1974), *Allen AM 120, (PRE);* **Orapa** *21° 22'S 25° 22'E* (11 Jun 1974), *Allen AM 139, (PRE);* **Orapa** *21° 22'S 25° 22'E* (16 Dec 1974), *Allen AM 193, (PRE);* **Orapa** *21° 22'S 25° 07'E* (28 Jan 1975), *Allen AM 253BCD, (PRE);* **Central Kalahari, Deception valley** *21° 22'S 23° 52'E* (2 Jan 1973), *Thompson MF 1703, (K);* **Ghanzi, Deception pan** *21° 30'S 23° 50'E* (Apr 1975), *Owens M 43, (SRGH);* **Kgalagadi, Kuke gate** *21° 00'S 23° 37'E* (1 Mar 1969),

Rains B & Yalala A 8, (PRE, SRGH); **Deception valley** *21° 26'S 23° 47'E* (18 Mar 1983), *Smith PA 4193, (PRE, SRGH);* **Northern Division, Lake Dow** *21° 10'S 24° 38'E* (22 Mar 1965), *Wild H & Drummond RB 7223, (K, PRE, SRGH);* **Toromoja** *21° 08'S 24° 39'E* (23 Apr 1971), *Coleman M 37, (SRGH);* **South East, Mopipi village** *21° 13'S 24° 59'E* (20 Nov 1978), *Smith PA 2516, (K, PRE, SRGH);* **Unknown, Dikhatlon Ranch** (14 Apr 1931), *Pole Evans IB 3189(39), (K, PRE);* **Merryhill farm** *22° 07'S 29° 07'E* (20 Dec 1971), *Stephen & Wilson 503, (PRE);* **Pudi hills** (1 Mar 1969), *Blair Rains A & Yalala A 8, (K);*

MOZAMBIQUE. Gaza, (28 Mar 1954), *Barbosa G E Balsinhas A 5500, (LISC, LMA);* **Chamusca** (19 Jun 1947), *Pedrogao J 352, (COI, LISJC, LMA);* **Chokwe** (26 Jun 1980), *Schafer PA 7158, (K);* **Estivane** (20 Nov 1957), *Grandvaux Barbosa LA e De Lemos F 8212, (COI, LISC, LMA);* **Guija** (2 Jul 1947), *Pedro & Pedrogao 1206, (COI, K, LISJC, SRGH);* **V.Gomes da costa** (31 Jul 1947), *Pedro & Pedrogao 1582, (LMA, LMU);* **Missao de S. Vicente de Paula** (26 Jun 1947), *Pedro & Pedrogao 2108, (LMA, LMU);* **Maputo,** (7 Jun 1948), *Torre AR 7968, (LISC);* **Boane** (24 Mar 1975), *Marques A 2633, (SRGH);* **Boane** (24 Apr 1947), *Pedro & Pedrogao 646, (LMA, LMU);* **Boane** (Nov 1907), *Braga C 106, (COI);* **Cabeca do Elefante** (1 May 1947), *Pedro & Pedrogao 1065, (LMA, LMU);* **Cabeca do Elefante** (1 Apr 1947), *Pedro & Pedrogao 1061, (LMA);* **Goba** *26° 00'S 32° 00'E* (25 Oct 1940), *Torre AR 1881, (LISC);* **Lourenco Marques** (Jan 1920), *Boole J 359, (FHO);* **Magude** (3 Jan 1948), *Torre AR 7027, (LISC);* **Maputo** (27 Feb 1947), *Hornby RM 2520, (K, LMA, SRGH);* **Maputo** (17 May 1947), *Pedrogao J 3227, (LMA);* **Maputo** (Jan 1920), *Borle J 359, (FHO);* **Matola** (29 Apr 1947), *Pedro & Pedrogao 896, (LMA, LMU);* **Matola** (4 Jun 1971), *Marques A 2302, (LMU);* **Metalola/Umbeluzi** (23 Dec 1944), *Mendonca FA 3492, (K, LISC, SRGH);* **Moamba** (14 Apr 1944), *Torre AR 6410, (LISC);* **Santaca** *26° 26'S 32° 10'E* (12 Jan 1948), *De Figueiredo Gomes E Sousa A 3647, (K, COI, LMA);* **Umbeluzi** (16 Jun 1941), *Hornby RM 1046, (LISC);* **Mahel** (30 Nov 1944), *Mendonca FA 3154, (LISC);* **Mapulanguene** (17 Feb 1953), *Myre M e Balsinhas A 1555, (LMA);* **Mazeminhama** (13 Mar 1968), *Myre M e Rosa N 4897, (LMA);* **Mazeminhama** (14 Mar 1968), *Myre M e Rosa N 4900, (LMA);* **Nampula, Magudo** (24 Jun 1969), *Correia MF & Marques A 789, (LISC, LMU, SRGH);* **Niassa, Monte Icoculo** (31 Aug 1948), *Pedro & Pedrogao 4997, (EA, LMA);* **Sulo do save, Maguisemane** (19 Jun 1947), *Pedrogao J 364, (LAM, SRGH);* **Maguisemane** (4 Jul 1947), *Pedro & Pedrogao 1273, (COI, LMA, SRGH);*

NAMIBIA. Damaraland, Grootberg ou 191 far *19° 37'S 14° 22'E* (21 Apr 1964), *Giess W 8159, (PRE, WIND);* **Uis** *21° 22'S 15° 07'E* (16 May 1976), *Oliver & Muller 6694, (PRE);* **Kaokoland, Epupa Falls** *17° 01'S 13° 13'E* (29 Nov 1992), *Fagg CW & Maggs GL 64, (FHO, WIND);* **Etanga** *17° 52'S 13° 07'E* (8 Apr 1957), *De Winter B & Leistner 5445, (PRE, WIND);* **Ondore** (1957), *Abner 65, (PRE, WIND);* **Karibib, Karibib** *21° 52'S 15° 52'E* (30 Jan 1934), *Dinter K 6926, (PRE, WIND);* **Karibib dist.** (18 Nov 1952), *Kinges HG 3433, (PRE);* **Maltahohe, Buellsport** (Dec 1947), *Strey RG 2314, (PRE);* **Mariental, Gideon dist.** (14 May 1955), *De Winter B 3542, (PRE, WIND);* **Mariental dist.** (10 Mar 1965), *Hardy DS 1952, (PRE, WIND);* **Marienthal** *24° 37'S 17° 52'E* (7 Feb 1974), *Grobbelaar N 1866, (PRE);* **Omaruru,** *21° 11'S 15° 41'E* (21 Nov 1992), *Fagg CW & Maggs GL 1, (FHO, WIND);* **Otjimbojo east farm** *21° 37'S 16° 07'E* (14 May 1953), *Kinges HG 3420, (PRE);* **Otjiwarongo, Omatjeni** (Mar 1948), *Keet JDM 1681, (PRE, WIND);* **Omatjenne dist.** (Apr 1949), *Liebenberg LCC 4816, (PRE, WIND);* **Outjo, Outjo dist.** (Jun 1960), *Esterhuizen C 449, (PRE, WIND);* **Owambo, Oshikango** *17° 22'S 15° 52'E* (1 May 1973), *Rodin RJ 9358, (PRE, WIND);* **Ovamboland** (14 Nov 1955), *De Winter B 3635, (PRE, WIND);* **Rehoboth,** (21 Nov 1952), *Walter H et E 181, (PRE, WIND);* **Unknown, Dusternbrock farm** (31 Dec 1947), *Wiss HJ & Kinges H 807, (PRE);* **Gainatseb** (21 Jul 1939), *Volk OH 2446, (PRE);* **Geinatseb** (11 Feb 1939), *Volk OH 2579A, (PRE);* **Haribes** (11 Apr 1956), *Volk OH 12319, (PRE, WIND);* **Okaliangama** (Nov 1906), *Dinter 222, (P);* **Wittklippberg** (6 Mar 1940), *Volk OH 2887C, (PRE);* **Windhoek, Khomas hocland** (27 Oct 1980), *Evrard C 9269, (PRE);* **Mertens farm** *23° 22'S 17° 22'E* (May 1969), *Boshoff & Mason 3627, (PRE);*

SOUTH AFRICA. Natal, *27° 22'S 31° 52'E* (6 Feb 1966), *Grobbelaar N 1344, (PRE); 26° 52'S 31° 22'E* (17 Apr 1968), *Strey RG 8179, (PRE);* **Black Umfolozi valley** (Mar 1927), *Kotze PC 243, (PRE);* **Black umfolozi** (16 Apr 1923), *Swynnerton C 94, (PRE);* **False bay** *28° 07'S 32° 22'E* (21 Jan 1949), *Bayer AW 1468, (PRE);* **Ganamanini pan** (20 Jun 1972), *Bella V & Stephen J 824, (EA);* **Ganamanint pan** *26° 52'S 31° 22'E* (20 Jun 1972), *Stephen JJF 824, (EA, PRE);* **Hlabisa** *28° 07'S 31° 52'E* (20 Apr 1958), *Skead & Ward 17, (PRE);* **Hluhluwe state dam** (11 Apr 1966), *Ward CJ 5614, (PRE);* **Jozinidam** (23 Jan 1963), *Edwards D 2894, (PRE);* **Jozinidam** *27° 37'S 31° 07'E* (24 Apr 1966), *Ross JH 1643, 1646, 1654 (PRE);* **Mandini** *29° 07'S 31° 22'E* (23 Apr 1966), *Ross JH 1630, (FHO, PRE);* **Mfolozi game reserve** (28 Mar 1964), *Moll EJ 793, (PRE);* **Middledrift** (9 Jun 1956), *Edwards D 1407, (PRE);* **Middledrift** (15 Jun 1956), *Edwards D 1428, (PRE);* **Middledrift.** (9 Jun 1956), *Edwards D 1411, (PRE);* **Mkuze** *27° 37'S 32° 07'E* (11 Mar 1964), *Edwards D 3286, (PRE);* **Mkuze game reserve** *27° 37'S 32° 22'E* (28 Jan 1982), *Bamps 7052, (PRE);* **Mkuze game reserve** *27° 37'S 32° 07'E* (23 Feb 1982), *Retief E 758, (PRE);* **Mkuzi game res.** (29 Jan 1962), *Ward CJ 3999, (PRE);* **Mkuzi game reserve** *27° 37'S 32° 07'E* (26 Jan 1980), *Henderson L 140, (PRE);* **Ndumu game reserve** (9 Jan 1962), *Oatley TB 75, (PRE);* **Ndumu game reserve** *26° 52'S 32° 07'E* (9 Jan 1954), *Ward CJ 2022, (PRE);* **Ndwandwe** (17 Aug 1945), *Acocks JPH 11681, (PRE);* **Reserve no 3** (13 Oct 1944), *Gerstner JJ 4933, (PRE);* **Tembe**

Elephant park *26° 52'S 32° 37'E* (10 Jan 1985), *Ward MC 902, (PRE);* **Transvaal,** *22° 52'S 29° 07'E* (21 Dec 1969), *Huntley BJ 1880, (PRE);* **Arabie** *24° 52'S 29° 22'E* (7 Dec 1981), *Ellery W 348, (PRE);* **Dongola reserve** *22° 22'S 29° 37'E* (27 Apr 1948), *Codd LEW 4087, (PRE);* **Eerste recht** *25° 10'S 30° 22'E* (3 Jan 1939), *Barnard & Mogg 699, (PRE);* **Ellisras** *23° 37'S 27° 37'E* (24 Feb 1954), *Codd LEW 8489, (PRE);* **Ellisras.** (13 Mar 1946), *Codd LEW 1015, (PRE);* **Figtree** *25° 37'S 31° 37'E* (16 Jan 1971), *Nel JP 93, (PRE);* **Klaserie priv. nat.** *24° 22'S 31° 22'E* (28 Nov 1973), *Zambatis N 598, (PRE);* **Kruger National park** (14 Jan 1954), *Van Der Schijf 3411, (PRE);* **Kruger nas. wildtuin** *25° 22'S 31° 52'E* (26 Feb 1987), *Wentzel JJ N.4, (PRE);* **Langjan nature reserve** *22° 52'S 29° 07'E* (Nov 1974), *Zwanziger S 143, (PRE);* **Limpopo** (15 Jul 1940), *Verdoorn IC 2081, (PRE);* **Magalakwena river** *22° 00'S 29° 00'E* (30 Apr 1971), *Schlieben HAR 12047, (PRE);* **Malelane** *25° 22'S 31° 22'E* (1 Dec 1970), *Buitendag E 785, (PRE);* **Nwanedzi dam** *23° 22'S 30° 22'E* (8 Feb 1976), *Brenan JPM 14170, (PRE);* **Pongolo Ro.** (23 Apr 1967), *Ross JH 1703, (P);* **Pongolo river** *27° 22'S 31° 52'E* (23 Apr 1967), *Ross JH 1702, (PRE);* **Pontdrift** *22° 07'S 29° 07'E* (9 Mar 1972), *Coetzee BJ 1305, (EA, PRE);* **Potgietersrust district** (5 Dec 1946), *Codd LEW 2293, (PRE);* **Potgietersrust district** (5 Dec 1946), *Story R 1582, (PRE);* **Schoemanskloof** (5 Aug 1933), *Pole Evans IB PRE 30008, (PRE);* **Schoonoord** *24° 37'S 30° 07'E* (Nov 1941), *Van Warmelo NJ 195, (PRE);* **Sekukuniland** (11 Nov 1935), *Barnard WG 435, (PRE);* **Shiela 10ku.** *24° 07'S 31° 07'E* (14 Aug 1984), *Retief IM 185, (PRE);* **Skukuza** *24° 52'S 31° 37'E* (5 Feb 1949), *Codd LEW & De Winter B 5030, (PRE);* **Skukuza** *24° 22'S 31° 22'E* (9 Jun 1987), *Steel BS 480, (PRE);* **Skukuza area** (11 Nov 1954), *Van Der Schijf 4008, (PRE);* **Soutpan** *22° 52'S 29° 22'E* (21 Jan 1931), *Bremekamp SCH 239, (PRE);* **Tom burke** *23° 00'S 28° 00'E* (26 Sep 1972), *Mogg AOD 37068, (PRE);* **Tshipise** *22° 37'S 30° 22'E* (6 Dec 1984), *Van Wyk AE 6893, (PRE);* **Usutu** *22° 37'S 28° 37'E* (2 May 1973), *Van Graan HAR 453, (PRE);* **Vanetzi** (4 Jul 1964), *Gerstner JJ 6203, (PRE);* **Vanetzi valley** (2 Mar 1946), *Gerstner JJ 6075, (PRE);* **Vanetzi valley** (4 Jul 1946), *Gerstner JJ 6222, (PRE);* **Villa nora** (21 Dec 1967), *Robbertse PJ 257, (PRE);* **Weipe** (26 Dec 1945), *Pole Evans IB 4491, (PRE, SRGH);* **Zoutpan** *22° 52'S 29° 22'E* (Nov 1932), *Obermeyer SCH 300, (PRE);* **Zoutpansberg, Dongola** (15 Mar 1948), *Verdoorn IC 2262, (PRE, SRGH);* **Weipe flats** (15 Mar 1948), *Verdoorn IC 2263, (PRE, SRGH);* **Weipe flats** (15 Mar 1948), *Verdoorn IC 2272, (PRE, SRGH);* **Weipe flats** (15 Mar 1948), *Verdoorn IC 2264, (SRGH);*

SWAZILAND. Unknown, Gollel area *26° 52'S 31° 22'E* (25 Sep 1959), *Compton RH 29093, (PRE);* **Hlane game reserve.** *26° 07'S 31° 52'E* (3 Sep 1984), *Prior J 571, (PRE);* **Hluti-gollel** (9 Dec 1931), *Pole Evans IB 3393, (PRE);* **Malinda hill** (26 Nov 1958), *Compton RH 28435, (PRE);* **Mbuluzi gorge** *26° 22'S 31° 52'E* (27 Dec 1976), *Culverwell J 0452, (PRE);* **Mbuluzi poort** *26° 22'S 31° 52'E* (23 May 1976), *Culverwell J 0137, (PRE);* **Mlindekwa** (11 Apr 1964), *Compton RH 32052, (PRE);* **Mzimpofu river** (11 Dec 1931), *Pole Evans IB 3418, (PRE);* **Ranches ltd** (26 May 1932), *Pole Evans IB 3487, (PRE);* **Sicusha** (31 Mar 1963), *Compton RH 31571, (PRE);* **Sicusha** *26° 22'S 31° 52'E* (12 Jan 1966), *Compton RH 32489, (PRE);* **Simunye nat. res.** *26° 07'S 31° 52'E* (26 Apr 1987), *Braun KP 507, (PRE);* **Tshaneni** *25° 52'S 31° 37'E* (20 Dec 1969), *Barrett SCH 386, (PRE);* **Umtintegwa** (10 Dec 1957), *Compton RH 27345, (PRE);* **Usutu river** (Mar 1940), *Miller OB S/248, (FHO, PRE);*

ZIMBABWE. Beitbridge, *22° 08'S 30° 51'E* (11 Jul 1988), *Barnes RD 523,* **Shashi/Limpopo confluence** *22° 10'S 29° 21'E* (22 Mar 1959), *Drummond RB 5936, (K, SRGH);* **Shashi/Limpopo confluence** (May 1959), *Thompson BR T/31/59, (SRGH);* **Buhera, Birchenough Bridge** *19° 58'S 32° 20'E* (30 Jan 1948), *Wild H 2458, (K, SRGH);* **Birchenough Bridge** *19° 58'S 32° 20'E* (Jul 1959), *Davies RM 2562, (SRGH);* **Birchenough Bridge** *19° 58'S 32° 20'E* (Jun 1954), *Davies RM 799, (SRGH);* **Gwanda, Shashi Plain** (18 Dec 1956), *Davies RM 2362, (K, SRGH);* **Unknown, Chikwizi quarry** (6 Aug 1988), *Carter & Coates Palgrave 2187, (K);* **Sabi river** *20° 24'S 31° 12'E* (28 Jun 1934), *Michelmore APG 285, (K, SRGH);*

Acacia senegal (L.) Willd. var. ***senegal***

BURKINA FASO. Centre, Kaya *13° 04'N 1° 09'W* (Nov 1934), *Aubreville M 2140, (P);* **Kaya** (Nov 1934), *Aubreville M 2141, (P);* **Kaya** (May 1935), *Aubreville M 2376, (P);* **Ouagadougou** *12° 20'N 1° 40'W* (Mar 1935), *Aubreville M 2331, (P);* **Unknown, In Tillit** (Jan 1970), *Gaston A 2714, (P);*

CAMEROON. Benoue, Garoua *9° 17'N 13° 22'E* (May 1946), *Aubreville M 826, (P);* **Chari Baguirmi, Fort Lamy** (27 Nov 1969), *Hepper FN Gaston A 4031, (K);* **Diamare, Maroua** *10° 35'N 14° 20'E* (18 Jun 1945), *Vaillant A 113, (P);* **Logne et Chari, Ft. Foureau** *12° 05'N 14° 56'E* (Apr 1942), *Jacques Felix H 1138, (P);* **Makari** *12° 35'N 14° 28'E* (28 Dec 1964), *Raynal J & A 12728, (P);* **Makari** (3 Oct 1964), *Letouzey R 7188, (K);* **Maltam** (28 Sep 1964), *Letouzey R 7090, (K);* **Margui Wandala, Mozogo** *10° 58'N 13° 55'E* (12 Sep 1964), *Letouzey R 6859, (K, P);* **Unknown, Kokio** (1954), *Recherchs Forestieres Du Cameroun 4424, (P);*

CHAD. Batha, Ati *13° 11'N 18° 20'E* (8 Apr 1963), *Descoings B 10817, (P);* **Lac Fittri** *12° 50'N 17° 28'E* (10 Aug 1903), *Chevalier A 9500, (P);* **Chari Baguirmi, Dilbini** *12° 05'N 17° 04'E* (17 Sep 1967), *Audry P C67, (P);* **Dol** *11° 09'N 16° 32'E* (5 Aug 1903), *Chevalier A 9429, (K, P);* **Fort Lamy** *12° 10'N 14° 59'E* (15 Jul 1938), *Creach P 54, (P);*

Massaguet *12° 28'N 15° 26'E* (Oct 1957), *Koechlin J 4776, (P);* **Massakori** *13° 02'N 15° 43'E* (13 Sep 1903), *Chevalier A 9885, (P);* **Massakori** *13° 02'N 15° 43'E* (17 Jun 1964), *Gaston A 34, (P);* **Moyto** *12° 35'N 16° 33'E* (27 Nov 1967), *Gaston A 1286, (P);* **Ennedi, Arsa** *17° 23'N 21° 34'E* (18 Jan 1967), *Monod TH 13937, (P);* **Mayo Kebbi, Mogroum** *9° 41'N 15° 04'E* (23 Oct 1969), *Fotius G 1806, (P);* **Mogroum** *9° 41'N 15° 04'E* (Feb 1946), *Aubreville M 809, (P);* **Unknown, Dori** (Oct 1935), *Aubreville M 12, (P);* **Mundi Ayna** (Jul 1907), *Gaillard SN, (P);*

ERITREA. Keren (1870), *Beccari O 33, (K);*

ETHIOPIA. Gamo Gofa, Foidjet (10 Feb 1973), *Boudet G 8267, (P);* **Gondar, Mega** *11° 37'N 38° 30'E* (28 Dec 1972), *Rippstein G 1595, (P);* **Unknown, Dirouhoria** (28 Aug 1904), *Neuville 249, (P);*

GHANA. Mesewam (3 Apr 1980), *Jefferies M 6, (K);*

INDIA. Dehli, Delhi ridge (11 Sep 1966), *Rodin RJ 8029, (K);* **Punjab,** (1876), *Dalzell NA 21, (K);* **Rajputana, Aravulli hills** (Jun 1870), *Brandis sn, (K);* **Unknown, Beyt** (13 Oct 1953), *Raizada MB 23863, (K);* **Scinde hills** (1867), *Ellerton Stocks J 502, (K);*

IVORY COAST. Nord, Bouroum *8° 03'N 7° 09'W* (Dec 1935), *Aubreville M 2676, (P);*

KENYA. Baringo, Chemogoch camp (11 Jan 1968), *Ahiti 221, (EA);* **Chemolingot** (21 Dec 1976), *Timberlake JR 967, (EA);* **Chemolingot** *0° 58'N 35° 57'E* (2 Sep 1976), *Timberlake JR 634, (EA);* **Chemolingot** *0° 58'N 35° 57'E* (17 Sep 1976), *Timberlake JR 773, (EA);* **Chemolingot bore-hole** *0° 58'N 35° 57'E* (24 Jul 1976), *Timberlake JR 128, (EA);* **Chemolingot bore-hole** *0° 58'N 35° 37'E* (24 Sep 1976), *Timberlake JR 891, (EA);* **Cheptapokwa** *0° 58'N 35° 57'E* (24 Sep 1976), *Timberlake JR & Hayes J 876, (EA);* **Endorois-Baringo** (20 Aug 1985), *Rottland T 308, (EA);* **Lorkortakim/Saima** (12 Aug 1985), *Rottland T D195, (EA);* **Marigat** (11 Nov 1978), *Nightingale JM s.n., (EA);* **Marigat** (1900), *Nganga SK 22, (EA);* **Marigat** *0° 42'N 36° 02'E* (24 Oct 1964), *Leippert H 5201, (EA);* **Nakuru** (12 May 1989), *Farah & Janet & Kimei 079, (EA);* **Nginyang** (Aug 1957), *Trapnell CG 2354, (EA);* **Pokot** (14 Aug 1985), *Rottland T D242, (EA);* **Scimo** (11 Mar 1985), *Roheand D13, (EA);* **Embu, Muthano hill complex-East** (15 Nov 1972), *Braun HMH 541, (EA);* **Garissa, Garissa** (Jan 1961), *Lucas GL & Williams J 66, (EA);* **Isiolo, Garbatula camp** (2 Jul 1960), *Paulo S 487, (EA);* **Isiolo** *0° 21'N 37° 35'E* (20 Nov 1952), *Hemming CF 97, (EA);* **Kajiado, Ilbissil** *2° 05'S 36° 45'E* (6 Dec 1975), *Galaty J 151, (EA);* **Kiambu, Juja** *1° 05'S 37° 10'E* (25 Nov 1983), *Seki T 102, (EA);* **Thika** (28 Jan 1967), *Faden RB 6758, (EA);* **Kilifi, Dakadima hill** (12 Jun 1975), *Bally PRO 16846, (EA, SRGH);* **Kilifi** (Jun 1945), *Graham RM 2098, (EA);* **Kitui, Kithyoko** *1° 05'S 37° 48'E* (30 Aug 1986), *Robertson SA 4287, (EA);* **Mutomo Plant Sanctuary** (30 Aug 1968), *Kimani ZJ 99, (EA);* **Nuu** (4 Oct 1982), *Kuchar P 14901, (EA);* **Kwale, Kwale** (Jul 1953), *Elliott CW 1373, (EA);* **Mrima Hill** (7 Sep 1957), *Verdcourt B 1916, (EA);* **Lamu, Dodori game reserve** (31 Oct 1980), *Muchiri J 570, (EA);* **Dodori reserve** (26 Oct 1980), *Kuchar P 13712, (EA);* **Kiyongwe** (20 Sep 1929), *Mohamed A 2203, (EA);* **Machakos, Machakos** (10 Jul 1970), *Arende JD 2668, (EA);* **Machakos** (12 Aug 1953), *Langdale-Brown I 13, (EA);* **Makipenzi** *1° 11'S 37° 30'E* (9 Jun 1954), *Bally PRO 9732, (EA);* **Mua Hills** *1° 30'S 37° 10'E* (28 Aug 1965), *Kokwaro JO 285, (EA);* **Mua Hills** *1° 27'S 37° 12'E* (2 Mar 1953), *Trump EC 27, (EA);* **Yatta plains** (2 Jul 1938), *Pole Evans IB & Erens J 1081, (P);* **Machakos/Kiui, Yatta plateau** (Jan 1937), *Gardner HM 1071, (EA);* **Mandera, Ramu-Malka** *4° 04'N 40° 59'E* (8 May 1978), *Gilbert MG & Thulin M 1580, (EA);* **Maralal, Dandu** *3° 26'N 39° 54'E* (5 May 1952), *Gillett JB 13052, (EA);* **Moyale** *3° 32'N 39° 03'E* (12 Aug 1952), *Gillett JB 13714, (EA);* **Meru, Kiboko Camp** (18 May 1972), *Ament J & Magogo FC 285, (EA);* **Kiolu** (13 May 1972), *Ament J & Magogo FC 198, (EA);* **Meru Game Reserve** (19 Mar 1968), *Mwangangi OM & Fosberg FR 646, (EA);* **Meru National Park** *0° 06'N 38° 12'E* (Dec 1979), *Lambrecht FL 1, (EA);* **Mughwango south swamp** (16 Apr 1972), *Ament J & Magogo FC 10, (EA);* **Nairobi, Nairobi National Park** (11 Mar 1973), *Mbuvi D 329, (EA);* **Nakuru, Menengai farm** (9 Mar 1971), *Nightingale JM 1, (EA);* **Narok, Maji Moto** (8 Oct 1976), *Kuchar P & Msafiri F 5274, (EA);* **Narok** (11 Jul 1953), *Rammell JC 3593, (EA);* **Narosura Rest Camp** (16 Aug 1961), *Glover Gwynne Samuel & Tucker 2398, (EA, K);* **Northern Frontier, Kinu Sogo** *3° 25'N 36° 35'E* (8 Aug 1980), *Hussein Adan 54, (EA);* **Kuisat** (Jan 1958), *Adamson T 1, (EA);* **Pokot, Kolowa** (Sep 1978), *Tanaka J 179, (EA);* **Rift valley, Barsalinga** *0° 47'N 37° 06'E* (6 Jun 1983), *Goething H(Dr.) 78, (EA);* **Samburu, Ewaso Nyiro** (16 May 1985), *Reif U 10, (EA);* **Samburu National Reserve** (10 May 1980), *Raeder W 5, (EA);* **Taita, Bachuma** *3° 38'S 38° 54'E* (10 May 1989), *Farah & Janet & Kimei 65, (EA);* **Kora Game Reserve** (12 May 1983), *Mungai GM Mutangah JG & Rucina SM 48, (EA);* **Kora Game Reserve** (6 Sep 1986), *Nyakundi DO 390, (EA);* **Kurawa** (3 Oct 1961), *Polhill R & Paulo S 584, (EA, K, P);* **Lake Chala** (1966), *Gilbert VC 57, (EA);* **Maungu** (1 Dec 1978), *Bally PRO 17124, (EA);* **National primate reserve** (19 Mar 1990), *Luke Q et al 645, (EA);* **Tana River** (Jul 1953), *Battiscombe 255, (EA);* **Wallis camp** (2 Feb 1952), *Trapnell CG 2211, (EA);* **Turkana,** (Aug 1980), *Itani J 16, (EA);* **Kacheliba** (11 Oct 1964), *Leippert H 5109, (EA);* **Kengatet** (7 Jul 1954), *Hemming CF 310, (EA);* **Lokitaung** (Jun 1968), *Carr CJ 164, (EA);* **Lokitaung & Lodwar (BTN)** (4 Sep 1968), *Bonnefille R 229, (EA);* **Makany** (12 Oct 1978), *Hughes P 28, (EA);* **Lomelo Hill** (14 Jun 1968), *Hemming CF 3029, (EA);*

Unknown, *5° 29'S 36° 58'E* (26 Jul 1965), *Leippert H 6050, (EA); 0° 00' 35° 57'E* (6 Oct 1981), *Gilbert MG & Tadesse M 6394, (ETH, K);* (17 Jul 1953), *Bally PRO 9029, (EA);* **Lolkisale** *3° 42'S 36° 26'E* (11 Jun 1965), *Leippert H 5869, (EA);* **Lolkisale** *3° 40'S 36° 27'E* (15 Jun 1965), *Leippert H 5901, (EA);* **Swegei-Asile** (28 Feb 1977), *Watkins R 30, (EA);* **Wajir, Wajir** (19 May 1972), *Gillett JB 19722, (EA);*

MALI. Gao, Hariboro *16° 10'N 2° 35'W* (21 Nov 1935), *Wailly M De 4908, (P);* **Tombouctou** *16° 49'N 2° 59'W* (18 Jul 1899), *Chevalier A 1184, (P);* **Tombouctou** *16° 49'N 2° 59'W* (Aug 1899), *Chevalier A 3124, (P);* **Kayes, Kayes** *14° 26'N 11° 28'W* (15 Nov 1938), *Aubreville M 2, (P);* **Mopti, Koboro** *15° 59'N 4° 03'W* (22 Jul 1899), *Chevalier A 1185, (P);* **Sumpi** *15° 51'N 4° 20'W* (Aug 1899), *Chevalier A 3352, (P);* **Segou, Boa** *14° 05'N 6° 07'W* (2 Dec 1935), *Roberty G 658, (P);* **Nyono** (27 Jul 1937), *Roberty G 2494, (P);* **Sansanding** *13° 44'N 6° 00'W* (28 Sep 1899), *Chevalier A 3353, (P);* **Sansanding** *13° 44'N 6° 00'W* (28 Sep 1899), *Chevalier A 3354, (P);* **Segou** *13° 28'N 6° 18'W* (6 Jul 1937), *Roberty G 2517, (P);* **Unknown,** (26 Oct 1885), *Bellamy 240, (P);* **Fada** (12 Jul 1910), *Chevalier A 24443, (P);* **Natuka** (13 Oct 1971), *Boudet G 7216, (P);* **Toguere de Banuita** (30 Jan 1952), *Davey JT 13, (K);* **Walet Nangai** (1 Sep 1989), *Diallo D Hveem B Mahmoud MAG 333bh, (K);* **Goumal** (8 Jun 1955), *Davey JT 238, (K);*

MAURITANIA. Adrar, Azougui *20° 35'N 13° 06'W* (13 May 1911), *Chudeau sn, (P);* **Inchiri, Akjoujt** *19° 45'N 14° 23'W* (Jun 1939), *Aubreville M sn, (P);* **Tagant, Talmeust** *19° 01'N 11° 32'W* (3 Aug 1934), *Monod TH 1606, (P);*

MOZAMBIQUE. Cabo Delgado, Montepuez (1 Sep 1948), *Barbosa 1952, (EA);* **Niassa, Larde** (17 Jul 1948), *Pedro & Pedrogao 4581, (EA, LMA);* **Alide** (1 Sep 1948), *Barbosa G 1952, (LISC, LMA);*

NIGER. Dogon Doutchi, Wadi Dallol (Jun 1968), *White LP 30, (K);* **Niamey,** (8 Sep 1978), *Saadou M & Garba M 954, (P);* **Bagarwa** *14° 10'N 3° 18'E* (31 Oct 1968), *Boudet G 5374, (P);* **Ouallam** *14° 19'N 2° 05'E* (9 Jun 1978), *Saadou M & Garba M 579, (P);* **Tin Boniatene** *15° 32'N 3° 43'E* (Sep 1962), *Koechlin J 6887, (P);* **Unknown, Sikilibati** (8 Sep 1962), *Peyre De Fabreues B 113 bis, (P);* **Toudoun Gao** (30 Oct 1968), *Boudet G 5368, (P);*

NIGERIA. Adamawa, Yola (26 May 1974), *Okeke Latilo & Odewo FHI 69326, (K);* **Bornu, Damaturu** (Jul 1944), *Kennedy JD 7268, (FHO);* **Geidam** (12 Jul 1910), *Dudgeon 1, (K);* **Lantewa** (3 Jul 1944), *Keay RWJ 7575, (FHO);* **Ibadan, Ibadan For. Res. Arboretum** (1 Jun 1966), *Adebusuyi JK FHI 58736, (FHO);* **Kano, Dawaki Kudu** (8 Aug 1949), *Onwudinjoh DC FHI 24017, (K);* **Katsina, Katsina N.A. plantation** (11 Nov 1959), *Latilo MG FHI 43770, (FHO);* **Maiduguri, Maiduguri** (1936), *Kennedy JD 2932, (FHO);* **Sokoto, Zamfara Forest reserve** (20 Apr 1946), *Keay RWJ FHI 16169, (FHO, K);* **Zurmi** (15 Apr 1946), *Keay RWJ FHI 16145, (FHO);*

PAKISTAN. Sind, Budhapur (4 May 1965), *Rechinger KH 28665, (K);*

RWANDA. Mutara, Biumba (24 May 1957), *Troupin G 3248, (EA, K);* **Unknown, Kakole** (13 Feb 1954), *Christiaensen R 360, (EA, K);*

SENEGAL. Diourbel, Diourbel *14° 39'N 16° 11'W* (19 Jul 1930), *Trochain J 28, (P);* **Fatick, Tataguine** *14° 27'N 16° 38'W* (18 Aug 1934), *Trochain J 4093, (P);* **Kaolack, M'Bap** *13° 43'N 15° 47'W* (23 Dec 1933), *Trochain J 2164, (P);* **Nioro** *13° 45'N 15° 48'W* (15 Nov 1938), *Aubreville M 1, (P);* **Louga, Khol Khol** *15° 29'N 15° 01'W* (17 Sep 1970), *Diallo AK 945, (P);* **Saint Louis, Dakar Bango** *16° 04'N 16° 28'W* (2 Oct 1965), *Audru J 2814, (P);* **M. Bidjem** (1865), *Franqueville Herb. 219, (K);* **Massara Foulane** *16° 11'N 16° 16'W* (8 Apr 1934), *Trochain J 3006, (P);* **Ranerou** *15° 18'N 13° 58'W* (May 1981), *Mariaux A 1269, (P);* **Ross Bethio** *16° 16'N 16° 08'W* (25 Aug 1965), *Audru J 2292, (P);* **Ross Bethio** *16° 16'N 16° 08'W* (27 Aug 1965), *Audru J 2315, (P);* **Tambacounda, Koussan** *14° 08'N 12° 26'W* (9 Jun 1934), *Trochain J 3565 bis, (P);* **Unknown,** (1749), *Herbier Adanson 16897, (P);* (1749), *Herbier Adanson 16898, (P);* (1749), *Herbier Adanson 16899, (P);* (), *Heudelot sn, (OXF);* **Roneraie de Pire** (3 Sep 1934), *Trochain J 4351, (P);* **Senegambia** (1839), *Heudelot sn, (K);* **St. Louis** (24 Jul 1960), *Kesby JD 27, (K);* **Yoroberikunda** (Nov 1953), *Faith AC 156, (K);*

SUDAN. Darfur, (18 Dec 1878), *Expedition Purdy 53, (P);* **Unknown, Galol** (20 Oct 1966), *Sahni KC 411, (FHO);* **Gebel Bagis** (14 Dec 1929), *Aylmer G 49, (FHO);* **Gebel Bouser** (Jan 1937), *Aylmer G sn, (FHO);* **Omdurman** (10 Feb 1922), *Aylmer G 40, (FHO);* **Sabonabi** (14 Mar 1923), *Aylmer G sn, (FHO);* **Saoleil** (9 Jan 1930), *Aylmer G 74, (FHO);*

TANZANIA. Central, Chakwale (15 Jun 1938), *Hornby Mr & Mrs 945, (FHO);* **Kolo** (23 Jan 1928), *Burtt BD 1636, (FHO);* **Kolo** (1 Feb 1928), *Burtt BD 1298, (FHO);* **Hadeni, Sindeni** (Jun 1964), *Procter J 2614, (EA);* **Lake, Kyerwa** *1° 29'S 30° 78'E* (May 1958), *Procter J 915, (EA);* **Kilima cha Fedthea** *2° 16'S 34° 55'E* (18 Nov 1956), *Greenway PJ 9034, (EA);* **Seronera** *2° 26'S 34° 49'E* (29 Mar 1961), *Greenway PJ 9929, (EA);* **Lubaga** *1° 56'S 32° 56'E* (12 May 1966), *Kiliwingo TDW 4414, (EA);* **Samuye** *3° 50'S 33° 23'E* (Nov 1938), *Koritschoner A 1754, (EA, K);* **Shinyanga**

3° 40'S 33° 26'E (Mar 1936), *Burtt BD 5646, (EA, FHO);* **Masai, Olmotonyi** (Jan 1955), *Salimu FRN 1, (EA);* **Masailand, Nabarera** (15 Oct 1934), *Hornby Mr & Mrs 8, (EA);* **Mbulu, Mongola** (5 Aug 1984), *Isaacs G 23, (EA);* **Mkalama, Usule** *3° 45'S 33° 13'E* (15 Dec 1933), *Michelmore APG 817, (EA);* **Monduli, Esilalei** *3° 22'S 35° 52'E* (24 Apr 1978), *Magogo FC 1902, (EA, K);* **Northern, Egare Naibo** (Oct 1977), *Peterson D 581, (EA);* **Engii** (21 Apr 1976), *Peterson D 80, (EA);* **Longido** (22 Feb 1953), *Drummond RB & Hemsley JH 1254, (EA, SRGH);* **Himo** *3° 23'S 37° 33'E* (22 Aug 1967), *Harris BJ & Jenik J BJH 783, (EA);* **Singinda,** *4° 49'S 34° 45'E* (27 May 1978), *Ruffo 1294, (K);* **Southern Highlands, Buhoro flats** (Jun 1959), *Procter J 1285, (EA);* **Wagingombe** *8° 52'S 34° 38'E* (9 Nov 1991), *Fagg CW 555, (FHO);* **Wagingombe** *8° 52'S 34° 38'E* (1 Nov 1991), *Fagg CW 548, (FHO);* **Tabora, Kazima** *5° 30'S 32° 30'E* (13 May 1924), *Swynnerton CFM 4037, (EA, K);* **Tanga, Mkomazi rail station** *4° 38'S 38° 05'E* (Mar 1966), *Procter J 3145, (EA);* **Unknown,** *5° 29'S 36° 58'E* (26 Jul 1965), *Leippert 6050, (EA);* **Gonja** (6 Sep 1966), *Leippert D 6112, (EA, K);* **Kakesio** (16 Jan 1966), *Herlocker D 1, (EA);* **Kerenge** (21 Oct 1915), *Zimmermann 6992, (EA);* **Kiombai** (Apr 1937), *Johnson DR 118, (EA);* **Kumauru** (May 1951), *Kemp Miss 33, (EA);* **Lolkisale** *3° 42'S 36° 26'E* (11 Jun 1965), *Leippert 5869, (EA);* **Lolkisale** *3° 40'S 36° 27'E* (15 Jun 1965), *Leippert 5901, (EA);* **Mbula hill** (11 Jul 1965), *Harris BJ 86, (EA);* **Ngamuriak** (21 Nov 1962), *Newbould JB 6277, (EA);* **Ras Kazone** (May 1942), *Lindeman HA 1028, (EA);* **Ruponda** (1 May 1949), *Anderson B 478, (EA);* **Songwe** (18 Jul 1911), *Braun 3523, (EA);* **Vitu Wini** (16 Aug 1965), *Harris BJ 88, (EA);* **Western,** *5° 01'S 32° 48'E* (12 Apr 1954), *Smith FG 1132, (K);* **Mwadni** (24 Jan 1970), *Mungure HE 94, (EA);* **Tabora** (12 Apr 1954), *Smith FG sn, (EA);* **Tabora** (16 Apr 1938), *Lindeman HA 639, (EA);*

UGANDA. Acholi, Kitgum (Dec 1932), *Eggeling WJ 773, (FHO);* **Madi Opei** *3° 37'N 33° 06'E* (26 Apr 1972), *Field DI 2502, (EA);* **Northern, Adzugopi** *0° 23'N 31° 58'E* (May 1932), *Hancock GLR FD 745, (EA);* **Kitgum** *3° 18'N 32° 52'E* (10 Nov 1945), *Thomas AS 4338, (EA);* **Kidepo Nat. Park** *3° 55'N 33° 50'E* (2 Jan 1973), *Synnott TJ 1408, (EA);* **Kidepo Nat. Park** *3° 36'N 33° 36'E* (10 Aug 1973), *Synnott TJ 1591, (EA);* **Kidepo Valley National Park** (7 Jul 1967), *Harrington GN 289, (EA);* **Kokumongole** *1° 54'N 34° 38'E* (6 Jan 1937), *Thomas AS 2194, (EA);* **Lodoketeminit catchment** *2° 17'N 34° 39'E* (14 Apr 1959), *Kerfoot O 875, (EA);* **Lodoketeminit catchment** *2° 17'N 34° 39'E* (29 Jan 1959), *Kerfoot O 803, (EA);* **Moroto** *2° 32'N 34° 39'E* (15 Jan 1958), *Kerfoot O U320, (EA);* **Unknown, Bwiaba escarpment** (2 Jul 1951), *Trapnell CG 2147, (EA);* **Lwampanga** *1° 30'N 32° 30'E* (13 Sep 1954), *Langdale-Brown I 1259, (K);*

ZAIRE. Orientale, Lac Albert plaine (2 Dec 1959), *Deville A 551, (K);* **Unknown, Rwita** (Jan 1938), *Lebrun J 9612, (K, P);*

APPENDIX 3. Seed collections of *Acacia senegal* distributed for trials and molecular studies.

Provenance	Country	Lat./Long.	Alt. (m.)	Ann. Rain (mm.)	Mean Temp (oC)	Bulk tree no.	Seed bank*
Acacia senegal var. *senegal*							
Fallatu Forest	Sudan	13.10N 30.14E	570	365		27	OFI/FAO
Dedoudi	Senegal	15.22N 13.31E	60	600		26	CIRAD
Chetmari	Niger	13.10N 12.25E	309	236	27.5		CIRAD
Arba Nosa	Ethiopia	7.49N 38.41E	1650			40	OFI
Bay region	Somalia	3.45N 43.10E	450	585	26.1	20	OFI
Kigwe	Tanzania	6.15S 35.35E	980	566	22.7	20	OFI
Mtandika 2	Tanzania	7.30S 37.43E	900	365	23.0	31	OFI
Wagingombe	Tanzania	8.51S 34.38E	1450	873	15.3	20	OFI
Acacia senegal var. *rostrata*							
Taupye 2	Botswana	23.25S 27.11E	900	439	20.8	10	OFI
Benfer	Zimbabwe	22.08S 30.51E	500	418	22.6	10	OFI
Acacia senegal var. *leiorhachis*							
Oltepesi	Kenya	1.33S 36.24E	1400	588	22.2	33	OFI
Lesosia**	Kenya	0.50N 37.57E	750				OFI

* OFI - Oxford Forestry Institute, Oxford, UK; CIRAD - CIRAD-Forêt, Montpellier, France; FAO - held DANIDA Forest Seed Centre, Humlebaek, Denmark. In June 2001, all seed held in the OFI seed store was transferred to the ICRAF Seed Store in Nairobi, Kenya.
** = Tree form of *A. senegal* var. *leiorhachis*.

ANNOTATED BIBLIOGRAPHY

This bibliography is arranged in alphabetical order of authorship. Subject groupings can be accessed by reference to the publication numbers at the end of each section in the main text of section 1. There is also an author index at the end of the bibliography in which the publication numbers are given for each author.

Both the published and the grey literature on *Acacia senegal* have been searched for this bibliography. In some abstracts, information is given on other species where this serves to place *A. senegal* in context in the subject being discussed.

Not all the publications cited were available to the authors. Where a publication was judged to be of significance from its title but neither the paper nor an abstract was available, it has, nevertheless, been included without annotation. Incomplete references have also been included, for example documents that have been seen but have not been dated or fully attributed, and incomplete references that have been picked up but have not been seen; the reader may have a better opportunity to follow up the latter.

In the monographic section, reference has been made to a number of works that do not specifically mention *Acacia senegal* but which are pertinent to the discussion of the particular topic. For ease of reference, these are included, without annotation, in this bibliography rather than in a separate section.

Many of the abstracts have been specifically written for this monograph but, where necessary, the author's or the CABI abstract has been used, sometimes with modification. There has been no attempt to attain a consistency of style in the abstracts; each abstract rather follows the style of the paper itself or of the individual abstracter.

The length of the abstract does not necessarily reflect the length or the importance of the document. If the publication is widely available in English, the abstract is generally briefer than one that is in the grey literature or one that has been translated from another language, mainly French.

1 ABATE, A.; FETENE, M; WOLDU, Z. **Investigations on canopy features of three indigenous woodland tree species of Ethiopia**. *Sinet, an Ethiopian Journal of Science* (1998) **21** (1) 113-132

Canopy features, diversity of understorey vegetation, and soil chemical characteristics of the tree species *Acacia tortilis*, *Acacia senegal* and *Balanites aegyptiaca* were studied at three different sites within the Great Rift Valley of Ethiopia; Adamitulu, Abijata Shalla National Park and Awash National Park. A total of 15 study trees at each site were selected from 50 X 50 m releves. Data on tree height, diameter at breast height (DBH), canopy depth and canopy diameter were collected from each tree. Soil samples were collected beneath and outside tree canopies to investigate the influence of tree species on the soil. *A. tortilis* had the highest DBH (0.42 ± 0.12 m) and canopy diameter (13.64 ± 2.25 m) whereas the greatest tree height (5.18 ± 0.77 m) and canopy depth (2.94 ± 0.73 m) were recorded for *B. aegyptiaca*. The highest vegetation diversity index under the tree canopy was recorded for *A. tortilis* (2.13) followed by *A. senegal* (1.92) and *B. aegyptiaca* (1.78). In general, surface soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and electrical conductivity were higher under tree canopies of all species than on soils outside the canopy. Soil conductivity, organic carbon, total nitrogen and available phosphorus were highest for surface soils under *A. tortilis*. However, no difference in soil nutrient content among the tree species was found at greater soil depth.

2 ABATUROV, B.D.; KUZNETSOV, G.I.; MAGOMEDOV, M.R.D.; PETELIN, D.A.; KASSAYE, F. **The food supply of wild ungulates in the dry season on grassland pastures in Ethiopia**. *Zoologicheskii Zhurnal* (1996) **75** (3) 439-450

Nutritional parameters of free living wild ungulates on grassland on the Nechissar Plateau of Ethiopia dominated by *Bothriochloa radicans, Chrysopogon plumulosus, Cenchrus ciliaris* and *Sehima nervosum*, with *Acacia senegal* and *Dichrostachys cinerea*, and on lake shores dominated by *Panicum repens, Cynodon aethiopicus, Sporobolus consimilis* and *C. spicatus* were studied by indirect methods in the dry season (November-December) of 1991. The digestibility of forage in zebras (*Equus burchelli*), Grant's gazelle (*Gazella granti*), hartebeest (*Alcelaphus buselaphus*) and hippopotamus (*Hippopotamus amphibius*, on lake shores) was determined from the ratio of lignin in forage and faeces. Daily food intake of zebras and gazelles was calculated from faecal production and forage digestibility. Zebra and hartebeest used mainly dry grasses; the protein content in their feed did not exceed 5%. Grant's gazelles fed mainly on green shoots on burnt areas and their intake contained >18% protein. Dry matter digestibility was 40-45% in non ruminants (zebras and hippopotamus), 50% in hartebeest and up to 60% in gazelles. Daily intake was 7.2 kg/head in zebras and 1.5-2.5 kg in gazelles. The high selectivity of grazing by gazelles and the large areas of burnt pasture with green regrowth in the dry season provided these animals with enough high quality food to ensure positive energy and protein balances. The abundance of dry grasses enabled zebras to maintain a positive energy balance in the dry season, but did not supply sufficient protein and caused acute N deficiency.

3 ABDALLA, I.H. **The killer axe: farming and deforestation in a fragile ecological system in Kordofan**. *Northeast African Studies* (1995) **7** (2) 99 59-65

4 ABDEL LATIF, A.H. **The economic significance of natural forests and man made plantations in the Sudan**. *Diploma Dissertation, Oxford Forestry Institute, University of Oxford* (1971) 1-39

Describes the natural forest cover, existing plantations (both irrigated and non irrigated) and plans for expansion of plantations in the Sudan. Estimates a further 3,780 ha of *A. senegal* plantations (non irrigated). The major areas which have *A. senegal* plantations are Kassala division (82%), followed by Eastern (8%), Kordofan (6%) and Darfur (5%).

5 ABEBE, T. **Growth performance of some multipurpose trees and shrubs in the semi arid areas of Southern Ethiopia**. *Agroforestry Systems* (1994) **26** (3) 237-248

Growth performances of 13 species of multipurpose trees and shrubs was studied for 5 yr at 2 locations (Alagie and Zewie) in the semi arid regions of southern Highlands of Ethiopia. The best performance in terms of rates of survival and growth rates (height and diameter growth) was attained by *Acacia nilotica* subsp. *nilotica*, *A. cyanophylla*, *A. seyal*, *Cassia siamea* and *Prosopis juliflora*. *A. senegal* had relatively good performance with survival rates of 85-96% and volume rates of 5.4 and 5.9 m^3/ha/yr at Alagie and Zewai respectively. Its height growth of 5-6 m and diameters of 7-8 cm DBH were achieved even though at Alagie its roots did not penetrate a calcic horizon at 60 - 80 cm deep in the soil profile.

6 ACOCKS, J.P.H. **Veld types of South Africa**. *Memoirs of the Botanical Survey of South Africa.* Pretoria, South Africa; Botanical Research Institute (1988) No.57 1-145

Detailed survey of the vegetation types in South Africa. *A. senegal var. leiorhachis* occurs in Lowveld bush, sometimes in arid lowveld in dense low bush, and in mixed bushveld characterised by *Acacia nigrescens, Combretum apiculatum* and *Kirkia wilmsii* in and between Olifants and Steelpoort Valleys.

7 ADAM, F.H. **Analysis of existing landowner/tenant relations and possibilities of their improvement in Sudan agriculture**. Sudan, Dept. of Rural Economy, Faculty of Agriculture, University of Khartoum (1981)

8 ADAMSON, A.D.; BELL, J.M. **The market for Gum Arabic**. *Tropical Products Institute, Paper G 87, Overseas Development Administration, London* (1974)

9 ADDERLEY, W.P.; JENKINS, D.A.; SINCLAIR, F.L.; STEVENS, P.S.; VERINUMBE, I. **The influence of soil variability on tree establishment at an experimental agroforestry site in North East Nigeria**. *Soil Use and Management* (1997) **13** (1) 1- 8

The characteristics and variability of soils (Aquic Ustipsamment) within a 30 ha experimental site in NE Nigeria were analysed in relation to tree establishment (*Acacia nilotica* subsp. *adstringens*, *A. senegal*, *A. seyal*, *Balanites aegyptiaca*, and *Prosopis juliflora*). Profile description and analyses for 480 surface samples of the sandy to clayey surface soils from Lake Chad lacustrine sediments provided baseline properties against which any subsequent modifications resulting from agroforestry practices could be assessed and to which initial tree performance could be related. This was undertaken using principal component and spatial analyses. Inherited soil properties showed spatial variations across the site which were related to soil textural parameters. The initial survival of trees planted for agroforestry experimentation showed strong correlations with the inherited characteristics of the soil rather than with acquired soil properties.

10 ADEOLA, A.O.; DADA, A.O. **Potential agroforestry plants in Nigeria: Effects of some pretreatments on seed germination of *Acacia albida* and *Acacia senegal*.** *Research Paper, Forest Research Institute of Nigeria* (1985) No.53 1-8

Studies of the effect of 5 pretreatments on the germination of 3-5 month old seeds of *Acacia albida* and *A. senegal* at the Forest Research Institute, Ibadan, Nigeria. Treatments include (a) manual scarification and soaking for 24 hours (b) covering with boiling water which then cooled for 24 hours (c) placing in 96% sulphuric acid for 10 mins and then soaking in water for 24 hours (d) placing in 96% sulphuric acid for 20 mins and then soaking in water for 24 hours and (e) soaking for 24 hours in water (control). For *A. albida*, treatments (a) and (c) were the most successful (99% germination after 4 days), but with *A. senegal* no pretreatment was satisfactory - though treatment (d) did have a signicicantly higher germination rate (57%) than the other treatments.

11 AFRICAN FORESTRY COMMISSION. **Gum arabic - Trends and Prospects, Secretariat Note**. *FAO, African Forestry Commission, Third Session Nairobi, Kenya*, 7-12 February 1972. (1972) 1-7

The note gives the salient features of gum arabic production and trade, marketing organizations and prices; it considers uses of and substitutes for gum arabic, as well as prospects for gum arabic production. It invites consideration of ways and means of ensuring the quantity and quality of supplies and local processing prior to exportation [from author's summary].

12 AGENCE DE COOPÉRATION CULTURELLE ET TECHNIQUE. [**Plant antitranspirants which regulate stomatal water relations.**] Antitranspirants végétaux de type hydrorégulators stomatiques. Muséum National d'Histoire Naturelle, France (1985) 1-32

Climate, drought and transpiration in the Sudano-Sahelien zone of N. Africa and the use of antitranspirants are discussed with reference to research on wheat, maize, tomatoes, mungbeans (*Vigna radiata)*, sorghum, *Medicago sativa* and woody spp., (*Acacia albida*, *A. nilotica*, *A. senegal*, *A. raddiana*, *Balanites aegyptiaca*, *Gmelina arborea*, *Prosopis juliflora*) in Sudan, Niger, Mauritania and Mali. The physiology of hydroregulatory transpirants and stomatal action and K-bonding chemicals are described.

13 AGGARWAL, R.K.; GUPTA, J.P.; SAXENA, S.K.; MUTHANA, K.D. **Studies on soil physico-chemical and ecological changes under twelve years old five desert tree species of western Rajasthan**. *Indian Forester* (1976) **102** (12) 863-872

Tree species studied in 12 year old plantations at Jodhpur were *Prosopis cineraria*, *P. juliflora*, *Tecomella undulata*, *Albizia lebbek* and *Acacia senegal*. Density, composition and above-ground biomass of ground flora, soil organic matter, N, P, K, Zn, Mn, Cu, Fe and moisture distribution under each tree species were compared with values for a bare site. Total macronutrients in the surface soil (N=241 kg/ha, P=13.4 kg/ha) in the soils under *Acacia senegal* increased slightly above values found from bare soil (N=203 kg/ha, P=7.7 kg/ha) but K values decreased to 319 kg/ha compared with 370 from the bare site. Zinc was the only micronutrient which increased under *Acacia senegal*, from 0.20 ppm to 0.74 ppm.

14 AHIYA, L.D.; SHAMA, S.K.; VERMA, C.M.; LAMBA, T.R. **Contribution of grass component (ground storey) in afforested areas in arid regions**. *Indian Forester* (1985) **111** (7) 542-547

Describes the production of indigenous herbs growing under various tree species planted in the arid lands around CAZRI, Jodhpur, India. Grazers were excluded from the plots and all the plants were harvested at the end of the growing season (November). From under a 12 year old plot of *Acacia senegal*, measurements were taken over the following 5 years (1972-76). The mean yield of 0.634 tons of air dried forage per year was recorded, with a planting density of 1,517 trees per hectare. Perennial grasses contributed most of the dry matter yields in years with poor rains.

15 AHMED, A.I. **Factors influencing tree establishment and Long-term survival: A case study of the restocking of the gum belt and Kordofan Agroforestry Extension Projects in Northern Kordofan Province, The Sudan**. M.Sc. thesis, University of Norway, Noragric. (1989)

16 AHMED, I. **The role of forestry in correct land use with emphasis on shelterbelts in Kano State, (Nigeria)**. *Samaru Agricultural Newsletter* (1972) **14** (1) 5-7

Briefly discusses the importance of forestry in the savanna region of Nigeria, the choice of species, and establishment of shelterbelts in Kano State. Trial plantings of *Acacia nilotica*, *A. albida* and *Azadirachta indica* to protect soils and crops against winds, particularly the dry 'harmattan' wind, were first established in 1964. *A. indica* has been the most successful and is now the main species used in the belts. Further research using *A. senegal* revealed uniform growth rates and high survival, but maintenance proved a difficult problem. *A. albida*, an indigenous species, suffered extremely slow and irregular growth rates, and was therefore thought more suitable for replacements, rather than hedgerows or block planting.

17 AHMED, S.S. **Phenology and protein content of three *Acacia* species during the Gu season**. *Thesis, Faculty of Agriculture, Somali National University* (1985) 1-31

A study of *Acacia nubica*, *A. horrida* and *A. senegal* (browse plants) at the Artificial Insemination Centre, Afgoi, central Somalia, during the rainy season.

18 AHUJA, L.D.; VERMA, C.M.; SHARMA, S.K.; LAMBA, T.R. **Range management studies on the contribution of ground storey (grass) in afforested areas in arid regions**. *Annals of Arid Zone* (1978) **17** (3) 304-310

The yield of herbage was measured during 1972-75 under 15-yr-old stands of *Albizzia [Albizia] lebbek*, *Prosopis cineraria*, *Tecomella undulata* and *Acacia senegal* at Jodhpur, Rajasthan. The av. annual yield was 1.4-1.5 t/ha (air-dried) under the first three species, but was significantly less (0.7 t/ha) under *A. senegal*, probably because of the higher density of plants of this species.

19 AIDGUM. [**Gum arabic, tree resource of the Sahel.**] L'acacia gommier, arbre ressource du Sahel. *Afrique Agriculture* (1986) No.32 10-17

A report of work done by the 'Association internationale pour le developpement des gommes naturelles' (Aidgum), including studies on a project for plant gum production in Mali (the world's 2nd largest producer of gum arabic, from *Acacia senegal*, after the Sudan), *in vitro* vegetative propagation, other uses of gum arabic and new marketing possibilites.

20 AKPO, L.E.; GROUZIS, M. [**Effect of tree cover on natural regeneration of woody vegetation in northern Senegal, West Africa.**] Influence du couvert sur la regeneration de quelques especes ligneuses sahelienennes (Nord *Senegal*, Afrique occidentale). *Webbia* (1996) **50** (2) 247-263

A survey was undertaken of natural regeneration of woody plant species beneath tree canopies (mainly *Balanites aegyptiaca*, *Acacia tortilis* subsp. *raddiana* [*A. raddiana*], *Sclerocarya birrea*, *A. senegal*, compared with that outside crown cover, in the Sahelian savanna zone near Souliene, 25 km S. of Dagana. Four principal biogeographic zones were identified, and data are tabulated for the regeneration of *Boscia senegalensis, Balanites aegyptiaca, Calotropis procera, Acacia raddiana, Commiphora africana, Grewia bicolor, Leptadenia hastata, Ziziphus mauritiana* and *Tinospora bakis* (found in decreasing order of frequency, over all areas surveyed). Regeneration was 7 times more frequent within canopy cover than in open situations. On average, three plants per tree were recorded; however, as a percentage of overall plant cover, the number of young regenerating plants was about 8.5% of total woody plant cover, which is low. The importance of mature tree canopies for the natural regeneration of woody species in the Sahel is emphasized, and relations between livestock grazing, livestock as seed dispersal agents, and natural regeneration are discussed.

21 ALI, M. **Les Gommiers au Tchad**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 81-102

General description of Chad, population, weather, vegetation formations, soils, agriculture and transport. Describes the principal gum Acacias of Chad, which are *A. senegal, A. laeta* and *A. seyal.* All three species have wide geographical ranges, and one estimate of their range is in the order of 36, 000 km^2. In an inventory of 714 hectares in the Chari-Baguirmi region, *A. senegal* has an average of 15 trees/ha. General estimates of 50-150 trees/ha in Sahelian region. Gives official export figures for gum arabic from 1955-1975 (annually and divided into regions) and after 1983. During 1955-1975 the highest production peaked at 1345 tonnes in 1967-68, and after 1983 a record of 2400 tonnes in 1986-7 (although of this total only 1100 tonnes were first grade (*A. senegal*) and 2/5 of it came across the border from Sudan. Briefly describes the gum research undertaken in Chad, with a 4 ha plantation in 1987 of *A. senegal* near Ndjamena, in 1988 a 2 ha plantation with 4 provenances of *A. senegal* from Mali (Kayes) with Rhizobium inoculation (IRANEX protocole), and a census of *A. senegal* populations south east of Njamena (between Dourbali and Melfi of 15,000 ha). STEGA (Chad gum arabic society) and IRANEX are also building a gum quality control laboratory in Chad. Also lists various gum development projects.

22 ALLISON, G.E. **Gum arabic: an ancient trade in decline?** *M.Sc thesis, Oxford Forestry Institute, Department of Plant Sciences, University of Oxford* (1993) 1-165

Historical survey of the gum arabic trade and markets. The development of the trade is traced from the earliest times to the present. Factors affecting supply to the world market are identified and there is a discussion on how the demand has changed over the years. The future of the trade is discussed in the context of current developments and findings. Section II which covers the history of gum arabic is derived from this thesis.

23 ALMEIDA, F.S. De. **Bush control in grassland by aerial spraying**. *Proceedings of the Grassland Society of Southern Africa* (1974) **9** 73-76

Herbicides were applied aerially to control bush on severely infested natural grassland in Mozambique. *Acacia nilotica*, *A. borleae* and *Dichrostachys cinerea* were killed by a mixture of 2,4-D and 1,4,5-T at 1.8 kg/ha, by 2,4,5-T alone at 1.8 kg/ha and by Silvex (fenoprop) at 0.5 kg/ha. *Schotia brachypetala* was killed by the last two treatments. Picloram was effective against all four species and also *A. senegal*. Many bush species were resistant to the herbicides.

24 AL TAHIR, I.H. **Agroforestry Systems in Northern Kordofan, Sudan**. Report for ICRAF course, 14-29 May 1987, ICRAF, Nairobi, Kenya. (1987) 1-17

Describes the gum gardens in Northern Kordofan, and the effects of desertification in the area. Over cultivation of the land, and the lack of a suitable fallow period in the gum rotation has led to the disappearance of some of the gum gardens, with the direct result of declining crop yields (sorghum reduced by 50-70%). Also unfavourable prices for gum arabic led to cutting for charcoal, whereby the farmer earns 200% more revenue from charcoal than from gum arabic. Recent changes in gum prices (300% more for the farmer) has considerably helped in rehabilitating the gum gardens. The effects of the droughts only compounded the deaths of large tracts of gum trees, through cutting for charcoal for revenue to compensate for low cereal yields, overgrazing and collecting pods for sale for fodder and seed for forestry projects thereby reducing the seed available for maintaining the gum gardens, and cutting trees to use the roots in lining the shallow hand-dug wells. Lists the benefits of the tree as understood by the farmers; increases soil fertility, protects top soil from wind erosion, increases infiltration of rain water, provides important cash crop during the fallow period, an important source of fuel wood and production of charcoal, provision of building materials for traditional hut, seed pods fodder for sheep and goats, leaves fodder for camels, roots used for lining hand-dug wells as well as in local craft-work such as baskets, food covers. The negative effects of the trees are seen as competition with other crops, harbouring pests (insect, birds) and reducing land available for crop production. Describes various initiatives (government and non-government organisations) to plant more trees and rejuvenate the gum fallow system.

25 ANDERSON, D.M.W. **Water-soluble plant gum exudates. (1) Gum arabic** *Process Biochemistry* (1977) **12** (10) 24-25, 29

World-wide production is discussed with emphasis on African developments. Analytical data are tabulated for: *Acacia senegal*, *A. seyal*, *A. laeta*, *A. campylacantha* and *A. drepanolobium*. The data confirmed the wide ranges of variation in %N (0.02-1.66), % uronic acid (4-37), optical rotation (-66 deg + 108 deg), mol. wt. (47 000-3 000 000), and intrinsic viscosity (4.2-27.7 ml/g).

26 ANDERSON, D.M.W. **Chemotaxonomic aspects of the chemistry of *Acacia* gum exudates**. *Kew Bulletin* (1978) **32** (3) 529-536

Data concerning the properties and carbohydrate composition of *Acacia* gums are collected for 23 species in 6 series and subseries. A taxonomic basis of gum characteristics is evident in species related to *A. senegal* (the major commercial source).

27 ANDERSON, D.M.W. **New plantations of gum-bearing Acacia trees**. *Nitrogen Fixing Tree Research Reports* (1983) **1** 26-27

Notes that since the exceptional droughts of 1972-74, one million *Acacia senegal* trees are being planted in western Sudan with the support of international aid programmes. These are expected to produce gum from their fifth year, and given that the market for the gum in foodstuffs is assured as the daily acceptable intake is classified by the Joint FAO/WHO Expert Committee on Food Additives (JEFCA) as without limit.

28 ANDERSON, D.M.W. **Gum exudation by *Leucaena leucocephala***. *Nitrogen Fixing Tree Research Reports* (1984a) **2** 24

A brief discussion of the mechanisms of gum formation by a single healthy tree, age 2.5 yr, at Pondicherry. A full chemical characterization showed the gum to be similar in chemical composition and physical properties to gum arabic from *Acacia senegal*.

29 ANDERSON, D.M.W. **Nitrogen fixation by *Acacia* spp**. *Nitrogen Fixing Tree Research Reports* (1984b) **2** 25

A brief note mentioning that possibly proper rhizobia may not occur in Sudanese soils as there is no direct evidence to show nitrogen fixation in *A. senegal* in the Sudan. Also notes that there are 1 million young seedlings of *A. senegal* being planted annually in Kordofan province.

30 ANDERSON, D.M.W. **The extension of studies of the proteinaceous components of Acacia gum exudates to other genera within the Mimosoideae.** *Bulletin of the International Group for the Study of Mimosoideae (IGSM)* (1985a) **13** 55-56

Gum arabic from *Acacia senegal* and the exudates of several other *Acacia* species are proteinaceous to a greater or lesser extent, and their proteinaceous components are characterised by the presence of a large proportion of hydroxyproline. There are indications that several proteins, peptides or polypeptides are involved and that these are located at a number of different sites. These studies are being extended to the gum exudates from a wide range of other botanical genera. Hydroxyproline is very small in other families but there are legume genera such as *Astragalus* and *Prosopis* which also have high contents, and similar amino acid compositions.

31 ANDERSON, D.M.W. **Gums and resins, and factors influencing their economic development.** In *Plants for Arid Lands (edited by Wickens, G.E.; Goodin, J.R.; Field, D.V.)* London, George Allen & Unwin (1985b) 343-368

Review of research on gums and resins, and the factors affecting their international trade. Increased demand for gums since the second world war, devastating droughts of the 1970's and high export taxes have contributed to many industrial gum users changing formulations away from the natural gums. Mentions the ecological benefits of increasing tree planting in arid zones, particularly in Sudan where 1 million new *Acacia senegal* trees have been planted annually in the last three years, but cautions that not all the gum from these plantations will necessary be marketable. Now there are more restrictions on microbiological safety for food uses, (gums must be free of *E.coli* and *Salmonella* type organisms), and importers in the EEC are deemed manufacturers and liable in law for the safety of their product. Of the natural gums, only gum arabic, guar gum and locust bean gum have now been tested by a complete range of toxicological tests. In the EEC, foodstuffs grade gum arabic (E414) is defined as gum from *A. senegal* and related species of *Acacia*. Chemical composition and properties of *A. senegal* gum varies from a wide range of producing regions. Present gum production exceeds supply, with sales around 35-40,000 tons. For sales to increase, the price of gum will have to fall 20% to compete effectively with modified starches for confectionary use. Gums from other Acacias is now of little commercial interest, and only *A. senegal* should be planted for gum production.

32 ANDERSON, D.M.W. **Gum exudation by *Leucaena leucocephala*.** *Leucaena Research Reports* (1986a) **7** 108-109

The amino acid composition of the proteinaceous component of *L. leucocephala* gum is compared with that of gum arabic from *Acacia senegal*. The compositions were similar, especially the large proportions of hydroxyproline and serine. It is suggested that *Leucaena* trees should be tapped to see if gum exudation results.

33 ANDERSON, D.M.W. **The proteinaceous components of the gum exudates from nitrogen fixing trees.** *Nigrogen Fixing Tree Research Reports* (1986b) **4** 47-48

Lists the 18 amino acid compositions of the proteinaceous components of *Acacia senegal* (L.) Willd., *Astragalus microcephalus* and *Prosopis* ssp. gum exudates (legume) and *Sterculia* ssp. gum exudates (non legume). *A. senegal* samples lacked cystine. There are major differences between leguminous and non leguminous genera studied with regard to the amino acid hydroxyprolin (higher values in leguminous trees).

34 ANDERSON, D.M.W. **The Future of Gum Arabic as an article of International Trade.** *International group for the study of Mimosoideae,* Bulletin (1986c) No.14 65-67

Gum arabic has for many years been an important export from Sudan, where the existence of extensive plantations of *Acacias* is essential for ecological reasons, provision of fodder and fuelwood. This paper discusses the reasons behind the uncertain future for *Acacia senegal,* the effects of 1973-75 and 1984-5 droughts in the Sudan and Sahelian countries where production drastically fell and future demand may now not rise above 25,000 tonnes (three times less than the world demand in the 1960's). The commercial development of other polysaccharides (modified starches) is also proving more attractive for the confectionay industry given the present inflated price of gum arabic.

35 ANDERSON, D. M.W. **Evidence for the safety of gum arabic (*Acacia senegal* (L.) Willd.) as a food additive - a brief review.** *Food Additives and Contaminants* (1986d) **3** (3) 225-230

Scrutiny of the experimental evidence of safety demanded by the international food safety authorities has led them to conclude that no limitation to the use of gum arabic as a food additive need to be specified when it conforms to the established criteria of identity and purity. This brief review collates the dietary, toxicological, immunological, chemical and other studies available. Lists early studies by U.S. Food and Drug Administration, and those by FAO/WHO including many undertaken by the author.

36 ANDERSON, D.M.W. **The amino acid components of some commercial gums.** In *Gums and Stabilisers for the food industry 3 (edited by Phillips, G.O.; Williams, P.A., Wedlock, D.J.).* London, UK; Elsevier Applied Science Publishers (1986e) 79-86

Summarises progress in studies of the amino acids in gum arabic (*Acacia senegal*) and five other gums. Eighteen amino acids were identified and the principal ones in gum arabic are hydroxyproline and serine. This was an average figure from 8 samples of gum arabic collected in Sudan, Senegal, Chad, Ethiopia and Nigeria.

37 ANDERSON, D.M.W. **The future prospects for gum arabic - the exudate from *Acacia senegal* (L.) Willd. and related species**. *Nitrogen Fixing Tree Research Reports* (1987) **5** 12-13

A discussion of the problems caused by the Sudanese droughts of 1973-75 and 1984-85, which led to extensive losses of *Acacia senegal* in the Kordofan gum belt, including the loss of many of the trees planted in the extensive regeneration programme of 1977-83, when 1 million trees were planted per year. The expected yield of gum arabic from 1 million trees is only 1000 tons, a few percent of previous world demand. The high prices and low quality of the gum arabic available have led to its partial replacement by modified lower priced starch products. The necessity of replanting with only *Acacia senegal* (or related species which give only laevorotatory optical rotations in solution) is emphasized. This definition includes members of the *A. senegal* complex, and possibly all members of the *Acacia* sub-series *Vulgares*, many Somalian or Ethiopian, and with a limited distribution, which have never been cultivated or tapped. Planting of *A. seyal* (which produces gum Talha, which is dextrorotatory in solution) and *Prosopis* species for gum should not be permitted, as neither is permissible in foodstuffs.

38 ANDERSON, D.M.W. **The amino acids in gum exudates - possible indicators of drought resistance factors**. *Nitrogen Fixing Tree Research Reports* (1988a) **6** 21-22

Gum formation of *Acacia senegal* is regarded as a natural response of trees under dehydration stress to store a strongly hydrophilic form of reserve polysaccharide. Gum arabic has an equilibrium bound water content of ca. 16% and drying the gum to below 8% moisture content impairs water solubility irreversibly, but between the two ranges gums can store and release water. In seeds proline content is regarded as an indicator of drought resistance, and all gum exudates have variable proportions of proline. They also contain high proportions of hydroxyproline, thought to be derived from proline. Recent studies by the author have shown that the predominant amino acids at the core of the gum structure are proline, serine and threonine.

39 ANDERSON, D.M.W. **The current toxicological status of permitted emulsifiers and stabilisers**. In *Gums and Stabilisers for the food industry 4 (edited by Phillips, G.O.; Williams, P.A., Wedlock, D.J.)*. Oxford, England; IRL Press (1988b) 417-424

Reviews the revisions of the toxicological status of the major permitted emulsifiers, stabilizers and thickeners, since this was summarized in 1983. Gum arabic from *Acacia senegal* (L.) Willd. is the only gum has been tested in a range of toxicological and dietary studies.

40 ANDERSON, D.M.W. **The structural significance of amino acids in some plant gums**. In *Gums and Stabilisers for the food industry 4 (edited by Phillips, G.O.; Williams, P.A., Wedlock, D.J.)*. Oxford, England; IRL Press (1988c) 31-37

Reviews data on the amino acid composition of the Acacia gums and other commercially important exudates gums. Wide range of natural hydrocolloids occur in the Acacia genus, and in technological matters the functionality of each gum may be dependant more on a minor proportion of amino acids than on a major proportion of sugars. The properties and functionality of the gums must be regarded as being those of proteoglycans rather than nitrogen-free polysaccharides.

41 ANDERSON, D.M.W. **The natural gums**. *Bulletin, British Nutrition Foundation* (1988d) No.53

42 ANDERSON, D.M.W. **NFT gums: ancient and modern commercial products**. Waimanalo, Hawaii, USA; Nitrogen Fixing Tree Association. *NFT Highlights* (1989a) No. 89-01 1-2

Brief accounts are given of the characteristics of gums for food uses (gum arabic from *Acacia senegal*, and gum tragacanth from *Astragalus spp.*) and gums for non-food applications (gum tahla from *Acacia seyal*, and gums from *Prosopis spp.*, *Sesbania spp.*, and *Leucaena spp.*). The non-food gums are of little commercial value, but may be used for local technological purposes. The two food gums are important commercially, and the accounts of these include information on their collection and production. *Acacia senegal* is the species that produce gum arabic, the only Acacia gum toxicologically tested to establish its safety as a food additive. It is native to the arid Sahelian regions of Africa and the Middle East being often the main source of revenue for semi nomadic African people who gather it from wild, untended trees. They are also grown commercially (gum gardens) in State Forests in the Sudan from nursery seedlings or from direct-seeded plantations spaced at about 4 x 4 m. Tapping which consists of slitting the bark, and then collecting the walnut-sized gum globules three weeks later during the dry season, begins five years after planting and continues for about 15 years. An average annual yield is 250 g/tree although production may range from a few grams to 10 kg. Gum arabic export prices in Sudan, the main exporter was US$3,450 in October 1987. Commercial high-tonnage of gum arabic requires severe physiological stress from water depletion and heat. Gum formation has been regarded as a natural

response of trees under dehydratation stress to store a strong hydrophilic form of reserve carbohydrate. Gum is known to be formed at leaf-fall and translocated to roots even though the tree has not been tapped. After two severe droughts (1973-75 and 1983-85), gum shortage increased prices leading to the development of more cost-effective modified starches, celluloses and biosynthetic / fermentation products that can replace or extend gum arabic. Consumption has dropped from 70,000 tons to 20,000 tons from 1972 to 1989. Market strategies in Sudan as well as methods of production, collecting and storage should be improved to maintain the commercial value of this product.

43 ANDERSON, D.M.W. **Future prospects for *Prosopis* gum exudates for commercial, non-food purposes**. *Nitrogen Fixing Tree Research Reports* (1989b) **7** 108-109

Market aspects of gum arabic (*Acacia senegal* gum) are reported with emphasis to the increasingly high demands of the food processors responsible for labelling of quality as well as competitively low prices. Markets for non-food trade gums such us gum talha (*Acacia seyal*) and gum mesquite (*Prosopis spp.*) was also discussed, noting that increasing quantities of gum mesquite are being collected and offered for sale in central and south America.

44 ANDERSON, D.M.W. **Commercial prospects for gum exudates from the *Acacia senegal* complex**. *Nitrogen Fixing Tree Research Reports* (1990) **8** 91-92

Notes that although world consumption of gum arabic fell to approx. 14,000 tons in the 1984-86 droughts, production and consumption has increased to around 20,000 in 1990, helped by significant price reductions to $2,300 US / ton. The Sudan still maintains the largest share of this world production although there is trade interest in the gum producing countries Senegal, Mali, Chad, Nigeria, Somalia, Kanya and Tanzania. The author notes that gum arabic sold for food use can only be from *A. senegal* together with members of its complex of species and that small seedlots from these species are available from him for planting in other arid areas of the world.

45 ANDERSON, D.M.W. **Food safety assurance: Revised specification for gum arabic**. *British Food Journal* (1991a) **93** (1) 20-24

Regulatory guidelines and principles for approval of food additives are reported. The high costs of the required toxicological tests (1 million pounds over 7 to 10 years) does not stimulate sponsors from the producing countries to conduct tests unless they are assured of success. Gum arabic (from *Acacia senegal*) is a major industrial food hydrocolloid but its use for food production in the UK has decreased from 70,000 tons per year in the 1960s to 25,000 tons in 1991 (US$ 2,300 per ton in Sudan) manly due to the growing competition of new generations of permitted modified starches. Fifty percent of the gum arabic exported by Sudan (which exports 85% of the world total production) is used in high concentration as a confectionery ingredient. The remainder is used in minor proportions (1 to 2%) as a food additive, mainly as a emulsifier/stabilizer/thickner. A major use for very high quality gum is an emulsifier for flavour oils in soft drinks, particularly in the cola type. About 25% of the world tonnage enters the UK. Gum arabic is a complex proteinaceous polysacharide which can be classified as a soluble dietary fibre. Because it is completely decomposed to volatile fatty acids by the natural anaerobic microflora in the large bowel, gum arabic has a digestible energy value of 3.5 kcal/g. In the US, gum arabic defined as exudate of *Acacia senegal* and related species, has being regarded as generally recognized and safe (GRAS) since 1974. Following EEC demands for evidence of safety issued in 1974 Directive, gum arabic was approved as E414 and classified "ADI non specified". Lately, new evaluations were done confirming the previous tests that led to that classification. The definition of gum arabic under the new specification is "a dried exudation from the stems and branches of *Acacia senegal* (L.) Willd. or closely related species. A range of values (minus 26 to minus 34 degrees) was quoted for the specific rotation in the regulation as well as a range (0.27 to 0.39%) is quoted for nitrogen content. The new regulations are an advance in chemical terms in ensuring that gum arabic do not become adulterated with other non-permitted botanical sources.

46 , ANDERSON, D.M.W. **Gum arabic from Niger-comparison with other sources and potential agroforestry development**. *Biochemical Systematics and Ecology* (1991b) **19** 447-452

47 ANDERSON, D.M.W. **Gum arabic: recent developments - Pros and Cons**. *British Food Journal* (1993a) **95** (2) 30-32

Laments the large price increases in the world price of gum arabic ($5500-7500/ton) due to shortages and deregulation of the Sudanese Gum Arabic company. The poorly defined specification of gum arabic (1990 JECFA revised specification) is allowing unscrupious dealers to sell a product which is not wholly from *A. senegal* and hence does not have the toxicological tests that were undertaken on *A. senegal* from Sudan. Mentions the support given by the International Trade Centre in Geneva to install gum cleaning machinery and a quality control laboratory in Port Sudan, the Sudanese government thereby maintaining a high quality gum arabic.

48 ANDERSON, D.M.W. **Some factors influencing the demand for gum arabic (*Acacia senegal* (L.) Willd.) and other water soluble tree exudates**. *Forest Ecology and Management.* (1993b) **58** (1/2) 1-18

Although tonnages of gum arabic (from *Acacia senegal*) and other water soluble tree exudates traded annually have tended to decrease steadily over the past 15 years for a number of identifiable reasons, there is still some commercial demand for those few gums that meet international specifications and are available in steady supply from year to year at competitive prices. This review emphasizes the potentially important role that wood scientists and those involved in forest management in gum producing or potential gum producing areas have, if the maximum possible economic return is to be realized by the countries concerned. Specific source tree species need to be identified and regenerated, non permitted species need to be eradicated from areas of intensive gum production, and educational programmes initiated to help those populations still involved in gum production by traditional methods need to become more aware of the changing requirements of international gum trading. It is recommended that all persons concerned should try to combine their professional interests, taking into account the economic, regulatory and other factors which now influence the supply of and demand for gum exudates on an international scale. The 1990 Revised Specification for gum arabic is outlined as are recent decisions of the international regulatory committees concerned with ensuring food safety. Details the trade and marketing of gum arabic and the demand by the importers for container load tonnages of unadulterated gum arabic and discourage the commercial ultization of gums from other unevaluated sources. Notes that while gum Arabic is used as a soluble form of dietary fibre, it has an energy value to be 84% of that of starch, and does not necessarily mean a reduced calorific intake. There are also indications that it reduces blood cholesterol levels.

49 ANDERSON, D.M.W.; BRIDGEMAN, M.M.E. **Studies on uronic acid materials, Part 59: the gum exudate from a cultivar of *Leucaena leucocephala* (Lam.) de Wit**. *International Tree Crops Journal* (1983) **2** (3/4) 291-295

The gum exuded by a South Indian cultivar of *L. leucocephala* was analysed and found to be similar to gum arabic (*Acacia senegal*) although it is more stable in acid solution. Its physico-chemical properties in aqueous solution (solubility, viscosity and colour) suggest that it could have commercial applications.

50 ANDERSON, D.M.W.; BRIDGEMAN, M.M.E.; FARQUHAR, J.G.K.; MCNAB, C.G.A. **The chemical characterization of the test article used in toxicological studies of gum arabic (*Acacia senegal* (L.) Willd.)**. *International Tree Crops Journal* (1983) **2** (3/4) 245-254

The sample of commercial gum arabic used as the 'Test Article' in recent toxicological studies submitted to the Joint WHO/FAO Expert Committee on Food Additives (JECFA), and obtained from Rowntree-Mackintosh as part of a normal production batch, has been characterized chemically. Comparative data presented for 7 other commercial gum arabic samples, and for 5 specimens collected from *A. senegal* trees in several gum-producing countries, indicate that the 'Test Article' is a fair and average representative sample of gum arabic conforming to established international standards of identity and purity.

51 ANDERSON, D.M.W.; BROWN DOUGLAS, D.M. **Composition of gum exudates from *Leucaena diversifolia* and *Leucaena esculenta x leucocephala***. *Leucaena Research Reports* (1989) **10** 56-57

Further analytical data presented on the gum composition of *Leucaena* species. They have specific rotations similar to gum arabic, and could be used for gums which would not be permitted in foodstuffs. Concludes that of the 13 gum samples studied so far the Indian sample of *Leucaena leucocephala* remains the closest to gum arabic in all the analytical parameters and has the greatest potential.

52 ANDERSON, D.M.W.; EASTWOOD, M.A. **The safety of gum arabic as a food additive and its energy value as an ingredient: a brief review**. *Journal of Human Nutrition & Dietetics* (1989) **2** (3) 137-144

53 ANDERSON, D.M.W.; DEA, I.C.M. **Studies on uronic acid materials. Parts XXIV & XXV**. *Carbohydrate Research, Amst.* (1968) **6** (1) 97-110

Part XXIV compares analytical data from gum from *Acacia senegal* for (a) 12 bulk samples of tapped gum from three districts of Senegal, (b) 13 single-nodule specimens of natural exudate from individual trees, (c) 3 samples of 'non-nodular' gum (forming long filaments, spirals and ribbons), (d) samples from trees infested with *Cerambycidae* or *Buprestidae*, and (e) 'Hennawi' gum, unusually dark in colour and sweet, exuded naturally from wounds in the lower stem. Samples of (a) and (b) show a range of variation similar to that for other *Acacia* spp., (c) and (d) do not show marked chemical differences from (a), but (e) has fewer uronic acids in the free form and a considerably lower rhamnose content. In part XXV further studies were made on (d) and (e).

54 ANDERSON, D.M.W.; DEA, I.C.M. **Studies on uronic acid materials. Parts XXXI. Some structural features of the Water-Soluble fraction of *Acacia drepanolobium* gum** *Carbohydrate Research, Amst.* (1968) **8** 448-459

Describes the main features of the molecular structure of fraction A of *A. drepanolobium* gum, which indicates that the arabinose side-chains, some of which are considerably longer than other *Acacia* gums including *A. senegal*, are attached to a compact, branched galactan framework. This gum is not totally soluble in water.

55 ANDERSON, D.M.W.; HOWLETT, J.F.; MCNAB, C.G.A. **The amino acid composition of gum exudates from *Prosopis* species**. *Phytochemistry* (1985) **24** (11) 2718-2720

Data are presented for gums from 6 species (*P. alba*, *P. chilensis*, *P. glandulosa*, *P. laevigata*, *P. torreyana* and *P. velutina*) and for a sample of commercial gum mesquite. In agreement with published data for polysaccharide components of the gums there were only minor differences between species. The amino acid composition of the gums was very similar to that published for gum arabic (from *Acacia senegal*). The data indicated that the source of the commercial gum mesquite analysed was probably *P. glandulosa* and *P. laevigata* with minor contributions from *P. velutina*. The preparation is used widely as an additive for traditional native dishes, although it is not in any permitted foodstuffs additives list.

56 ANDERSON, D.M.W.; MILLAR, J.R.A.; WANG WEIPING, P. **Gum arabic (*Acacia senegal*) from Niger - Comparison with other sources and potential agroforestry development**. *Biochemical Systematics and Ecology* (1991) **19** (6) 447-452

Given the stricter specifications for gum arabic recently published by JECFA (Joint FAO/WHO Expert Committee on Food Additves, based on analyses of Sudanese gum arabic, gum from three trees of *A. senegal* from Niger was analysed. Analytical data and nuclear magnetic resonance spectra for the samples showed that the samples complied with revised specifications for gum arabic. Authors favour increased planting of *A. senegal* as an agroforestry crop in other countries, provided gum is strictly only collected from this one botanical source. In Niger there are extensive populations *of Combretum nigricans, A. seyal* or *A. sieberiana* which also produce gum, but these are not acceptable in the new specifications for food use and care is needed not to contaminate the gum arabic samples for export.

57 ANDERSON, D.M.W.; MILLAR, J.R.A.; WANG WEIPING, P. **Gum exudates from *Leucaena* species** . *International Tree Crops Journal* (1992) **7** (3) 155-166

Analytical data, including physico-chemical properties and 13C NMR spectra, are presented for the gums from five Central American *Leucaena* species (*L. diversifolia* subsp. *stenocarpa, L. shannonii* subsp. *shannonii, Leucaena* sp., *L. collinsii* subsp. *zacapana* and *L. esculenta* subsp. *esculenta*). In addition, for comparative purposes, 13C NMR spectra are given for two gum samples for which some analytical data were reported previously, viz. an Indian sample from *Leucaena leucocephala* and a Hawaiian sample from *L. esculenta X L. leucocephala*. The new analytical data confirm that *Leucaena* gums have negative specific rotations and compositions that are remarkably similar to that of gum arabic (from *Acacia senegal*), but the NMR spectroscopic evidence now available reveals that the *Leucaena* gums differ structurally from gum arabic to a considerable extent. The *Leucaena* gums can nevertheless be expected to have technological application, particularly in those countries with extensive *Leucaena* afforestation, but they are not permitted for foodstuff use by any of the international regulatory authorities. In this connection, it is of interest that even the recently revised, more detailed, international specification for gum arabic remains inadequate to differentiate between it and the gum from *Leucaena leucocephala.*

58 ANDERSON, D.M.W.; MORRISON, N.A. **The identification of *Combretum* gums which are not permitted food additives, 2**. *Food Additives and Contaminants* (1990) **7** (2) 181-188

Data that characterize gums from 6 *Combretum* species so that their use in foods can be prevented are presented. Additional analyses necessary to differentiate between *Combretum* gums and gum arabic [from *Acacia senegal*] are discussed.

59 ANDERSON, D.M.W.; MUNRO, A.C. **The structure of *Acacia campylacantha* gum**. *Carbohydrate Research, Amst.* (1970) **12** (1) 9-22

Results of analyses are given in tables, showing the yields of the various components. Graphs show the yields of certain polysaccharides for gum exudates of 7 *Acacia* spp. The gum of *A. polyacantha* subsp. *campylacantha [A. campylacantha]* is broadly similar in structure to the gums of *A. senegal* and *A. laeta.*

60 ANDERSON, D.M.W.; PINTO, G. **Variations in the composition and properties of the gum exuded by *Acacia karroo* Hayne in different African locations**. *Botanical Journal of the Linnean Society* (1980) **80** 85-89

The variation in chemical composition of 15 specimens of the gum exudate from *Acacia karroo* Hayne, obtained from four different African locations has been investigated. The range of analytical values found reflect the well-known variability of this *Acacia* species. The major analytical difference concerns the unusually wide range of molecular weights observed. The material of highest molecular weight, from trees infested with Cerambycid beetles, is consumed by bush-babies (Galagidae). The range of analytical values found for *A. karroo* was consistently wider than those found for some other species such as *A. senegal.*

61 ANDERSON, D.M.W.; SMITH, R.N. **Studies on uronic acid materials. Part XIX. The composition of the gum from *Acacia laeta* var. *hashab***. *Carbohydrate Research, Amst.* (1967) **4** (1) 55- 62

A. laeta is a natural hybrid of *A. senegal* and *A. mellifera*, and comparison of the gum of its two varieties with that of the two parent species may elucidate the

mechanism of gum formation. The gum of *A. laeta* var. *hashab* is similar in composition to that of *A. senegal*.

62 ANDERSON, D.M.W.; STEFANI, A.; WANG WEIPING, P. ***Combretum nigricans* gum its unusual structure/properties and differences from gum arabic (*Acacia senegal*).** *International Tree Crops Journal* (1991) **6** (4) 275-285

Combretum nigricans is the major source of commercial 'gum *Combretum*' which is widely available in West African markets, and used as an adulterant of gum arabic with adverse results because the desirable properties of the latter are thereby greatly reduced. Gum arabic commands a price of 2,300 US$/tonne and gum combretum only 600 US$/tonne. Production of best quality gum combretum seems to be centered around Sokoto (N. Nigeria). Gum *Combretum* itself has an unfortunate reputation for self adhesion to form 'blocked' gum, although it is desirable for some commercial applications if stored and used appropriately. 13C Nuclear magnetic resonance spectrometry and degradative procedures reported here (using gum *Combretum* collected from trees in Niger, and commercial samples from Mali and Nigeria) have shown the essential difference in chemical structure involved; the constituent rhamnose and uronic acid units, which occupy peripheral, chain terminal structural positions in gum arabic, are located in internal positions in gum *Combretum*.

63 ANDERSON, D.M.W.; WANG WEIPING, P. ***Acacia* gum exudates from Somalia and Tanzania: the *Acacia senegal* complex.** *Biochemical Systematics and Ecology* (1990a) **18** (6) 413-418

Analytical data are presented for the polysaccaride and proteinaceous components of gum exudates from 3 Somalian *Acacia* species, namely *Acacia* sp. nov. [Fagg & Styles 85] and *A. cheilanthifolia* (members of the *A. senegal* complex) and *A. leucospira*, plus a Tanzanian specimen of gum arabic and one from *A. senegal*. The gum from *A. leucospira* was dextrorotatory and had a low rhamnose, high uronic acid and high methoxyl content; it therefore has affinities to the sources of commercial gum talha (*A. seyal* Del.). In contrast, the gums from *A. cheilanthifolia* and *Acacia* sp. nov. were laevorotatory and provided the first opportunity to study positively identified members of the *A. senegal* complex backed by properly documented herbarium voucher specimens. Although undoubtedly closely related species, chemical and spectroscopic data indicated that their gum exudates, and that from the Tanzanian sample, were analytically and structurally distinct from that of *A. senegal* [from the authors summary].

64 ANDERSON, D.M.W.; WANG WEIPING, P. **Composition of the gum from *Combretum paniculatum* and four other gums which are not permitted food additives.** *Phytochemistry* (1990b) **29** (4) 1193-1195

Presents analytical data for the gum exudates of 5 species (from *Atalaya hemiglauca*, *Cassine aethiopica*, *Combretum paniculatum*, *Sclerocarya birrea* and *Pseudocedrela kotschyi*) which have local uses but are not permitted for food and pharmaceutical use by the international regulatory authorities. Only 3 gum exudates, gum tragacanth (Asiatic *Astragalus spp.*), gum karaya (*Sterculia spp.*) and gum arabic (*Acacia senegal*), have passed all the toxicological tests and are permitted for these uses. The gums of the 5 species may have local technological applications, but are not recommended for addition to foodstuffs owing to their tannin contents (0.2-0.6%).

65 ANDERSON, D.M.W.; WANG WEIPING, P. **The composition of some *Sesbania* gum exudates.** *Biochemical Systematics and Ecology* (1990c) **18** (1) 43-44

Analytical data are presented for gums of *Sesbania sesban* (from Nairobi, Kenya), and *S. sesban* var. *rubica* and *S. grandiflora* (from Hawaii). Comparisons are made with those of *Acacia seyal* and *A. senegal*. They have some similarities with gum talha (*A. seyal*) but their dark red brown colour limits their use in commercial applications.

66 ANDERSON, D.M.W.; WANG WEIPING, P. ***Acacia seyal* and *Acacia sieberana* sources of commercial gum talha in Niger and Uganda.** *International Tree Crops Journal* (1991a) **7** 29-40

Because of the high cost of food grade gum arabic (2,300 US$/tonne which is obtained from *Acacia senegal*), there is increasing international demand for good quality gum talha (from *A. seyal*) for technological applications. Gum talha (mainly from *A. seyal* but can include other related Acacias) has a positive optical rotation as opposed to the negative optical rotation from gum arabic. Analytical data using Fourier-transform 13C Nuclear magnetic resonance spectra are reported for gum samples collected from trees of *A. seyal* (growing in Niger and northern Uganda) and *A. sieberana* (growing in Niger). All the samples studied were of good quality and conform with the known properties of Gum talha. It is suggested that there are good opportunities for developing gum production in these 2 countries if increased attention is given to meeting the modern marketing requirements (quality control) of gum trading.

67 ANDERSON, D.M.W.; WANG WEIPING, P. **The characterization of gum arabic (*Acacia senegal*) samples from Uganda.** *Food Hydrocolloids* (1991b) **5** (3) 297-306

Analyses presented of 7 small samples of gum from *Acacia senegal* trees growing in the Karamoja region, NE Uganda. In general, the gums satisfied the revised specifications for gum arabic in food, but there were significant differences with the typical Sudanese commercial samples.

They had lower methoxyl, rhamnose, and hydroxylroline contents and vary considerably in their emulsification functionality, with high proportions of aluminium, chromium, copper and iron. Fourier-transform 13C Nuclear magnetic resonance spectra confirm that the variations in the anaylitical parameters of these samples reflect differences in their fine structure.

68 ANDERSON, D.M.W.; WANG WEIPING, P. **Gum arabic (*Acacia senegal*) from Uganda: characteristic N.M.R. spectra, amino acid compositions, and gum/soil cationic relationships**. *International Tree Crops Journal* (1992) **7** (3) 167-179

Data are presented from further samples obtained in order to extend previous results which indicated that gum arabic from Uganda differed in several respects from typical Sudanese commercial samples. Differences in terms of fine structural features (13C NMR spectroscopy), amino acid composition, and high contents of aluminium and iron (but not of chromium and copper) are confirmed. Data for soil samples taken from beneath gum bearing trees indicate strong preferential uptake of potassium, calcium and magnesium, and that there is a relation between the acid leachable amounts of aluminium, barium, chromium, copper, iron, lead, titanium and zinc in a soil, and their content in the gum produced by the tree growing thereon.

69 ANDERSON, D.M.W.; WANG WEIPING, P. **The tree exudate gums permitted in foodstuffs as emulsifiers, stabilisers and thickeners**. *Chemistry and Industry of Forest Products* (1994) **14** (2) 73-83

A review is presented of the regulatory procedures surrounding the approval of substances for food additives. Currently there are only 3 commercially available types of gum exudate that are permitted as food additives, viz. gum arabic, from *Acacia senegal*, gum karaya, from *Sterculia urens, S. caudata* and *S. setigera*, and gum tragacanth from asiatic *Astragalus* species.

70 ANNISON, G.; TRIMBLE, R.P.; TOPPING, D.L. **Feeding Australian *Acacia* gums and gum arabic leads to non starch polysaccharide accumulation in the cecum of rats**. *Journal of Nutrition* (1995) **125** (2) 283-292

Gums from two Australian *Acacia* species (*A. pycnantha* and *A. baileyana*) were fed to rats as well as gum arabic (from *A. senegal*) to compare their suitability for use as human feed ingredients. The gums were fed at graded levels (0, 20, 40, 80 g/kg) to 48 rats, replacing cellulose in purified diets containing cholesterol plus cholic acid. After 14 days, consumption of the gums had no significant effects on concentrations of plasma or liver cholesterol, compared with the control diet containing cellulose only. The low apparent fermentability of the gums was confirmed by the accumulation of non starch polysaccharides in caecal digesta. Concluded that the Australian Acacia gums had similar biological activities to gum arabic.

71 ANON. ***Acacia laeta* gum from Nigeria**. *Bull. Imp. Inst., Lond.* (1940) **38**, 297-9

An examination of a sample of the gum showed it to be inferior in quality to *A. senegal* gum, being less soluble and forming gelatinous mucilages with comparatively weak solutions.

72 ANON. **Gum acacia in the Sudan**. *The Chemist and Druggist* (1954) June 26, 702-705.

Describes the history of the gum arabic trade, methods of collection, the tapping of the tree illustrated with photos, and the marketing and export of the gum. Apart from the section on marketing and exporting, information was mainly derived from Blunt (1926). Gum exports from the Sudan during 1953 anounted to 40,000 tonnes, with the UK being the principal importing country followed by USA, Italy and France. Details of gum exports of gum hasab and gum talh are listed. With shortages in 1954 it seemed likely that prices would increase further giving incentives for supplies from other countries (Nigeria, French Senegal). The advantage that Sudan has over the other producing countries is the quality selected without obvious impurities (adulturants). The major user of gum arabic was in the confectionary industry.

73 ANON. **Test of arboricides in East Africa**. *Colon. Res., Lond.* 1955/56 (1956) 194

The Colonial Insecticides Research Unit has made a number of trials of arboricides, applied by ground spraying. It appears probable that many of the more troublesome tree and shrub species in Tanganyika can be killed, and regeneration prevented or inhibited for some time, by spraying with solutions of 2,4,5-T or 2,4-D esters. Some species of *Lannea* (*L. triphylla* and *L. humilis*) and of *Commiphora* (*C. schimperi* and *C. subsessifolia*) are susceptible to 0.5% concentrations of 2,4,5-T. Some *Combretum* species appear to be more resistant, but *C. zeyheri* has been killed by a basal spray of 2.5% 2,4,5-T with little regeneration after 10 months. Large *Acacia senegal* have been killed by 3% 2,4,5-T applied to frills. Two trees of particular importance at higher altitudes in Kenya are *Euclea divinorum* and *Tarchonanthus camphoratus*, and preliminary results indicate that the former is relatively resistant to 2,4-D and 2,4,5-T; further experiments on these species are in progress.

74 ANON. [**Intervention techniques for the village woodlot action**.] Les techniques d'intervention pour l'action bois de villages. *Project Bois de Villages - Fiche Technique* (1982) No.2 1-20

The role of trees in the conservation and amelioration of soils are presented, and techniques for the planting of agroforestry specis are described. There is also a general summary on the protection against, and conflict with fires.

75 ANON. [**Special issue: trees of the month.**] Special arbres du mois. *Flamboyant* (1993) No.27, 4-39

This issue contains 13 short (2-3 pages) guides to important trees of the Sahel and Sudanian Guinean zones of Africa, which were first published, one per month, in the journal. Brief notes are given on botanical synonyms, vernacular names, distribution, ecology, morphology, uses (timber, fodder, medicinal, etc.), forest nursery production, vegetative propagation, and silviculture. The species are: *Acacia nilotica, Argania spinosa, Balanites aegyptiaca, Adansonia digitata, Cordyla richiardi, Faidherbia albida, Acacia senegal, Ziziphus mauritiana, Vitellaria paradoxa, Parkia biglobosa, Borassus aethiopum, Stereospermum kunthianum*, and *Tamarindus indica.*

76 ARBONNIER, M. **Arbes, arbustes et lianes des zones sèches d'Afrique de l'Ouest**. CIRAD, MNHN, UICN, Montpellier, France. (2000) ISBN CIRAD 2-87614-431-X. 1-542

Practical guide to the commoner trees shrubs and lianas of the dry zones of western Africa, with clear illustrated keys and botanical descriptions and photographs of more than 350 species. *Acacia senegal* is described as usually a small tree from 2-6 m high, flowering at the beginning and during the rainy season, occuring in the sahelian and sudano-sahelian vegetation regions, preferring sandy soils and is very drought resistent (withstand 8-11 months without rain). Has a wide range of economic uses, particularly in local medicines, in sand dune fixation, soil improvement and gum trade.

77 ARYA, L.M.; WOLDETATIOS, T.; RILEY, J.J. **Potentials for increasing crop productivity through soil and water conservation in the Sahelian and Savannah zones of Sudan**. In *Arid lands: today and tomorrow. Proceedings of an international research and development conference, Tucson, Arizona, Oct 20-25, 1985 (edited by Whitehead, E.E., Hutchinson, C.F., Timmermann, B.N.; Varady, R.G.).* Westview,Belhaven, USA (1988) 459-476

Water availability and degradation of soil fertility are the most serious constraints to rainfed crop production in the Sahelian and sudanian zones of Sudan and this paper describes further trials undertaken by the Western Sudan Agricultural Research Project to improve crop management practices and increase productivity of farmers and pastoralists in these zones. Rapid loss of moisture from the surface zone of qoz sands were identified as a major cause of seedling failure. Addition of gum arabic or clay materials were tried to improve moisture retention. In a pot experiment small amounts of powdered gum arabic were beneficial to sorghum growth, but the field trials proved the opposite effect. The ground clay proved more effective increasing yields. Of the other techniques tried, mulching and residue management proved the most effective means of moisture conservation. Agroforestry cropping with *A. senegal* was not evaluated.

78 ASPINALL, G.O.; CHARLSON, A.J.; HIRST, E.L.; YOUNG, R. **The location of L-rhamnopyranose residues in gum arabic [*Acacia senegal*]**. *J. Chem. Soc.,* March (1963) 1696-1702

79 ASSEFA, K.; KLEINER, D. **Nodulation pattern and acetylene reduction (nitrogen fixation) activity of some highland and lowland *Acacia* species of Ethiopia**. *Biology and Fertility of Soils* (1998) **27** (1) 60-64

Endosymbionts from the Ethiopian highland species *Acacia abyssinica, A. negrii* and *A. etbaica*, and the lowland species *A. nilotica*, A. *prasinata, A. senegal, A. seyal, A. tortilis* and *Faidherbia albida* (formerly *A. albida*) were isolated and characterized. Seven species were found to be nodulated by species of both *Rhizobium* and *BradyRhizobium. F. albida* and *A. senegal* were nodulated only by *BradyRhizobium* or *Rhizobium*, respectively. In *A. abyssinica*, both genera were isolated from the same nodule, whereas in *A. nilotica* and *A. tortilis*, both strains were isolated from different nodules of the same plant. The nitrogen fixation (acetylene reduction) activities varied considerably and showed no correlation with the nitrogen content of the plant. Highland species were as effective as lowland plants, thus demonstrating good potential for soil reclamation. The endosymbionts isolated proved rather promiscuous, efficiently nodulating other *Acacia* spp. and some tropical grain legumes, but did not nodulate temperate legumes.

80 AUBREVILLE, A. [**Contribution to the study of charcoals from French West Africa.**] Contribution à l'etude des charbons de bois de l'Afrique occidentale Francaise. *Actes et Comptes Rendus de l'Association Colonies - Sciences* (1941) No.177 1-31

Reports on experiments made by the government of French West Africa in 1983-89. The results are presented in a number of tables. Among the commoner species which were found to make good charcoal were *A. nilotica, A. raddiana, A. senegal, Balanites aegyptiace, Zizyphus jujuba, Dichrostachys glomerata, Combretum micranthum* and *C. glutinosum.*

81 AUBREVILLE, A. **Flore Forestière Soudano-Guinéenne, A.O.F.-Cameroun-A.E.F** Paris: Société D'Editions Géographiques, Maritimes et Coloniales (1950) 1-523

Detailed description of the woody flora from the Sudanian-Guinean zone of west Africa. Long list of common names of the west African Acacias, and for *A. senegal*: Senegal verek (oulof), ngobop, ouki (sérère), Mali donkori, dibé (malinké et bambara) Mauritania irouar, awarwar, erwar (maure) AOF patouki, patterlahi delbi (peuhl), Sahara iouarnar (tamachek), Ivory Coast banikoro (cado), Niger tamatschi, kandili (haussa), kolol, kolil (kanouri), danngha, deligna (djerma), touguéhi (toubou), Chad ashaat, kitré (arab). Describes the distribution of the species in west Africa, on a country by country basis, and illustrates with a map. Describes the ecology, soils, natural regeneration and growth and gives the production and export figures of gum from 1922-1940.

82 AWONAIKE, K.O.; DANSO, S.K.A.; ZAPATA, F. **Biological nitrogen fixation by *Gliricidia sepium* and *Acacia senegal* in association with *Rhizobium* and *BradyRhizobium* strains**. *Nitrogen Fixing Tree Research Reports* (1992) **10** 36-39

Five strains of *Rhizobium* and 3 of *BradyRhizobium* were used to inoculate *Gliricidia sepium* and *Acacia senegal* in a greenhouse experiment to assess nitrogen fixation at 24 weeks after planting, using the 15N isotope technique. *G.sepium* fixed significantly more nitrogen in association with *Rhizobium* than *BradyRhizobium*. The nitrogen fixation performance of *A. senegal* was not influenced by inoculation treatment fixing 60% N was derived from the atmosphere, and its growth was poor.

83 AWOUDA, E.H.M. **The Social and Economic Problems of the Gum Arabic Industry**. B.Litt Thesis, University of Oxford (1973)

84 AWOUDA, E.H.M. **The demand curve for gum arabic and calculation of elasticity**. *Sudan Silva* (1976) **21** (3) 46-53

A demand curve was calculated by analysing world export figures for gum arabic from 1955-1972. Concludes that the demand for Gum arabic is still inelastic and that the annual increase in world demand for gum arabic is about 600 tons. The period 1955 to 1965 was considered the golden age of the commodity reaching 65,000 tons on average.

85 AWOUDA, E.H.M. **Outlook for gum arabic production and supply**. In *Gums and Stabilisers for the food industry 4 (edited by Phillips, G.O.; Williams, P.A.; Wedlock, D.J.)* Oxford, England; IRL Press (1988) 425-434

Describes the factors affecting production, distribution, marketing, of gum arabic (from *A. senegal*) in Sudan by a member of the National Gum Arabic Company. Suggests a new marketing system, instead of traditional labour selling to smaller markets which are then transported to auction markets and through merchants to the gum exporting company, to producers selling direct to producer associations which then pass to the Gum arabic Company. This government policy is intended to be on-stream by 1990, and of the three zones identified there should be an average of 20,000 tonnes per zone produced that year. The three zones in the gum belt are (1) north of lat. 13°N, (2) middle part between latitudes 12-13°N, and southern part south of latitude 12° N. Zone (1) has been seriously affected by drought with loss of agricultural production, destruction of trees and high rate of migration (suggested policy in restoration of the gum arabic cultivation cycle); zone (2) is relatively unaffected by drought and is the main area for gum production (suggested policy in enrichment planting to fill gaps, rehabilitation of mechanized farming schemes, and creation of large plantations); zone 3 is a new naturally regenerated area with the southward shift of the vegetation zones (suggested policy in demarcation and initiation of gum production).

86 AWOUDA, E.H.M. **Indicators for present and future supply of gum arabic**. In *Gums and Stabilizers for the Food Industry 5 (edited by Phillips, G.O.; Williams, P.A.; Wedlock, D.J.)* (1990) Conference held July 1989, Clwyd. 45-54

General paper highlighting the efforts made by the Sudan Government in developing the species quantitatively and qualitatively, thus securing supplies, maintaining confidence and creating a strong baseline for the long term involvement of both producers and consumers. The gum belt is a natural buffer zone between the desert proper in the North and the agricultural tall grass savanna in the south. Destruction or misuse in the zone will induce desert encroachment and threaten agricultural production. The region also supports an enormous livestock population, up to 20 million head of camels, cattle, sheep and goats. Sudan has been the biggest producer and exporter of gum Arabic since the time of the Pharaohs (4000 years ago). Notes the importance of the tree ecologically, as a soil improver and stabilizer, for easy establishment and provider of income during the dry months (idle for agriculture). Details the two main production areas in Sudan, west (N. Kordofan, N. Darfur and White Nile) which produces 80% of gum Arabic and east (Blue Nile, Kassalla and S. Kordofan) which produces around 20%. They markedly differ in soils, climate and mode of production. The western area has sandy soils, rainfall 300 mm/annum, traditional subsistence agriculture, often remote areas difficult to access and with acute drinking water problems. The eastern area has clay plains, an average rainfall of 600 mm/annum, large scale mechanized rainfed agriculture with pockets of gum Arabic established by mechanized sowing, easily accessible with better water supplies, but a lack of experienced gum producers on large private holdings and government land. Also discusses the planning and development factors including institutional, development

strategy and projects, pricing policies, organization of producers, improvement of infrastructure, research, creation of buffer stocks, and quality assurance.

87 AXELROD, D.I. **Climatic pulses, a major factor in legume evolution.** In: *Advances in Legume Systematics Part 4. The Fossil Record, (edited by Herendeen, P.S. & Dilcher, D.L.) Royal Botanic Gardens, Kew, UK* (1992) 259-279

88 AYOUB, S.M.H. **Flavanol molluscicides from the Sudan *Acacias*.** *International Journal of Crude Drug Research* (1985) **23** (2) 87-90

The isolation of (-)-epigallocatechin-7-gallate and (-)- epigallocatechin-5, 7-digallate from the ethyl acetate extracts of the fruits and stem bark of *Acacia nilotica* ssp. *nilotica*, *tomentosa* and *adstringens* (previously shown to have high molluscicidal activity against *Bulinus truncatus* and *Biomphalaria pfeifferi*, which transmit schistosomiasis in Sudan and Egypt) is reported. These 2 active compounds were also isolated from the bark and fruit extracts of 20 other *Acacia* taxa including *A. albida* Del., *A. senegal* var. *senegal* and *A. tortilis* ssp. *raddiana*, *spirocarpa* and *tortilis*. Tannins in the plants are the source of these flavonal derivatives.

89 BADI, K.H. **Afforestation in the clay plains of Kassala Province [Sudan]: (A) High rainfall clay plains, (B) Arid clay plains.** *Bulletin, Forests Department, Sudan* (1967) No.13 1-20

Reviews afforestation trials on the clay plains of Kassalla Province, Eastern Sudan. These plains are divided into 2 sections by the 450 mm isohyet which is approximately along latitude 14°30'N. In section A (above 450 mm mean annual rainfall) where crop production is possible, soil ploughing and mechanical seeding of *Acacia senegal* around Gedaref is successful. On these deep black cracking clays, it is essential to drill deep so that the seedling has deep root penetration to survive the dry season. The seedlings are thinned to 4 x 4 m spacing and a sorghum (dura) drilled between them. Previous failures were due to sowing in shallow pits. Deeper ploughing with weeding and mulching allowed seedlings to reach over 60 cm after the second rainy season. Rats can be a problem but with clean weeding kites can then control the rat population. In section B, which are brown non cracking clays with less than 450 mm annual rainfall) such as Hawata, the best results were achieved by planting in 35 cm deep contour furrows, prepared from a tractor and ridger.

90 BADI, K.H.; AHMED, H.A.; BAYOUMI, A.A. **The Forests of the Sudan.** Khartoum (1989) 1-184

Describes the natural woody vegetation zones in Sudan, the established plantations and silvicultural characteristics of a number of species including *A. senegal*. It is the most widely planted species, estimated at 124,300 feddans throughout the country, with the greatest plantations in the eastern region (Kassala) 70,777 feddans and the central region (Blue & Whilte Nile) with 32,180 feddans. The natural gum belt (both *A. seyal* and *A. senegal*) is estimated at 8,640,000 feddans (36,000 km^2 or 3,628,800 ha). The productive area is estimated to be 2,904,000 feddans (12,202 km^2 or 1,220,200 ha), of which the majority is found in the Kordofan (554,660 ha) and Darfur (369,750 ha) regions. In Sudan fruiting is more variable on the sandy soils, and often only one in five years do trees produce abundant seeds, around 8-10,000 seeds/kg. Coppice regeneration is commun in the gum gardens. Coppice growth rates in Kordofan gum gardens reach 1.2 m high after 3-4 years, and 3-4 m after 10 years. On clay soils of Kassala region, plantation seedlings grew 1.4 m in 7 years.

91 BADJI, S.; COLONNA, J.P.; DREYFUS, B. **[Capacity for infection and effectiveness of several *Senegalese Rhizobium* strains on the main gum producing *Acacia*, *Acacia senegal*.]** Infectivite et effectivite de quelques souches de *Rhizobium* du *Senegal* sur le principal *Acacia* gommier: *A. senegal*. Les arbres fixateurs d'azote. L'amelioration biologique de la fertilite du sol. Actes des seminaires, 17-25 mars, 1987 Dakar, Senegal. Editions de l'ORSTOM, Paris, France (1987) 94-121

A. senegal seedlings were inoculated with 6 Rhizobium strains from the host species and 4 from *A. laeta*. The seedlings formed nodules with all the strains, and there was no significant difference between strains from the 2 species in number of nodules formed and nodule dry weight. Nodulated plants had significantly greater N contents in the above-ground parts than non-inoculated controls. There was no significant difference in N contents between plants nodulated with strains from the 2 species. The best strains were ASN1 and AS2 from *A. senegal* and ALN1 from *A. laeta*.

92 BADJI, S.; DUCOUSSO, M.; GUEYE, M.; COLONNA, J.P. **[Nitrogen fixation and the possibility of cross-nodulation in two *acacia species* which produce gum arabic: *Acacia senegal* and *A. laeta*.]** Fixation biologique de l'azote et possibilite de nodulation croisee chez les deux especes producteurs de gomme dure: *Acacia senegal* L. Willd. et *Acacia laeta* R. Br. ex. Benth. *Comptes Rendus de l'Academie des Sciences, Series 3, Sciences de la Vie* (1988) **307** (11) 663-668

Nine fast-growing Rhizobium strains isolated from *A. senegal* and *A. laeta* produced nodules on both species after 3 weeks under laboratory conditions. After 5 weeks, the nodulated plants showed av. increases in shoot N content of 49% in *A. senegal* and 98% in *A. laeta* compared with non-nodulated controls.

93 BADJI, S.; MAIRONE, Y.; N'DIAYE, I.; MERLIN, G.; DANTHU, P.; NEVILLE, P.; COLONNA, J.P. ***In vitro* propagation of the gum arabic tree (*Acacia senegal* (L.) Willd.). 1. Developing a rapid method for producing plants**. *Plant Cell Reports* (1993) **12** (11) 629-633

Results of a successful method for micropropogation of young tissues from *Acacia senegal* in *Senegal*, as opposed to the horticultural cuttings reported in Badji *et al.*. (1991). Explants from seedlings or four year old plants maintained in a juvenile state were cloned. Three or four micropropagules were produced from one uninodal explant. Different cytokinin concentrations of zeatin or benzyladenine (BA) in a modified MS medium (half strength macroelements) were evaluated for their effect on shoot development. A concentration of 5 X 10^5 M zeatin produced a better multiplication rate after 60 days for both types of stock plant than BA. A two stage process was necessary to obtain a 100% rooting rate of the small cuttings. The initial induction stage consisted of leaving the cuttings for 6 to 12 days on a modified Jordan's medium (JN) (half strength macroelements) containing 5 X 10^5 M NAA. The root extension stage involved culture of small cuttings on hormone free JN medium. Roots appeared after a few days. Acclimatization in a greenhouse occurred with a survival rate of close to 100%. The success of this method is a prerequisite for producing microcuttings from adult trees.

94 BADJI, S.; MERLIN, G.; N'DIAYE, I.; MAIRONE, Y.; DOIRE, P.; PALMA, B.; COLONNA, J.P.; G ESLOT, A.; NEVILLE, P. **Multiplication végétative *in vitro* d'Acacia *senegal* (L.) Willd**. In *Physiologie des Arbes et Arbustes en zones arides et semi-arides. Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadnam, C.; Joly, H.; Bory, G.)* (1993) 303-308

Essentially the same results that were presented in Badji *et al.*(1993).

95 BADJI, S.; N'DIAYE, I.; DANTHU, P.; COLONNA, J.P. **Vegetative propagation studies of gum arabic trees. 1. Propagation of *Acacia senegal* (L.) Willd. using lignified cuttings of small diameter with eight nodes**. *Agroforestry Systems* (1991) **14** (3) 183-191

Preliminary results of vegetative propogation of *Acacia senegal* using eight node lignified cuttings. Small diameter stem cuttings (<0.4 cm) with 8 nodes (12-14 cm long) were taken from 4 year old trees in the field in *Senegal* at different times of the year. Tests were carried out with small batches of cuttings with or without leaves, using 4 substrates (sterilized Dior type soil; a 1:1 (v/v) mixture of sterilized Dior soil and decomposed sawdust; 'Fertiss' turf; or well drained crushed basalt powder placed on a bed of gravel). Rooting and callusing were poor, and only occurred in cuttings with leaves. Results indicate the need for a well drained rooting medium (crushed basalt powder), retention of four active leaves on the cuttings, collection of the cuttings during the rainy season, and treatment with a rooting hormone IBA 8% gave a rooting rate between 50-70%. Hormonal treatments also had a significant effect on the survival rate of the cuttings during the 2 month observation period. IBA (8%) resulted in significantly better rooting (50 -70%) than did 2% IBA, 0.2% NAA or 1% IAA.

96 BAKSHI, B.K.; SINGH, S. **Rusts on Indian forest trees**. *Indian Forest Records (New Series) Forest Pathology* (1967) **2** (8) 139-198

Gives illustrated descriptions to the 88 rust fungi found on Indian trees, with *Ravenelia acaciae-senegalae* Mundk. & Thirum. and *Ravenelia acacicola* Sanwal found on the leaves of *Acacia senegal* Willd. in Delhi.

97 BAL, S.N.; PRASAD, S. **Indigenous substitutes for imported drugs**. *Indian J. Pharm.* (1943) **5** 30-6

Possible substitutes for several drug plants commonly imported into India are discussed. Gums from *Astragalus strobiliferous* Royle, *Sterculia urens*, *Cochlospermum gossypium* or *Bombax malabaricum* can be substituted for gum tragacanth from *A. gummifer* Labill., and gum acacia from *Acacia indica* or *arabica* [*A. nilotica* ssp. *indica*] for that from *A. senegal* and *Ferula foetida*. Other possible substitutions are discussed.

98 BALASUNDARAM, V.R. **Studies on the native nodulation and biomass production of some tree legumes**. *Indian Journal of Forestry* (1987) **10** (2) 94-96

Natural nodulation of 19 species was studied after growth for 6 months in 1-m^2 micro-plots at the Indian Forest Research Institute in March-Sep. 1984. Species studied were: 8 *Acacia spp.*; 4 *Bauhinia spp.*; *Cassia nodusa*; *Colophospermum mopane*; *Dichrostachys nutans*; *Leucaena leucocephala*; *Parkinsonia aculeata*; *Prosopis juliflora* - local and from Peru and Arizona; and *Tamarindus indica*. Plots were irrigated when necessary. Records were also made of shoot dry wt., shoot N and Rhizobium type. Only 4 of the species (*A. tortilis*, *A. farnesiana*, *A. nilotica* and *L. leucocephala*) formed nodules, although reports have been made of nodulation in 9 other species as well as these. Results indicate a lack of the proper rhizobia in the plots. All the rhizobia present were of the fast-growing type. Most aerial biomass was produced by *C. nodosa* (184.7 g/plant), followed by *L. leucocephala* (149.7 g), *D. nutans* (66.1 g) and *A. nilotica* (59.8 g); all the other species produced much less. Net N accumulation was also highest in these species. The failure to nodulate in so many of the species indicates the need for inoculation before sowing.

99 BALDWIN, T.C.; QUAH, P.E.; MENZIES, A.R. **A serotaxonomic study of *Acacia* gum exudates**. *Phytochemistry* (1999) **50** 599-606

100 BALOGUN, A.M.; FETUGA, B.L. **Chemical composition of some under exploited leguminous crop seeds in Nigeria**. *Journal of Agricultural and Food Chemistry* (1986) **34** (2) 189-192

Mature seeds of 16 leguminous species collected from the savanna regions of N. Nigeria were analysed chemically to ascertain their proximate and mineral compositions for preparing livestock and fish feeds. Crude protein levels were high in the Mimosoideae with *Acacia senegal* having the greatest level (38.9%). Also given was the ether extract, crude fibre (20.56%), ash and nitrogen free extract. In the mineral composition, the macroelements (Ca, Mg, Na, K, P) and microelements (Zn, Cu, Fe, Mn) were listed. *A. senegal* seeds were good sources of Ca (0.3%), K (1.2%) and P (0.5%) but low in Na (0.02%).

101 BANERJI, R.; CHOWDHURY, A.R.; MISRA, G.; NIGAM, S.K. **Chemical composition of *Acacia* seeds**. *Journal of the American Oil Chemists Society* (1988) **65** (12) 1959-1960

The seeds of 12 species of *Acacia*, although rich in C-18 unsaturated acids (47.9 to 93.5%), have low oil contents (2.5 to 10.2%). Highest concentration of octadecatrienoic acid was in *A. lenticularis* (80.3%), *A. suma* (76.8%) and *A. tortilis* (71.7%) oils. *A. mollissima* [*A. mearnsii*] was rich in octadecadienoic (69.1%) and *A. senegal* in octadecenoic (42.5%) acids. All the seed oils contained epoxy 18:1 acid, 0.6 to 3.8%. The protein content of the processed seed meals was 13.4 to 37.2%, the highest being in *A. senegal*. Fibre content varied from 8.8 to 11.9%.

102 BARBIER, E.B. **Natural resources in the economy of the Sudan**. In *Sustainable development: economics and environment in the third world (edited by Pearce, D.; Barbier, E.; Markandya, A.)* London, UK; Earthscan (1990a) 1-217

103 BARBIER, E.B. **The economics of controlling degradation: rehabilitating gum arabic systems in Sudan**. *London Environmantal Economics Centre* Paper 90-03 (1990b) 1-53

The economic and environmental benefits of gum arabic production [from *Acacia senegal*] in the Sudano-Sahelian zone appear attractive. However, the farm level economics of gum arabic production are complex, and much more needs to be understood about the economic environmental interactions determining farmers' gum arabic cropping. This paper explores these issues in the Sudan through a crop profitability analysis of gum and other crops combined with financial and economic analyses of six representative gum arabic production systems (Blue and White Nile, South and North Kordofan and South and North Darfur). Although the returns from gum compare favourably with other crops in Sudan, essential investments by farmers in cultivating gum will depend on its real producer price being maintained and other incentives determining the relative profitability of gum. Lists the direct benefits from gum cultivation (apart from gum) as fodder, and older trees fuelwood and charcoal. The indirect benefits include nitrogen fixation improving the range, reducing wind erosion through wind breaks and dune fixation, reducing soil erosion and water runoff and stabilising soils, and acts as a buffer against desertification in the Sahelian-Northern Sudanian zone. Gives relatively high rate of return for gum cultivation which compares favourably with other rainfed crops (millet and sorghum) but less than the cash crops of sesame and groundnuts, and cautions that maintaining a good producer price is essential for further planting of stands. Farmers also perceive the benefits of gum production, including off-season income (gum collected in the dry season), more stable returns, the perception that the trees produce beneficial environmental impacts and the need for on-farm supplies of fuelwood and fodder. The annex provides detailed analysis from the six areas.

104 BARBIER, E.B. **Rehabilitating gum arabic systems in Sudan: economic and environmental implications**. *Environmental and Resource Economics* (1992) **2** (4) 341-358

Same paper presented in Barbier (1990b).

105 BARBIER, E.B.; PEARCE, D.W.; EL KHALIFA, M.D. **Gum arabic rehabilitation in the Republic of Sudan: Stage 1 Report**. London, International Institute for Environment and Development & Khartoum, Institute of Environmental Studies (1990) In 3 volumes, 532 pp. in total.

An unpublished technical report summarising research undertaken in Sudan with a view to rehabilitate traditional production of gum arabic. The report shows that gum arabic offers two major benefits to the people of Sudan, commercial benefits in the form of cash for local economies and foreign exchange for the economy as a whole, and environmental benefits in the form of products (fodder, fuelwood, soil amelioration) of direct benefit to the farming communities and in the form of wider 'anti-desertification' insurance. Concludes that the gum belt is under threat, and there has been a steady southwards shift in gum tapping due to degrading environmental conditions in the north. There has been a reduction in gum production on the traditional goz soils in western Sudan, and increasing production on the clay soils. The key issues for gum arabic in Sudan are how to maintain the existing gum output in the face of competition from substitutes and from competing west African suppliers and how to expand it. Production targets can be met by commercial plantations alone, by expanding production in the traditional farming areas, or by both. The latter option is more important for protecting and enhancing the living standards of the people in the gum

belt (10-14°N latitude) which occupies about 20% of the Sudan. This excellent report summarises research undertaken in the Sudan which is not easily available elsewhere. Found that there has been a clear shift of production from sandy to clay areas and that water supply, though crucial for the gum tappers, does not necessarily lead to increased gum production nor its absence stop tapping. All scenarios employed to estimate potential production indicated that it is possible to double current annual production levels of 25-30,000 tonnes from existing tree stocks.

106 BARNES, R.D.; MARUNDA, C.T.; MARUZANE, D.; ZIROBWA, M. **African acacias: genetic evaluation:Phase I**. *Final Report of DFID Forestry Research Scheme R.5653*. Oxford Forestry Institute and Zimbabwe Forestry Commission (1996) 1-209

Preliminary results from the screening and main *Acacia* trials that are detailed below in Phase II. Germination time of manually scarified *A. senegal* seeds was very rapid, swelling up within 3 hours and the radicle emerging within 6 hours of adding to the germination cabinet. The seedlings however were susceptible to damping off, aphids, frost, general yellowing and loss of leaves starting from the tip. Growth of seedlings of *A. senegal* was relatively slow in comparison with the other Acacia species tested, and after 7 months average heights varied between 14.4 cm in var. *leiorhachis,* 9.8-12.1 cm in var. *senegal* and 8.8 cm in var. *rostrata.* Survival at 12 months in the eight sites tried in Zimbabwe varied from 18-97% for var. *senegal* and 12-94% in var. *leiorhachis.* The best site was Chesa Forest Research station for survival, but for tree height Guyu and Mahiye performed best. Frost damage was recorded in the first winter after planting, and the percentage of seedlings of var. *senegal* severely affected varied from 66% in the Cyrene site and 16% in the Lucydale site (both sites at Matopus Research Station between 1310-1340 m altitude).

107 BARNES, R.D.; MARUNDA, C.T.; MARUZANE, D.; ZIROBWA, M. **African acacias: genetic evaluation:Phase II**. *Final Report of DFID Forestry Research Scheme R.6550*. Oxford Forestry Institute and Zimbabwe Forestry Commission (1999) 1-49

This is the Final Report of the second DFID/OFI genetic evaluation project of the African acacias in Zimbabwe. This report gives the latest results of the screening trials and the first results of the main trials which were planted as one of the objectives of the project. Five provenances of *A. senegal*, four of var. *senegal* and one of var. *leiorhachis* were used in the screening trials at seven sites (Guyu, Lucydale, and Cyrene with sandy loam soils, Mahiye with sandy clay soils, and Chesa Forest, Chesa FRS, Madlulani on fine grained sandy soils) in Zimbabwe. The initial results of the screening trials showed that the species did best at Guyu, a frost-free site on granite-derived soils. The next best sites were the harsh Kalahari sands localities of Chesa Forest and Madlulani. At Guyu the seedlings flowered and produced fruits by 18 months, and the northern provenances of var. *senegal* exuded small quantities of gum by the second year, but the southern provenances from Tanzania of var. *senegal* (higher altitude) and var. *leiorchachis* from Kenya did not. These results indicated that the main trials should focus on the northern provenances of var. *senegal* only on granite and Kalahari sand soils in frost-free localities. Wide spacings and single tree plots were used in the main trial designs as the best compromise to avoid early competition and to provide enough replications to impose selection and management studies on the experiments. Sixteen provenances of var. *senegal* were included in the main trials, and second year assessments have shown that the Ethiopian provenance, Arba Nosa, is giving the best growth. By the third year, the northern provenances were producing gum from natural lesions in the stem without tapping, whereas the Tanzanian provenances were not producing gum although they had some of the best growth rates. The conclusion of the community studies on six *Acacia* species including *A. senegal* was that research should focus on exploring the markets for locally produced gum arabic and pods and stimulating the demand for these products to provide the incentive for enhanced management and planting. An objective of this project has been to create a resource of information on and materials of the African acacias that can be used for future research with funding attracted from international agencies for projects from a wide variety of disciplines. This had started to happen before the end of the project by which time funds were assured for research into using acacias to restore fertility to degraded land, on-farm evaluation of *Acacia* species and livestock feeding trials with acacia pods.

108 BARNES, R.D. **The African acacias: a thorny subject**. Keynote paper in *Forest genetics for the next millennium, Proceedings IUFRO Working Party 2.08.01, Durban, South Africa, 8-13 October 2000.* ICFR, PO Box 200281, Scottsville 3209, South Africa (2000) 9-15

There are 129 *Acacia* species in Africa. They are intermediate in plant succession, and colonize degraded land. They restore fertility and can be maintained indefinitely in agricultural systems. They provide many benefits but are disliked for their thorns and invasiveness. Seed was collected across the ranges of *Acacia erioloba, A. karroo, A nilotica, A.senegal, A. tortilis* and *Faidherbia albida.* Screening trials indicated that, with selection, all had potential inside and outside their natural ranges. Two varieties of *A. senegal* were included in the screening trials in Zimbabwe, varieties *senegal* and *leiorhachis*, but only one provenance of *leiorhachis* was used as the economic potential appears to occur in the

type variety. The species did best on a frost-free site on granite-derived soils, and the next best sites were on the Kalahari sand localities (deep sandy soils). By the second year after planting, gum was being produced without tapping, from the northern (Niger, Senegal and Sudan) provenances of var. *senegal*, but not from the southern Tanzanian provenance or from var. *leiorhachis*. Given the value of gum as a cash crop in areas where little else is grown, these northern provenances show potential for introduction into southern Africa.

109 BASAK, M.K.; GOYAL, S.K. **Studies on tree legumes. 1. Nodulation pattern and characterization of the symbiont**. *Annals of Arid Zone* (1975) **14** (4) 367-370

The development of root nodules is described for *Albizzia [Albizia] lebbek*, *Prosopis juliflora*, *P. cineraria*, *Acacia senegal* and *A. tortilis*, grown from sterilized seed in pots of unsterilized soil. In cross-inoculation studies with the last three species, cross-nodulation occurred between *A. senegal* and *P. cineraria* only. Of five Rhizobium strains from non-woody legumes that were tested, only that from *Phaseolus aureus* produced nodules in *A. senegal* and *P. cineraria*. *A. tortilis* was not nodulated by this strain.

110 BATESON, W.M.; EL TOHAMI, A.R. **Sudanese gum arabic production supply function estimates and policy implications**. Khartoum Sudan, Ministry of Agriculture (1986)

111 BATESON, W.M.; UMBADDA, S.; NOUR, H.O.; ABDEL HAI, A.M. **Sudan's gum arabic sector: analysis and policy options**. United States Agency for International Development, Khartoum (1988) 1-260

Report for the USAID, covering the role of gum arabic in the Sudanese economy, its production and processing, supply and demand, short and long term policy options and appropriate interventions for recovery following the major effects of recent drought 1984 and the following supply crisis in 1985. In the last two decades Sudan has twice been unable to supply world demand for gum arabic at the posted FOB price. Each time substantial fraction of the market was lost to starch based substitutes. The root causes were low producer prices in the late 1970's and early 1980's. The most immediate policy change that the government could make would be to allow the Gum Arabic Company (GAC) an exchange rate not less than 80% of the open market value of the Sudanese pound. This would allow the GAC to reduce the FOB price and maintain the producer price at a real level sufficient to rebuild demand.

112 BAUMER, M. ***Acacia senegal***. In *Notes on trees and shrubs in arid and semi arid regions*. EMASAR Phase II / F.A.O., Plant Production and Protection Division, Rome, Italy (1983) 44-50

A compilation of datasheets of trees & shrubs of economic importance in the arid and semi arid rangelands of Africa and the near and middle East. Gives a general description of the tree, its distribution, ecology and silviculture. Natural regeneration of *Acacia senegal* is very easy in favourable environments. One of the rare trees which may be economically cultivated in the sub desertic zone, relying only on the natural rainfall. The wood is used for making tool handles, roofing poles, lining wells, and the timber framing of huts. It provides good firewood and good charcoal but gum is the most important product. The Sudan is the major gum producer and supplier in the World.

113 BAUMER, M. [**Agroforestry in arid regions of Africa**.] Agroforesterie pour les zones seches africaines. *Bois et Forêts des Tropiques* (1990a) No. 225, 55-64

A discussion of the characteristics of agroforestry systems in use in African arid regions, including various agrosilvipastoral systems 'Karite' (*Butyrospermum parkii* [*Vitellaria paradoxa*]) or 'kadd' (*Faidherbia* [*Acacia*] *albida*) gardens, palms (*Phoenix dactylifera*) in oases and gum (*Acacia senegal*) gardens or plantations). Problems encountered, particularly limitations to agriculture due to soil fertility and/or aridity, and the potential for overcoming these problems using various agroforestry techniques and species described are discussed.

114 BAUMER, M. **The potential of agroforestry in combating desertification and environmental degradation with special reference to Africa**. ICRAF/ICARC, Netherlands (1990b) 224-5

Describes the agro-silvi-pastoral system of the gum gardens of Kordofan in the Sudan, where a sufficiently long fallow period of 15-20 years allows the soil to recuperate after intensive cereal cropping. A system of rotation cropping exists, with one fallow patch with gum trees for about 15 years and two cultivated patches, one rather intensive for 6-8 years, and one semi-cultivated and semi-grazed which then becomes the gum garden. With population increases the fallow period has been shortened, not allowing the soil to fully regain its fertility and thereby producing declining harvests. Other advantages of the system, such as tapping in the dry season when most farming jobs are completed, abundant regeneration of seeds of *A. senegal* in the cultivated patches, and charcoal production from old gum trees makes for a balanced and permanent system. Notes on the attempts by Mauritania, Senegal and Sudan to create new gum gardens based on the Kordofan model. Calculates that a gum plantation of 100 km^2 could produce all the gum needed in the world market, and that if all these plantations succeeded the market could be oversaturated.

115 BEGUE, L. **Return to the Sudan**. *Bois et Forêts des Tropiques* (1964) No. 98 3-11

Reviews progress since 1958 particularly as regards reservation, irrigated plantations in the dry zones, silviculture of *Acacia senegal*, and the timber plantation programme. Preliminary trials of *Pinus patula*, *P. khasya*, and *P. caribaea* in Equatoria outside the Imatong Mts. area are encouraging.

116 BEIJERINCK **Natuurk**. Verh. d. Koninkl. Acad. V. Wetensch. Amsterdam t.XXIII in 4° (1883) 46

117 BEKUNDA, M.A. **Response of some nitrogen fixing tree seedlings to *Rhizobium* cross inoculation**. *African Crop Science Journal* (1993) **1** (1) 25-29

Seven nitrogen fixing tree species (*Acacia albida* [*Faidherbia albida*], *A. senegal*, *A. auriculiformis*, *Calliandra calothyrsus*, *Gliricidia sepium*, *Leucaena leucocephala* and *Prosopis juliflora*) were grown in pots in a non sterilized Inceptisol either not inoculated, or inoculated with: species specific *Rhizobium* strains; *Rhizobium* strain TAL 1145, a *Leucaena* isolate; and *BradyRhizobium japonicum* strain TAL 169. Twelve weeks later, significant species differences in dry matter yield, total N yield and nitrogen derived from the atmosphere (Ndfa) were obtained. In contrast to earlier reports, *F. albida* and *A. senegal* were better N2 fixers than *L. leucocephala*. Significant dry matter yield increases in response to inoculation with species specific rhizobia were observed in *G. sepium* genotypes and in *A. senegal*, while increases in response to inoculation with TAL 1145 were obtained in *G. sepium* genotypes and in *C. calothyrsus*. There was no response to inoculation with TAL 169. Mean dry matter yield differed between species, with *G. sepium* genotypes yielding most and *A. auriculiformis* yielding least. All tree seedlings inoculated with species specific rhizobia showed significant total N yield and Ndfa increases expect for *F. albida* and *A. auriculiformis*. *G. sepium* and *L. leucocephala* genotypes and *P. juliflora* responded to inoculation with TAL 1145. Similarly, no significant response to inoculation with TAL 169 was observed. Where response to TAL 1145 and to the species specific rhizobia occurred simultaneously, there were no significant differences between the two treatments.

118 BELLOUARD, P. [**Gum arabic in French West Africa**.] La gomme arabique en A.O.F. *Bois et Forêts des Tropiques* (1949) No. 9 3-18

A short account is given of the distribution of *Acacia senegal* with a description of the stands in different parts of French West Africa. In general they consist largely of old trees, regeneration being destroyed by bush fires and browsing by nomadic herds. Experiments in direct sowing have been unsuccessful, chiefly owing to drought. Experiments in cutting down the trees which have ceased to yield gum, led to the conclusion that coppice regrowth occurs only in trees of 12-13 cm. in diameter or less. Larger trees do not coppice, and to fell them makes the situation still worse, by removing seedbearers. The method now recommended is fire exclusion with exclusion of cattle for a period sufficient to get regeneration beyond the stage at which it is browsed. When herdsmen are allowed access to the stands, they should be encouraged to lop or cut down *Balanites aegyptiaca* and *Acacia raddiana*, which constitute 95% of the stands and are the most dangerous competitors of *A. senegal*. Cattle are an almost essential factor in natural regeneration as a vehicle of dissemination. Some notes are given on methods of collecting the gum, yield, and market conditions.

119 BEN SHAHAR, R. **Successional patterns of woody plants in catchment areas in a semi arid region**. *Vegetatio* (1991) **93** (1) 19-27

The dispersal patterns of woody plants were studied in the semi arid Sabi Sand Wildtuin private game reserve, Eastern Transvaal, South Africa. The study revealed that trees have spread from core areas and have converted previously open grasslands to densely vegetated woodlands. These patterns were found in catchment areas of the gently undulating terrain which characterizes the region. Two plant communities dominated by *Acacia senegal*/*A. tortilis* and *Euclea divinorum*/*A. nilotica* were distinguished. Analysis of nearest neighbour distances, dispersal patterns of seedlings and mature woody plants identified successional processes. These were manifested through intra and inter specific competition among the dominant tree species. Within each plant community, a transition of relative abundance was occurring, viz. *A. senegal* became dominant in areas previously dominated by *A. tortilis* while *E. divinorum* was replacing *A. nilotica* as the dominant species. Comparative assessment of the two plant communities was facilitated by the summary of competition and seedling dispersal indices in a multivariate analysis. Results indicated that tree species had characteristic dispersal strategies. Identification of the patterns of woody plant establishment could advance the evaluation of successional dynamics and management of savannas in areas prone to bush encroachment.

120 BERGERET, A.; RIBOT, J. **L'arbre Nourricier en Pays Sahelien**. Editions de la maison des sciences de l'homme, Paris (1990). Ministere de la cooperation et du developpement.

121 BERGONZINI, J.C.; JOLY, H.I. **Rapport de Mission au Senegal et au Burkina Faso au 11 - 20 Mai, 1992**. CIRAD/CTFT (1992) 1-17

Report of a mission to Senegal and Burkina Faso to review research undertaken in collaboration with CTFT, mainly in two areas, forest tree improvement and genetics,

and microbiology, ecology and physiology of woody species. *Acacia senegal* is one of the main species studied, for the objective to stabilize and improve gum arabic production. Studies on the plantations at M'Biddi are detailed elsewhere (see Dione and Vassal 1998). In the evaluation of genetic diversity, 11 populations in Senegal were analysed using 8 isoenzyme systems. The mean number of alleles per locus was 1.4, and the mean heterozygosity was 0.175. Of the two groups of *A. senegal* in Senegal, no difference in isoenzymes was found between the two types (light and dark grey types).

122 BERHAUT, J. **Flore illustrée du Sénégal. *Ficoidées* à *Légumineuses***. Dakar; Gouvernement du Sénégal (1975) 1-635

Floral treatment of Senegal including two Acacias from the *Acacia senegal* complex. *Acacia senegal* is a small tree which reaches 6 – 8 metres tall with leaves having 3 – 6 pinnae pairs. The young foliage is a good forage, and the gum used medicinally or eaten by the Maures and Touareg tribes. The black heartwood makes good charcoal and the root sheath cordage. *Acacia dudgeoni* is also a small tree, which was known previously as *A. senegal* var. *samoryana* Rob., and differes distinctly from *A. senegal* by having leaves with 7 – 17 pinnae pairs, and usually greater numbers of leaflet pairs as well. It occurs in more humid areas (Sudanian region) than *A. senegal* which is mostly found in the Sahelian region, and does not appear to produce gum in any quantity.

123 BERNHARD-REVERSAT, F. **Biogeochemical cycle of nitrogen in a semi-arid savanna**. *Oikos* (1982) **38**, 321-332

The nitrogen cycle was studied in a savanna in the sahelian zone at Fete Ole, North Senegal. Estimates were made of the impact of some trees (including *A. senegal* and *Balanities aegyptica*) on soil nitrogen distribution and nitrogen cycling via mineralization and plant uptake. Organic matter and N content of the soil were low and concentrated in the first centimetres of soil and increased under the trees. In situ N mineralization in the 0-10 cm layer was relatively high, ranging from 5 - 8% of total N per year, according to the relief. It occurred mainly from the beginning of the rainy season (July) to August, although rainfall occurred up to October. *In vitro* measurements showed that N mineralization was a function of the number of days during which the soil was wet, for a given temperature and N content. Prediction of in situ mineralization on this basis was in good agreement with in situ data. N fluxes between the vegetation and soil were higher in soil-tree systems than in the open, but litter-fall and canopy weathering accounted for a small part in the N cycling, the major fluxes occuring via the herbaceous stratum.

124 BERNHARD-REVERSAT, F.; HARMAND, J.M.; UGUEN, K. **Forest litter and nitrogen cycling in various *Acacia* biotopes in western and central Africa**. [Les litieres et la dynamique de l'azote dans divers biotopes a *Acacia* d'Afrique occidentale et centrale.] In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.)* L'Orstom, Collection colloques et séminaires, Paris, France (1998) 205-219, 457-458

A summary is presented of research carried out (1969-1996) at 8 sites in Senegal, Cameroon, Congo and Cote d'Ivoire into nitrogen cycling in various stands (natural or planted) which included nitrogen fixing *Acacia* species (*A. senegal*, *A. albida* [*Faidherbia albida*], *A. seyal*, *A. holosericea*, *A. polyacantha*, *A. mangium* and *A. auriculiformis*). Other species recorded in the stands included *Eucalyptus spp.*, *Cassia siamea*, *Balanites aegyptiaca* and *Guiera senegalensis*. Rainfall at the sites varied from 300 to 1350 mm annually. Nitrogen (N) and carbon (C) contents of tree foliage, forest litter, soil organic matter and soil horizons were measured, and decomposition coefficients calculated. For all vegetation types studied, rainfall was significantly correlated with annual N cycling rates (although more so in the case of non *Acacia* vegetation), with N mineralization, and with annual N mineralization rates. There was a significant correlation between N contents of litter and soil organic matter; however, there was no significant relation between total soil N and litter N content. Leaf decomposition rates were more than double under the *Acacia* trees than under the other species, presumably due to the fine leaflets. Presents two models for nitrogen cycling under *Acacia* trees and under other trees which don't fix nitrogen, which show the importance of rainfall and clay content in the soils on the nitrogen available.

125 BERNHARD-REVERSAT, F.; POUPON, H. **Nitrogen cycling in a soil-tree system in a Sahelian savanna example of *Acacia senegal***. In *Nitrogen cycling in West African ecosytems (edited by Rossal, T.)* (1980) 363-369

Gives results of a study of the nitrogen cycling in a population of *Acacia senegal* in the Sahelian savanna of North Senegal. They measured the nitrogen accumulation in different parts of the tree biomass, herbaceous biomass and in the soil. Found that the annual flow of nitrogen from under adult *Acacia* trees to the soil was about 12 g/m^2/yr. This was comparable to some forest ecosystems. An important part of the nitrogen flow passes through the herbaceous stratum and is then available to cattle.

126 BESHAI, A.A. **The economics of a primary commodity: gum arabic**. *Oxford Bulletin of Economics and Statistics* (1984) **46** (4) 371-381

Gum arabic has a remarkably wide range of uses of which there are four main categories: foodstuffs; pharmaceutical products; textiles; paper, ink and other manufactures. The price elasticity of demand for gum arabic

is low, while elasticity of supply is high. The Sudan has a near monopoly position on the world market, producing 82.6% of total production over the 1978-81 period and deriving 10% of its foreign exchange earnings from total export proceeds. Unlike many other primary commodities, the terms of trade for gum have been improving through time for both the nation as a whole and its producers. However, the government has a difficult job of judging how far it should use its near monopoly power to raise prices, bearing in mind the ensuing possibility of a fall in demand. Experience was gained in 1973 and 1974 of the effects of exceptional price rises. Since 1978, the publicly owned Sudanese Gum Arabic Company has gained experience with respect to the implications of stabilizing the price of gum at $ 1200 per t. It has to balance any raising of prices against maintaining them fairly stable, a factor which is important in the long run. The general feeling is that there may be some scope for raising that price without fear of substitutes emerging.

127 BHANDARI, M.M. **Flora of the Indian Desert**. *India: Scientific Publishers, Jodhpur* (1978) 1-471

Description of the flora of the Thar desert in north western Rajasthan, including *A. senegal* (L.) Willd. It is found on hillsides and gravel throughout the area, and is said to be one of the chief jungle forming trees! Local names Kumbat and Kumatiyo.

128 BHATT, J.R.; MOHAN RAM, H.Y. **Ethephon induced gum production in *Acacia senegal* and its potential value in the semi arid regions of India**. *Current Science* (1990) **59** (23) 1247-1250

This paper reports a preliminary study using Ethephon solution to induce gum production in *A. senegal* trees. Extensive stands of *A. senegal* (both wild and planted) occur in Gujarat and Rajasthan, but the trees exude little or no gum naturally. Nine trees growing in the Chambal ravines, near Barhi, Madhya Pradesh and 5 trees at CAZRI, Jodhpur, Rajasthan were treated with the solution. Four mls of the solution (containing 480, 720 or 960 mg a.i.) was introduced through a hole 5 cm deep and 2.5 cm wide in the bark at 1.0-1.5 m above ground, slanting downwards, in April/May. The hole was subsequently covered with beeswax, and an area of bark 2.5-4.0 cm^2 above the hole bruised to encourage gum production. Little or no gum was produced by control trees (holes bored but no ethephon added), and the most gum exudation (806-950 g/tree) occurred in the 960 mg treatment. Exudation started 4-8 days after treatment.

129 BHIMAYA, C.P.; KAUL, R.N.; GANGULI, B.N.; BHATT, P.N. **Experimental afforestation of rocky refractory sites in the arid zone [of Rajasthan]**. *Indian Forester* (1964) **90** (3) 160-3

Describes a successful experiment in planting on a typical baffen, rocky site of 12.5 ha. in Jodhpur city. Sprouted stumps of *Prosopis julifora* were planted, and seeds of *Acacia senegal* sown, in pits half-filled with a mixture of manure and transported soil in 6 x 6m spacing along the contours. With periodical watering in the first growing season, good survival and growth were obtained, and after 4 years the average seedling heights of the *Prosopis julifora* were 315 cm and *Acacia senegal* 74 cm.

130 BHIMAYA, C.P.; KAUL, R.N. **Root system of four desert tree species**. *Annals Arid Zone, Jodhpur* (1965) **4** (2) 185-194

The root systems of 6 year old plants of *Prosopis cineraria*, *Acacia senegal*, *Tecomella undulata* and *Albizia lebbec* growing at CAZRI, India, were excavated and studied. A plant of each species directly sown was compared with one transplanted, into sandy soils overlying a marram pan. In *A. senegal*, the majority of the roots developed within a metre of the surface in the upper half of the sandy layer, spreading laterally about 3 m. Deep tap roots penetrated the hard pan to over 6 m. Increased tap root lengths were found with the transplanted plants as was the secondary root development.

131 BHIMAYA, C.P.; KAUL, R.N. **Role of seedling root habit on initial seedling survival in some desert tree species**. *Science & Culture* (1966) **32** (4) 204-6

The root systems of the seedlings of (a) *Acacia senegal*, (b) *Albizzia lebbek*, (c) *Tecomella undulata* and (d) *Prosopis spicigera* were examined after one season's growth in large containers, but otherwise under natural conditions, near Jodhpur. Survival rates were 91, 80, 60 and 54% respectively. (a) had the lowest shoot/root ratio and shed its leaves more rapidly on the onset of drought and remained leafless longer than (b)-(d). Survival of (b)-(d) showed some correlation with the intensity and extent, but not the depth, of lateral root development.

132 BHOWMIK, A.K.; MISHRA, A.K.; MISHRA, P.N.; BANERJEE, S.K. **Performance of different NFT and non NFT species on iron mine overburden**. *Environment and Ecology* (1996) **14** (3) 607-611

Observation recorded after 8 months of planting 12 NFT (nitrogen fixing) and 8 non NFT species in pots in iron ore mining overburden collected in Madhya Pradesh, showed that *Leucaena leucocephala* gave maximum height, collar diameter, root length, and leaf and stem biomass production. Overall performance of the tree species was assessed using a suitability index based on mean height, mean collar diameter and biomass. *Leucaena leucocephala* (an NFT) gave the highest value, followed by Eucalyptus hybrid [*E. tereticornis*], *Ipomoea fistula* [*Ipomoea carnea* subsp. *fistulosa*] and *Gmelina arborea* (all non NFT). The other species tested were (in descending order of suitability score for each

category): NFTs, *Sesbania sesban, Albizia lebbeck, Dalbergia sissoo, Acacia holosericea, Albizia procera, Acacia catechu, Acacia auriculiformis, Acacia mangium, Acacia nilotica, Acacia senegal, Acacia leucophloea*; non NFTs, *Eucalyptus camaldulensis, Ficus benghalensis, Emblica officinalis [Phyllanthus emblica], Zizyphus jujuba [Ziziphus mauritiana], Syzygium cumini.*

133 BILLE, J.C. **Measuring the primary palatable production of browse plants**. In *Browse in Africa; the current state of knowledge (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980) 185-195

Records results from an International Biological Programme measuring browse plant productivity, including *Acacia senegal* at Ferlo in Senegal with annual rainfall of 250 mm. The average biomass values are given for different diameter sizes of *A. senegal,* with leaves producing approx. 20% and fruit 7% of the total above ground biomass.

Diameter (cm)	Branches/ branchlets (kg/DM)	Leaves (g/DM)	Fruit (g/DM)
6.4	2.9	580	200
10.5	4.3	860	300
15.9	19.2	3840	1340

134 BIRD, N.M.; SHEPHERD, G. **Charcoal in Somalia; A woodfuel inventory in the Bay region of Somalia**. Chatham; Overseas Development Natural Resources Institute, for ODA London and NRA Mogadishu. *Somali Forestry Series* 2 (1989) 1-126

An inventory of the main charcoal-producing area of southern Somalia, which has sufficient wood to produce 208,800 tonnes of charcoal (less than two years supply for the capital Mogadishu). The vegetation type is Somali-Masai *Acacia/Commiphora* deciduous bushland and thicket, of which *A. senegal* var. *leiorhachis* (arborescent form in this area), is one of the upper canopy species. With *A. bussei* it is a major species used for charcoal production. The report gives estimates on the woody biomass of the two major species of the study area, their ecology, and charcoal consumption and supply. For *A. senegal*, it has an inverted J distribution for its size class distribution. Its regeneration is good in the bush layer and is more shade tolerant than *A. bussei.* Pods are wind dispersed which then get trapped in the bush layer and may be browsed. Seeds readily germinate, one test gave 75% germination in 18 hours without any pretreatment. The woody biomass of the species was calculated in two areas, giving 1,024 and 1,368 kg/ha. The conversion of wood (oven dried) to charcoal was estimated at 25-40%, the latter being chosen to estimate the tonnage available in the woodlands. Estimated moisture content of the wood as 45% in stems over 15 cm diameter.

135 BISBY, F.A.; BUCKINGHAM, J.; HARBORNE, J.B. **Phytochemical Dictionary of the Leguminosae. Plants and their constituents. Volume 1**. Chapman and Hall (1994) p. 45

Summarises geographical distribution and uses of *Acacia senegal* (L.) Willd., as well as listing the chemical constituents that have been cited in the literature. Compounds found in *A. senegal* are listed under the headings: Aliphatic natural products, Carbohydrates, Flavonoides, Terpenoids, Steroids, Aminoacids, Peptides and Alkaloids.

136 BISWAS, B.; PHILLIPS, G.O. **Classification of natural gums. V. Identification of commercial gum arabic from Africa by Euclidean modelling**. *Food Hydrocolloids* (1993) **7** (6) 507-520

This is part of a series of papers using multivariate statistical analyses to assist in the characterisation of natural gums. Previous chemometric systems have centered on the application of Principal Component Ananysis and Discriminent Component Analysis (I-IV). In this paper a chemometric method based on geometric modelling of amino acid data has been developed to classify commercial gum arabic in relation to authenticated *Acacia senegal.* A parameter can be identified (Senegal Distance) which provides the divergence of any gum specimen from the centroid of an authentic *Acacia senegal* cluster. Commercial gum arabic samples can in this way be distinguished from arabinogalactan protein gums of *Combretum* and *Albizia* classes, which are potential adulterants in terms of existing food regulations.

137 BISWAS, S.; BISWAS, B.; PHILLIPS, G.O. **Classification of natural gums. Part VIII. Chemometric assignment of commercial gum exudates from Africa using cluster analysis on the protein amino acid compositions**. *Food Hydrocolloids* (1995) **9** (3) 151-163

Describes a method using multivariate statistical techniques for analysing chemical data and distinguishing different arabinogalactan protein gums from *Combretum* and *Albizia* species, which are possible adulterants in commercial gum arabic samples. Cluster analysis methods based on distance values between pairs of entities are developed to classify commercial gum arabic in relation to authenticated samples from *Acacia senegal* for regulatory and quality control purposes. Two parameters are defined for these gums which measure the closeness of any gum specimen to *A. senegal.* One of the parameters is described in terms of multiple nearest neighbours yielding a number designated the 'Senegal Number', and the other is a discriminant function of 'taxi distances' of all gums from the centroids of 2 pre-eminent classes.

138 BJORKELO, A. **Prelude to the Mahdiyya. Peasants and Traders in the Shendi Region 1821 - 1885**. *African Studies Series, Cambridge University Press* 62 (1989) 1-192.

139 BLACK, R.A.; EL HADI, F.M. **Presowing treatments of *Acacia senegal* seed; germination and growth**. *Tropical Agriculture (Trinidad)* **69** (1) 15-20

Investigated differing seed pretreatments (scarification, osmotic priming and hardening) on *Acacia senegal* seed from Goz Ashgar, Sudan, and the response of these treatments on their seedling growth. Pretreatments increased germination rates over control but overall biomass was not changed in the subsequent growth of the seedlings. Hardening (soaking in water for 10 hours) showed the most promise.

140 BLUNT, H.S. **Gum arabic with special reference to its production in the Sudan**. Oxford, UK; Oxford University Press (1926) 50 pp.

A small but valuable book on gum arabic production, it describes the history of the gum trade and gives export figures (1879 - 1925) from Sudan. It is one of the major exports, valuing often between 20-30% of all exports from the country. From 1912-24 UK was the major importer followed by France, USA and Germany. Describes the tree with details on its locality, description, climatic variables, root structure, economic uses, cultivation and pests. It grows on sandy soils with low water soluble salts. Notes the benefits on sand dune fixation, where planted seedlings continued to grow through 2 feet of sand which had accumulated on top of them over 2 years. Most regeneration is natural in the gum gardens, with a small proportion sown by seed. Average life of the trees is around 25-30 years. Describes some of the biotic and abiotic factors which affect the seedlings establishing themselves: competition against grass (*Pennisetum cenchroides* Rich.), cut worms, grasshoppers, locusts, and sometimes insufficient rain at the right time. Notes that a good seed year only occurs once every five years in any locality, and fires can kill off seedlings. Overgrazing by goats and camels can cause serious damage, and older trees were attacked by white ants, longicorn bettles, bores and locusts. The plant can develop long lateral roots up to 20 ft long on sandy soils as well as a deep tap root. Gives detailes on Kordofan province where two thirds of all exported Sudanese gum originates. Trees are grown on fallow land (after 4-5 years of cropping) near the village (gum gardens) or collected away in the savanna woodlands. Gum gardens can have 15 trees over 15 acres or over 200 trees/acre. All the community has the right to cultivate, and small taxes are paid to the Sheik and Omdah. Tapping depends on the quality of the agricultural harvest, in a good harvest year much less tapping occurs as there is less need for income to buy food. Gum tapping occurs when the leaves of the trees are wilting and dropping, well into the dry season. Manual tapping only started around the 1890's otherwise gum was collected from natural exudation. Details the tapping procedure, using a tradional axe. Tapping (pulling a strip of bark from the upper trunk of the tree), is done by working a new section of the bark each year. Trees from 6-7 years old can produce abundant gum but tapping too young will kill them. Gum is collected 20-30 days after tapping if the weather is hot and dry, but if cold exudation can take up to 60 days. The marketing, with the introduction of auctions (1922) in El Obeid following the arrival of the railway in 1913 improved production and increased prices for the farmer. Describes the freight costs, taxation, chemical properties and uses including the ability to hold from 13-15% water. The water supply in Kordofan province, has a direct effect on collecting gum as some areas do not have proper wells. Describes the creation of the government gum research station at Um Ruaba, its plantations and regular tapping of trees in and outside the experimental plots. Details gum yields from the 87 (12 feddan) plots, and from the 1922 crop at 200 trees/feddan it would need 813,600 acres to supply a world demand of 18,000 tons/annum. The average amount of gum /tree was 0.14 of a rottle (63 grams) and the average highest production from a tree was 1.41 rottles (634.5 grams). The average tree density over the plantation was 1,602 trees per plot, with plot 1 having the highest density of 5,926 trees. Discussed the origin of gummosis suggesting that it is produced by some form of infection, whether the infection is bacterial or fungoidal. Notes that any stress on the trees affects gum production, be it a lack of moisture, poor exhausted soils, hot weather, and favours the view that starch is converted into gum by bacterial infection. Also describes forest policy in Sudan.

141 BLUNT, H.S. **Further notes on forestry in the Sudan**. *J. Oxf. Univ. For. Soc. (3rd Ser.)* (1948) No. 3 28-31

Notes on (1) tapping of *Acacia verek* [*A. senegal*] to obtain gum arabic, and (2) regeneration of the`basin' forests of *Acacia arabica* in pockets or basins behind the Blue Nile. When the waters are very high, the river spills over the bank into the basins, where the water stands for 2-3 months; this is sufficient to allow germination of the *Acacia* seed, which remains viable for at least 15 years.

142 BOA, E.; LENNE, J. **Diseases of Nitrogen Fixing Trees in Developing Countries: An Annotated List**. Chatham, UK: Natural Resources Institute (1994) 1-82

A comprehensive annotated list of Nitrogen Fixing Tree diseases found in tropical countries. A wide range of diseases are listed for the genus *Acacia*, but specifically for *A. senegal* are listed *Ascochyta sp.*, *Botryodiplodia theobromae*, and *Sphaeropsis sp.* all without symptoms recorded from Pakistan, and the leaf rusts *Ravanelia acaciae-senegalae* Sanwal or by *R. acaciicola* Sanwal from India [the latter two from Gibson 1975].

143 BOIVIN, C.; LORTET, G.; LORQUIN, J.; BA, S.; MEAR, N.; FERRO, M.; LAJUDIE, P. De.; PROME, J.C.; DREYFUS, B. **Using Nod factors for identifying symbiotic characteristics of rhizobia: application to roots of *Acacia* and *Sesbania* in *Senegal*.** [Utilisation des facteurs Nod pour la caracterisation symbiotique des *Rhizobiums*: application aux souches d'*Acacia* et de *Sesbania* du Senegal.] *In L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.).* L'Orstom, Collection colloques et séminaires, Paris, France (1998) 377-386, 465-466

Presents a new approach for classifying the roots of legume species, as opposed to nodulation tests, according to the specific symbionts present or able to be present, and studies into host specificity of bacteria were also carried out (in Senegal). Bacterial genes which control nodulation (nod, nol, noe), and the proteins (Nod) regulating the expression of these genes, were studied using gene transformation (into natural rhizobia). The tests involved a range of multipurpose species, both indigenous and exotic, including *Acacia senegal, A. raddiana [A. tortilis* ssp. *raddiana], A. nilotica, Prosopis juliflora, Leucaena leucocephala, Sesbania rostrata, S. grandiflora* and *S. pubescens*. Most of the fast growing rhizobia isolated from *Acacia* and *Sesbania* roots were Sino*Rhizobium saheli* (from *Sesbania* sp.), *SinoRhizobium teranga* bv. *acaciae* & bv. *sesbaniae* (from *Acacia* and *Sesbania* sp.) or group U (from *Acacia ORS 1040 & 1001*).

144 BOND, W.R.G. **Rotation of crops in gum gardens of the White Nile**. *Sudan Notes and Records* (1918) 1 80-87

Describes the gum garden rotation, in an area 80 km west of Kosti on clay soils on both sides of the Kosti-El Obeid railway. Traditionally it is a 24 year rotation, divided into 4 equal periods. The first is named Bildat, a 6 year cropping period until the soils are exhausted; then this is followed by Seraya and Shigl, a 6 year fallow period, where seed of *A. senegal* naturally regenerates and grows up; then this is followed by Geneina or gum garden where gum is harvested for 6 years and finally the fourth period is Bur, where gum yields deteriorate and clearence and cultivation begins. He suggests that the final period could be eliminated reducing it to a 18 year rotation.

145 BONNEVAL, P. ***Acacia senegal* et la gomme arabique dans les flacons des forestiers de Dakar**. *Horizons Sud. Mensuel D'Information interne du CIRAD Montpellier* (1994) No.33 1, 3.

Describes the work of the ISRA/CIRAD-Orstom team in Dakar working on improvement and selection of *Acacia senegal*. In Senegal, the local farmers are not accostomed to plant the tree as in the gum gardens in Sudan. In the 1970's Senegal exported 10,000 tons to Europe, in particular Rouen in France where it was processed and resold. The best gum was "Ferlo dure" which was sold for 5000 CFA Francs/kg. Notes the use of gum arabic in Valda pastilles has been replaced by a synthetic substitute but that Valda afrique (in Dakar) still make the original pastilles.

146 BOOTH, F.E.M.; WICKENS, G.E. **Non-timber uses of selected arid zone trees and shrubs in Africa**. *FAO Conservation Guide* (1988) No.19 1-176

Notes are given on names, distribution, description, main uses, other uses, economic importance, climate, site, life cycle, pests and diseases, seed supply, agronomy, yield, sociological factors, production potential, processing, development constraints, recommendations, related species, and references, for 27 species (including *Acacia senegal* and *A. seyal.)* The main uses of *A. senegal* are gum arabic, fuel wood, forage, bee forage, food and fibre, with various land use systems including agroforestry in desertification control, sand dune fixation, soil conservation and wind breaks. Gum arabic is used in the food industry to prevent crystallization of sugar, as a stabiliser in frozen dairy products, as a flavour fixative and emulsifier, and a foam stabiliser and clouding agent in beer. In pharmaceuticals it is used as a stabiliser for emulsions, binder and coating for tablets, emollient and demulcent for cough drops and syrups and intravenously for nephritic edema. In the cosmetic industry, used as an adhesive for facial masks and face powder, and to give a smooth feel to lotions and creams. Used industrially as an adhesive, as a protective colloid and safeguarding agent for inks, as a sensitizer for special lithographic plates and as a protector and ingredient of fountain solutions, as a coating for special papers and as a coacervate in carbon free paper, as a protective colloid for paints, a flocculent and emulsifier in vinyl resin emulsions, as a sizing agent for cloth to give body to certain fabrics and as a thickener and binding agent for vat sizes, and aa a template to prevent metal corrosion. Local uses include in the manufacture of matches, in ceramic pottery, and local medicinal uses; in the treatment of local inflammations and nodular leprosy (west Africa), dysentery, mixed with fried wheat flour and sugar for women after childbirth (India), and generally eaten as a sweet.

147 BOSCH, O.J.H.; VAN WYK, J.J.P. **The influence of bushveld trees on the productivity of *Panicum maximum*: A preliminary report.** *Hand. Weidingsveren. S. Afr.* (1970) **5** 69-74

The influence of four important bushveld trees, *Acacia senegal, A. tortilis, Boscia albitrunca* and *Combretum apiculatum* on the distribution and productivity of perrenial grass *Panicum maximum* were investigated. Belt transects (30 x 1 ft) were laid out under 30 individuals of each of the four species, the central section of the transect lay underneath the crowns which had an average crown diameter of 10 ft. The fieldwork was carried out in the Lower Crocodile valley, north-west of Thabuzimbi in western Transvaal, South Africa. There

was a strong association of *P. maximum* especially underneath the crowns of the *Acacia* species. Surface soil samples were then collected from under and away from the crowns of the four species, and the yields of *P. maximum* grown in them compared in greenhouse experiments. *Panicum* seedlings were established in the pots and grown for 36 days under two different light (full light and shading by cheese cloth) and water regimes, and much higher yields were harvested from the canopy soils than from those outside the crown area. For *Acacia senegal*, average *Panicum* yields of 5.26 gm were recorded for canopy soil compared to 0.74 gm from open ground soil (sun treatment) and 2.93 gm compared with 0.27 gm respectively in the shade treatment. Soil analyses indicated that the canopy soils were richer in nutrients, and further experiments with additions of N, P and K to the open soils increased yields to those found under canopy soils. Concluded that the *Panicum*-tree association is largely due to soil enrichment by the trees.

148 BOSSHARD, W.C. **Drought resistance of tree species**. *Pamphlet, Forestry Research and Education Project, Forests Department, Sudan* (1966) No.32 1-45

From 1964 to 1966 a series of experiments were carried out in the Khartoum Greenbelt, to test for tree species suitable for the extreme conditions of climate and soil, and able to tolerate 3-4 months without irrigation. *Eucalyptus camaldulensis* and *E. tereticornis* failed and *E. microtheca* showed poor performance. From various trials, a priority list of species was drawn, mainly based on observations of seedlings which were irrigated for 3-4 months and assessed 5-8 months later without any irrigation. *A. senegal* proved to have the highest drought resistence with *A. farnesiana* of the 28 species tested surviving well over 6 months, and those with a high resistance were local Khartoum provenances of *A. nilotica*, *A. mellifera* and *Conocarpus lancifolius* (Somali provenance) and *Prosopis chilensis*.

149 BOUDET, G. [**Livestock production and possibilities of intensification in the Sahelian zone**.] Production animales et possibilites d'intensification en zone Sahelienne. *Bull. Recherches Agronom, Gembloux* (1972) 445-451

Animal rearing (cattle, goats, sheep) in Sahel is essentially itinerant on account of watering difficulties Flocks are moved north in rainy season and south in dry season. Nitrogen is available in shoots in the wet season but pasture is deficient in this in the dry and increasingly so as desertification advances. Some nitrogen-rich plants survive around permanent water holes. Fruits of some woody plants are eaten by animals but the seeds are not digested. Scarification of the seed coat in the digestive tract increases germination potential with result that there is regeneration of species such as *Acacia raddiana* and *A. senegal*. Traditional transhumant animal rearing is adapted to rough climatic conditions but is not helping in economic and social development objectives. These require improvement of habitat, hygiene and education of transhumant populations, the controlled and increased use of the pasture, improvement of animal stock, intensification of management of flocks and of marketing of related products. The possibility of developing pasturage around watering points is major preoccupation of national authorities but is dependent on geological and hydrographical possibilities and cost is often exorbitant. In spite of risks of parasitic infestation, management of surface waters could be interesting for pasture in rainy seasons. Wells would be needed for the dry season with improved techniques for raising water. Fire controls would need to be introduced for protection during dry season. Better management of flocks would transform traditional transhumant systems. Young males would be being marketed at the age 3-4 years to be sent on either to reception and waiting ranches, set up in areas traditionally unused because of lack of access to water, or given to farmers in the Sudanese zone for local fattening. In the reception ranches abundance of pasture and of water would eliminate loss of weight in the dry season, which can reach 100 g per day in May and June. Weight gain can be maintained throughout the year due to the contribution of nitrogen at the critical period, either in the form of cotton seeds (1 to 3 kg per head and per day) or in the form of young leaves and fruits of woody tree species.

150 BOER, E. ***Acacia senegal* (L.) Willd**. In: *Plant Resources of Tropical Africa Precursor. (edited by Oyen, ' L.P.A. & Lemmens, R.H.M.J.), PROTA Programme, Wageningen, the Nederlands* (2002) 35-41

Compilation and short review of the tree and the properties, yield and trade in gum arabic.

151 BOUET-WILLAUMEZ, E. **Commerce et Traite des Noirs aux côtes occidentals d'Afrique**. *Archives Nationales Francaises Section Outre Mer*, 42, Paris (1848) 1-230

152 BOURREIL, P. [**Index of assessment of the preference of herbivores for certain plants in the Province of Darfour (Sudan**).] Sur une indice d'appréciation de l'appétence des herbivores pour certaines plantes de la province du Darfour (Soudan). *Journal D'Agri. Trop. et de Botanique Appliquée* (1968) **15** (4) 200-201

A study of the preferences of different herbivores to a range of fodder species in the pastoral areas of Darfur province. The areas selected were dominated by the highly palatable grass genus *Aristida*. Inspection of plants was accompanied by questioning of nomadic and sedentary pastoral people. He found that camels were the preferencial browsers of *A. senegal* plant and fruits, goats browsed the plant less and goats and sheep preferred the fruits when available, while sheep, donkeys, horses and

cows did not browse the plant at all, although cows would browse the fruits a little.

153 BOUXIN, G. **Action of seasonal fires on the woody stratum in the Akagera National Park (Rwanda, central Africa).** *Vegetatio* (1975) **30** (3) 189-196

Reports the % distribution of stems by diameter classes for various woody species at two sites 15 km apart: a savanna area and a dry monodominant forest of *Strychnos usambarensis*, not penetrated by fire owing to the virtual absence of ground vegetation. Woody savanna species were divided into three classes of fire sensitivity on the basis of stem-diameter distribution, since the more sensitive species were prevented from reaching a larger size. It is concluded that the presence of large numbers of certain species in the smaller diameter classes does not necessarily indicate a succession towards forest. The most fire-resistant species were judged to be *Acacia senegal* and *A. gerrardii*.

154 BOVILL, E.W. **The golden trade of the Moors.** Oxford, UK; Oxford University Press (1963) 1-281

155 BOWEN, E. **Cuts to the Complete Geograph. A new and accurate chart of the world.** *Geographer to His Majesty, London.* (1744) map 56

156 BOWEN, G.D.; SANGINGA, N.; DANSO, S.K.A. **Biological nitrogen fixation in agroforestry - an overview**. *Transactions 14th International Congress of Soil Science, Kyoto, Japan, August 1990, Volume III* (1990) 170-175

A brief review is presented covering: the measurement of biological nitrogen fixation in nitrogen fixing trees; nitrogen fixing potential in relation to plant species and genotype, microbial symbiont, plant age, management; and the effects of soil environment on nitrogen fixation. Some tree species can fix 200 to 300 kg N/ha annually (e.g. *Acacia mangium, Leucaena leucocephala*), whereas others may fix less than 20 kg N/ha annually (e.g. *Acacia albida, A. senegal*). Large differences occur not only in plant genotype/microbial symbiont combinations, but also in tolerance to soil conditions (such as low soil P). Approximately half of all N fixed may be in below ground plant parts, and release of this N may be managed by various harvesting regimes.

157 BRAIN, P. **Immunology and phylogeny: a preliminary study of *Acacia*.** *South African Journal of Science* (1987) **83** 422-427

The seed proteins of 37 species of the genus *Acacia* were investigated serologically by double diffusion and immuno-eletrophoresis using rabbit antisera to *A. karroo, A. ataxacantha* and *A. mearnsii*. Identity and absorption tests revealed remarkable homogeneity in the series Gummiferae; all African species reacting identically except *A. albida* (which reacts atypically with all the antisera). The seed proteins of Acacias from Africa and Australia were found to have virtually identical reactions with the antisera. The African Vulgares species studied were found to be serologically quite different from the Gummiferae, suggesting that the Gummiferae arose independantly from the Vulgares.

158 BRANDIS, D. **Indian Trees** *London: Archibald Constable & Co.* (1906) 1-767

An account of trees, shrubs, woody climbers, bamboos and palms indigenous or commonly cultivated in India. *A. senegal* Willd. is described and illustrated, and occurs in dry hills in Sind, Aravalli range.

159 BRENAN, J.P.M. ***Acacia senegal* (L.) Willd. var. *leiorhachis* Brenan and var. *rostrata* Brenen.** *Kew Bulletin* (1953) 98-100

Gives the type descriptions of the two varieties.

160 BRENAN, J.P.M. **Flora of tropical East Africa: *Leguminosae-Mimosoideae*.** London; Crown Agents for Overseas Governments (1959) 1-173

The first part of a floral treatment of the subfamily Mimosoideae in Tropical East Africa (Uganda, Tanzania and Kenya). Botanical description of the Acacias with a keys based on floral and vegetative and pod and vegetative characters. Gives a botanical description with notes on distribution and ecology of *Acacia senegal* (L.) Willd., including two varieties in the area (var. *senegal* and var. *kerensis*). Variety *senegal* is a tree 3-12 m high common in east Africa in wooded grassland, deciduous bushland, dry scrub with trees between 120-1680 m in altitude. Variety *kerensis* is a spreading bush up to 5 m high, branching from its base, in a similar habitat to var. *senegal* and recorded between 460-1130 m above sea level. Notes that variation is very variable and present treatment unsatisfactory. Treats var. *leiorhachis* as *A. circummarginata* based on field observations of the habit and peeling bark, but on herbarium sheets the difference is a glabrous inflorescence axis, possibly slightly longer petioles and rather smooth purplish twigs. *A. circummarginata* occurs in dry scrub with trees from 730-1180 m. a.s.l.

161 BRENAN, J.P.M. ***Acacia senegal* (L.) Willd.** *Flora Zambesiaca* (1970) **3** (1) 56, 79-80

Floral treatment of the family Leguminosae in Flora Zambesiaca area of Africa (Mozambique, Malawi, Zambia, Zimbabwe and Botswana). Botanical description of the Acacias with a keys based on floral and vegetative and pod and vegetative characters. Gives a botanical description with notes on distribution and ecology of *Acacia senegal* (L.) Willd., including three varieties in

the area (var. *senegal, rostrata* and *leiorhachis*). In this area var.*senegal* is tree with a usually dense flat-toped crown, var. *rostrata* is either a shrub branching at or near its base or a small tree to 4 m high with flaking papery peel and pods rostrate at their apex, in woodland, wooded grassland and bushland from 0-600 m a.s.l. Variety *leiorhachis* is a tree with a central stem with either a rounded crown or irregular with straggling branches, bark with a conspicuous papery peel and glabrous inflorescence axis. In woodland and bushland, often with mopane from 460-910m a.s.l. Here he treats *A. circummarginata* as a synonym of var. *leiorhachis*.

162 BRENAN, J.P.M. **Manual on taxonomy of Acacia species: present taxonomy of four species of Acacia (*A. albida, A. senegal, A. nilotica, A. tortilis*).** Rome, Italy; FAO (1983) 1-47

The most up to date synopsis of the taxonomy of four widespread species of *Acacia* in Africa (*A. albida, A. senegal, A. tortilis* and *A. nilotica*). For each species a brief description is given with comments on recognition, relationships, distribution and a summary of previous taxonomic work. The variation within the species is described, with its recognised subspecies and varieties, and keys provided for identification.

163 BRIMER, L.; KROGH, L.; MEYER, M. **Natural resources and social conflicts in the Sahel.** *Proceedings of the 5th Sahel Workshop, 4-6 January 1993.* Aarhus, Denmark; Aarhus University Press (1993) 1-232

Eighteen papers (15 in English and three in French) are presented from this workshop held at Sandbjerg Manor, Denmark. Topics discussed were divided into three major groups: social conflicts, management of natural resources, and food and cash crop production. Individual topics not mentioned above include production of *Acacia* gum, education in Burkina Faso, exchange rate policy in sub Saharan Africa, natural forest management, the effect of world market frozen meat imports on West African trade in livestock products, gender relations and economic transformations in Niger, demographic changes and schistosomiasis, trees and sustainable rural production, pastoralism, agrosilvopastoralism, food security and pest management.

164 BRITISH PHARMACOPOEIA. **Acacia**. In *British Pharmacopoeia*, London (1993) **1** 19-20

165 BRITISH PHARMACOPOEIA. **Acacia**. In *British Pharmacopoeia*, London (2002) **1** 31-32

166 BRUNCK, F.; COLONNA, J.P.; DOMMERGUES, Y.; DUCOUSSO, M.; GALIANA, A.; PRIN, Y.; ROEDERER, Y.; SOUGOUFARA, B.; DOMMERGUES, Y.R. **[Control of inoculation of trees with root symbionts. A synthesis of a selection of trials in the tropics.]** La maitrise de l'inoculation des arbres avec leurs symbioses racinaires. Synthese d'une selection d'essais auchamp en zone tropicale. *Bois et Forêts des Tropiques* (1990) No.223 24-42

Briefly discussed from 14 sample trials representing a large number of field tests carried out in various countries over the last 10 yr, which studied the effects of inoculation of various tree species with *Rhizobium, BradyRhizobium*, Frankia and ecto- and endo- mycorrhizas. The results presented for *A. senegal* are: (1) positive effects of inoculating with *Rhizobium* on growth in Senegal but only with the addition of phosphate to the poor phosphate deficient soils and non significant differences in growth between innoculating with *Glomus mosseae* and *Rhizobium* compared with *Rhizobium* on its own (more details presented in 1990 seminar and reported in Colonna *et al.*, 1993).

167 BUKHARI, Y.M. **Cytoevolution of taxa in *Acacia* and *Prosopis* (Mimosaceae).** *Australian Journal of Botany* (1997a) **45** 879-891

The present study used chromosome counts and arm ratios for comparative karyotype analysis of 23 species of *Acacia* and 11 species of *Prosopis* to elucidate their cytoevolution and current cytogenetics. Somatic numbers in subgenus *Aculeiferum* were invariably 26 including 7 accessions of *A. senegal*, with the exception of *A. polyacantha ssp. camplyacantha. In Acacia,* subgeneric and specific differentiations are probably caused by structural changes in the chromosomes, whereas differences in the degree of euploidy appear to create infraspecies. Subgenus *Aculeiferum* is a possible progenitor of all other taxa of *Acacia* and *Prosopis.* The study suggests that *Prosopis* has diverged later in geological times from a diploid ancestor (2n = 26) of *Aculeiferum* through centric fission of the second-largest chromosome pair.

168 BUKHARI, Y.M. **A simple method of chromosome preparation for *Acacia* and *Prosopis* (Mimosaceae).** *Hereditas* (1997b) **126** 195-197

Both these genera have small and numerous chromosomes which make detailed cytological investigations difficult. The aim of this study was to find a pre-fixing treatments that could give well-spread and sizable chromosomes suitable for study. Seeds of six *Acacia (*including *A. senegal)* and two *Prosopis* species were germinated and the radicles pretreated with various solutions of colchicine and 8-hydroxyquinoline at different temperatures (4, 12, 16, 29°C) and durations (15, 60, 120, 240 mins), prior to soaking in 75nM KCL for 10 mins and fixing in acetic acid:ethanol (1:3). All 4 time durations of the two solutions gave similar results, producing condensed mitotic chromosomes. Treating root tips with water at 20°C for 4 hours, and then treating with 75 nM KCL for 10 minutes obtained the best results.

169 BUNDERSON, W.T.; EL WAKEEL, A.; SAAD, Z.A.; HASHIM, I. **Agroforestry practices and potentials in western Sudan. Planning for agroforestry**. *Chapter 10, selected contributions from an international symposium held at Washington State University, Pullman, Washington, 24-27 April 1989 (edited by Budd, W.W.; Duchhart, I.; Hardesty, L.H.; Steiner, F.)*. Amsterdam, Netherlands; Elsevier Science Publishers (1990) 227-246

In a separate paper from this conference (Noel *et al.*, Chapter 9) management issues associated with the design and implementation of the Western Sudan Agricultural Research Project (WSARP) were discussed. The evolution of WSARP's approach to research was stressed in relation to traditional systems of production and the role of agroforestry. Building on that management base, this paper discusses WSARP's planning process for initiating and improving agroforestry practices among traditional production systems in the rainfed areas of western Sudan. Lack of an adequate database necessitated an early emphasis on characterizing major production systems and constraints. During this work 3 distinct production systems were identified: (a) sedentary farming communities focusing on crop production with some livestock; (b) transhumant, cattle-oriented agropastoralists migrating between well-defined wet and dry season areas; and (c) nomadic camel-dominated pastoralists in more arid environments, where movements were more frequent, migration patterns less distinct, and cultivation mostly opportunistic. The first two systems are targeted here, but many of the production strategies and problems of transhumant groups are also common to camel nomads. The sedentary systems are mainly based on bush fallow, but also include gum arabic production (from *Acacia senegal*) and irrigated gardens. Mention is also made of the *Acacia albida* farming system on the Jebel Marra massif in Darfur, even though this falls outside the region discussed. Resource and production constraints are identified as land tenure, a deteriorating natural resource base (including disappearing tree species), problems of soil fertility and erosion, and livestock nutritional deficiencies. WSARP has implemented a comprehensive research programme aimed at increasing or maintaining production among smallholder farmers and pastoralists. This has included system improvement and development strategies compatible with the target producers, and research on crops, livestock and pest and disease control. Several promising agroforestry interventions have been identified: fallow improvement by the introduction of leguminous (and other) trees and shrubs; permanent tree intercropping; improved home and irrigated gardens; shelterbelts; gum arabic production; and supplementary livestock feeding with leguminous tree pods. A list of tree species with agroforestry potential is included, indicating suitable systems/products for each.

170 BURKILL, H.M. **The Useful Plants of West Tropical Africa. edit. 2 families J-L** Kew, UK:Royal Botanic Gardens (1995) **3** 1-857

Details a large number of common and trade names from western Africa, and the common uses and trade of *A. senegal* (L.)Willd. from published sources and data from herbarium specimens. Describes the influence of the dry harmattan winds on increasing gum production, and on various tapping systems used. The *sira* tapping system from Senegal follows a 4 year tapping cycle. The main trunk and branches over 35-40 cm in diameter have long strips of bark removed over one quarter of the circumference in any one year. The next year another quarter circumference is stripped, and so on until the fifth year where tapping in back on the renewed bark. Gum arabic can be grouped into 3 grades depending on size and colour. Nigerian gum, which may be of mixed origin, is divided into 3 classes: *falli*, any white or nearly colourless gum, *marrua*, tinted yellow or reddish gums and *mumuye* dark lumpy or coalesced gum. Apart from a wide use in local medicines, the bark of the branches and roots are used as cordage, roots used for structural poles in nomadic huts. Wood colour does vary considerably within the species and provenance, from white through veined black to black although this may in part be due to differences between sapwood/heartwood.

171 CADET, P.; DUPONNOIS, R.; SENGHOR, K. **Relations between nematodes and *Acacia* species. A synthesis of preliminary work in *Senegal***. (Relations entre les nematodes et les Acacia. Synthese des travaux preliminaires au *Senegal*.) In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.)*. L'Orstom, Collection colloques et séminaires, Paris, France (1998) 397-411

Like most plants, the Acacias are attacked by many species of nematodes. In Senegal nematodes of the genera *Meloidogyne, Pratylenchus, Helicotylenchus, Tylenchorhynchus* and *Scutellonema* were found in the rhizospheres of *Acacia tortilis, A. senegal, Faidherbia albida* and *A. holosericea*. The authors summarize recent research, focusing on a means of identifying plants affected by gall nematodes (*Meloidogyne sp.*) through the presence of large cells within roots, and using the rate of increase in nematode populations to evaluate host plant susceptibility and resistance. Tree species particularly susceptible to nematodes include *Acacia holosericea, A. mangium, A. hilliana* and *A. nilotica*; species more resistant include *A. tumida, A. lysophila [A. lysiphloia], A. albida [Faidherbia albida]* and *A. senegal*. Resistance also increases with tree age. In fact the effect of innoculation of nematodes was to stimulate nodulation in *F. albida, A. senegal* and *A. raddiana* [*A. tortilis* ssp. *raddiana*], and with *A. hilliana* and *A. tumida* nodules did not appear on trees which were not infested with nematodes. In *F. albida*, phenolic compounds in roots suggest a resistance mechanism. Concluded that the best candidates for planting in the farmers fields were those resistant to nemadoes which also have their nodulation stimulated (*A. tumida, A. lysophila [A. lysiphloia], A. trachycarpa, A. albida [Faidherbia albida]* and *A. senegal).*

172 CAIUS, J.F.; RADHA, K.S. **The gum arabic of the bazaars and shops of Bombay**. *Journal of the Bombay Natural History Society* (1941) **XLI** 261-271

Describes the history of gum trade and naming of gums which were called after the ports they were exported from, hence gum arabic from Arabian ports, Turkey gum from Turkish ports, East Indian gum from India (Bombay). The East Indian gum is a re-export of gum from Arabia and Africa, and not produced in India. They then descibe some of the properties of gum arabic and investigate the gum arabic sold in the Indian markets. There are 3 types sold in the markets of Bombay, true gum arabic of Sudan, East Indian gum (Iraq and Iran) and Indian gum. The latter is mainly of Indian origin, of a mixture of gums from a wide range of plant families, and rarely clean. They then prepared a key to distinguish the various gums from different species based on the solubility of the gums in water and the behaviour of the aqueous solutions to lead acetate, lead subacetate, ferric chloride and borax. They found that the various samples collected in the markets were either from one plant, or mixtures of 2,3, and 4 different species. They also list a wide range of gum bearing trees in India, from eight different families.

173 CALAMINI, G.; CAPRETTI, P.; MARAI, R. **Fixation and afforestation of the Shamanbot's dune (Democratic republic of Somaliland): seven years after planting results**. (Fissazione e riflorestazione della duna de Shalambot (R.D. Somala): resultati a sette anni dall'impianto.) *Rivista de Agricoltura Subtropicale e Tropicale* (1987) 3-4, 517-521

Gives results, after seven years, of eight species tried in sand dune afforestation trials in southern Somalia. The indigenous species including *A. senegal* showed slow growth, *A. senegal* grew on average to 2.5 m high and an average diameter increment of 6.4 cm (*Eucalyptus camaldulensis* 6.2 m high and 12.8 cm.)

174 CALLAGHAN, T.V.; ABDELNOUR, H.; LINDLEY, D.K. **The environmental crisis in the Sudan: the effect of water-absorbing synthetic polymers on tree germination and early survival**. *Journal of Arid Environments* (1988) **14** (3) 301-317

Newly developed water-absorbing polymers have been suggested to aid plant survival and growth when added to soils in arid regions. A polyacrylamide and a polyvinylalcohol were tested in the Sudan on trees of economic importance. The polyvinylalcohol almost doubled the field capacity of sandy soil when added at 0.5% and retained 22% of this water after 23 days, whereas the control soil retained only 5%. There were no clear effects of the polymers on the germination of three species of tree seedlings (*Acacia senegal*, which is grown for gum arabic, timber and fuelwood; *A. mellifera*, grown for hedges and charcoal; and *Prosopis chilensis*, grown for fuelwood), but they aided survival and growth. Seedling establishment after 50 days was increased by up to 40%. Under severe water stress, only seeds in soils with polymer additives germinated. Both polymers significantly increased the period of tree survival in two nursery experiments. The greatest effect was a five fold increase in survival in the most severe water stress treatment, achieved by using the polyvinylalcohol at 0.5% v/v. However, it is unlikely that applications of the higher concentrations of the polymers will be justified economically. Water-absorbing polymers potentially have an important role to play in tree planting practices in arid regions.

175 CALLAGHAN, T.V.; LINDLEY, D.K.; ABDELNOUR, H.; ALI, O.M.; BACON, P.J. **Application of water storing crosslinked polymers to forestry practices in the Sudan**. In *The Sahel: present problems and future prospects (edited by Lindley, D.K.; Callaghan, T.V.). Proceedings of the Symposium at Grange-over-Sands, 1986*. Cambridge; ITE (1986) 1-9

In order to investigate ways of increasing the success of tree raising and planting using two of a new generation of water absorbing polymers a series of experiments involving trees of economic importance tested their effects on: a. waterloss from sandy soils, b. tree germination and early survival, c. tree seedling survival in the nursery and d. the survival of transplanted young trees. Seeds of *Acacia senegal*, *A. mellifera* and *Prosopis chilensis* were chosen to measure the effect of polymers on seed germination and establishment. No seeds of any of the three species germinated when no water was supplied after sowing; seeds of all species germinated under each polymer treatment when water was added each day; only seeds of *A. senegal* and *A. mellifera* germinated when water was added every third day. Two experiments to determine the effect of polymers on survival of *A. senegal* were carried out, using standard nursery facilities and practices; testing the effect of two polymer additives, each at 2 different concentrations on the survival and height growth of gum arabic seedlings. The tests showed that the polymers had a clear buffering effect as the quantity of the daily-added water decreased. Both polymers increased the survival rates.

176 CAMPBELL, S.; HALL, B.; KLAUSNER, D. **Health, disease and healing in Medieval culture**. Macmillan (1992) 1-204

177 CARR, J.D. ***Acacia senegal* (L.) Willd. var. *leiorhachis* & var. *rostrata***. In: *The South African Acacias*. Conservation Press Ltd., Johannesburg, South Africa (1976) 280-285

A botanical description of both varieties in south Africa, var. *leiorhachis* being a tall straggling up to 17 m high whereas var. *rostrata* is usually a low multistemed shrub to 3-4 m high. Flowering also differs between varieties, var. *leiorhachis* from mid-August through to

September before the trees come into leaf, and var. *rostrata* from December to January, after leaf flush. Both flower on previous seasons growth. Pods are up to 90 mm long, 15-20 mm wide with up to 6 seeds/pod in var. *leiorhachis* and 45-70 mm long, 20-30 mm wide, and usually 2-3 (4) seeds/pod in var. *rostrata*. Cultivation: In var. *leiorhachis* seedlings emerge 4-5 days after nicking and sowing, with relatively slow growth (12 cm in first year, 25 to 35 cm in first season after planting out). In var. *rostrata* germination was slower, 10-24 days after nicking and sowing, and slow growth (10 cm in first season, and 35 cm after 4 years of planting out). A tree planted in the Botanic garden at Brummeria grew to the adult size of 3.6 m after 17 years. Both varieties are drought resistant, and var. *rostrata* can withstand the frosts of Pretoria.

178 CATHRO, J. **Additives and attitudes - a UK perspective**. *Consumer Focus No 7, Information Group Services* (1991)

179 CAZET, M. [**Tree plantation in line and alley cropping on degraded sandy soils of central north Senegal. Influence of inoculation of trees with rhizobium sp. and the treatment of soils with nematicides on the behaviour of trees and cultivation.**] Plantation en lignes et cultures intercalaires sur les sols sableux degrades de la zone centre nord du Senegal. Influence de l'inoculation des arbres avec le rhizobium sp. et du traitement nematicide des sols sur le comportement des arbres et des cultures. Direction des Recherches sur les productions Forestieres, ISRA (1987a) 1-15

A comparative study of five leguminous species planted on degraded sandy soils of Thianaba, Senegal. It aims to test the effect of rhizobium inoculation and nematocide treatment on development of the trees, and crop behaviour. The species planted are *Faidherbia albida*, *Acacia tortilis*, *Acacia nilotica*, *Acacia senegal* and *Prosopis juliflora*.

180 CAZET, M. [**Linear planting and intercalary cultivation on degraded sandy soil in Central North Senegal. Initial results of experiments conducted at Thienaba since 1985.**] Plantation en lignes et cultures intercalaires sur les sols sableux degrades de la zone centre nord du Senegal. *Unpublished document, Institut Senegalais de Recherches Agricoles, Ministere du Developpement Rural, Senegal* (1987b) 1-15

Regeneration and enrichment with *Faidherbia albida* is generally the solution recommended for improving the condition of degraded soils in the zone north of the Senegalese groundnut basin. This solution has proved effective but it has its limits. Other species capable of improving soils and of providing varied yields while having more rapid growth were tested in an agroforestry system of cultivation in lanes compatible with the constraints of harnessed/yoked farming. The present experiment enabled comparison to be made of the behaviour at a young age of five species, *Faidherbia albida*, *Acacia tortilis* ssp. *raddiana*, *Acacia nilotica* ssp. *adstringens*, *Acacia senegal* and *Prosopis juliflora* on the sandy degraded soils of Thienaba and their eventual influence on the yield of intercalary cultivation to be tested. In this respect, *Acacia senegal* seems to be a particularly interesting species, as much in terms of its remarkable behaviour as of the improving role which it seems to play on intercalary cultivation. This experiment was aimed also at testing the effect of the inoculation of nursery plants on the behaviour of the trees after transplantation and eventually on the yield of intercalary cultivation. What the experiment made clear was the beneficial effect of inoculation on the growth at a young age of certain species only, namely *Prosopis juliflora* and *Faidherbia albida*, and, correlatively, an improvement in the yield of cultivation alongside these two species. Recognizing the interest shown in nematicide treatment of plots of cultivation, the third objective of this experiment was to look at the eventual effects of this treatment on the behaviour of trees, as well as possible interaction between the three factors studied. It appears that the nematicide treatment improves the growth of trees during the first year of growth, but it can also annul the effects of inoculation on the yield of intercalary cultivation with certain species such as *Prosopis juliflora*.

181 CAZET, M. **Les plantations linéaires denses sur les sols sableux degrades de la zone center-nord du Sénégal**. *Bois et Forêts des Tropiques* (1989) **222** 27-37

Similar results that appear in the above two papers by Cazet. Rooting profiles are presented for 32 month old seedlings in plantation trials in Senegal. *Acacia senegal* and *A. tortilis* ssp. *raddiana* were deep rooting, up to 3.5 m in *A. senegal*, whereas *F. albida* only extended to 2 m depth and *A. nilotica* ssp. *adstringens* to 1.5 m deep. The latter had more abundant surface roots in the top 0.5 m of soil. The lines of *A. senegal* planted with 2.5 m spacing between trees and intercropped with local crops reached a 2m high dense hedge after 30 months old, producing 3 tonnes of above ground biomass per hectare.

182 CHADWICK, M.G.A. **The market for gum arabic**. *Trop. Sci.* (1961) **3** (1) 31-9

A review of the market, covering: source of product (chiefly *Acacia senegal* and *A. seyal*) and statistics of production in the main exporting countries; consumption in selected importing countries; main uses, in confectionery and adhesives, with notes on other industrial uses, e.g. textiles, drugs; substitutes; and prices. Data are appended on the main commercial grades of Sudan gum 'hashab' or 'Kordofan' gum, and on pharmacopoeia requirements. In spite of competition from substitutes in the manufacture and processing of textiles, paints, and inks, the general

demand for gum arabic is expected to continue at about its present level in the foreseeable future.

183 CHARPENTIER, G. **Recueil de Materiaux Epigraphiques Relatifs a la Botanique de l'Egypte Antique**. Paris, France; Trismegiste (1981) 1-968

184 CHATTOPADHYAY, S.; SINGHAL, R.S.; KULKARNI, P.R.; SONI, P.L. **Micro encapsulation of vanillin using *Acacia nilotica* gum**. *Journal of Scientific and Industrial Research* (1997) **56** (2) 109-110

The prospects of utilization of gum from the widely grown *Acacia nilotica* were investigated. Micro encapsulation of flavours using *A. senegal* gum, imported from African countries, is a common practice. Results show that *A. nilotica* gum can ideally be substituted for *A. senegal* gum for micro encapsulation of food flavour [although this gum has not undergone the same toxicological tests].

185 CHAUDHRI, I.I.; SALEEM, R.A. **Medicinal plants of West Pakistan: *Acacia senegal* Willd.** *Pakistan J. Sci. Industr. Res.* (1962) **5** (3) 197-8

Gives a description, and ecology of the species in West Pakistan, with a review of possible collecting techniques for gum arabic. Its distribution in Pakistan is in the Thar desert, colonising slopes of high sand dunes (rich in calcium) and also on the calcareous rocky slopes bordering the Arabian sea. Concludes that given the extensive distribution of the tree in Pakistan it should be collected as large amounts (2,250 maunds) of gum arabic are imported every year from India and Iran.

186 CHEEMA, M.S.Z.A.; QADIR, S.A. **Autecology of *Acacia senegal* (L.) Willd.** *Vegetatio* (1973) **27** (1-3) 131-162

Describes the ecology and uses of *Acacia senegal* (*var. senegal*) growing in 25 sites around Karachi, South West Pakistan. Phenological observations are recorded, soil analyses given, seed pretreatments and propagation by shoot cuttings tried. The primary climatic factors, which favour A. senegal distribution, are low rainfall (250 mm) and absence of frost. Seeds from different sites showed considerable variation in germination capacity and rate of germination was increased 12 fold in 6 month old seeds compared to fresh seed. *A. senegal* grew best on dry streambeds with coarse textured soils, elsewhere preferring rocky hills (calcareous) to the plains. Flowers August to December in Pakistan, and fruits ripen from the end of August.

187 CHEVALIER, A. **Sur la production de la gomme arabique en Afrique Occidentale Francaise**. *Revue de Botanique Coloniale* XXXII, 30 April (1932), 261

188 CHEVALIER, A. **Michel Adanson: voyageur, naturaliste et philosophe**. Larose, Paris (1934)

189 CHEVALLIER, M.H.; BORGEL, A. [**Genetic diversity of acacias.**] Diversité génétique des acacias. In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.)* L'Orstom, Collection colloques et séminaires, Paris, France (1998) 287-308, 462-463

As the introductory paper to the plant genetic resource section of the conference, the authors discuss the species and genetic diversity of the genus Acacia. Techniques for studying genetic variation (particularly the use of molecular markers) are noted. The genetic structure of the genus *Acacia* is heterogeneous. In comparison with African *Acacia* spp., the Australasian species exhibit lower intra population variation, but have far greater inter population differences, which is correlated to well defined geographical regions. Although *Acacia* spp. generally are cross fertilizing species, several African species have a high rate of selfing. Discusses results of several molecular studies in Senegal into the *A. nilotica* and *A. senegal* 'complexes' of species, and *F. albida*. For *A. senegal* the genetic diversity was assessed using isoenzymatic markers for 12 populations within Senegal. The mean percentage of polymorphic loci per population was 47%, the mean number of alleles per locus was 1.54 and had a low genetic diversity (H = 0.17). Another study including populations from Mali, Mauritania, Sudan, Kenya and Pakistan found a clear separation between west and east Africa. Also summarized the work comparing *A. senegal* with other related west African species: *A. dudgeoni, A laeta, A. mellifera* and *A. gourmaensis*, described in Chevallier *et al.* (1994).

190 CHEVALLIER, M.H.; BRIZARD, J.P.; DIALLO, I.; LEBLANC, J.M. **Genetic diversity in the *Acacia senegal* complex**. [La diversite genetique dans le complexe *Acacia senegal*.] *Bois et Forêts des Tropiques* (1994) No.240 5-12

After successive droughts in Senegal it is estimated in 1977 that 60% of the tree cover of *A. senegal* in North Ferlo has disappeared. Faced with this genetic erosion, collections of *Acacia senegal* seeds were made throughout the range of the species in Senegal. Genetic diversity was assessed using isoenzymatic markers for 15 provenances. A hypothesis for the mode of inheritance of each of 10 enzymatic systems is proposed. Polymorphism is weak with only 12 genes found to be polymorphic. *A. senegal* exhibits a low genetic diversity (H = 0.175) and a wide variation within populations. What little difference between populations was noted from populations from the south eastern Senegal and those from the north. The genetic diversity of *A. senegal* is compared to the diversity observed in other related species: *A. dudgeoni, A laeta, A. mellifera* and *A. gourmaensis*. *A. senegal* was found to have many similarities with *A. dudgeoni*, *A. laeta* was found to have a fixed heterozygosity intermediate between

A. mellifera and *A. senegal*, and *A. gourmaensis* was found to possess few bands in common with the other species.

191 CHIKAMAI, B.N. **The availability, quality and processing aspects of gum arabic from Kenya.** *Ph.D. Thesis, Bangor University, Wales, UK* (1994) [from thesis summary]

Studies reported in this thesis were carried out to determine: a) the availability of *Acacia senegal* resources for gum arabic in northern Kenya, b) chemical properties and hence quality of gum arabic from Kenya, c) simple quality control and monitoring procedures appropriate for producer countries and d) processing of gum arabic for improved functionality. Results of the resource survey led to the identification of *Acacia senegal* var. *kerensis* as the main source of gum arabic in Kenya, other *Acacia* species producing gum arabic growing in association with *Acacia senegal* (hence possible contaminants) and development of *Acacia senegal* vegetation maps for Isiolo, Marsabit and Turkana Districts. Characterisation of the gum revealed that gum from var. *kerensis* differs from the current specification of commercial gum arabic i.e. var. *senegal* by having a higher specific rotation, nitrogen content and intrinsic viscosity thereby confirming the taxonomic differences observed. Overall however, the gum is comparable to commercial gum arabic in emulsification and other properties. Differences were observed in properties between regions and samples in a region, and were attributed to local adaptations and genetic differences respectively. These differences represent future opportunities for improving gum production through tree improvement and handling practices. An evaluation of methods for monitoring revealed that gel permeation chromatography provides a quick and consistent diagnosis of gum arabic of commerce. The use of physico-chemical and carbohydrate parameters (i.e. analytical) and enzyme linked immunosorbent assay (ELISA) are also useful but tend to be influenced more by natural product variability. However, the ELISA technique needs refining to make it specific to gum arabic from *Acacia senegal*. Results on processing showed that heating the gum solution at 100°C (current industrial practice) results in the significant degradation of the gum molecule after 6 hours affecting emulsification functionality while heating at 65°C is a favourable alternative. The use of enzyme biotechnology has a promising future.

192 CHIKAMAI, B.N.; BANKS, W.B. **Gum arabic from *Acacia senegal* (L.) Willd. in Kenya.** *Food Hydrocolloids* (1993) **7** (6) 521-534

Fifty-seven samples of *Acacia senegal* var. *kerensis* gum from four areas in the gum producing region of northern Kenya were characterized using physico-chemical and carbohydrate parameters, amino acid composition and metal content. The analytical data showed differences in specific rotation, nitrogen content and intrinsic viscosity compared with gum from Sudan, Nigeria and Uganda. Slight differences were also observed in the sugar content. These differences probably reflect a different variety of *A. senegal* (var. *kerensis*) producing the gum in Kenya compared to the other countries (var. *senegal*). Differences were also observed in specific rotation, nitrogen content, intrinsic viscosity and metal content between different regions. These differences may reflect adaptation by the trees to the local climatic and edaphic conditions. Some of the gums had high specific rotations, from -34 to -40 out of the recommended FAO Food and nutrition paper (1990) (-26 to -34). Nitrogen and protein contents were also exceeding the upper limit set by FAO (1990) specification. No distinct differences in amino acid composition among the regions were observed but an increasing trend was seen in the amount of some amino acids with increase in nitrogen content. Overall however, gum arabic from Kenya is comparable in functional emulsification properties to acceptable commercial consignments from the other countries. The relationship between analytical properties and certain functional properties of the gum are discussed.

193 CHIKAMAI, B.N.; BANKS, W.B.; ANDERSON, D.M.W.; WANG WEIPING, P. **Processing of gum arabic and some new opportunities.** *Food Hydrocolloids* (1996) **10** (3) 309-316

Because gum from *A. senegal* var. *kerensis* in Kenya has properties that are different from that of *A. senegal* var. *senegal* from Sudan (higher viscosity and tending to gel at lower concentrations) this study looked at approaches for processing the gum to reduce these undesirable properties. Gum arabic from *Acacia senegal* var. *kerensis* was processed following two approaches: heating the gum solution and using enzyme biotechnology. Studies on heat processing were carried out at 100 degrees C (i.e. simulating the conventional industrial method) and at 65 degrees C. Experiments on enzyme biotechnology were carried out using three enzymes: a Pronase, Viscozyme and a beta-D-galactosidase. In both experiments the solutions were allowed to stand for 96 h with samples of 100 ml being removed every 3, 6, 12, 24 and 48 h. Results of heat processing showed that heating gum solution at 100 degrees C for more than 6 h caused significant degradation of the protein component and subsequent loss of emulsification properties, though a reduction in viscosity and gelling to desired levels was achieved. Heating at 65 degrees C achieved reduction in gelling within 24 h without drastic loss in emulsification functionality. Thus process time and temperature were confirmed as important parameters during heat processing. The three enzymes caused loss in viscosity and gelling but with different implications for the other gum properties. Pronase degraded the gum to 16 ml/g within 12 h but there was loss in protein and emulsification properties. It is therefore not suitable for processing gum where emulsification and stabilization are important properties.

Both viscozyme and beta-D-galactosidase attained reduction in viscosity and gelling to levels desired for industrial uses within 24 h. The former enzyme however, caused some degradation of the protein component giving rise to unstable emulsions; the amino acids released selectively were arginine, histidine, hydroxyproline, leucine, serine and threonine and there was also release of neutral sugars, particularly rhamnose. The effect of beta-D-galactosidase was to increase the overall protein content and subsequent emulsification properties.

194 CHIKAMAI, B.N.; HALL, J.B.; BANKS, W.B. **Survey of *Acacia senegal* resources for gum arabic in northern Kenya**. *Commonwealth Forestry Review* (1995) **74** (3) 246-252

Acacia senegal stands were surveyed in the Isiolo, Marsabit and Turkana Districts of northern Kenya, to assess their commercial availability as sources of gum arabic. Existing vegetation maps from the three districts were used as the starting point for planning the survey and production of provisional *A. senegal* maps. Results of the survey by district showed that Turkana contains the highest number of trees while Isiolo has the least, although all three districts have sufficient stands for production of gum arabic. *A. senegal* var. *kerensis* was observed in all areas and is the main source of gum arabic. The tree form of *A. senegal* var. *leiorhachis* (understood at present as *A. circummarginata*) has a restricted distribution in Marsabit and Isiolo Districts along luggas (dry river streams), and attempts to collect gum from this variety were unsuccessful confirming the experience of the local communities. A multivariate analysis assessment of the relationship between stocking and environment showed that topography has a strong influence on the density and distribution of the resource with higher densities observed on hills than along luggas or on plains. It has been used as an indicator species of basement hills and ridges. These soils are usually coarse in texture and well drained. However, in more arid environments, higher densities were occasionally associated with luggas. In some areas, land use patterns were responsible for the differences observed in stocking densities. *A. senegal* grows in association with other species of *Acacia, which produce gums,* and hence knowledge about these species and the gums they produce is important to minimize adulteration. The most common associates of *A. senegal* were *A.tortilis* and *A. reficiens* on the plains and along the luggas, and the *Commiphora* species (with the exception of *C. africana*) were characteristic of the hills, although in frequency *A. senegal* was by far the dominant species. *A. senegal* var. *kerensis* thrives under arid conditions, in Turkana around 250 mm of rainfall and in Isiolo district a mean around 590 mm. Also Isiolo district can suffer from cold dry months which from evidence in Sudan restrict the productive dry season.

195 CHIKAMAI, B.N.; OSMAN, M.E.; MENZIES, A.R.; BANKS, W.B. **An evaluation of methods for characterising and monitoring gum arabic of commerce and related *Acacia* gums**. *Wood Science and Technology* (1995) **30** (1) 49-61

Three methods that have been suggested as inexpensive for characterization of gum arabic were evaluated in characterizing and monitoring gum arabic of commerce. The methods were: physico-chemical and carbohydrate analysis (analytical), determination of molecular mass by gel permeation chromatography (gpc), and an Enzyme Linked Immunosorbent Assay (ELISA). The results revealed that gpc provides quick and consistent information on gum arabic of commerce from *Acacia senegal*. It was able to detect the three chemical species: arabinogalactan protein complex (AGP), arabinogalactan (AG) and glycoprotein (GP) fractions that are typical of *Acacia senegal* and could differentiate gum from the two varieties *A. senegal* var. *senegal* and var. *kerensis* on the basis of the enhanced UV peaks in the latter. Some problems with the analytical method are detailed. The ELISA method was thought to have future scope but will require the development of more specific monoclonal antibodies.

196 CISSÉ, M.I. **Programme des Zones Aride et Semi-Aride. Synthèse des essais d'ébranchages pratiqués sur quelques arbres fourragers sahéliens de 1978 à 1983**. Programme Document, ILCA Mali (1984) No.AZ 103 1-18

Various pruning techniques on *Acacia senegal* and *Pterocarpus lucens* in the southern Sahel, and on *Acacia albida* in the north Sudan from 1878 to 1983 were put into practice to determine whether method and timing had an influence on the foliage production of the species. According to the species, the treatments has a depressive effect on *A. senegal* and *P. lucens*, but stimulated the yield of *A. albida*. None of the species supported an exploitative regime.

197 CLOUDSLEY THOMPSON, J.L. **Etosha and the Kaokoveld: problems of conservation in Namibia**. *Environmental Conservation.* (1990) **17** (4) 351-354

Etosha National Park in NW Namibia is an area extremely rich in game. Etosha Pan, a 6,133 km^2 saltpan, is bordered on the south by natural springs and artificial waterholes where animals congregate in large numbers and cause overgrazing and browsing pressure. Notes the occurrence of *A. senegal* in mixed *Acacia* woodland in the eastern sector. This woodland provides fodder for many wild ungulates in the Park.

198 COE, M.; BEENTJE, H. **A field guide to the Acacias of Kenya**. Oxford, UK; Oxford University Press (1991)1-148

A useful field guide to the 50 taxa of *Acacia* that occur in Kenya, with various keys, descriptions and illustrations highlighting the variation. *Acacia senegal* has

three varieties that occur in Kenya, if *A. circumarginata* is treated as a synonym of var. *leiorhachis*. The species is widespread in the country, occurring in river valleys to woodland and arid thorn scrub. Often at lugga margins (clayish pans) and locally dominant. Said to form dense thickets in many areas after the removal of the black rhino.

199 COETZEE, J.A. **The morphology of *Acacia* pollen**. *South African Journal of Science* (1955) **52** 23-7

Describes a study made of the pollen morphology of 28 South African and 31 Australian species of *Acacia*. It was discovered that by studying the furrow configuration in the exine of the polyads, the South African species can be distinctly separated from the Australian species. The pollen of the South African species can further be divided by the two types of inflorescence in this genus. *Acacia senegal* was found to have no furrow on the pollen grain, a 16 celled polyad and a spicate inflorescence.

200 COLONNA, J.P.; DUCOUSSO, M.; BADJI, S. **Peut-on améliorer la croissance de l'*Acacia senegal* (L.) Willd. et du système symbiotique "*Acacia senegal-Rhizobium*"?** In *Physiologie des Arbes et Arbustes en zones arides et semiarides. Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadnam, C.; Joly, H.; Bory, G.).* (1993) 195-204

Greenhouse plants of *A. senegal* where grown in poor sandy Dior soil in Senegal, which is poor in phosphorus (11 ppm available phosphorus), in 12 treatments involving inoculation with endomycorrhiza (*Glomus mosseae*), rhizobium, double inoculation with them both, and under 2 levels of phosphorus fertilization in soils which were sterilized or not. Growth parameters were measured in the seedlings after 6 months. The plants without inoculation grew very poorly, and the other treatments were also poor if additional phosphorus was not added. Biomass (aerial part) and nodulation was considerably increased (over 300%) over the natural conditions control with the best treatment being inoculation with the Rhizobium ORS 1007 and 60 ppm of phosphorus added per plant in non sterilized soil. Both this treatment and nodulation with 30 ppm of phosphorus increased nodule dry weight c. 7 times; total N, P and Mg 4-5 times; total K and Ca 3-4 times. Mycorrhizal inoculation had a positive effect on plant growth and mineral composition and double inoculation better still although not as good as the phosphorus treatments.

201 COLONNA, J.P.; THOEN, D.; DUCOUSSO, M.; BADJI, S. **Comparative effects of *Glomus* mosseae and P fertilizer on foliar mineral composition of *Acacia senegal* seedlings inoculated with *Rhizobium*.** *Mycorrhiza* (1991) **1** (1) 35-38

Essentially the same experiments presented in 1990 seminar and reported in Colonna *et al.* (1993).

202 COMMONWEALTH AGRICULTURAL BUREAU INTERNATIONAL (CABI) ***Acacia senegal* (L.) Willd** In Forestry Compendium Global Module CD-Rom. CABI, Wallingford, UK. (2000) Full data sheet

Review article of the species, including taxonomic, distributional and climatic data, soils, land use and environmental and service aspects, and uses, written by the senior author. *A. senegal* is a pioneer, nitrogen-fixing tree, that produces a valuable product (gum arabic) which is sold in international markets. It also has a secondary role as a restorer of soil fertility and a provider of fuel and fodder in many agricultural systems. The increased crop yields on land cleared of acacias are recognized in many parts of Africa even where there is no tradition of bush-fallow. It has value in desertification control through sand dune stabilization and wind breaks. Being a prolific seeder and thorny, it can form thickets and become invasive. More work is needed in identifying the mechanisms of gum producion and evaluating its genetic variation.

203 COOMES, J.J.; ISLIP, H.T. **Gum arabic from Somaliland Protectorate**. *Colonial Plant and Animal Products* (1953) **3** (3) 242-8

Gum samples collected from small leaved *Acacia senegal* L. Willd. in Somaliland [N. Somalia], were analysed chemically and compared with commercial gum arabic samples from Kordofan, Sudan, and Nigeria. Samples were also submitted to the commercial trade (importers and a confectionary manufacturer) but the initial samples were unsuitable having a high content of insoluble material when placed in cold water and a high viscosity. The importance of a clean clear appearence to the gum was stressed by the trade, and further 'cleaner' samples collected from Somalia showed potential for marketing.

204 COPPEN, J.J.W. **Gum arabic, Gum talha and other Acacia gums**. In *Gums, resins and latexes of plant origin. Non-Wood Forest Products No.6.* Rome, Italy; Food and Agriculture Organization of the United Nations (1995) 11-25

A survey of Acacia gums, their uses, supply and demand on the world markets, value added processing and development potential. The major uses are divided into food, pharmaceutical and technical. Sudan dominates world production and trade producing the best quality gum arabic, and the European Community is by far the largest market, averaging 28,000 tons between 1988-93. Gum is graded both in Sudan and Nigeria, and some processed in Sudan since 1994 (by using a hammer mill to pound to a smaller uniform size - kibbling), with differing export prices depending on the grades. Gum is collected from a range of Acacia species, primarily from *A. senegal* (L.) Willd. and *A. seyal*, Del. but also from *A. karroo Hayne, A. paoli Chiov., A. polyacantha* Willd. and *A. sieberana* DC. Describes the methods of collection including the use of a "sunki" as a modern

tapping tool, which damages the tree less than the traditional axe. For trees planted from seed tapping starts around 4-5 years of age, for those planted as seedlings, tapping can start in the third year. Yields are very variable from individual trees, best yields from 15-20 year old trees in Sudan and 7-15 year trees in Mali. Apart from kibbling, powdered gum is produced by spray drying in the consumer countries. Gum is dissolved in water, filtered, pasteurized and sprayed into a stream of hot air. A energy intensive process, using large quantities of pure water, and high ambient temperatures in the producing countries are some reasons why it has not been taken up there even though the prices for the end product are much higher.

205 CORBY, H.D.L. **Systematic implications of nodulation among Rhodesian legumes**. *Kirkia* (1974) **9** 300-329

Reports on nodulation in 489 Rhodesian [Zimbabwian]species of legumes, including both varieties of *A. senegal (var. leiorhachis and var. rostrata)*, from the 539 species surveyed. Most woody plants were grown from seed, and the seedlings examined for nodules. If they failed to nodulate, the seed was regrown with either rhizosphere soil from flourishing plants of the same or related species or with rhizobial cultures from its near relatives, and the seedlings checked around 100 days later.

206 CORBY, H.D.L. **Types of Rhizobial nodules and their distribution among the Leguminosae**. *Kirkia* (1988) **13** (1) 53-123

Describes a survey of 210 genera of the Leguminoseae, comprising 83% of all species, where five types of rhizobial nodules have been found on seedlings grown from inoculated seed. The vast majority of species, characteristic of woody tribes, belong to the Caesalpinioid type. The morphology and evolution of these nodule types within the family are discussed. Lists in the appendices the dimensions and morphology of the nodules for each species, and for *Acacia senegal* records the Caesalpinioid nodule type and for *Faidherbia albida* both Caesalpinioid and Crotalarioid nodule types.

207 COSSALTER, C. **Introduction of Australian *acacias* into dry tropical west Africa**. *Forest Ecology and Management* (1986) **16** (1-4) 367-389

About 50 species of Australian *acacias* are undergoing trials in Burkina Faso, Cameroon, Niger, Senegal. The largest number of experiments being made in Senegal. Initial results show that these species on the whole are sensitive to drought conditions. At Bandia, a coastal region of Senegal, *A. schlerosperma* was the best adapted Australian *acacia* and one of the most interesting species for the area, along with *Prosopis juliflora*, *A. senegal* and *A. seyal*.

208 COSSALTER, C. ***Acacia senegal*: Gum tree with promise for Agroforestry**. *NFT Highlights, Winrock International, USA* (1991) 91-02 1-2

Brief highlights from the literature are given on the botany, distribution, ecology, uses, propagation, and pests and diseases of *Acacia senegal*. Its uses include: fuel wood; poles for construction; fence posts; tool handles; shuttles; ropes (from the root bark fibers). Other uses apart from gum and wood are food (from the seeds) and fodder (foliage and pods), dune stabilization and agro forestry (bush fallow for agricultural crop production, and afterwards, controlled grazing). Its propagation and pests and diseases that may effect it include: *Stictocephala bubalus*, spiders, *Coleoptera*, locusts and the fungi *Cladosporium herbarium*, *Fusarium* sp., *Ravenelia acaciae-senegalae* and *R. acaciocola*.

209 COUGHENOUR, M.B.; ELLIS, J.E. **Landscape and climatic control of woody vegetation in a dry tropical ecosystem: Turkana District, Kenya**. *Journal of Biogeography* (1993) **20** (4) 383-398

Spatial organization of a dry woodland/savanna/shrub steppe ecosystem in a 9000 km^2 region of arid N. Kenya, analysed for abundance and distribution of woody vegetation in relation to gradients in landscape and rainfall, showed 4 major woody species assemblages dominated by *Acacia tortilis, A. senegal, A. reficiens, Phyllanthus reticularis [P. reticulatus]/Trichilia roka [T. emetica]* respectively.

210 COULIBALY, K. **Le Gommier et les Actions en cours pour sa Rehabilitation au Mali**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 25-31

Describes the natural distribution of the *A. senegal* in Mali, which occurs between longitudes 14°and 16° N, and dense populations (over 100 trees/ha) which only occur in Kayes and Timbuctu regions. These trees are not exploited, their value is underestimated, and they are often cut down because they could provide nesting sites for birds that attack millet fields. Describes the work of the UNSO project "Rehabilitation of *A. senegal* in Mali" which aims to promote planting of the tree, commercialization of gum arabic, with the long-term effects on reducing soil degradation. Gives export figures of gum arabic from 1971-1981 which increased to about 2000 tonnes in the early 1980's, and presently (1988) is between 3 - 4,000 tonnes.

211 COULIBALY, O.; SANGA, M., BRIZARD, J.P.; BORGEL, A. **Compte Rendu de Mission ISRA-ORSTOM. Recherche de Populations d'*Acacia senegal A. raddiana, A. albida* dans la Region de Tambacounda**. ISRA/DRFF, Senegal (1991)

212 COVENEY, R.D.; ISLIP, H.T. **Gum arabic and soil from Somaliland protectorate**. *Colon. Plant Anim. Prod.* (1954) **4** (1) 42-5

Examination of 30 samples of gum from *Acacia senegal* and of the soil on which it grows, showed no correlation between the viscosity of the gum and (a) ash content, (b) its Ca content, or (c) content of other mineral constituents. Thus though *Acacia* trees yielding gum in Somaliland grow on markedly calcareous soils and have a high viscosity, there is no relationship between these two circumstances.

213 CRANE, E.; WALKER, P.; DAY, R. **Directory of important world honey sources**. *International Bee Research Association* (IBRA), London, U.K. (1984) 30-31

A. senegal is an important species for honeybees. Its honey properties are: Pfund amber, Granulation rapid, Aroma v. mild. It has a nectar rating of N1.

214 CROWDER, M. **West Africa under Colonial rule, 2nd edition**. Hutchinson of London (1970) 1-511

215 CURTIN, P.D. **Economic change in precolonial Africa. Senegambia in the Era of the Slave Trade**. Madison USA, University of Wisconsin Press (1975) 1-363

216 DABO, M. **Situation et organisation du commerce interieur de la gomme arabique au Senegal**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 239-245

Discusses the marketing and trade of gum arabic within Senegal, and the problems affecting its trade such as price fixing and drought. Gum can be sold to authorized dealers in three major regions, only during the season from 20 December to 20 July each year. The government strictly regulates the distribution and taxing of the gum. Apart from the export market there is a local pastille industry, VALDAFRIQUE, which uses 150 tons of gum per annum.

217 DAGGASH, M. **Comparative figures for coppice growth in the Sudan savannah [of N. Nigeria]**. *Inform. Bull. For. Dep. Nigeria* (1954) No.15 1-2 [En]

Height-growth data of coppice regrowth are given from experimental plots at Dutsin Kura, to illustrate comparative rates of growth of different species under various conditions of grass burning (burning early in the dry season (1) annually, (2) biennially, (3) every 4th year, (4) burning annually late in the dry season; and (5) completely protected from fire). The data refer to the following species: *Acacia ataxacantha, A. macrostachya, A. senegal, A. seyal, Anogeissus schimperi, Cassia singueana, Combretum glutinosum, C. micranthum, Commiphora africana, Croton amabilis, Dichrostachys glomerata, Feretia canthioides, Grewia flavescens, G. mollis, Guiera senegalensis, Piliostigma reticulatum, Randia nilotica, Ximenia americana, Zizyphus mauritiana* and *Z. mucronata*.

218 DALE, I.R.; GREENWAY, P.J. **Kenya trees and shrubs**. Nairobi, Buchanan's Kenya Estates Limited, in association with Hatchards, Piccadilly, London (1961) 293-294

Describes the taxonomy and distribution of *Acacia senegal* (L.) Willd. in Kenya. Also describes the tapping of gum arabic and the best conditions for trees to bear gum; the best areas being, where there is an annual rainfall of 10-14 in., in the Sudan.

219 DALY, M.W. **Empire on the Nile: The Anglo-Egyptian Sudan 1898-1934**. Cambridge UK, Cambridge University Press (1986) 1-542

220 DANTHU, P.; ICKOWICZ, A.; FRIOT, D.; MANGA, D.; SARR, A. **Effect of the passage through the digestive tracts of domestic ruminants on the germination of woody leguminous tree seeds in the semi arid tropics**. [Effet du passage par le tractus digestif des ruminants domestiques sur la germination des graines de legumineuses ligneuses des zones tropicales seches.] *Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux* (1996) **49** (3) 235-242

The survival and germination rates of seeds of seven leguminous tree species (*Acacia nilotica* ssp. *adansonii, A. raddiana, A. senegal, A. seyal, Bauhinia rufescens, Faidherbia albida* and *Prosopis juliflora*) were studied after their ingestion and excretion by cattle, sheep and goats. The results show that hard seeds remain intact and keep their viability after excretion by domestic ruminants, whereas seeds with permeable integuments are destroyed, and cattle excrete a higher proportion of intact seeds than small ruminants. This difference seems mainly related to a stronger masticatory activity of sheep and goats; germination of hard seeds is not improved by passage through the digestive tracts of ruminants. In conclusion, ingestion of hard seeds by domestic ruminants cannot be considered as a way of breaking dormancy, but only as a means of dispersing seeds which are intact.

221 DANTHU, P.; LEBLANC, J.M.; BADJI, S.; COLONNA, J.P. **Vegetative propagation studies of gum arabic trees. 2. The vegetative propagation of adult *Acacia senegal***. *Agroforestry Systems* (1992) **19** (1) 15-25

In studies carried out in Senegal in 1990, vegetative propagation of *Acacia senegal* was found to be possible from branch fragments taken from the crown of mature trees (13 years old), without causing ortet destruction.

Cuttings 7, 15 and 23 cm long were taken immediately before use from 50 cm branches already removed from the trees and kept in a humidified jute cloth for up to 8 days old. Four diameter classes were tested: <4, 4-9.9, 10-15.9 and 16-25 mm. The cuttings were treated with 4% IBA (in talcum powder) before planting at 3-5 cm depth in perforated polybags in a medium of basalt chips, sand and humus rich soil (9:2:1), and placed in a cold frame under an awning in which the temperature varied from 20 to 38°C. Weekly fungicidal treatments were applied. The most responsive planting stock was taken from cuttings 15 cm long (with 12 to 15 nodes) and a diameter of 10±6 mm (wood of 2 to 4 years old). Rooting was optimal when the cuttings had no leaves and were collected in the rainy season (June-October). However these cuttings retained the physiological characteristics of mature trees, with slow growth, plagiotrophy, and producing flowers and fruits. These cuttings allow the conservation of the selected genotypes, with the possibility of maintaining them for up to 8 days prior to rooting in the nursery. The next step is to initiate a process of rejuvenation with the aim of *in vitro* cloning.

222 DANTHU, P; ROUSSEL, J.; DIA, M.; SARR, A. **Effect of different pretreatments on the germination of *Acacia senegal* seeds**. *Seed Science and Technology* (1992) **20** (1) 111-117

Seeds of *A. senegal*, collected from several stands in Senegal and ranging from 3 months to >5 years old, were soaked in water for 2-48 h, manually scarified, soaked in 95% sulfuric acid for 14 min, or immersed in boiling water for 5-40 s before being tested for percentage germination. Total percentage germination was 85% with no pretreatment, 65% after soaking for 48 h, 30% after 5 s scalding in boiling water and 0% after 10-40 s scalding. Other pretreatments did not greatly affect overall germination, but germination rate was advanced by scarification with acid, 12-24 h soaking in water, or manual scarification. Untreated seeds were recommended for field sowing, and 12-24 h soaking in water for tree nurseries.

223 DANTHU, P.; SALL, P.N.; SECK, M. **Grafting compatibility between some African acacias: first results**. [Compatibilite de greffage entre quelques acacias africains: premiers resultats.] *Bois et Forêts des Tropiques* (1998) No.258, 49-57

Graft compatibility and grafting potential were investigated in Dakar-Hann, Senegal for four *Acacia* and a *Faidherbia* species indigenous to Africa. Cleft grafts were carried out on 8 month old container grown plants (a total of 25 stock/scion combinations were made); the grafted plants were grown under shelter for 2 months, then in nursery beds for 10 months. Some were transplanted to the Bandia experimental field station. Parameters measured were graft survival after 10 months and 5 years, and fruiting. Nine species combinations had a survival rate between 10-47%, 10 months after grafting: these were both the homografts and the heterografts between *Acacia senegal* and *A. laeta* (both belonging to subgenus Aculeiferum), and between *A. nilotica* ssp. *adstringens* and *A. tortilis* ssp. *raddiana* (belonging to subgenus Acacia). After 5 years in the field, there was a 100% survival rate for *Acacia senegal* and *A. laeta* grafts, and 70-90% survival rate for grafts between *A. nilotica* ssp. *adstringens* and *A. tortilis* ssp. *raddiana*. All four Acacia species produced fruit from the fourth year. *Faidherbia albida* was only compatible with itself. This graft compatibility pattern backs up the taxonomic classification system proposed by Vassal and previously by Bentham. Suggest that *A. laeta* could be used as the stock plant in clonal orchards on gum arabic tree (*A. senegal*) tree improvement programs.

224 DARLINGTON, C.D.; WYLIE, A.P. **Chromosome atlas of flowering plants**. London; George Allen and Unwin Ltd (1955) 151-152

Comprehensive listing of chromosome counts in its day, covering 241 families of flowering plants. Fifty-six species of *Acacia* are recorded and one hybrid. For *A. senegal* refers to Khan's 1951 paper, where 2n = 26 is recorded, and the *senegal x mellifera* hybrid 2n = 39.

225 DAVIDSON, L.; JEPPE, B. **Acacias - A field guide to the Acacias of southern Africa**. South Africa; Johannesburg, Centaur Publishers (1981) 1-121

A field guide to the 51 Southern African *Acacia* species, which occur south of the Zambesi and Cunene rivers. Two varieties of *Acacia senegal* (var. *rostrata* and var. *leiorhachis*) are described and illustrated, with a list of simple characters, and a general distribution. In southern Africa it is the only *Acacia* with three prickles at the node, and the two varieties are clearly distinguishable by their habit, bark and pod characters.

226 DE KONING, J. **Checklist of vernacular plant names in Mozambique** *Wageningen Agricultural University Papers* (1993) **93** (2) 1-274

Lists around 7000 common names for the flora of Mozambique, including 6 local names for *A. senegal* Willd.

227 DE ROCHEBRUNE, A.T. **Toxicologie Africaine sur les Végétaux toxiques et suspects propres au continent Africain et aux iles adjacentes** *Paris; Octave Doin* Tome second 2° Fascicule (1899) 1-500

Includes a detailed study of the gum producing Acacias, including the identification, medical uses of the gums and the historical and marketing aspects of the gum trade.

228 DEANS, J.D.; ALI, O.M.; LINDLEY, D.K.; NOUR, H.O.A. **Rhizobial inoculation of *Acacia* tree**

species in Sudan: soil inoculum potential and effects of peat *Journal of Tropical Forest Science* (1993) **6** (1) 56-64

Soil cores were removed in 20 cm fractions to 1 m depth from beneath 5 apparently unnodulated mature *Acacia mellifera* trees growing in the clay plains of east Sudan. The soil was a dark deep 'cracking clay' Vertisol, with a pH 8.5-9.5. Seedlings of *Acacia mellifera* grown in this soil in pots at Khartoum, and in a tropical glasshouse near Edinburgh, Scotland, produced root nodules regardless of the depth or tree from which the soil had been taken. Supplementary nutrition and inoculation with *Rhizobium* (a mixture of 5 strains known to nodulate with *A. mellifera*) had no significant effect on nodulation, although nutrition increased seedling growth. It was concluded that the inoculum potential of the soil in Sudan was high, but that nodulation in the field was inhibited by lack of water. In a separate study, seedlings of *A. mellifera*, *A. senegal* and *A. seyal* grown in a tree nursery in Sudan produced substantial numbers of nodules when peat was added to the Nile silt/sand medium, and *A. senegal* and *A. mellifera* failed to produce nodules without peat being added. Improved aeration seemed the most likely reason for the stimulation of nodule production, and a locally produced alternative to peat is suggested for use in tropical nurseries.

229 DEANS, J.D.; DIAGNE, O.; LINDLEY, D.K.; DIONE, M.; PARKINSON, J.A. **Nutrient and organic-matter accumulation in *Acacia senegal* fallows over 18 years**. *Forest Ecology and Management* (1999) **124** 153-167

Biomass and tissue nutrients of trees from 3 to 18 year plantations of *A. senegal* were assessed as well as the soil nutrients close to and away from the trees in northern Senegal, to provide quantitative information on the rate of nutrient enrichment in tree fallows. Tree biomass increased linearly with age and above and below biomass accumulation averaged 1770 kg/ha/yr for trees at 6 x 6m spacing. By 18 years of age, an average tree had accumulated 945, 38 and 420 g of N, P and K respectively. [Similar results reported in Lindley *et al.* 1997.] Soil organic matter, N, P and K concentrations were always greatest in the surface horizons close to the stems. However, unlike N and K, there was little evidence to show P concentrations increasing in the surface horizons. N and K increased in the surface soil by ca. 24 and 4 kg/ha/yr respectively, and soil organic matter increased by ca. 0.05% and 0.035%/yr under the tree canopies and in open ground respectively. Felling the trees and harvesting all wood >2cm diameter at age 15 would remove ca. 60, 2.7 and 35 kg/ha of N, P and K respectively at 6 x 6m spacing. At the same age harvesting only a single years production of leaves and fruits would remove 75%, 80% and 40% of those N, P and K amounts. It would appear that regular large scale fodder harvesting would remove much more from the site than harvesting the wood at the end of the tree rotation. This effect was more serious for K and P, because at 15 years there was more N in the surface soil than in the tree tissues.

230 DEEGAN, M.; SCRAGG, D.C. **Medicine in early Mediaeval England: 4 Papers**. *Manchester University Pamphlet* (1989) 1-40

231 DELCOURT, A. **La France et les etablissements Francais au Senegal entre 1713 et 1763**. Dakar; Institut Francais d'Afrique Noire (IFAN) (1952)

232 DELWAULLE, J.C. [**The role of the forester in the development of the Sahel.**] Le role du forestier dans l'amenagement du Sahel. *Bois et Forêts des Tropiques* (1975) No.160 3-22

The natural vegetation of the Sahelian regions consists of steppe featuring thorny plants, which plays a very important role in soil fixation, the prevention of erosion, cattle feed, firewood, and wood for other purposes. The forester's role then is as follows: in the regeneration and conservation of vegetation and soil, notably through a policy of prohibiting grazing in certain areas in order to safeguard natural regeneration; in the pastoral economy (combating excessive lopping of branches and bush fires, and planting forage trees); in the supply of firewood and service wood (forest plantations of local or introduced species; development of plantation techniques). The role of natural regeneration in *Acacia senegal* is noted.

233 DELWAULLE, J.C. [**The role of forestry in combating desertification and its contribution to development.**] Le role de la Foresterie dans le lutte contre la desertification et sa contribution an developpement. *Bois et Forêts des Tropiques* (1977a) No.174 3-25

Critical review of the overall measures which the forester may take in the Sahel zone and the fringe of Sudan which borders it to the South in order to combat desertification, protect the soil, and increase agricultural, timber and forage production. *Acacia senegal* is recorded as being a pioneer species that is able to regenerate easily in, for example, abandoned fields.

234 DELWAULLE, J.C. **Species, techniques and problems of semi-arid zones (The Sahel)**. In *Savanna afforestation in Africa. Food and Agriculture Report* (1977b) No. FOR:TF-RAF 95DEN0 160-195

Special emphasis on village woodlots, and the roles of *Acacia albida* and *A. senegal*.

235 DELWAULLE, J.C. [**Forest plantations in dry tropical Africa. Techniques and species to use.**] Plantations forestieres en Afrique tropicale seche.

Techniques et especes a utiliser. *Bois et Forêts des Tropiques* (1979) No.185 3-23

Chapter VII. Soil conservation. Clearing the ground for reforestation leaves it open to serious erosion, particularly on steep slopes and near watercourses. Systems are described for planting plots separated by bands of vegetation and firebreaks; for 'herring-bone' arrangements of channels directing run-off to planted trees with a low bank below each; and for a chequerboard layout of micro-catchments. Chapter VIII. Anti-termite treatments. The pesticide and manpower requirements for treating new plantations with dieldrin is outlined; since further supply of this insecticide is uncertain, 7 other (named) products were tested but without conclusive results. Chapter IX. Date of planting. Examples are given of how to calculate the best planting date from climatic data of individual stations, and trials at 3 sites are described. Recommendations are given on planting date for different regions and annual rainfalls. Chapter X. Method of planting. Experiments in Cameroon and Niger are described in which container-grown and bare-rooted plants, direct seeding and cuttings were used. Other trials investigated bare-rooted planting of *Eucalyptus camaldulensis* treated with alginate; the use of stump plants (not recommended) and direct sowing of *Acacia senegal* and *Anacardium occidentale*. In dry and difficult areas only container-grown plants succeed; elsewhere the lower costs of bare-rooted planting or direct sowing offset the lower survival rate.

236 DEPIERRE, D. [**Experiments with cultivated gum trees in Chad.**] Les experiences de Gommeraie cultivee et leurs en seignements au Chad. *Bois et Forêts des Tropiques* (1969) No.125 27-34.

Gives results from experiments into establishing gum tree plantations in Northern Chad. Direct seeding of *Acacia senegal* with millet cultivation or broadcast seeding on abandoned cultivated fields were compared. The latter was recommended as being simpler and cheaper and preferred by farmers. Seeds broadcast at 4-5 kg/ha and enclosed by a thorn bush fence would expect a population of 1000 plants/ha after 5 years. The value of gum production over 10 years was estimated to return 10 times the initial cost of establishment (15,000 F/ha). Annual production from natural stands in Chad was estimated at 3000 tons.

237 DEPIERRE, D. **Experiments with cultivated gum trees (*Acacia senegal* and *A. laeta*) in Chad.** CSIRO (Commonwealth and Scientific Industrial Research Organisation) Australia Translation No. 9951 (1970) 1-8 [Transl. by A. Dalby from *Bois et Forêts des Tropiques* 1969 (125) 27-34]

English translation of above paper.

238 DEPIERRE, D.; GILLET, H. [**Desertification in the Sahelian zone of Chad.**] Désertification de la zone Sahélienne au Tchad. *Bois et Forêts des Tropiques* (1971) **139** 3-25

The increasingly unproductiveness of the Sahelian zone in Chad, its causes and means of remedying it were discussed. The study of vegetation of similar types within and without the perimeter of a reforestation area, which has been protected for ten years, has made it possible to compare seedlings in protected zones with those browsed by cattle. This study reveals that defensive measures (fencing) gives good results, with higher regeneration within the protected area than outside. Height curves for various species are included, with *Acacia senegal* being lumped in with *A. laeta* as well (being the gum acacias). The greatest density of trees outside the protected area occurred around one meter in height (range 25 - 430 cm), whereas within it was 60-80 cm (range 10-490 cm). Cattle and humans are identified as the main causes of the degradation.

239 DERING, C.; WILKE, B.M.; ZECH, W. [**The nutrient status of *Acacia senegal*: foliage and soil analyses in N. Senegal**]. Uber den Ernährungszustand von *Acacia senegal*: Blattanalytische und bodenkundliche *Untersuchungen* in Nord Senegal. *Forstwissenschaftliches Centralblatt* (1978) **97** 341-352

A study in the context of replanting *Acacia* spp. after losses caused by the Sahelian drought. Foliage was analysed in October 1977 from *A. senegal* trees of large, intermediate and small size (range 0.8-4 m) in a 3½ year old plantation. The results are compared with published data for other *Acacia* species. The foliar N content was relatively high (3.8-4.5%), but the P content low (0.07-0.1%). None of the nutrients analysed were positively correlated with tree height. The P status of the soil (P content 55-97 mg/kg) was studied by determining P adsorption isotherms. The results were used to estimate the P fertilizer requirement. The low P adsorption capacity of the soil indicated that P applications should not exceed 83 kg/ha; the use of slow-acting granulated triple superphosphate is recommended.

240 DEWEY, F.M.; THURSTON, M.I.; CRONK, Q.C.B. **Monoclonal antibodies that differentiate between Gum arabic, Gum seyal and Combretum gum.** *Food and Agricultural Immunology* (1997) **9** 123-134

Describes the development of monoclonal antibody immunoassays to detect possible adulterant gum from *Acacia seyal* and *Combretum* gum in commercial gum arabic (*A. senegal*) [see also Thurston *et al.* 1998]. Seven hybridoma cell lines were raised that secrete monoclonal antibodies which recognise the arabinogalactan protein in gum arabic but not that in gum seyal. From these two monoclonal antibodies, OX FB8 and SY CC7, have been identified with potential use in immunoassays (ELISAs) for detection of gum arabic and *Combretum* gum, SY CC7 being highly specific for gum arabic whereas OX

FB8 recognizes both gum arabic and *Combretum* gum, but not gum seyal.

241 DHAR, B.L.; JHA, M.N.; SINGH, K. **Studies on some calcareous alluvial soils of Haryana in relation to plantations**. *Annals of Forestry* (1998) **6** (1) 54-66

Soil pedons from Kalsia, Thanesar and Jind Forest Ranges of Haryana, were studied. These soils have formed from recent fluvial deposits, and have different drainage and landform features. They are calcareous and alkaline, and the saturation extracts show higher bicarbonate and carbonate than chloride ions at high pH values. The soils of the Sekhpura Block (Kalsia Forest Range) are very deep, mixed, Ustipsamments and low in organic carbon. In Shahbad Block (Thanesar Forest Range) the soils are very deep, fine loamy mixed, Typic Ustochrepts characterized by medium organic carbon distribution and a kankar layer at 115-120 cm depth. The Birbada Ban (Jind Forest Range) soils are fine, mixed, Typic Haplaquepts and offer a high water table with dry and hard surface horizons. The sub surface horizons are moist, sticky and plastic, low in organic carbon with kankar nodules below 30 cm depth. Quartz, feldspar and micas were the dominant minerals present in the sand fractions as the light minerals. The heavy minerals comprised chlorite, epidote, tourmaline, garnet, zircon, and opaques. The clay minerals included illite, chlorite, and kaolinite. It is postulated that the soils receive sufficient bases as inputs for neo formation of smectite like minerals through intermediate stages of (1.0-1.4 nm) interstratification of illite. The soils are planted with poplar [*Populus*] and *Dalbergia sissoo* at Sekhpura, with poplar at Shahbad Block, and with *Acacia nilotica*, *A. senegal*, *A. mangium* and *Prosopis chilensis* at Birbada Ban (as provenance trials). Some modifications in tree planting are required due to site-specific requirements of the planting stock. Due to flooding in Sekhpura Forest Block, *D. sissoo* can be grown satisfactorily on raised mounds to avoid water logging. Poplar may fail due to the high calcareousness ($CaCO_3$ up to 11%) in the top 52 cm of soil. *Prosopis chilensis* can be grown well in the Birbada Ban Block while growth of *Acacia* species will not be satisfactory due to the high $CaCO_3$ (12-18%) and kankar nodules mixed with hard soil in the top 67 cm of the pedon and a hard kankar pan below this depth this needs mechanical perforation for planting acacias.

242 DIALLO, I.; SAMB, P.I.; GAYE, A.; SALL, P.N.; DUHOUX, E.; BA, A.T. [**Floral biology and pollination in *Acacia senegal* (L.) Willd.**] Biologie florale et pollinisation chez *Acacia senegal* (L.) Willd. *Acta Botanica Gallica* (1997) **144** (1) 73-82

Floral morphology, dynamics of flowering, maturity periods of reproductive organs and pollinating insects were studied in an *Acacia senegal* plantation established at Bambey, Senegal, in 1986. The pollen is composed of 16 monads bound into 1 polyad. The anthers open around 10 in the morning and by 3 pm all the anthers are open on the flowers that mature that day. The stigma is receptive from around midday. The receptive stigma cannot receive more than one polyad. Pollination is preferentially allogamic, with possibilities of self pollination *sensu lato*. In Senegal the pollinating insect species belong to three main insect groups; Hymenoptera, Lepidoptera and Coleoptera. The bees, with the genus *Xylocopa* and the wasps are the most important visitors both in frequency and quantity of pollen carried. They are most active between 10 am to 2 pm. They found that by controlled pollination, the percentage of flowers setting fruit varied from 0.12% for pollination of flowers within the same inflorescence, 0.69% for pollination between flowers within the same tree and 1.44% for pollination of flowers between different trees. This was compared with 1.75% for natural pollination. As expected cross-pollination is naturally the preferred method.

243 DICKINSON, E.; GALAZKA, V.B.; ANDERSON, D.M.W. **Emulsifying behaviour of acacia gums**. In *Gums and stabilizers for the food industry 5 (edited by Phillips, G.O.; Williams, P.A.; Wedlock, D.J.)* (1990) 41-45

Time dependent droplet-size distributions are reported for D-limonene-in-water emulsions (1 wt%, 10 vol% oil, pH7) made under standard conditions with six *Acacia* gum samples with nitrogen contents in the range 0.1-7.5% (*A. senegal* had 0.33% N). The best emulsion stability was found with the two *Acacia* gum samples with the highest nitrogen content (*A. gerrardii* (1.86% N) and *A. difficilis* (7.5%)). The relative emulsifying abilities of the different samples are broadly in conformity with those reported previously for hydrocarbon-in-oil emulsions, though the mechanism of droplet growth is distinctly different for the two cases.

244 DICKO, M.S.; SIKENA, L.K. **Fodder trees and shrubs in range and farming systems in dry tropical Africa**. In *Legume trees and other fodder trees as protein sources for livestock (edited by Speedy, A.; Pugiese, P.L.). FAO Animal Production and Health Paper* (1992) No.102 27-41

A review of the literature. Fodder trees and shrubs provide a vital component in livestock productivity in dry tropical Africa, and this article lists 124 species that are commonly exploited including *A. senegal*. The proportion of annual pod production per year of *A. senegal* in Senegal (1.34 kg dry matter) is about a third of the total leaf production (3.84 kg of dry matter), data from Bille (1980). Stresses the nutritional value of the browse species, with high crude protein and mineral contents contributing to a lack of photophobia or eye infections in those browsing species (camels and goats) compared to cattle. Notes the incorporation of *Acacia senegal* in crop

rotations, especially in Niger and Sudan, providing browse, soil improver and gum for subsistence farmers.

245 DICKO-TOURE, M.S. **The contribution of browse to cattle fodder in the sedentary system of the Office du Niger**. In: *Browse in Africa; the current state of knowledge (edited by Houérou, H.N. le.)* Ethiopia; ILCA (1980) 313-319

Information is given on 16 palatable browse species including some characteristics and relative proportions on different types of pasture in Niger. *Acacia senegal* is classified as a thorny shrub; with the period of total defoliation being the dry season [October-June] and a fruit period in the cold season and early rainy season. The species is found in natural pastures and millet fallows.

246 DIEM, H.G.; GUEYE, I.; GIANINAZZI-PEARSON, V.; FORTIN, J.A.; DOMMERGUES, Y.R. **Ecology of vesicular arbuscular mycorrhizae in the tropics: the semi arid zone of Senegal**. *Acta Oecologica, Oecologia Plantarum* (1981) **2** (1) 53-62

Discusses the importance of vesicular arbuscular (V.A.) mycorrhiza in trees and crop plants in the dry tropics, particularly with *Azadirachta indica*, *Casuarina equisetifolia* and *Acacia senegal*. Suggested that V.A. mycorrhiza contribute not only to drought resistance of plants but also the improvement of plant growth by increasing P uptake under water stressed conditions. In 2-month-old seedlings of *A. senegal* grown under nursery conditions, 45% of the lateral roots were found to be infected by mycorrhizae, and 26% of the main roots. Mycorrhizal infection penetrated to the root cortex as well. The soils around Dakar, Senegal had an abundance of mycorrhizal fungi belonging mainly to the *Glomus* and *Gigaspora* genera.

247 DILLER, J.; HOENISCH, U. **Programme de regeneration des formations vegetales de la zone Sahelienne Sénégalaise et en particuier, de la Gommeraie Acacia**. *Club du Sahel* (1980) 1-18

248 DIONE, M. [**Role of *Acacia senegal* stands in the north and north-eastern zone of Senegal: assessment of action taken and future prospects.**] Role des peuplements d'acacia-gommier de la zone nord et nord est du *Senegal*: bilan d'actions et perspectives. In: *Les arbres fixateurs d'azote. L'amelioration biologique de la fertilite du sol. Actes des seminaires, 17-25 mars, 1987, Dakar, Senegal. Editions de l'ORSTOM Paris, France* (1987) 122-153

The socio-economic importance in Senegal of the production of and trade in gum arabic from *A. senegal*, the use of its leaves, pods and fruits as forage, and the ecological requirements of the species are described. Reforestation projects in the arid northern half of Senegal, where *A. senegal* has suffered overexploitation, are outlined. Agroforestry projects make up 40% of the area of plantations. Details are given of plans for future *A. senegal* plantations, which aim to produce exportable forest products, improve and maintain the equilibrium of natural ecosystems, and reduce fuel wood deficits in rural areas.

249 DIONE, M. **Le Gommier et la Gomme Arabique au Senegal: Bilan des Actions de Recherche et de Developpement. Perspectives d'Avenir**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique St Louis, Senegal, 25-28 Octobre* (1988a) 45-70

Reviews the present research and development on gum arabic and its future prospects in Senegal. The gum zone in Senegal occupies an area between latitudes 13 to 16°50' North and longitudes 12°30' to 16°30' west. Research into improving gum production was started in 1954, with some irrigated plantations installed at Tatki, Mbiddi and Labgar. These proved too expensive to irrigate and future plantations in 1973 were not irrigated. Two thrusts of research are improved management of natural populations and replanting. There are trials on direct seeding, vegetative propagation, Rhizobia and Mycorrhiza research, genetic improvement as well as silvi-pastoral management. Spacing trials have shown an optimum spacing of 6x6m with thinning after 6 years. Great variability in yields from trials, also considerably affected by rainfall with a massive mortality during the 1968-73 droughts. Up to 130-240 g of gum/tree has been recorded, and 240 kg/ha in a good year. Lists various gum development projects and in 1985 there existed nearly 14,000 ha. of plantations between 5 development projects. Describes the production, commercialisation and socio-economics of the gum trade in Senegal with a marketing network in place (over 30 centers scattered in the Louga and San Louis regions were gum is bought at guaranteed prices). Tabulates gum production from 3 regions of Senegal from 1981-7.

250 DIONE, M. **Quelques resultats sylvicoles preliminaires concernant les deux phenotypes de *Acacia senegal*.** In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988b)

Reports on the identification of two phenotypes of *A. senegal* in Senegal, and trials installed in Mbiddi to compare their early growth using seed collected from the two "phenotypes". The two phenotypes are distinguished by bark colour, light and dark grey, and the dark grey type also produces more gum, at a faster rate and a better quality than the light grey type. Differences were noted in the survival, speed of germination, and early growth between the two (although sample sizes were small and not subject to statistical analysis). Also noted that in natural populations where the two are mixed, the

light grey will grow in the depressions where the other variety does not grow.

251 DIONE, M. **Periode de saignee et potentialites en Gomme Arabique de quelques localites de la zone Gommiere du Senegal**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988c) 117-126

Study to investigate the best time for tapping trees of *A. senegal* in various sites in Senegal, and its correlation with climatic and phenological factors. The experiments were conducted from 1983-1987 on 90 trees, 10 trees tapped every 10 days, and on average the optimal dates for tapping were found to vary with the years, and the most common periods being between 5 October to 9 November. Found correlations between gum exudation and the total amount of winter rainfall and the number of rain days per annum. There was a correlation between higher gum exudation and higher temperatures and leaf drop more than 60%. In a separate experiment in 1982 found four different size classes in trunk diameters (53,62,72 and 83 mm) in the plots studied and the greater gum yields were found in the largest diameter class (454.8g). The natural distribution of the species is mapped in Senegal, mostly between 350-600 mm isohyets (annual rainfall) with a limit for gum exudation at the 1000 mm isohyet.

252 DIONE, M.; VASSAL, J. **Gummosis and gum production cycles in *Acacia senegal***. [Gommose et rythmes de production gommiere chez *Acacia senegal* (L.) Willd.] In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M., Hamon, S.). L'Orstom, Collection colloques et séminaires, Paris, France* (1998) 123-134, 454

The ways in which *Acacia senegal* produces gum arabic, and histological data on the production of the gum, are reviewed. As part of a study into *Acacia senegal* gum production in Senegal, the relations between gum arabic production, phenology (leaf fall) and ecological conditions (soil water, climate and seasonal variations) and topography were investigated, in an experimental plot at M'Biddi, comprising 30 - 40 trees aged 11 to 14 years old situated on summits, slopes or hollows of dunes. Peak gum production (in December-January) was apparently stimulated by the onset of drought conditions as the rainy season ended, with maximum leaf fall and air temperature rising, and occurred when incisions were made in October/November. During 1989/90 they also found variation in gum production depending on the topography of the dunes which was correlated with the range of soil water levels. Hence the trees on the dune summits had the highest gum yields (average yields from 250-460 g/tree) and a low variation in soil water levels, while the dune hollows (around 100 g/tree) had a variation eight times greater in soil water levels. The slopes had values intermediate between the two. The results in the following three years were less clear.

253 DIONE, M.; VASSAL, J. **Experimental study on the means of production of gum trees of *Acacia senegal*; looking back on the gum tree development programmes in the Senegalese Sahel**. [Etude experimentale de la modalites de la production gommiere d'*Acacia senegal* retrospective des programmes de developpement gommier au Sahel Senegalais.] In: *Natural resources and social conflicts in the Sahel: Proceedings of the 5th Sahel Workshop, 4-6 January 1993 (edited by Brimer, L.; Krogh, L; Meyer, M.)* (1993) 22-41

The paper has 2 parts: an account of an experimental plantation research programme carried out at Mbiddi, northern Senegal, in 1989-91. 7 populations of gum Acacias were studied in 3 distinct dune sites, and differences in behaviour noted from the 3 sites. From the bottom to the top of the dunes, there was observed a decreasing rate of growth and survival, an accelerated defoliation and increasing mean gum yields per tree. In parallel there was noted a decrease in water storage from the hollows to the dune tops. The second part gave a historical look at gum *Acacia* projects from the colonial period.

254 DISSA, D.; CUNNVOR, B.; AHAMOUND, A.; BRITT, M.; MAIGA, A. **Study of traditional medicine in Mali result of an ethnobotanic study conducted in the "Gourma"**. In *Ethnobiology in human welfare. Abstracts of the fourth international congress of ethnobiology, Lucknow, Uttar Pradesh, India, 17- 21 November 1994.* (1994) 107

In the Malian traditional systems, plants are most commonly used as medicine. All parts of the plants are used, as decoctions, macerations, infusions or powders. Fifty medicinal plants have been identified, including *Acacia senegal.*

255 DOAT, J. [**Application of thin-layer chromatography to analysis of gums and tropical woods**.] *Bois et Forêts des Tropiques* (1974) No.156 63-74

Describes analyses by thin-layer chromatography of a commercial sample of gum arabic (usually derived from *Acacia verek* or *A. senegal*), a Nirmali (*Strychnos potatorum*) gum, wood specimens of *Terminalia superba* and Doussié and an inclusion from a log of *Balanites aegyptiaca*, shows that the results are valid, and concludes that thin-layer chromatography of gums and woods is therefore useful in complementing the results obtained by conventional chemical analyses.

256 DOMMERGUES, Y. **Workshop on *Acacia* symbioses**. [L'atelier sur les symbioses acacias.] *Bois et Forêts des Tropiques* (1993) No.238 21-34

The aim of the workshop which took place on 24-25 June 1993 at Nogent sur Marne, France, and was attended by 40 researchers from Senegal, Burkina Faso

and France, was to present and discuss results of investigations carried out in Africa over the last five years on symbioses, principally between root nodulating bacteria and *Acacia* species. Research has been directed towards the development of sustainable silviculture and agroforestry methods. Twenty-two summaries are presented. Research topics covered a broad spectrum, from the biology, physiology, phenology and distribution of symbionts to the establishment and functioning of the symbiosis, and environmental factors which affect nitrogen fixing ability. Tree species covered by the research are *Acacia raddiana, A. senegal, Faidherbia albida* and *A. mangium,* the symbionts *Rhizobium* and *BradyRhizobium,* and the Mycorrhiza *Glomus* sp.

257 DORAN, A.C.; TURNBULL, J.W.; BOLAND, D.J.; GUNN, B.V. **Handbook on seeds of dry-zone acacias**. Rome, Italy; Food and Agriculture Organization of the United Nations (1983) 1-92

A useful guide to seed collection and storage of dry zone Acacias, with special reference to *Acacia albida, A. aneura, A. caven, A. nilotica, A. senegal* and *A. tortilis*. Chapters are included on habit, taxonomy, occurrence and ecology, and reproductive biology. Reviews literature, including unpublished data, on a number of seed pretreatments that have been tried for the *Acacia* species. Fresh seeds with soft seed coats need no pretreatment. Prior to seed storage, seeds need to be treated to kill the insect pests (especially bruchids) either by fumigating with carbon disulphide or carbon dioxide in a sealed bag or dusting with an insecticide. A 57-word glossary is included.

258 DOUGALL, H.W.; DRYSDALE, V.M. **The chemical composition of Kenya browse and pasture herbage**. *East African Wildlife Journal* (1964) 286-121

Tabulates 296 chemical analyses of a large number of East African indigenous fodder plants from 47 families using the parts of the plant eaten by the herbivores for each analysis. Details of ash, crude protein, ether extract, crude fibre, nitrogen free extract, silica, silica free ash, and macro elements (Ca, Na, K, P) are given, based on a percentage of dry matter. In *Acacia tortilis* ssp. *spirocarpa* analyses of twigs and leaves, bark, and pod with seeds are included. Emphasises that legumes are the richest source of protein and the least fibrous of all the vegetation groups. In *A. nilotica* ssp. *subalata* analyses of twigs, top branches and leaves and flowers, pods and seeds are included. In *A. senegal* analyses of young twigs and leaves are included from the Mara, with crude protein levels of 20-21% for the two analyses.

259 DREYFUS, B.; DOMMERGUES, Y.D. **Nodulation of *Acacia* species by fast and slow growing tropical strains of Rhizobium**. *Applied and Environmental Microbiology* (1981a) **41** (1) 97-99

A cross-inoculation study of rhizobia, (isolated from native and introduced *Acacia* spp. and *Leucaena leucocephala* growing in Senegalese Sahel) with seedlings of 13 *Acacia* spp. and *L. leucocephala*. The *Acacias* could be divided into three groups depending on *Rhizobium* strain which nodulated with them. Group (1) such as *Acacia albida*, nodulated only with slow growing strains, Group (2) only nodulated with fast growing strains including *A. raddiana* [*A. tortilis* ssp. *raddiana*], *A. nilotica* ssp. *tomentosa* and *A. senegal*. Group (3) such as *A. seyal*, nodulated with both fast and slow growing strains. *L. leucocephala* also belonged to (2). Since slow growing strains of *Rhizobium* of the cowpea complex are common in many tropical soils, *Acacia* spp. nodulating with these strains would respond poorly to inoculation. Fast growing strains are assumed to be more specific and inoculation of *Acacia* spp. in group (2) in the nursery would show increased benefits in growth similar to those found in *L. leucocephala*. For *A. senegal* inoculating with the most effective Rhizobium strain (ORS 901) produced over a five-fold increase in fresh weight of 2 month old seedlings compared to the uninoculated control.

260 DREYFUS, B.; DOMMERGUES, Y.D. **Relationships between rhizobia of *Leucaena leucocephala* and *Acacia* species**. *Leucaena Research Reports* (1981b) **2** 43-44

A table summarises the same results as in the previous paper; a cross inoculation experiment using *Acacia* species and *Leucaena leucocephala* as host plants. *A. senegal* nodulates effectively only with the faster growing strains from *Acacia senegal* and *L. leucocephala.*

261 DUBE, J.S.; REED, J.D.; NDLOVU, L.R **Proanthocyanidins and other phenolics in Acacia leaves of Southern Africa**. In: *Tannins: analysis and biological effects in ruminant feeds. Polyphenolics in tropical ruminant production. (edited by Pell, A.N.; Mackie, R.I.; Mueller-Harvey, I.; Ndlovu, L.R.) Matopos Conference Center, Bulawayo, Zimbabwe, 11-14 October, 1999. Animal Feed Science and Technology Special issue* (2001) **91** (1-2) 59-67

Four provenances each of *Acacia karroo, Acacia nilotica, Acacia tortilis, Acacia senegal, Acacia erioloba* and *Faidherbia albida* were sampled at Cyrene, Lucydale and Mahiye in the Matopos Research Station. Provenances were not replicated within site. The leaves and leaf stalks sampled were dried at 55°C and then analysed for total phenolics and proanthocyanidins (PAs). Variations in content of PAs and total phenolics of the Acacias were studied. Three assay methods for phenolics were evaluated. Total phenolics were estimated by precipitation with trivalent ytterbium after extraction with acetone:water (7:3 v/v) or colorimetrically by the Folin-Ciocalteu method. PAs were estimated colorimetrically by the butanol-HCl method. The results from the colorimetric methods are reported as absorbance

units (au). *A. senegal* contained the lowest level of ytterbium precipitated phenolics (Ybppt) (mean = 47 g/kg DM), while *A. nilotica* contained the highest (mean = 298 g/kg DM). Amounts of Ybppt for *A. karroo, A. erioloba* and *F. albida* were not significantly different (P > 0.05) from one another. The amount of Ybppt for *A. tortilis* was significantly different (P < 0.05) from the amount for *A. karroo* but not different from the amount for *F. albida* and *A. erioloba* (P > 0.05). *A. senegal* was again the lowest in total phenolics detected by the Folin-Ciocalteu method (A675 = 0.370 au/g DM), while *A. nilotica* was the highest (A675 = 5.261 au/g DM). *A. karroo, F. albida* and *A. tortilis* were not significantly different (P > 0.05) from one another. PAs were lowest for *A. senegal* (A550 = 0.040 au/g DM) and highest for *A. karroo* (A550 = 2.011 au/g DM). Values for *A. tortilis, F. albida* and *A. erioloba* were not significantly different (P > 0.05) from one another. For all the three assay methods, there were no significant differences (P > 0.05) between Cyrene and Mahiye sites. The regression analysis of PAs on Ybppt showed the relationship to be highly significant (P < 0.05) for *A. karroo, F. albida* and *A. erioloba* (R2=0.904, 0.892, 0.884, respectively), and significant for *A. tortilis* (R2 = 0.680). It was poor for *A. senegal* and *A. nilotica* (R2 = 0.347 and 0.460, respectively). The relationship between total phenolics and Ybppt was similarly good for *F. albida, A. erioloba, A. nilotica* and *A. karroo* (R2 = 0.957, 0.808, 0.792, and 0.725, respectively) but poor for *A. senegal*, and *A. tortilis* (R2 = 0.413 and 0.004, respectively).

262 DUCOUSSO, M.; BADJI, S.; COLONNA, J.P.; THOEN, D. **Growth and nitrogen fixing abilities of three Australian and two African Acacia species**. *Nitrogen Fixing Tree Research Reports* (1989) **7** 40-42

The results of nodulation, early growth and nitrogen content of two native Acacia species (*A. senegal* and *A. seyal*) and three introduced Australian Acacias grown under nursery conditions in Bel-Air, Senegal are reported. Heights, shoot dry weights, dry weights of nodules, and total nitrogen contents were much higher after 6 months in the introduced species. Root dry weights were not measured. The African species had a higher nitrogen percentage, *A. senegal* with 1.67% compared with *A. holosericea* with 0.85%, but with much higher shoot biomass in the Australian species gave much higher total nitrogen contents in the shoots (*A. holosericea* 0.36g/plant and *A. senegal* 0.02g/plant). Suggested that the Australian species showed potential for further trials.

263 DUCOUSSO, M.; COLONNA, J.P.; THOEN, D. **Occurrence of nodulation among woody legumes in Senegal**. *Nitrogen Fixing Tree Research Reports* (1991) **9** 53-55

Results of nodulation of native and introduced legume trees in the field in three climatic zones of Senegal, and a nodulation experiment of 60 *Acacia* species in the greenhouse where they were inoculated with a mixture of *Rhizobium* and *Bradyrhizobium* strains. Nodules were found on *A. senegal* trees growing in the field only in the semi arid zone, and they were also found on its seedlings in the greenhouse experiment.

264 DUFFY, E.A.J. **A monograph of the immature stages of African timber beetles (*Cerambycidae*)**. *Monograph, British Museum (Natural History), London* (1957) 1-338

A monograph on the wood boring beetles (*Cerambycidae*), which attack a large range of African timbers, pods and seeds. Reference is made to 400 species, with keys to identify 286 species of larvae and pupae. A wide range of *Acacia* species are attacked, and specifically recorded for *A. senegal is Stromatium barbatum* Fabricius (wood boring beetles that are of considerable economic importance, because of its preference for seasoned timbers). In the field it will usually oviposit on dry wood, such as the dead crowns of trees. Only recorded attacking *A. senegal* in India, as its natural distribution is outside of Africa.

265 DUHOUX, E.; GALIANA, A.; AHEE, J.; FRANCHE, C. ***In vitro* micro propagation of the genus *Acacia***. [Applications des cultures *in vitro* dans le genre Acacia.] *In L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.). L'Orstom, Collection colloques et séminaires, Paris, France* (1998) 237-255, 459-460

A literature review, focusing on research into the use of micropropagation techniques (bud and stem cultures, organogenesis, somatic embryogenesis, genetic transformation, experimental *in vitro* symbioses with *Rhizobium* and *BradyRhizobium* cultures) for four African *Acacia* species: *A. nilotica, A. senegal, A. tortilis* and *A. tortilis* subsp. *raddiana* [*A. raddiana*]. Describes the research into in vitro cell culture of *Acacia senegal* and the secondary metabolites produced [see Mollard & Joseleau 1994]. They hope that this work will help to understand the biosynthetic pathways in gum arabic production.

266 DUKE, J.A. **Handbook of legumes of world of economic importance**. Plenum Press, New York, USA; USDA (1987) 1-345

Concise descriptions on a 146 useful legume species. For *Acacia senegal* (L.) Willd. several uses are described including pharmaceutical preparations, inks, pottery pigments, for dressing fabrics, giving luster to silks and crepes, in confections and sweetmeats, and ropes made from root fibres. In folk medicine the gum is used internally in inflammation of intestinal mucosa, and externally to cover inflamed surfaces, as burns, sore nipples and nodular leprosy. Main component of gum arabic

is arabic acid, a polysaccharide composed of L-arabinose, L-rhamnose, D- galactose, and D-glucuronic acid in different molar ratios, depending on the species of source. It is reported to contain trypsin inhibitors. Botanical descriptions of the varieties are given including variety *pseudoglaucophylla* (which is now treated as a synonym of var. *senegal*), their distribution range, methods of cultivation and harvesting. Gum yield and economics are also given, with young trees said to produce 188-2856 g/yr (average 900g/yr) and older trees 379-6754 g/yr (average 2,000 g/yr).

267 DUPONNOIS, R.; SENGHOR, K.; THIOULOUSE, J; BA, A.M. **Susceptibility of several sahelian *Acacia* to *Meloidogyne javanica* (Treub) Chitw.** *Agroforestry Systems* (1999) **46** 123-130

Four *Acacia* species were tested for the susceptibility to the root-knot nematode, *Meloidogyne javanica*, commonly found in sahelian areas. *Faidherbia albida* and *A. senegal* were resistent to this nematode and suffered little effect on their growth, and their rhizobial symbiosis was even stimulated by its presence, with a significantly greater total dry weight of nodules found in the seedlings of *A. senegal* under the highest inoculum treatment (10,000 second stage juveniles). [Similar results presented in Cadet *et al.* 1998.]

268 DUTTA, B.K.; TEWARI, J.C.; BOHRA, M.D. **Note on effect of nitrogen and phosphorus fertilizer on early growth of four arid zone tree species.** *Current Agriculture* (1997) **21** (1-2) 123-124

The effect of fertilizer application to the early growth of tree seedlings was investigated in trials at CAZRI, Jodhpur, Rajasthan, India. Nitrogen fertilizer (urea: 0, 25 and 50 g/planting pit) and phosphorus fertilizer (diammonium phosphate: 0, 10 and 20 g per pit) were applied separately and in combination to 4 tree species (*Acacia bivenosa, Acacia senegal, Tecomella undulata* and *Hardwickia binata*). The trees were planted in July 1991 at 3 x 3 m spacing, and growth was recorded over 4 yr. In general, nitrogen alone did not influence the plant growth positively. However, nitrogen with phosphorus and also sole application phosphorus increased height and diameter growth, with different species responding best to different treatments.

269 DUVALLET, S.; FENYO, J.C.; VANDEVELDE, M.C. **The characterization of gum arabic from an experimental field of Ferlo (North Senegal).** *Food Hydrocolloids* (1993) **7** (4) 319-326

Viscosity, specific rotation and nitrogen content of 75 samples exudated by authenticated *Acacia senegal* trees of the sahelian station of M'Biddi (Ferlo, North Senegal) have been measured closely after their collection. The values of these parameters (specific rotations between -25 to -62 degrees and nitrogen content 0.12 to 0.57%) are largely scattered when compared with data generally accepted for commercial products, and only few fall completely within the specifications proposed by the JECFA-FAO (1990 specification includes specific optical rotations from -26 to -34 degrees and nitrogen content of 0.27-0.39%). This behaviour is analyzed mainly in terms of the macromolecular structure of these fresh samples and the inherent heterogeneity of the exudates. Mechanical or moderate heat treatments are able to reduce this discrepancy. Moreover, no correlation has been found between the physico-chemical parameters and external conditions such as the location of the trees, tapping, harvesting or yields.

270 DYSON, W.G.; THOGO, S. **The Growth of *Acacia* Mill. at Muguga Arboretum 1952-1975.** *East African Agriculture and Forestry Research Organization, Forestry Technical Note* (1976) No.35 1-16

Acacia senegal (L) Willd. was planted in 1953 at the Arboretum at Muguga. Described as a variable flat topped thorny Acacia widely distributed in tropical Africa and extending from Zululand in the south to North Africa and into Arabia and north India. A very hardy species from which gum arabic is collected in Sudan. At Muguga the seed planted came from Kordofan in the Sudan; although the seed germinated well, further growth was disappointing and the plot was abandoned in 1957.

271 ECONOMIST INTELLIGENCE UNIT **Sudan-country profile.** Economist Intelligence Unit (Great Britain) London (1993)

272 EDMONDS, M. **The market for gum arabic.** *T.P.I. Report. Tropical Products Institute, London* (1965) 1-27

A survey of the market, covering: gum species (mainly *Acacia senegal* and *A. seyal*, which produce ca. 90% (high grade) and 10% (lower grade) of world consumption respectively): utilization and substitutes: sources of supply: prices: and markets. A slow expansion of demand to ca. 65,000 and 70,000 tons in 1970 and 1975 respectively is predicted.

273 EGBOH, E. O. **The Nigerian gum arabic industry 1897-1940.** *Cahiers d'Etudes Africaines* (1978) **18** (69-70) 215-221

274 EGGELING, W.J. **The *Mimosaceae* of Uganda. Provisional keys for their identification.** *Forest Department Bulletin, Entebbe, Uganda* (1934) No.1 1-20

Keys to 14 species of *Acacia* including *A. senegal* and *A. albida*. *A. senegal* confined to northerly part of the country. Flowering in Buruli (September to November),

Kitgum, Lango, and Bunyoro (December), Bunyoro and E. Madi (June), Lango (August). *A. albida* recorded from Kitgum and Ankole only. Flowers in East Ankole (August to October), Kitgum (September to December.)

275 EGGELING, W.J. **The Indigenous trees of the Uganda Protectorate.** *Uganda: Government Printer, Entebbe.* (1940) 1-296

Description and keys to all the Ugandian trees, including *A. senegal* (L.) Willd, a savanna tree that frequently forms thickets. Wood is white with a mottled red and white slash. It is the source of gum arabic but this is not collected in Uganda.

276 EL AMIN, H.M. **Taxonomic studies on Sudan acacias.** *M.Sc. thesis, University of Edinburgh.* (1972) 1-282

An excellent thesis whose aim is to revise the taxonomy of the Sudanese Acacias, and discuss the general classification of the genus in Africa. In particular new data on palynology, anatomy, cytology and seedling development are discussed in relation to classification, and the various findings were later published in Sudan Silva. *A. senegal* belongs to group two, one of four *Acacia* groupings suggested in the thesis. In its timber characters, *A. senegal* has aliform parenchyma type along with *A. laeta* and *A. asak*. The fibrous tissue is always more abundant the parenchyma tissue. Pore numbers/cm^2 is 14 and pore diameter 10 μ. The rays are multiseriate type, their width ranging from 1-4 cells wide, and the number of rays per square cm is 41. *A. albida* in group four is very different from all other Acacias and supports its exclusion.

277 EL AMIN, H.M. **Sudan *Acacias*.** *Forest Research Institute Bulletin No.1, Khartoum* (1973) 1-64

Gives a key to 31 *Acacia* species native to Sudan followed by a descriptive taxonomic account and botanical review of each one. *Acacia senegal* (L.) Willd. var. *senegal* occurs on sandy and clay plains of savanna grasslands, distributed in a continuous belt from east to western Sudan, though more successful on the western sand plains of Kordofan and Darfur, either pure or mixed with *A. mellifera*. A shrub or small tree 2-12 m high. Flowering November to February, fruiting January to April. Source of gum arabic.

278 EL AMIN, H.M. **Gum arabic production in the Blue Nile Province.** *Sudan Silva* (1975a) **3** (20) 18-19

Describes the conventional techniques of gum tapping of *Acacia senegal* (hashab) and *A. seyal* (talha) in the Blue Nile Province, Sudan. They occur in the low rainfall woodland savanna on clay soils in *Acacia mellifera* thornland. Gum yields from 1962 to 1973 for both *Acacia* species are given and the factors affecting the fluctuating yields. Gum exudation also depends on the weather, with nodules forming after 30-40 days in hot conditions, and 50-60 days in colder temperatures.

279 EL AMIN, H.M. **Germination and seedling development of the Sudan *Acacias*.** *Sudan Silva* (1975b) **3** (20) 23-33

Work detailing the germination and seedling development of 24 Sudanese species - the results are utilized towards the classification and the evolutionary trends in the *Acacias*. Three patterns of seedling development are described, and *A. senegal* belongs to pattern 2, which is mostly the non spinescent Acacias (although there are exceptions). *A. senegal* - its seedlings have 2 opposite pinnate first leaves and then bipinnate leaves alternating upwards. Hypocotyl is 1.5 cm in 4 weeks. The cotyledons are circular or orbicular and petiolate. Two scale-like stipules arise at the nodes, with 3 falcate whitish-yellow prickles appearing under the stipules 3 weeks later. Hypocotyl terete.

280 EL AMIN, H.M. ***Acacia laeta* (R. Br.) ex. Benth., considered as a species of hybrid origin.** *Sudan Silva* (1976) **3** (21) 14-23

Specimens of *A. laeta*, *A. mellifera* and *A. senegal* were collected from throughout their ranges in Sudan; 33 morphological characters were studied and compared between the species. Characteristics of *A. laeta* were intermediate, though slightly closer to those of *A. mellifera*. *A. mellifera* and *A. senegal* were found to be diploid (2n = 26), and *A. laeta* a fertile triploid (2n = 39).

281 EL AMIN, H.M. **Trees and shrubs of the Sudan.** Exeter, UK; Ithaca Press (1990) 1-484

A floral account including trees and shrubs (both Angiosperms and Gymnosperms) of the Sudan, extracted from his Ph.D. thesis. *A. senegal* var. *senegal is* described, which occurs on the sandy and clay plains in short grass savanna forming a continuous belt from east to west in central Sudan. It is more common on the western sandy plains of Kordofan and Darfur, where it can dominate along with *A. mellifera*. Flowers November to February and fruits from January to April.

282 EL DEEN, F.A.M. **The use of GIS, GPS and satellite remote sensing to map woody vegetation in Kazgail area, Sudan.** *ITC Journal* (1991) No.1 3-10

A pilot project is described for the mapping and inventory by the National Forests Corporation (SFNC) of Sudan of the *Acacia senegal* lands (known as the 'Gum Belt') in central Sudan in 1989-90. New base maps (1:250 000 and 1:100 000) were prepared based on Landsat TM 1985 data and a sample field survey of 53 plots (20X100 m) using the Global Positioning System

(GPS) to locate the plots in the Kazgail rural district, Kordofan Province (350 km SW of Khartoum). All trees with a diameter at root collar (DRC) >5 cm were identified and measured for diameter at breast height, total height along bole and crown diameter for estimates of timber volume. A smaller plot (1X10 m) was nested within the sample plot where only trees <5 cm DRC were recorded to assess regeneration rates. A stand table was produced showing that more than 70% of the trees are <15 cm DRC. Of these, more than half (66.7%) are *Acacia mellifera*, which is also the dominant tree, representing 58% of total standing timber volume. *Acacia senegal*, producer of gum arabic and also fuelwood and charcoal, is the second most important tree species, representing 10.6% of standing timber volume.

283 EL DIN, A.G.S. **The natural regeneration of *Acacia senegal* Willd.** M.Sc. *Thesis, Dept. of Botany, University of Khartoum* (1969) 1-184

The present thesis is a study to investigate why *A. senegal* has been disappearing from many of its natural sites in Sudan, identify the factors involved and recommend possible solutions. Study revealed that there are many factors affecting the regeneration and growth of the tree at different stages of its lifecycle. At the fruit stage, there are heavy seed losses in the trees by many insect species (only about 16% were found to germinate). When the seeds fall on the ground, large numbers are eaten by insects and rodents. At the beginning of the rainy season, more seed is eaten by insects and millipedes that appear during that period. Grass fires can also increase seed mortality. The amount of rainfall and its distribution and the soil type seem to have a direct impact on seed germination (can germinate as low as 250 mm of rainfall on sands, but requires a minimum of 550 mm or more on heavy clays). In the early seedling stages insects and millipedes are the chief causes of seedling mortality. The ground flora competition, and the shade cast by flora reduces the vitality of the seedlings. *A. senegal* does not appear to be shade tolerant whereas *A. mellifera* is more so, and can replace it on the clay soils where they both coexist. The main factors affecting seedling mortality during October-May (dry season) are high soil temperatures and low soil moisture content. Seedlings that survive the hazards of the first dry season are then not affected by these variables. Losses are greater among seedlings in natural forest (only 1.3% survival) than in cultivated land (4.5% survival). Established seedlings can be completely destroyed by grass fires that are common, and browsing by goats and rodents can cause serious losses. Although moderate grazing can be beneficial to the development of the seedlings, heavy grazing can completely eliminate the species from the areas affected. This complex of factors seem to hinder regeneration and contribute to the disappearance of the species from many sites particularly the northern most ones. Experimental evidence indicates that plantations can be raised by mixed cropping (Taungya system), cultivating seedlings or direct sowing of seeds of *A. senegal* with the traditional crops (*Sorghum* and *Pennisetum spp.*, Groundnuts, sesame and karkade) of the area. (Papers published from this thesis include the El Din & Obeid and Obeid & El Din series.)

284 EL DIN, A.G.S. **[Rainfall and vegetation growth in the Sahel - a study on *Acacia senegal*.]** Pluviosité et croissance de la végétation au Sahel - Étudde centrée sur *Acacia senegal* (L) Willd. In: *The role of trees in the Sahel. Proceedings of a conference held at Dakar* (Senegal) *5-10 Nov 1979*. Ottawa, Canada; IDRC (1980) 43-50

Data based on records for 1902-1975 are given for average monthly rainfall and temperature in the Sudan, and related to germination, growth and gum production in *A. senegal*. Implications for artificial regeneration are discussed.

285 EL DIN, A.G.S. **Agroforestry practices in the dry regions.** *Kenya national seminar on agroforestry (edited by Buck, L.)* (1981a) 419-434

Agroforestry practices found in dry regions of Africa mainly characterized by long dry seasons (8 to 10 months) are presented. The rainfall in these regions is very low at 200 to 600 mm with high yearly fluctuations and temperatures up to and above 40 degrees centigrade. The traditional land-use systems are described, with species including *Acacia senegal*, *A. albida*, *Adansonia digitata* and *Borassus aethiopicum.*

286 EL DIN, A.G.S. **The study of the formation of gum arabic in relation to the anatomy of *Acacia senegal* Willd.** *Sudan Silva* (1981b) **4** (24) 14-18

Stem and root samples were collected from healthy *A. senegal* trees in Sudan, sliced and studied under a microscope to evaluate for the presence of gum. Microscopic sectons of different tissues were studied. Results showed that the bark and outer wood contained high amounts of gum, deposited in parenchyma, vessels and ray cells. Inner wood contained less gum, and roots contained only very small amounts. The structure of the bark appeared to be well adapted against excessive heat from sunlight and grass fires, with a thick bark and suberized cells. Presence of amylum grains and gum deposits in the ray cells suggest that the gum is derived from amylum and the two products interchangeable through chain reactions induced by enzymes. Contradicts the view that gum produced by bacterial or fungal infections (Blunt 1926). Tests indicate that the food material amylum is mostly found in the outer layers of the branches, and most tannins in the bark and the roots. Distinct growth rings were found in the wood, which have numerous vessels in the early wood and none in the late wood.

287 EL DIN, A.G.S. **Agroforestry practices in the dry regions. At Tasahhur.** *A paper presented at a*

Regional Seminar on Desertification at Darfur/ Kordofan, 1982. (1984) **2** 7-11

A brief account of the main land-use practices in the dry regions of Africa, with particular emphasis on the gum gardens of Sudan (*Acacia senegal*), the Bougage land rotation system in Niger (a sustainable variation of the traditional bush-fallow system in which there is an annual shift of a small portion of land from cultivation and livestock herding to fallow), and the use of multipurpose farm trees (particularly *Adansonia digitata*, *Borassus aethiopum*, *Acacia albida* and *Acacia tortilis* but also including small numbers of various other species).

288 EL DIN, A.G.S. **Gum hashab and land tenure in western Sudan**. In *Land trees and tenure (edited by Raintree, J.B)*. ICRAF (1987) 1-412

289 EL DIN, A.G.S.; OBEID, M. **Ecological studies of the vegetation of the Sudan. II. The germination of seeds and establishment of seedlings of *Acacia senegal* under controlled conditions in the Sudan**. *Journal of Applied Ecology* (1971a) **8** (1) 191-201

Seeds were sown on (a) undisturbed forest sites, (b) sites cleaned by pulling out the weeds, and (c) hoed forest sites, in Kordofan. On all three sites, ca. 84% of the seed was destroyed before or at the time of germination, mainly by insect larvae and millipedes. Subsequent seedling mortality was attributed mainly to high soil temperatures and low soil moisture during the dry season. Survival of seedlings up to the third rainy season was significantly better on (b) and (c) than on (a). In a related study in a nursery, moderate to light mulch provided significantly better conditions for seed germination and seedling establishment than either dense mulch or no mulch.

290 EL DIN, A.G.S.; OBEID, M. **Ecological studies of the vegetation of the Sudan. IV. The effect of simulated grazing on the growth of *Acacia senegal* seedlings**. *Journal of Applied Ecology* (1971b) **8** (1) 211-216

Describes a study of seedling survival after simulated browsing (removal of the cotyledons of 3-day seedlings, or the leading shoots of seedlings 1-11 weeks old). Simulated browsing caused serious mortality and a great reduction in dry-matter production and the numbers of lateral roots formed. Mortality was greatest when the plants were browsed at age 2-7 weeks, and this critical stage appears to coincide with the formation of the lateral roots.

291 EL DIN, A.G.S.; ZARROUG, M. **Production and commercialization of gum arabic in Sudan**. In *Domestication and commercialization of non-timber forest products in agroforestry systems (edited by Leakey, R.R.B.; Temu, A.B.; Melnyk, M.; Vantomme, P.). Proceedings of an international conference held in Nairobi, Kenya 19-23 February 1996. Non Wood Forest Products, FAO* (1996) No.9 176-182

Describes the methods used in Sudan to supply up to 85% of the world demand for gum arabic. The methods include maintaining the gum gardens, tapping techniques and gum collection and marketing. One of the reasons for maintaining its dominant position in the world trade is the supply of high quality graded gum from *A. senegal* var. *senegal*, which forms a major vegetation type on the qoz sands of western Sudan and it is also encouraged on farmland in gum gardens or in plantations. The sandy soils of western Sudan produce the majority of gum arabic exported, for instance Kordofan and Darfur produced 72.1% of the total Sudanese production in 1995, the clay plains of east and central Sudan producing the remainder. The marketing and export of the gum is managed by the official Gum Arabic Company (introduced in 1967-8) paying a minimum price and then a 40% export tax is levied when shipped from Port Sudan. They argue that this monopoly held by the company should be deregulated, as there is active smuggling to neighbouring countries to avoid the 40% export tax.

292 EL FADL, M.A. **Management of *Prosopis juliflora* for use in agroforestry systems in the Sudan**. *Tropical Forestry Reports, Department of Forest Ecology, University of Helsinki* (1997) No. 6 1-107 (Published thesis.)

A study on the suitability of integrating *Prosopis juliflora* (introduced into the Tendelti area in 1980) within the farming systems of central Sudan. The silvicultural management and yield components were investigated. The soil under the canopy had a higher total nitrogen and available phosphorus content, and lower soil pH than the soil from the adjacent open field. The potential allelopathic effect of both *Prosopis* and *Acacia senegal* on agricultural crop seed germination and seedling growth was investigated. Laboratory results indicated that aqueous leaf extracts of both tree species contain substances that inhibit sorghum, pearl millet and sesame seed germination and retard seedling development when applied at concentrations greater than 5%. However, increased amounts of litter in the soil from the trees increased crop production.

293 EL HADI, F.M. **Studies on *Acacia senegal* (L.) Willd. in western Sudan with special reference to variation among populations, host x soil inoculum interaction among populations, and host x rhizobium strains interactions**. *Ph.D. Thesis, Oregon State University, USA* (1987) [From thesis summary.]

Seeds of *A. senegal* (L.) Willd. from four populations across a rainfall gradient in western Sudan were grown in two sites. One site is on an upper dune crest (sandy soil) and the other site is on the lower slope of the same dune (sandy loam soil). Soils significantly influenced

all growth parameters except foliar N concentrations. Seedlings of all populations survived and grew better on the upper dune crest (sandy soil). Populations differed only in foliar N concentration. Although the number of first order branches did not differ among populations, there were large differences among individual seedlings in two of the populations. In a second study four populations of *A. senegal* from western Sudan were cross inoculated with soil from the same populations. Population x soil inoculum interaction was significant for all measured growth parameters. Significant nitrogenase activity, averaging 22.2 µml/g fw/h, did not differ significantly between populations, soil inoculum sources, or with the interaction between the two. The greatest specificity between populations and source of inoculum was shown by shoot and nodule weights in populations from the extremes of the rainfall gradient. Seedlings from all populations exhibited a relatively high relationship between home soil and root length. In a third experiment, two *A. senegal* seed lots, one collected near El Obeid, a relatively low rainfall zone, and the other near Kas, a high rainfall zone (both in western Sudan), were inoculated with each of the following Rhizobium strains: strain AR 14, isolated from *A. raddiana [A. tortilis ssp. raddiana]*, strain AN 12, isolated from *A. nilotica* ssp. *adstringens*, strain PJ 12, isolated from *Prosopis juliflora*, strain TAL 1595 isolated from *A. pennatula*, and strain ASK isolated from *A. senegal*. Population x Rhizobium strain interaction was significant for shoot height. Height of Kas seedlings from the high rainfall zone were more sensitive to strain treatment than that of El Obeid seedlings from the low rainfall zone. Strain main effect was highly significant for shoot weight. Seedlings inoculated with ASK strain had a greater weight, especially in comparison to PJ 12 strains. Seedlings inoculated with the ASK strain nodulated earlier than seedlings inoculated with the other strains.

294 EL HOURI AHMED, A. **Effects of land use on soil characteristics in the Sudan**. In *Soils Research in Agroforestry (edited by Mongi, H.O.; Huxley, P.A.)*. ICRAF (1979) 1-13

The traditional farming systems of Western and Eastern Sudan have resulted in a rapid deterioration of both soil fertility and productivity, and a build-up of pernicious weeds, which eventually give way to desertification, as rotations become shorter and cultivation continues. Both *Acacia albida* and *Acacia senegal* have been found beneficial for (1) the improvement of soil characteristics and arresting ecosystems degradation (2) the increasing of soil N fertility and a more favourable C/N ratio (3) supplying considerable amount of livestock fodder and (4) the production of fuel wood and gum arabic.

295 EL HOURI AHMED, A. **Some *aspects* of dry land afforestation in the Sudan with special reference to *Acacia tortilis* (Forsk.) Hayne, *A. senegal* Willd. and *Prosopis chilensis* (Molina) Stuntz**. *Forest Ecology and Management* (1986) **16** (1-4) 209-222

Discusses the benefits of planting *Acacia tortilis* ssp. *spirocarpa* and ssp. *raddiana*, *A. senegal* [var. *senegal*] and *Prosopis chilensis* in arid degraded lands of Sudan to restore soil fertility, and provide fodder, fuel wood and other products. Plantations of *A. senegal* were established by mechanised seeding at a seed rate of 15-25 kg ha^{-1}, on dark cracking clays in Central Sudan. They were on abandoned cultivated lands where sorghum yields had declined due to loss of soil fertility. With disc harrowing and sowing during the rains, the plantations were successful, with weed growth not being too vigorous and the seeds being cheap.

296 EL NAGHEEB, A.H.; BROMLEY, D.W. **Rain fed mechanized farming and deforestation in central Sudan**. *Environmental and Resource Economics* (1992) **2** (4) 359-371

Sudan is threatened by a serious deforestation problem. Total forested area decreased by about 20% over the last two decades, largely as a result of the expansion of rain fed mechanized farming (RMF). To safeguard against the problems of deforestation, the government's Mechanized Farming Corporation requires each farmer to leave at least 10% of the total farm area under shelterbelts. Few farmers pay attention to this clause. This paper addresses the problem of RMF expansion and analyses the effects of different factors on the preservation of shelterbelts. The data used were collected through interviews with farmers in the Damazin region of central Sudan in 1988. Results indicate that the following factors influence the decision to preserve shelterbelts: farmer's belief in the value of shelterbelts, the production of gum arabic [from *Acacia senegal*], farm size, farmer's wealth, the number of years a farm has been cultivated, and type of farm.

297 EL RASHEED, M.A. **The production and role of gum arabic in the economy of the Sudan**. *Coedwigwr* (1970/71) **6** (3) 84-87

A general account, describing the *Acacia* woodland resources, tapping, gum exports and uses, and research. Of the two types of commercial gum arabic, 'gum hashab' is derived from *A. senegal* (and to a lesser extent, *A. laeta*) and 'gum talh' from *A. seyal*. In western Sudan *Acacia* savanna on sandy soils occupy approx. 48,000 sq. miles (ann. rainfall 450-600 mm,) and on the clay soils of central and eastern Sudan around 105,000 sq. miles (ann. rainfall 570-800mm). The former region being the main source of gum hashab and the latter the main source of gum talh. Estimates to produce current export figures of 62,000 tons/yr suggest the need to tap 280 million gum trees!

298 EL RASOUL, H.; EL SAEED, H.; SARHAN, M.E. **Marketing costs and margins for selected agricultural commodities in Sudan, 1986-1987**. BIDS.

Marketing Section, Department of Agricultural Economics, Planning and Agricultural Economics Administration, Ministry of Agriculture and Natural Resources, Khartoum, Sudan (1988) 1-189

This report contains the results of the 1986/87 market survey for selected agricultural commodities in Sudan, namely sorghum, millet, groundnuts (for export and for local processing), sesame, and gum arabic [from *Acacia senegal*]. The survey was carried out in the mechanized and traditional rain fed areas and covered commodity assemblers, wholesalers, exporters, processors, and retailers. A total of 1266 merchants were involved. The results for each commodity are presented in tabular and graphical forms. Specifically, for every commodity and each market, a detailed list of marketing costs and margins for each market participant is presented, and a breakdown of the marketing costs into cost components along with the relative importance of each item is given. Appendices contain detailed data on length and cost of storage, and port expenses for exported goods.

299 EL TINAY, A.H.; KARAMALLA, K.A.; EL AMIN, H.M.; SHIGIDI, M.T.A.; ISHAG, K.E.A. **Serotaxonomic studies on Sudan *Acacias*.** *Journal of Experimental Botany* (1979) **30** (116) 607-615

Seed proteins from 22 *Acacia* species collected from Northern, Central and Western Sudan were compared by serological methods in an attempt to classify the Sudanese *Acacias*. The results of immuno-diffusion and immuno-electrophoresis studies showed that the studied *Acacias* could be broadly divided into two main established taxonomic groups and six subgroups. *Acacia senegal* fitted into the second group of species (series Vulgares), which all had spicate inflorescence types. Both *A. mellifera* and *A. laeta* were found to be closely related and grouped in a subgroup with *A. polyacantha* and *A. senegal* was grouped with *A. asak* and *A. ataxacantha* in the other subgroup in series Vulgares. *Acacia albida* did not fit into either group. The three subspecies of *A. nilotica* (*nilotica*, *tomentosa* and *adstringens*) were found to be serologically identical and were grouped together in a subgroup within Group 1 (subgenus *Acacia*).

300 ESHETE, G.; STAHL, G. **Functions for multi phase assessment of biomass in *Acacia* woodlands of the rift valley of Ethiopia**. *Forest Ecology and Management* (1998) **105** (1-3) 79-90

Single tree biomass functions for *Acacia* woodland tree species are developed and presented. The main aim of developing the functions was for utilizing them in a multi-phase sampling design in estimating the woody biomass in *Acacia* woodlands of the Rift Valley of Ethiopia. Eighty-five trees (5-35 cm diameter) were selected randomly to represent the 5 dominant tree species present: *Acacia tortilis, Acacia senegal, Acacia seyal, Acacia etbaica* and *Balanites aegyptiaca*. Diameter at 0.8 m and at stump height (0.3 m), crown diameter, and tree and bole height were determined on standing trees, and diameter at crown base, and stem and branch weights on felled trees, with sample discs taken to determine the relationship between wood fresh and dry weights. Four categories of functions were developed. These were: (i) functions with crown area as independent variable, to be applied using high resolution satellite images or aerial photographs; (ii) functions with crown area and tree height as independent variables, to be applied using data from aerial photos; (iii) functions for quick estimation in ground surveys, based on the diameter at 0.8 m; and (iv) functions for thorough estimation in ground surveys, in which the diameter at 0.8 m, the diameter at stump height, and the crown area were included. Also, 2 sets of functions were developed, one with and one without species indicator variables. In gathering data for developing the biomass functions, the selection of sample discs from trees for determining the ratio between dry weight and fresh weight is important. In addition to the functions, a robust method for the disc sampling is proposed.

301 ETHIOPIA, FORESTRY RESEARCH CENTER. **Growth of some forest trees in Ethiopia and suggestions for species selection in different climatic zones**. *Research Note* (1986) No.2 1-52

Planting trials were carried out concerning species selection (species elimination tests) in the Tigre, Wollo and Harerge regions of Ethiopia. Survival rates fluctuated according to the physical parameters of the site; annual rainfall, altitude and soil structure. Species that were recommended for planting in the dry lowlands and plateau with rainfall between 300-700mm were *Acacia albida, A. saligna, A. senegal, A. tortilis* and *Prosopis juliflora*. *A. senegal* was tried at Meki, at 1600m in sandy alkaline soil, with 600 mm of rainfall and had the highest survival rate there with 92%.

302 EUROPEAN PHARMACOPOEIA ***Acacia***. In *European Pharmacopoeia, 3rd edition*. Strasbourg, Council of Europe (1997) 337-338

303 EVANS, C.S.; QUERSHI, M.Y.; BELL, E.A. **Free amino acids in the seeds of *Acacia* species**. *Phytochemistry* (1977) **16** 565-570

Results of a study to determine free amino acids in 80 species of *Acacia*. The possible taxonomic and phylogenetic significance of these results are discussed, with particular reference to five species, *A. albida, A. confusa, A. heterophylla, A. coulteri* and *A. kauaiensis*.

304 EWALD, J.J. **Soldiers, traders and slaves: State formation and economic transformation in the Greater Nile Valley 1700 -1885**. Madison Wisconsin, University of Wisconsin Press (1990) 1-270

305 FAGG, C.W.; BARNES, R.D. **African acacias: study and assembly of the genetic resources**. *Final Report of ODA Forestry Research Schemes R.4583 and R.5655.* Oxford Forestry Institute (1995) 1-173

The first of the ODA-funded projects (R.4348) on the study and assembly of the genetic resources of the African acacias at the OFI started in 1987 in response to an internationally identified need for improved use of the genetic variation in the genus. The objectives of these projects were, for *Faidherbia (Acacia) albida, A. tortilis, A. nilotica, A. senegal* and *A. erioloba*, to: - assemble rangewide material for evaluation, domestication and conservation; investigate selfing levels, breeding systems and genetic variation; distribute seed for evaluation; produce annotated bibliographies; describe phenology and morphology; collect rhizobia for taxonomic studies; establish the feasibility of dating the trees by dendrochronology; and to collect material to elucidate and resolve the taxonomic problems of the five species and their close relatives. It took a second three-year project plus a two-year extension to achieve these objectives. This report covers the work done in the second Research Scheme (R4583) and its extension (R5655). The products of these projects yielded information and materials that provided the basis for research on various aspects of the African acacias by many scientists in many other organizations. A summary of outputs from this research is included in this report. Rangewide seed collections were assembled with a total of 141 provenances of the 21 taxa that comprise the 5 species. The information gained from the concurrent investigations into selfing levels, breeding systems and genetic variation was used to improve the precision of sampling the natural range of each species. For *Acacia senegal* detailed distribution maps are presented and the variation in the species discussed. The flowering and fruiting phenology of the four varieties is summarized. Because the main interest in the species has been for gum production, the collecting strategy concentrated on *A. senegal* var. *senegal*, although a little seed of the two growth forms of var. *leiorhachis* and var. *rostrata* was collected for taxonomic studies. Some seed of the hybrid *Acacia laeta (senegal x mellifera)* was also collected. In all 12 provenances were collected throughout Africa. Initial studies undertaken by Cirad Foret and researchers in Senegal indicate that the west African provenances show little variation in isozymes and the number of polymorphic loci are rare. The vision of the role that the African acacias can play in increasing the productivity of non-arable land in the semi-arid zones of the continent has expanded since this work started eight years ago. The projects have begun to reveal the acacias' genetic prospects. There is also increasing evidence that the devastating droughts in Africa are likely to be long term; and the potential role of exotics in this situation has diminished with the growing concern about their invasive propensities. The most important areas for future research into the African acacias are in the fields of: - evaluation of the genetic potential of the acacias; socio-economic studies to quantify their current and potential value in farming systems; the relationship between seedling physiology and adaptation; selfing studies to determine genetic load; hybrid studies to assess heterosis, to resolve taxonomic inconsistencies and to produce sterile, fast-growing, productive cultivars; rhizobial studies; and investigations into the stand dynamics of invasion. These projects have now provided the information and materials on which much of this research can be based. The task in the future is to manage this resource efficiently to supply the needs of well-focussed research projects.

306 FAGG, C.W.; BARNES, R.D.; MARUNDA, C.T. **African *Acacia* trials network: a seed collection of six species for provenance/progeny tests held at the Oxford Forestry Institute**. *Forest Genetic Resources*, FAO, Rome (1997) No.25 39-50

This paper provides a brief account of the sampling procedures used by the Oxford Forestry Institute in making seed collections of 5 important *Acacia* species (*A. tortilis, A. nilotica, A. senegal, A. karroo* and *A. erioloba*), and one of *Faidherbia* (*F. albida*), throughout their native range in Africa. The species distributions were mapped as well as the seed collection sites, and seed is available from these collections for research trials. For *A. senegal* collections were predominantly made for the variety *senegal, which* is the main gum producing variety. Small collections were also made from two other varieties, var. *leiorhachis* and var. *kerensis* for taxonomic studies.

307 FAGG, C.W.; STEWART, J.L. **The value of *Acacia* and *Prosopis* in arid and semiarid environments**. *Journal of Arid Environments* (1994) **27** 1-23

The great biological diversity in *Acacia* and *Prosopis* is reflected in their wide distribution and ecological amplitude, and particularly in the tolerance of some species to extremes of drought and salinity. Their value, however, lies not only in their ability to thrive under adverse conditions, but also in the range of useful products that they provide. Among these, animal fodder, both pods and browse, is of central importance. The wood of both genera is an essential source of fuel in the arid and semi-arid areas, and the timber is also valued for a wide range of purposes. The greatest economic value of *Acacia*, however, lies in the production of gums and tannins for industrial uses. Gives details on the gum properties from *A. senegal*, which is being used in the pharmaceutical, and confectionary and printing industries, acting as an emulsifier and clarifying agent for food flavours and beverages, a source of high soluble fibre and a cholesterol reducer. The Acacia gums may have evolved to protect the tree from damage by plugging wounds, as well as acting as a medium for water storage. They are mostly composed of easily digestible sugars, but are also rich in minerals (Ca, Mg, P and other trace salts) and were specifically used for this reason by pregnant women in ancient Egypt.

308 FALL, M. [**Acacia senegal; the species, its products and uses**.] L'*Acacia senegal*, l'espece, son produit, ses utilisations. In *Recueil des Communications Presentes au Seminaire National sur les Essences Forestieres Locales, tenu a Ougadougou, 6-10 Juillet.* Ouagadougou, Burkina Faso; Institute Panafricain pour le Development (1987) 164-203

Describes the species, its botany, its natural distribution, and ecological characteristics. It is found in a wide range of soil types, from poor sandy soils to sandy clays (in Affole in Mauritania), sandstone clays (Brakna in Mauritania, Kayes in Mali) and lithosols over quartz (Assaba in Mauritania). An important species for soil improvement, it is also a vital browse providing foliage from July to January in the Sahelian regions, and fallen pods from February to March. In Fété-Olé (Senegal) an estimated 5,6 kg of fodder per hectare was consumed in 1973, split into 3.7 kg of leaves and 1.8 kg of flowers and fruits. Gives the gum arabic production figures for Senegal from 1959-1976, which rose to a peak of 10,872 tons in the 1970/1 season, and dropping drastically in the following years because of droughts. When Mauritania, Niger, Nigeria and Chad were also included, the production totals rose to 17,000 tons in 1971, and dropped to 2,000 in 1977. In Mauritania and Niger the commerce is controlled by a nationalised monopoly, which has the adverse effects of not motivating the collectors and middlemen, whereas in Mali, Nigeria and Senegal it is under private sector control. Gives details on the prices paid in West Africa for the gum (Ferlo gum 150 Francs CFA/kg, Bakel gum 135 Francs CFA/kg). Highlights the need for projects to identify and protect natural populations of gum trees, with fire breaks around blocks of 100-200 hectares, clearing and thinning thickets to about 300 gum trees/ha, manage these blocks on 15-18 year rotation when the trees become economically unproductive.

309 FAROOQI, M.I.H.; KAPOOR, L.D. **Some Indian plant gums - their botany, chemistry and utilization**. *Indian Forester* (1968) **94** (9) 662-6

Commercial gums from 11 Indian tree species were examined and some adulterant tests are described. Detailed chemical studies have been made of the gum from *Albizzia procera*, which for many purposes can be used as a substitute for imported gum arabic from *Acacia senegal.*

310 FELKER, P. **Tree plantings in semi arid regions**. *Proceedings of a symposium on establishment and productivity of tree plantings in semi arid regions, Texas, April 29 - May 2.* Elsevier (1986) 1-444

311 FENYO, J.C.; SERVANT-DUVALLET, S.; VANDEVELDE, M.C. **Chemical and physico chemical identification of exudations from acacias**. [Identifications chimique et physico chimique des exsudats d'acacias.] In L'Acacia *au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.) L'Orstom, Collection colloques et séminaires, Paris, France* (1998) 329-349, 463-464

The physiology and gummosis in *Acacia senegal*, which produces the commercial gum arabic, is described. Tapping the bark, peeling a strip around 50 cm long, produces most gum. While present evidence points to a transformation of starch to gum under certain conditions, the process of gummosis is still not completely understood. Describes the composition and variability of the gum by reviewing the literature, and showing a large proportion of the analyses from Senegal are outside the JEFCA specifications. They suggest that the complex macromolecular structure of the gum is consistent with the wattle-blossom model. Data on 134 exudations from a wide range of *Acacia* species are tabulated and briefly discussed.

312 FENYO, J.C.; VANDEVELDE, M.C.; CONNOLLY, S. **Gommose et propriétés de la gomme d'*Acacia senegal***. In *Physiologie des Arbes et Arbustes en zones arides et semi*-arides. *Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadnam, C.; Joly, H.; Bory, G.).* (1993) 283-287

Discussion article of the literature on the gummosis of *A. senegal* and identifying the structure and chemical composition of this complex macromolecular gum.

313 FERLIN, G.R. [**Reforestation techniques in the semi-arid zones of Africa south of the Sahara.**] Techniques de reboisement dans les zones subdesertiques d'Afrique au sud de Sahara. In *The role of trees in the Sahel. Proceedings of a conference held at Dakar (Senegal), 5-10 November 1979.* Canada; International Development Research Centre (1980) 51-56

With particular reference to *Acacia* and *Prosopis spp.*, and 8 other genera.

314 FLOWERMAN, P.M. **Marketing Sudanese gum in the U.S.A.: Facts and options**. *Mimeo Khartoum Sudan: Checchi and Company Consulting prepared for the United States Agency for International Development, Bureau for Africa* (1985)

315 FOOD AND AGRICULTURE ORGANIZATION **Gum arabic-trends and prospects**. Item 8 - African Forestry Commission 3rd Session, Nairobi, Kenya 7-12 Feb., Secretariat note (1972) FO: AFC-72/2 1-7

This note gives the salient features of gum arabic trade up to 1970, the gum marketing organizations in the producing countries, the prices and uses for gum arabic, substitutes for gum arabic and imports by consuming countries. The major producing countries are Sudan, Nigeria, Senegal and Mauritania in descending order of importance, and the majority of marketing organizations

are based on private enterprise. Starches and their derivatives account for up to 85% of the total market for water-soluble gums, but not all can compete with gum arabic. There are a range of synthetic gums which also compete with gum arabic, but gum arabic has been used for many years and has superior performance in the confectionary industry. It main disadvantage is variable quality, supply and prices. In summary the prospects for gum arabic are not very bright with demand likely to fall in the future, although demand in the flavour and lithographic industries are likely to rise. Concludes that the commission could look at measures to ensure quantity and quality of supply, stabilise prices and instruct collectors in proper methods of tapping, and possibly processing in the producer countries.

316 FOOD AND AGRICULTURE ORGANIZATION **The characterisation and specification of gum arabic**. *Unpublished FAO project report* [supplement to: A Review of Production, Markets and Quality Control of Gum Arabic in Africa, prepared by Chikamai, B.N. from mission reports by Coppen, J.J.W.; Casadei, E.; Abdel Nour, H.O.; Cesareo, D. - Project no.TCP / RAF / 4557] (1996)

317 FOOD AND AGRICULTURE ORGANIZATION / WORLD HEALTH ORGANIZATION **Joint expert committee on food additives, specifications for identity and priority of certain food additives**. *FAO Food and Nutrition Paper* (1990) No.49 23-25

The specifications listed for the identity and purity of food additives established by JEFCA are listed including those governing gum arabic (INS No E414). Its definition, description, functional uses, characteristics, and identification and purity tests are described. Its definition is "a dried exudation obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or closely related species. It consists mainly of high molecular weight polysaccharides and their calcium, magnesium and potassium salts, which on hydrolysis yield arabinose, galactose, rhamnose and glucuronic acid. The article of commerce may be further specified as to viscosity".

318 FOOD AND AGRICULTURE ORGANIZATION / WORLD HEALTH ORGANIZATION **Gum arabic**. In *Compendium of food additive specifications, Addendum 3. FAO Food and Nutrition Paper* (1995) 52 Add. 3 1-3

The specifications listed for the identity and purity of food additives established by JEFCA are listed including those governing gum arabic. Its definition, description, functional uses, characteristics, and identification and purity tests are described. Its definition is "a dried exudation obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or closely related species of *Acacia* (fam. Leguminosae). It consists mainly of high molecular weight polysaccharides and their calcium, magnesium and potassium salts, which on hydrolysis yield arabinose, galactose, rhamnose and glucuronic acid".

319 FOOD AND AGRICULTURE ORGANIZATION / WORLD HEALTH ORGANIZATION **Gum arabic**. In *Compendium of food additive specifications, Addendum 5. FAO Food and Nutrition Paper* (1997) 52 Add. 5 53-55

320 FOOD AND AGRICULTURE ORGANIZATION / WORLD HEALTH ORGANIZATION **Gum arabic**. In *Compendium of food additive specifications, Addendum 6. FAO Food and Nutrition Paper* (1998) 52 Add. 6 69-70

321 FOOD AND AGRICULTURE ORGANIZATION / WORLD HEALTH ORGANIZATION **Gum arabic**. In *Compendium of food additive specifications, Addendum 7. FAO Food and Nutrition Paper* (1999) 52 Add. 7 49-50

322 FORBES, F.J. **Studies in ancient technology**. Leiden; E.J. Brill (1955) Vol.IIII, 1-268

323 FRANK **Sur la formation de la gomme dans le bois et sa signification physiologique** Berlin; *Beriche. D. deutsch. Botan. Gesselsch* vol II (1884) 321

324 FRANKLIN, J.; PRINCE, S.D.; STRAHLER, A.H.; HANAN, N.P.; SIMONETT, D.S. **Reflectance and transmission properties of West African savanna trees from ground radiometer measurements**. *International Journal of Remote Sensing* (1991) **12** (6) 1369-1385

Reflectance and transmission properties of West African *savanna* trees were measured using a pole-mounted radiometer for four Sahelian (*Balanites aegyptiaca, Acacia seyal, A. senegal, Combretum glutinosum*) and two Sudanian (*Acacia albida, Butyrospermum parkii [Vitellaria paradoxa]*) species taken between November 1986 to October 1987 in Mali. Thirty two trees in total were measured. The measurements showed that canopy spectral components (shadowed and sunlit tree crown and background) have distinct reflectance characteristics in red and infrared wavebands. Sunlit canopy was the greenest component (greatest infrared to red contrast), and sunlit background (consisting mostly of bare soil) the brightest (greatest summed red and infrared reflectance). Shadowed crown, the darkest component, was greener than shadowed background. The field radiometer measurements were used to calculate the normalized difference vegetation

index (NDVI), and the spatial integral of the NDVI over the canopy was related to crown volume yielding per species r2 of 0.75 to 0.81. Measurements of canopy transmission indicated that only 12-47% of incoming radiation was absorbed in these wavebands.

325 FREUDENBERGER, M.S. **Contradictions of gum arabic afforestation projects: Observations from the Linguere Dept. of Senegal.** *International group for the study of Mimosoideae* (1988a) Bulletin No.16 87-122

Gum arabic has been exported from northern Senegal and southern Mauritania since the early 18 th century. Gives a detailed historical overview on gum arabic forest protection and afforestation schemes since that time. In the 1920's French colonial authorities started projects to protect and regenerate the gum arabic tree (*A. senegal*) in the Linguere department of northern Senegal. This paper looks at the evolution of these and subsequent afforestation projects up to the present day. Since the mid 1970's the Senegalese have raised 4,700 hectares of gum arabic in the western zone of Linguere department. Those planted between 1975-1981 are now being exploited for forage and gum arabic. Despite this apparent success, some project personnel feel that the projects are not generating the projected benefits, with poor pricing, property rights and tribal conflicts leading to little tapping for gum and using the tree for forage. Plantations are most likely to be tapped in drought years when field crops fail. The high costs of establishing these state run monoculture plantations (200,000 CFA/ha or 670 US$/ha), and the low and variable international price for gum arabic, has led to a shift in focus on managing natural populations and assuring quality control through enforcement of government regulatory measures. Neither of these export orientated models are viable today.

326 FREUDENBERGER, M.S. **Contradictions of gum arabic afforestation projects: Observations from the Linguere Dept. of Senegal**. Dakar, Senegal; Centre Culturel Americain (1988b) 1-24

Same data presented in the above abstract.

327 FREUDENBERGER, M.S. **The great gum gamble: a planning perspective on environmental change in Northern Senegal (Gum arabic).** PhD. Thesis, University of Los Angeles, USA (1992) 1-490 [from thesis summary]

The study charts the evolution of the gum arabic tree crop economy from its inception in the early seventeenth century in southern Mauritania to the present in the Department of Linguere. Four themes are explored: (1) the process by which rural society has been incorporated into the international economy through the export of gum arabic; (2) the transformation of institutions which regulate access to the tree; (3) the evolution of the labor systems used to extract gum arabic; and (4) the changing and contradictory role of the state in managing and manipulating the natural resource base. The national archives of Senegal were extensively used to reconstruct the history of the economy in the Department of Linguere. Field work took place from 1987 to 1989 and consisted primarily of in-depth interviews with Fulbe, Wolof, and Maure gum collectors, with gum arabic merchants in Europe, the United States, and Senegal, and with Senegalese and expatriate foresters and government officials. The conclusions consist of policy recommendations concerning measures required to devolve resource management control primarily to Maure gum collectors, the true specialists of the gum collection system.

328 GACHATHI, F.N.M. **Variation in *Acacia senegal* and its relationship with *Acacia circummaginata* and *Acacia thomasii* in Kenya.** *MSc thesis, University of Reading, U.K.* (1994) 1-81

Four growth forms previously recognised as constituting three of the four varieties within *Acacia senegal* (L.) Willd. were carefully observed in their natural environment in Kenya and their habits and habitats recorded and presented in form of photographs. Herbarium specimens from the species range in south and north-east Tropical Africa were critically examined and all measurable morphological parameters compared for similarities, differences and variations. The previous relationship of *A. senegal* to *A. circummarginata* was discussed and reassessed as were the apparent similarities between one of the previously recognised growth form of *A. senegal* and *A. thomasii*. From the field observations of living trees and the herbarium examination of dry specimens, variation within *A. senegal* was found not as much as previously perceived. The two growth forms, previously considered as constituting *A. senegal* var. *leiorhachis* were found to be distinct and different taxa from *A. senegal*. It was recommended that the growth form with the rounded spreading crown retain its original name *A. circummarginata* while a new name *A. flagellum* nom. nov. for the whippy form was suggested. The large flowers and lack of rachis glands were found to be the most reliable characters for distinguishing *A. thomasii* from this latter taxon.

329 GACHATHI, F.N.M. ***Acacia circummaginata*, a distinct species or a variety of *A. senegal*?** *XVI International Botanical Congress, Missouri Botanical Gardens, Missouri, USA* (1999) [Abstract 4356 from CD-ROM.]

Four growth forms recognized as constituting three of the four varieties within *Acacia senegal* (L.) Willd. were observed in their natural habitat in Kenya. Herbarium specimens from the species range in South and North-East Tropical Africa were examined for the measurable morphological parameters. From the field observations and the herbarium examination of specimens, variation of *A. senegal* in Kenya was found to be

restricted to var. *senegal* and var. *kerensis*. The two growth forms under var. *leiorhachis* were found to be clearly recognizable as distinct taxa. It was recommended that the growth form with rounded spreading crown revert to its former name *A. circummaginata* while a new name for the whippy growth form be suggested.

330 GADEN, E. F. **La gomme en Mauritanie**. In *Annales de l'Academie des Sciences Coloniales* (1929) **IV** 219 - 227

331 GAGNE, R.J.; MAROHASY, J. **The gall midges (Diptera: Cecidomyiidae) of *Acacia* spp. (Mimosaceae) in Kenya**. *Insecta Mundi* (1993) **7** (1-2) 77-124

Twenty eight new species of plant feeding Cecidomyiidae are described by the 1st author from galls on *Acacia nilotica, A. drepanolobium, A. tortilis, A. mellifera* and *A. senegal* in Kenya. These include *Acacidiplosis spinosa* gen. et sp. nov., *Aposchizomyia acuta* gen. et sp. nov., *Athidiplosis walteri* gen. et sp. nov. and *Kimadiplosis diversa* gen. et sp. nov., all of which are the type species of their respective genera. Keys to genera of 3rd instar larvae, adults and galls are provided for Kenya. Galls of several additional species of gall midges from *Acacia* spp. in Kenya are described and gall midges from acacias in Africa, India and Australia are reviewed. Two of the new species, *Acacidiplosis spinosa* and *Aposchizomyia acuta*, inhabit flowers of *Acacia nilotica* and are potential biological control agents of their host in Australia.

332 GANGULY, S.C.; HOSSAIN, T.; MUKERJI, B. **'Ghatti gum' as an emulsifying agent**. *Indian Journal of Pharmacy* (1945) **7** (4) 106-8

'Ghatti gum', from the stem of *Anogeissus latifolia*, was compared with gum of *Acacia senegal* and *A. arabica [A. nilotica]*. It has little or no emulsifying power and very poor solubility in water, and is not recommended as a substitute for gum of *A. senegal*. Indian *Acacia*, however, obtained from *A. arabica*, is a good substitute and has even better emulsifying power than gum of *A. senegal*.

333 GANRY, F.; DOMMERGUES, Y.R. **Nitrogen fixing trees: a research area**. [Arbres fixateurs d'azote: champ ouvert pour la recherche.] *Agriculture et Developpement* (1995) No.7 38-55

A review of recent research into nitrogen fixing trees. The emphasis is on the use of such tree species in agroforestry systems in the tropics. An outline is given of nitrogen fixation, bacterial and mycorrhizal symbionts, methods for measuring nitrogen fixation, and field trials for investigating the effects of nitrogen fixing trees on associated crop growth (whether in alley cropping with hedges, bush fallows or long term rotations). *Acacia raddiana [A. tortilis ssp. raddiana], A. senegal, A. cyclops, Faidherbia albida* are included in a list of trees with low nitrogen fixing potential, *Prosopis juliflora* and *A. saligna* of average potential, and *Leucaena leucocephala, Calliandra spp., Casuarina spp., A. mangium, A. mearnsii, A. seyal, Gliricidia sepium and Sesbania spp.* of high nitrogen fixing potential.

334 GASMSER, M.S. **Letting the piper call the tune: experimenting with different forestry extension methods in the northern Sudan**. *ODI Network Paper* 4A (1987) 1-19

The paper presents examples of the outcome of some of the grants made by the Energy Council (ERC) and within it the Government of Sudan/USAID-sponsored Sudan Renewable Energy Project (SREP) examining the impact of institutional innovations upon social forestry development. The importance of peoples' participation in social forestry projects is described as the most important component and is discussed in detail.

335 GAYE, C.S. **Comportement de *Acacia senegal* en plantation et dans la nature au Sahel Senegalais. Perspectives d'Avenir des Reboissements Gommiers**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 139-169

Reviews ecological studies undertaken at Mbiddi in the Senegalese Sahelian zone, where annual rainfall is less than 400 mm. Studies included ecology and growth of the species in plantation and natural populations, survival, natural regeneration, growth, phenology and gum production. The species has a wide distribution between the isohyets 900-150 mm of annual rainfall, and within the Mbiddi area prefers deep hydromorphic and pseudogley soils found in depressions and bases of sand dunes. Describes two phenotypes of the species in Senegal, a light grey bark type and a dark grey one, the latter producing more gum and of better quality. Other characters distinguishing the light and dark grey types are; colour of young shoots light brown versus whitish respectively, seed size greater and more variable in the dark grey type and seed colour light brown versus greenish brown respectively. The dark grey type is naturally more abundant at the base of the dunes and depressions and should be selected for planting there. Higher rates of survival occur with seedlings planted in the depressions compared with on the dunes, where species more resistant to drought such as *Balanites aegyptica, Boscia senegalensis* and *A. tortilis* ssp. *raddiana* would survive better. Apart from droughts, mortality of *A. senegal* is attributed to parasitic insects, fire, rats, and overgrazing by man and his livestock. Heights of plants of the same age varied considerably from the top of the dunes to the basal depressions. Found that gum production of trees was affected by previous winters rainfall, that gum production varied from 7.5-30 g/tree/annum at the top of the

dune and 12.9-68.1 g/tree/annum in the basal depressions. Little correlation was found between increasing stem circumference and gum yields. Only in the depressions did the plants flower and fruit, presumably due to more soil moisture available than on the dunes, and the optimal time for gum exudation was at the end of October, when temperatures increase and over half of the leaves have fallen.

336 GERAKIS, P.A.; TSANGARAKIS, C.Z. **The influence of *Acacia senegal* on the fertility of a sand sheet ('goz') soil in the central Sudan**. *Plant and Soil* (1970) **33** (1) 81-86

On the sand-sheet soils of the *A. senegal* region of the Sudan, 12-20 years of *A. senegal* fallow is followed by ca. 3-10 years of field cropping. In 1962, soil cultivated after a 12-year fallow was better on sites where *A. senegal* had been felled and uprooted than on other sites. Soil analyses showed that *A. senegal* increases total N (possibly through symbiotic fixation) and C contents, but has no effect on soil texture, pH, or available P and K. Recommendations are made for minimizing soil variability is such areas when making field trials.

337 GHEDDI, A.M. [**Qualitative (chemical) characteristics and nutritive value of foliage of various trees and shrubs from Somalian forests.**] Caratteristiche qualitative e valore nutritivo delle foglie di alcune piante arboree e arbustive della boscoglia Somala. *Thesis, Facolta di Agraria, Universita Nazionale Somala* (1980) 1-31

Data are reported for 15 species: *Acacia horrida*, *A. nilotica*, *A. nubica*, *A. oxyosprion*, *A. senegal*, *A. tortilis*, *Anisotis [Anisotes] involucratus*, *Balanites scillin*, *Boscia somalensis*, *Calotropis procera*, *Cordyla africana*, *Delonix elata*, *Dobera glabra*, *Grewia villosa* and *Solanum arundo*.

338 GHOSH, S.S.; PURKAYASTHA, S.K. **Anatomical studies of wood and bark of *Acacia senegal* Willd. trees with special reference to gum exudation**. *Indian Forester* (1962) **88** (2) 92-99

The study is based on a large number of cambial stocks (cambium + bark + wood) as well as twigs and branches, of *A. senegal*, collected at different seasons of the year, from trees yielding gum and not yielding gum. The gum comes from gum cysts that develop, in the inner bark of some trees, in tangential rows in the axial parenchyma strands of the phloem adjacent to the cambial zone. They are first developed schizogenously, but later enlarged considerably through the breakdown of neighbouring cells; they have no definite shape or size. The specimens showing spontaneous exudation of gum indicated that the development of gum cysts is proceeded by widespread changes, such as profuse development of parenchymatous tissue and disappearance of starch, in both xylem and phloem, as well as disintegration of the pith. Formation of cysts and the other changes occur only in localized areas of the stem. Blazing the tree sometimes leads to the formation of gum cysts, but unaccompanied by changes in the xylem. Rod-shaped bacteria have been found in all tissues affected by gummosis, but these are not thought to be the causal agents of gummosis.

339 GIBBON, D.; PAIN, A. **Crops of the drier regions of the tropics**. London, UK; Longman (1985) 1-157

The first part of this book (in the Intermediate Tropical Agriculture series), entitled General Considerations, includes chapters on: 1. The characteristics and ecology of the dry regions of the tropics, 2. The origin of the tree and field crops and the evolution of land use systems in the dry tropics, 3. Present farming practices and systems, and 4. Characteristics of the main semi-arid tropical regions. The second part, Specific Crops, includes: 11. Industrial and miscellaneous crops (gum arabic (*Acacia senegal*, *A. seyal*), sugarcane, tobacco and wattle (*A. mearnsii*). The third part of the book, Future Developments, consists of one chapter, 16. The potential for improvement of output from trees, crops and farming systems within the dry regions of the tropics. The authors conclude that agroforestry or mixed systems, which represent the closest approximation to older farming systems or natural ecosystems, hold out the greatest promise for many dry lands.

340 GIBSON, I.A.S. (compiler) **Diseases of forest trees widely planted as exotics in the tropics and Southern Hemisphere. Part I. Important members of the Myrtaceae, Leguminosae, Verbenaceae and Meliaceae**. Surrey, UK; Commonwealth Mycological Institute, and Oxford, UK; Commonwealth Forestry Institute (1975) 1-51

Lists the diseases according to the circumstances of their occurrence and gives descriptions of the symptoms and information on control methods. The following fungal diseases of *Acacia senegal* are recorded: *Leaf and stem diseases: Acacia senegal* may be attacked by *Ravanelia acaciae-senegalae* Sanwal or by *R. acaciicola* Sanwal which form amphigenous pustules on the leaves. *Heart Rots*: *Inonotus hispidus* (Bull. ex Fr.) Karst has been recorded in *A. senegal* in France.

341 GIFFARD, P.L. **Etude des possibilites du Tchad en Gomme Arabique**. Ministère de la Cooperation, Republique Française (1965)

342 GIFFARD, P.L. [**Gum arabic trees: *Acacia senegal* Willd., *Acacia laeta* R.Br.**] *Bois et Forêts des Tropiques* (1966) No.105 21-32

The botanical characteristics of the closely related *Acacia senegal*, *A. laeta* and *A. mellifera* (not a gum

producer) are described. Research in Chad since 1956 has shown that the gum of *A. laeta* is comparable in quality and rate of production with that of *A. senegal*, and inferior only in being slightly more coloured; a comparative analysis is tabulated. For the tree species, the habitat, climate, associated species and soils are described; *A. laeta* occurs in Egypt, Ethiopia, Sudan, Chad and Niger, but not Senegal or Mauritania, and is found on neutral or slightly alkaline sandy-clay soils containing a little more organic matter and N than the sandy steppes colonized by *A. senegal*. The production, utilization and marketing of gum arabic are examined. Natural regeneration of *A. senegal* and *A. laeta* is uncertain. Coppicing of declining trees has usually been unsuccessful, but felling at ca. 1 m. high, without cutting the stems through completely, temporarily promotes flowering and fruiting, while any seedlings that germinate survive well under the branches. Artificial regeneration by direct sowing, cuttings or stumps is expensive and unsatisfactory owing to losses from termites, browsing, drought etc.; a method in conjunction with shifting cultivation, as in the Sudan, is recommended.

343 GIFFARD, P.L. **Les essences de reboisement au Senegal. Les Gommiers: *Acacia senegal* et *Acacia laeta*.** Republique du Senegal, Delagation generale a la recherche scientifique et technique, Centre Technique Forestier Tropicale, Dakar. *Mimeo* (1973) 1-31

A. senegal is known in Chad as Kittir Abiod or gommier blanc and *A. laeta* as Kittir Azarack or gommier noir. Describes the ecology of both species, their distribution in west and northern Africa, the climatic range and soils. In Chad, *A. senegal* occurs on sandy soils, which have quartz with some elements of felspar, and poor in organic matter and nitrogen. The levels of clay and alluvium never exceed 10% in the horizons, and the level of infiltration of water is very rapid. The pH slightly acid to neutral on the surface becomes more acidic deeper down. The total cations of these poor soils are around 2.5 meq%. *A. laeta* on the other hand prefers sandy clay soils, which have a low level of infiltration, pH usually neutral to slightly alkaline, the total cation exchange around 20 meq%, and generally richer soils compared with *A. senegal*. Notes that the natural exudation of gum depends on the previous years rainfall, with poor rains producing abundant gum. Gum yields are less in Senegal and Mauritania with 300 g/tree being an exceptional maximum. Various hormone treatments were sprayed on the trees (Netragone 600, Rhodia 600, Netrazol double and Tropotone) to increase exudation without success. The natural regeneration depends on good rains, and insects, fire, and overgrazing contribute to poor establishment of the trees. Regeneration is best in the recently worked fields where competition with other plants is reduced. In enrichment planting the area around the seedlings needs to be cleared to reduce competition. Describes the gum gardens of Kordofan, where seeds are sown directly with the cereal crops. In Chad direct sowing has proved successful if the plantation is looked after in the first years after planting, and the costs of afforestation are estimated at 120 man-days per hectare. The best results in Senegal are sowing nursery raised plants, although there needs to a good source of water ($1m^3$/10,000 seedlings/day), windbreaks and barbed wire fences around the nursery. Three to four seedlings per polythene sac (30 x 10 cm) are sown, with germination starting around the fifth day. Estimated time in the nursery is 100-115 days. In planting out, the land needs to be cleared of vegetation, and the best method found was to dig a 60 x 60 x 60cm holes spaced every 4 to 5 m apart (recommends 5 x 5m for easy vehicles access). Estimated planting 3-4,000 trees daily. Important to weed the plantation, protect against livestock, and apply insecticides against termites although the Acacias are not very susceptible to them. Gives the cost of plantations, and initial growth and survival data of plantations (some as old as 78 months). A tapping experiment on a six year old plantations in Bambey (Senegal), yielded on average 81g/plant of *A. laeta* and between 36-53 g/plant of *A. senegal*, with max. yields per plant of 840 g for the former and between 100-340 g/plant for the latter.

344 GIFFARD, P.L. **[Gum trees, species for afforestation in Sahelian regions.]** Les Gommiers, essences de reboisement pour les régions sahéliennes. *Bois et Forêts des Tropiques* (1975) No.161 3-21

Of the many species of *Acacia* that yield gum, *Acacia senegal* and *A. laeta* are considered the true gum trees because both are commercial sources of gum arabic. A review paper, it describes their botanical features, distribution and ecology (only in the northern hemisphere), and discusses the production (including tapping and natural exudation), uses (traditional and industrial) and marketing of the gum. It has been eaten since prehistory in the Sahelian region, and as a panacea in traditional medicine. It was also cited as being used as such in European medicine towards the end of the seventeenth century. Details export figures of gum arabic from Senegal during 1946-1974. Natural regeneration of both species is difficult to obtain, and neither the rejuvenation of plantations by cutting back nor their enrichment by scattering seeds have proved feasible. The 'gum-tree' method used in the Sudan, where *A. senegal* and *A. laeta* regenerate naturally on areas of abandoned cultivation is not applicable in Senegal because the existing stands are too thinly stocked and too small. In Chad, a combination of direct sowing and 'taungya' has proved successful if tending in subsequent years has been adequate, but in Senegal, where this method would be too expensive, planting is the accepted regeneration method.

345 GILLETT, J.B. **The plant formations of western British Somaliland and the Harar Province of Abyssinia.** *Kew Bulletin* (1941) 37-199

Seven plant formations occur in this region: (i) subdesert (ii) *Commiphora/* bush-*Acacia* open deciduous scrub; (iii) tree-*Acacia* open woodland; (iv) tree-*Commiphora/Acacia/Combretaceae* deciduous scrub; (v) evergreen scrub; (vi) evergreen forest; and (vii) *Erica* thickets. The component associations and secondary communities of these formations are described, with brief notes on occurrence, site factors, and economic use. The *Commiphora/*bush-*Acacia* formation yields gums and resins, of which myrrh from *Commiphora cuspidata* and gum arabic from *A. somalensis* are the chief products. The tree-*Acacia* open woodland formation produces gum arabic from *A. senegal* and *A. bussei*, and if the demand were sufficient, most of the *Acacia* association could be converted, by broadcast sowing and protection from grazing, into *A. senegal* stands; *A. bussei* and *Terminalia brownei* produce barks used for tanning, but these may be of little economic importance.

346 GLICKSMAN, M.; SAND, R.E. **Gum arabic.** *Industrial Gum polysaccharides and their derivatives (edited by Whistler, R.L.; Bemiller, J.N.).* New York & London (1973) 197-263

Describes the sources and production of gum arabic used in the trade (many African species of *Acacia*), their physical and chemical properties and their uses. Lists over 76 trade names for gum arabic of which 33 specifically refer to *Acacia senegal.*

347 GOLDBLATT, P. **Cytology and the phylogeny of Leguminosae**. In *Advances in Legume Systematics (edited by Polhill, R.M.; Raven, P.H.).* (1981) Part 2 427-463

The patterns of chromosomal change and evolution in plants as understood today are applied to the Leguminosae. Mimosoideae appear to be fundamentally tetraploid, with a base number of x=14, and aneuploid reduction is evident in the widespread occurrence of x=13 (as is the case of *Acacia*.) Polyploidy appears to be well developed only in the subgenus *Acacia* (series Gummiferae) with x=26, with diploids in the other two subgenera.

348 GONDWE, D. **Determination of optimum boiling periods to improve germination of 4 *Acacia* spp.** *FRIM Newsletter Forestry Research Institute of Malawi* (1999) No.84 1-2

Seeds of 4 African *Acacia* species (*A. polyacantha ssp. camplyacantha, A. senegal, A. nilotica, A. tortilis*) were soaked in boiling water for up to 300 s, and the germination percentages attained compared for the different periods with a non soaking (control) treatment. Germination of *A. polyacantha* was increased to 89% by soaking in boiling water for 80 s, while unsoaked seeds gave only 7% germination. Germination of *A. nilotica* was increased from 25 to 54% by soaking in boiling water for 300 s. Germination of *A. tortilis* was only increased slightly by soaking in boiling water (range 24-27.5%), while that of *A. senegal* was reduced by soaking, the highest germination (42.5%) being in the control unsoaked seeds [age of seeds and level of Bruchid infestation not given].

349 GOSSEYE, P. **Introduction of browse plants in the Sahelo-Sudanian zone**. In *Browse in Africa* (edited by Houérou, H.N. le). Ethiopia; ILCA (1980) 393-397

Gives details of propagation studies and establishment trials of both exotic and indigenous browse species sown at Niono in Mali from 1977-79. Seeds of 19 species including *Acacia senegal* were grown in pots with a mixture of earth, coarse sand and manure and planted out on ranch land. Survival at the nursery stage showed that local species were more successful than exotic varieties, with *A. senegal* having a 4% emergence rate and a 3% survival rate.

350 GOURLAY, I.D. **Age and Growth rate determination of some African Acacia species.** MSc thesis, Oxford Forestry Institute, University of Oxford (1992) 1-130

The radial cross-sections of wood samples from individual trees of known age of 21 African Acacia species were examined for growth rings. These were apparent in most species as narrow bands of marginal parenchyma filled with long crystal chains. The crystals were subsequently identified through the use of a scanning proton microprobe, as calcium oxalate. The number of bands formed annually corresponded to the number of peaks in the annual rainfall distribution. Where the rainfall pattern was unimodal, one crystalliferous band was also laid down during the dry season; at lower latitudes where the rainfall pattern was bimodal, two bands were formed annually. Ring widths were highly correlated with the rainfall recorded in each wet season. While not directly working with *A. senegal* of known age, he found that wood samples of *A. senegal* from Sudan (Oxford xylarium no. 2398) and Tanzania (Oxford xylarium no. 13431) had similar crystal chains present, indicating the potential for tree dating in this species.

351 GOURLAY, I.D. **Growth ring characteristics of some African *Acacia* species.** *Journal of Tropical Ecology* (1995) **11** 121-140

A study of the anatomical features of the wood of nineteen species of *Acacia* and *Faidherbia* to determine their age. Trees of known age and management history were selected from east and southern Africa, and growth bands of marginal parenchyma determined (see Goulay 1992). These were found to correspond to the number of peaks in annual rainfall distribution. Mean annual ring widths appeared to be similar for most of the Acacia

species studied, between 6 to 7 mm of radial growth per year.

352 GREENWAY, P.J. **A Swahili – Botanical – English Dictionary of Plant Names.** *Tanzania: East African Agricultural Research Station Amani/ Government Printer, Dar es Salaam. Second edition* (1940) 1-308

A useful pocket dictionary of Swahili plant names, and for *A. senegal* two names are included, Mgunga which is generic for many east African *Acacia* species and Kikwata which is restricted to *A. mellifera* Benth. and *A. senegal* Willd.

353 GREWAL, S.S.; MITTAL, S.P.; DYAL, S.; AGNIHOTRI, Y. **Agroforestry systems for soil and water conservation and sustainable production from foothill areas of north India**. *Agroforestry Systems* (1992) **17** (3) 183-191

Conservation based agroforestry systems have been developed for possible adoption in place of high risk rain fed farming on land capability classes (LCC) I IV of the 2 million hectare foothill areas of north India (located in parts of the Indian Punjab, Haryana and Himachal Pradesh). The field studies described in this paper were carried out in the 1980s and used a typical topo sequence of 4 LCCs stretching from the valley bottom to the piedmont top at the Research Farm of the Central Soil and Water Conservation Research and Training Institute at Chandigarh, in Haryana; the sequence covered a horizontal distance of 900 m and a vertical distance of 117 m. The class IV system (on sloping gravelly marginal land) was also silvopastoral, and consisted of Bhabbar grass raised under 5 drought tolerant species of Acacia. Grass yields and net returns were highest under *A. senegal*, and decreased under the 4 other species in the order *A. tortilis*, *A. modesta, A. suma, A. lenticularis*; the mean annual grass yield and net returns (over 6 yr and all species) were 3.9 t/ha and Rs 2402/ha. All 4 of the agroforestry systems described were superior to traditional farming systems in each LCC.

354 GREWAL, S.S.; SINGH, K.; JUNEJA, M.L.; SINGH, S.C. **Relative growth, fuel wood yield, litter accumulation and conservation potential of seven *Acacia* species and an understorey grass on a sloping bouldery soil**. *Indian Journal of Forestry* (1996) **19** (2) 174-182

Deforestation, soil erosion, poor crop yields, and fuel wood and forage scarcity are common features of the agro ecosystem of the foothills of north India. The performance of 7 *Acacia* species was compared in a long term (1976 -92) field study conducted on a 35-40% sloping eroded bouldery soil (Udic Ustochrept) near Chandigarh. The species were planted at 3 X 3 m spacing in contiguous blocks on the berms of 150 X 45 X 45 cm staggered contour trenches constructed against the slope. Subsequently a sod forming perennial grass (bhabar grass, *Eulaliopsis binata*, used for paper pulp) was uniformly planted at 75 X 75 cm spacing in the understorey. *Acacia suma* recorded the maximum height (14.13 m) and diameter at breast height (dbh, 26.3 cm) after 16 yr of growth, followed by *Acacia lenticularis* (12.63 m height, 21.6 cm dbh). Fuel wood yield from poles followed the order: *Acacia nilotica* (39.34 t/ha), *Acacia tortilis*, (36.36), *Acacia senegal* (26.94), *Acacia modesta* (20.81), *Acacia lenticularis* (19.11) and *Acacia suma* (14.64); no fuel wood data are given for *Acacia catechu* since the wood is more valuable as a source of katha. The highest net returns of Rs 32 121 and 23 972/ha were given by *Acacia nilotica* and *Acacia tortilis*. The 10 yr (1983-92) mean annual bhabar grass yield was highest under *Acacia senegal* (3.51 t/ha) followed by *Acacia tortilis* (3.07 t/ha.), with an average over all species of 2.49 t/ha. The 4 yr (1989-92) mean runoff from a representative block of *Acacia tortilis* and grass was only 1.75% and annual soil loss 0.21 t/ha with a mean monsoon rainfall of 904 mm. Leaf litter accumulation varied from 6.73 under A. *suma* to 10.0 t/ha under *Acacia lenticularis*, with a mean of 8.67 t/ha. These results indicate that the eroded bouldery slopes can be best managed under *Acacia nilotica* with bhabar grass.

355 GRIEG SMITH, R. **The bacterial origin of the gums of the arabin group**. *Proc. Linn. Soc., Sydney,* (1903) **28** 114-131

356 GRIEVE, M. **A modern herbal, Vol. 1.** London; Jonathan Cape (1931) 1-427

Describes various forms of Acacia gum that are marketed and exported from Africa, chiefly from the ports Suakin (Sudan), Alexandria (Egypt), and St Louis (Senegambia). Kordofan gum collected in Upper Egypt, Sudan (Kordofan and Darfur) and Arabia are exported from Alexandria and is the best for medicinal use. Senegal gum comes in two varieties, a red and a white gum and both types and the Kordofan gum are said to come from *A. senegal*). Notes gum from other sources: *A. abyssinica* (Hochst.) and *A. glaucophylla* (Staud.) yield a good gum but little reaches the market; Mogadore gum from the Moroccan endemic *A. gummifera* resembles Kordofan gum in appearance; Indian gum from *A. arabica* [*A. nilotica*] which is inferior; Cape gum of pale yellow quality and also inferior [probably *A. karroo*]; Australian gum from South Australia which is not entirely soluble and contains tannin. Describes the appearance, taste, solubility of gum for medicinal purposes, and the need to yield less than 4% ash. Describes the adulterants used, principally inferior gums which often have tannins, or when ground the additions of starch or dextrins which are recognised by the iodine test. Lists the chemical constituents of gum, and its medicinal action and uses (referred in the British and US

Pharmacopias). Principle uses include pill coatings, and use as a soothing agent in inflammatory conditions of respiratory, digestive and urinary tracts, as well as a demulcent in cough mixtures and linctures. The gum is reputed to be highly nutritious, where a Moor can subsist on 6 oz. per day during the gum harvest.

357 GRIFFITH, A.L. **The vegetation of the Thar desert of Sind**. *Indian Forester* (1946) **72** (7) 307-309

The Thar desert is a generally arid region (rainfall 5-10 in.) consisting largely of sand hills and smaller dunes running in the general direction (SW/NE) of the prevailing wind. The vegetation is surprising in its density and variety. Among the commoner tree species are *Acacia senegal*, *Melia azadirachta*, *Cordia rothii*, *Phoenix dactylifera*, *Prosopis spicigera*, and *Tecoma undulata*. Wind erosion is a serious problem, and regulation of grazing is essential. Rats also aggravate erosion. A list is given of the botanical and local names of the commoner trees, small trees, shrubs, herbs and grasses found in the area.

358 GRINDLEY, D.N. **Investigation of the seed oils of some Sudan Mimosaceae**. *J. Soc. Chem. Ind., Lond.* (1945) **64** 152

A brief description of the characteristics, principal constants and approximate compositions of the fixed fatty acids of *Acacia albida*, *A. sieberiana*, *A. verek [A. senegal]*, *A. mellifera*, *A. seyal*, *A. arabica* and *Albizzia lebbek*. They contain a high percentage of unsaponifiable matter and no linoleic acid could be detected. The oil from *A. senegal* contained oleic and palmitic acids. The mixed unsaponifiable matter from all these oils had an iodine value of 115 as determined by the Rosenmund and Kuhnenn method.

359 GROUZIS, M.; DIOUF, M.; ROCHETEAU, A.; BERGER, A. **Plant water relations and responses to drought conditions of six woody Sahelian species**. [Fonctionnement hydrique et reponses des ligneux sahéliens a l'aridite.] In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.)*. L'Orstom, Collection colloques et séminaires, Paris, France (1998) 47-61 450

Six woody species were studied at Souilene, Senegal. Two of the species had regressing populations (*Combretum glutinosum* and *Acacia senegal*), two (*Balanites aegyptiaca* and *Boscia senegalensis*) were expanding, and two (*Acacia tortilis* and *Ziziphus mauritiana*) had relatively stable populations. The species exhibited a variety of phenological and leaf characteristics. Sap flow, leaf water potential and stomatal conductance were measured hourly. The different species exhibited a great diversity in response to water stress. Stomatal conductance for *Acacia tortilis* and *A. senegal* was modeled, and the responses of these two species discussed in terms of seasonal climatic changes, sap flow, and soil plant relations. The two species were characterized by a high rise of sap tension at the beginning of the dry season, intermediate values of sap tension (-1.6 to -2.7 MPa) during the dry season, a relative equilibrium during the rainy season, and a large variation in transpiration linked to leaf loss.

360 GUEYE, M. ***Acacia albida:* Nodulation by fast- and slow-growing rhizobia**. In *Faidherbia albida in the West African semi-arid tropics. Proceedings of a workshop 22-26 April 1991, Niamey, Niger (edited by Vanderbeldt, R.J.)*. ICRISAT, Patancheru, A.P. 502 324, India & ICRAF (1992) 149-150

Reports for the first time on the isolation of 3 fast growing strains of *Rhizobium* in nodules of *A. albida*. Seedlings of *A. albida* were grown in soil from nine sites in central Senegal, and 25 *Rhizobium* strains isolated their nodules, most proving to be slow growing. It was assumed that they were all *Bradyrhizobium* strains. Seedlings of *A. raddiana [A. tortilis ssp. raddiana]* and *A. senegal* inoculated with the fast growing strains did not nodulate.

361 GUEYE, M.; NDOYE, I. **Genetic diversity and nitrogen fixation of acacias**. [Diversite genetique et fixation biologique de l'azote chez les acacias.] In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.)*. L'Orstom, Collection colloques et séminaires, Paris, France (1998) 351-355, 464-465

A short discussion article on the intra and interspecific variation in nitrogen fixing capacity, nodulation, and type of N fixing organism (*Rhizobium* or *BradyRhizobium*) found in *Acacia* species. *A. senegal* and *A. laeta* form nodules when inoculated with fast growing Rhizobium, and the latter species produces 50% more nodule biomass. A fairly high N fixing potential has been recorded for *Acacia mangium*, *A. seyal* and *A. raddiana*; and relatively low N fixing potential has been noted for species such as *A. senegal*, *Faidherbia albida* and *A. pellita*. There was also a great deal of variation between provenances of *F. albida* in nitrogen fixing rates both within Senegal and throughout Africa, and the provenance with highest rate in Senegal was Kabrousse.

362 GUINET, Ph. **Les Mimosacées: etude de palynologie fondamentale, correlations, evolution**. *Trav. Sect. Sci. Tech. Inst. Fr. Pondichéry* (1969) **9** 1-293

Studies on pollen morphology of the family Mimosaceae, examining 1900 herbarium specimens. Divided the genus Acacia into 3 major groups, I species in the sections Filicinae and Vulgares, II species in the sections Phyllodineae, Botryocephalae and Pulchellae and III species in the Gummiferae. Found a correlation between the nature of stipules and the degree of differentiation in the pollen grains of African species (both I and III groups). Species in group I which include

A. senegal have a low degree of differentiation, such as the lack of furrows on the exine. Lists dimensions and structure of the pollen grains studied, and *A. senegal* has 16 grains grouped into a polyad.

363 GUINET, Ph. **Mimosoideae: the characters of their pollen grains.** In *Advances in Legume Systematics (edited by Polhill, R.M.; Raven, P.H.)* (1981) Part 2 835-855

A comprehensive survey of the main pollen characters in the subfamily Mimosoideae, the most obvious feature of this pollen being that it is shed at anthesis in permanent compound units, and in the case of *A. senegal* in a 16 grain polyad. Within Acacia three pollen types are recognized which fit into the three subgenera (Vassal 1972). The two subgenera Aculeiferum (which includes *A. senegal*) and Heterophyllum are closely related, having their pollen exine devoid of columellae and simple porate apertures. These two subgenera can be distinguished by the exclusive occurrence of a supratectal reticulum in subgenera Heterophyllum. By contrast subgen. Acacia is very distinct on account of the columellar structure of its exine and the occurrence of complex (colporate) apertures whose location at the distal parts of the cells is different. The grains of subgenus. Aculeiferum are acalymmated, weakly heteromorphic, 16 celled polyads with proximal pores and simple porate apertures located in non-equatorial positions. The exine is smooth with columellae present and a tectum perforated. Discusses the fossil record as well, noting the occurrence of pollen characters of subgenus. Aculeiferum in the upper Eocene (45 m.yrs before present).

364 GUINET, Ph.; FERGUSON, I.K. **Structure, Evolution and Biology of Pollen in Leguminosae.** In *Advances in Legume Biology (edited by Stirton, C.H. & Zarucchi, J.L.) Monographs in Systematic Botany* (1981) 29 77-103

365 GUINET, Ph.; LUGARDON, B. **Diversity of exine structures in the genus *Acacia* (Mimosaceae).** *Pollen et spores* (1976) **18** (4) 483-511

The fine structure of the exine in the 3 pollen types found within the genus *Acacia* is described. When the pollen grains are without furrows or when they have pseudo-furrows (extra-porate pollen type), the exine structure is granular. When the pollen grains are colporate the exine structure is columellar. The granular structure of the exine is also found in the tribe *Ingeae* when the pollen grains are porate.

366 GUM ARABIC Co. **Gum Arabic; a product of nature.** *Publicity brochure* (1993)

367 GUM RESEARCH STATION **Annual report for the year 1969/70.** Sudan; Agricultural Research Corporation, Wad Medani. (1969/70)

368 GUM RESEARCH STATION **Annual report for the year 1978/79.** Sudan; Agricultural Research Corporation, Wad Medani. (1978/79)

369 GUNN, C.R. **Fruits and seeds of genera in the subfamily *Mimosoideae* (Fabaceae).** *U.S. Department of Agriculture, Technical Bulletin* (1984) No.1681 1-194

Data is derived from extensive sampling of the species of all 64 genera of mimosoid legumes. Three keys provide for (1) the differentiation of mimosoid from other legume seeds, (2) the identification of mimosoid genera based on fruit and seed characters, and (3) the identification of mimosoid genera based on seeds alone.

370 GUPTA, A.K.; JINDAL, S.K. **Variability for quality traits in *Prosopis cineraria* and *Acacia senegal*.** *Nitrogen Fixing Tree Research Reports* (1985) **3** 15-16

Leaf samples were collected in Nov. 1982 from 20 trees of each species planted during 1960 at Jodhpur. Data for *A. senegal* are shown on content of crude protein (mean 18.3), neutral and acid detergent fibre (mean 27.5 and 13.2 respectively), lignin (mean 4.7), cellulose (mean 8.2), silica (mean 0.2) and hemicellulose (mean 14.4). Tannins were abscent in *A. senegal* and present in *P. cineraria*. It was concluded that leaves of *A. senegal* were more nutritive than those of *P. cineraria* and qualitative traits of *P. cineraria* were more variable.

371 GUPTA, R.K. **Resource survey of gummiferous *Acacias* in western Rajasthan.** *Tropical Ecology* (1970) **11** (2) 148-161

The most important gum-yielding species of *Acacia* in W. Rajasthan are *A. nilotica* ssp. *indica*, *A. leucophloea*, *A. jacquemontii* and *A. senegal*. Brief notes are given on the trees, their distribution, phenology, utilization and ecology. Regeneration of an afforestation with *A. senegal*, a potential source of gum arabic in arid regions of W. Rajasthan, are discussed.

372 GUPTA, R.K. **Ecological distribution and amplitude of some indigenous species vis-à-vis their role in afforestation of the arid regions of NW India.** *Environmental Physiology and Ecology of Plants* (1978) 423-436

The distribution of 21 woody species in relation to soil type, and indices of temperature, precipitation and aridity, as shown in a table. A 'coefficient of amplitude' based on these results is also shown. Notes are given on the distribution of 19 of the species in NW India.

373 GUPTA, R.K. ***Acacia senegal* (L.) Willd.** In Multipurpose trees for agroforestry and wasteland utilisation. New Delhi, India; Oxford University Press (1993) 104-106

The main attributes of this species is that it can survive dry arid climates and establish on poor soils, and provides excellent firewood, fodder, and a source of gum arabic (although in India yields are low). The plant is naturally found on sand-dunes and hills of rhyolite and sandstone. Prefers 300-450 mm of annual rainfall but will survive as low as 200 mm with 8-11 dry months, and occurs in areas as high as 800 mm. Average temperatures vary from 4 to 48°C in India. The plant is suitable for use in both agri-silvi and silvi-pastoral systems of farming.

374 GUPTA, R.K.; SAXENA, S.K.; DUTTA, R.K. **Germination, seedling behaviour and phytomass of some *Acacias* in the nursery stage**. *Indian Forester* (1973) **99** (6) 352-358

Seeds of *Acacia albida*, *A. senegal* [*A. verek*] and *A. tortilis* (ex Israel) were sown in a loamy sand at the Central Arid Research Farm, Jodhpur. Subsequent observations made on germination percentage, seedling morphology and phytomass are tabulated. After 200 days the dry matter production in both the shoot and root of *A. tortilis* greatly exceeded that of the other species.

375 HABISH, H.A. **Effect of certain soil conditions on nodulation of *Acacia* species**. *Plant and Soil* (1970) **33** (1) 1-6

Reports on the effect of variation in soil moisture, temperature and pH on the growth nodulation and N fixation of *Acacia* species grown in sand. Five *Acacia* species (*A. albida*, *A. mellifera*, *A. orfota*, *A. senegal*, *A. sieberiana*) were initially tried and then only *A. mellifera* as they all showed similar responses. Growth and nodulation increased to an optimum of 15% soil moisture. With a soil temperature of 35°C nodulation was higher than 30°C (significantly more nodules produced). Nodulation only occurred between pH 6.5-9.0 and the optimal range was pH 6.5-7.0. Suggests that alkaline soils (pH 8.5-9.0) in Northern Sudan may tend to limit nodulation.

376 HABISH, H.A.; KHARI, S.M. **Nodulation of legumes in the Sudan. II. Rhizobium strains and cross-inoculations of *Acacia* spp**. *Experimental Agriculture* (1970) **6** (2) 171-176

Describes and discusses the results of rhizobia cross-inoculation tests among 10 *Acacia* spp. (*A. albida*, *A. arabica*, [*A. nilotica*], *A. ehrenbergina*, *A. farnesiana*, *A. mellifera*, *A. orfota*, *A. polycantha*, *A. senegal*, *A. seyal*, *A. sieberiana*) and cowpea (*Vigna sinensis*). The successful nodulation of cowpea with rhizobia from most of the *Acacia* spp., although non-reciprocal in some cases, confirmed *Acacia* as belonging to the cowpea cross-inoculation group. *A. arabica* and *A. sieberiana* nodulated with all the *Rhizobium* strains, but this may have been caused by contaminations. Every strain grew best at pH 6.5-7.0, less at pH 8.0, and little or not at all at pH 4.0-4.6. The growth of the rhizobia of cowpea, *A. mellifera* and *A. senegal* decreased at 35°C, but growth of the other strains reached a maximum at 30-35°C. This suggested that the rhizobia of 8 of the *Acacia* spp. are well-adapted to the warm dry conditions that prevail in the soils of the Sudan for 4-8 months every year.

377 HABISH, H.A.; KHARI, S.M. **Nodulations of legumes in the Sudan I. Cross inoculation groups and associated Rhizobium strains**. *Experimental Agriculture* (1986) **4** (3) 227-34

Gives results of cross inoculation tests of 21 species of legumes in Sudan, including 4 species of *Acacia* (*A. senegal*, *A. seyal*, *A. albida* and *A. mellifera*). Rhizobium strains were isolated from active red nodules; which were later cross-inoculated with the other species, and nodule formation, dry weight and nitrogen contents were recorded. *Acacia* species readily cross-inoculated within themselves except *A. albida*, but not with other species. *A. albida* ineffectively produced nodules with *A. senegal* and *Vigna sineasis*. Dry weight and nitrogen contents of the plants increased in nodulating plants when compared with uninoculated plants.

378 HAIN, W. [**The production of gum arabic in the Sudan Republic**.] *Beiträge zur Tropischen und Subtropischen Landwirtschaft und Tropenveterinärmedizin* (1970) **8** (4) 281-286

The Sudan produces 80-85% of the world's supply. Large reserves of *Acacia senegalensis* (*A. senegal*) stands are still not utilised. Factors limiting an increase in production are outlined on the basis of studies in the main producing areas. The government aims at developing a co-operative system of gum collection.

379 HAMILTON, A.P.E. **Chambal ravines reclamation scheme**. *Indian Forester* (1947) **73** (3) 99-101

An afforestation scheme was begun in 1925 with the object of preventing erosion in areas adjoining the Chambal River in Gwalior State and providing firewood, small timber and fodder for the local population, but operations (except for maintenance) ceased in 1929-30 after the reclamation of only 1,283 acres. As regards erosion control, the scheme has proved to be a complete success (except at the extremities of the ravines where control of run-off from the fields is also necessary). The crop is not yet fully mature and up to the present only dead wood and ordinary thinnings have been removed, but these have produced a useful supply of firewood, and it seems probable that a net annual profit will eventually be realized. Shisham (*Dalbergia sissoo*) has done well in the ravine bottoms, and although it is dying out in some places, it had produced trees of firewood size in 16 to 18 years. Other species which have done quite well are *Tectona grandis*, *Gmelina arborea* and *Prosopsis juliflora*. Results with *Anogeissus pendula*, *Acacia arabica*,

Dendrocalamus strictus and *Pongamia glabra* have been unsatisfactory. The author considers that, in general, the scheme has been a success and that further reclamation of the ravine area is fully justified. As there is an acute shortage of firewood in the locality, the production of firewood is as important an object of management as erosion control. *Acacia senegal*, *Melia azedarach*, *Azadirachta indica* and *Butea frondosa* are species deserving trial in the new plantations.

380 HAMMER, T. **Reforestation and community development in the Sudan**. *DERAP Publications, Christian Michelsen Institute, Norway* (1982) No.150 1-84

The description of traditional uses and rights of land in the semi-arid savanna of north Sudan concludes that its utilization until the middle of this century was well adapted to the environment. Since then, the soil has become less productive, wood and water have become scarce and desertification has occurred. Proposals to protect the environment have begun to be implemented. This study details one measure that aims at assisting farmers in reviving the traditional agro forestry practices that combine food crops with tending the tree species *Acacia senegal* on a rotational basis, with the fallow period exceeding the cultivation period.

381 HANAN, N.P.; PRINCE, S.D.; FRANKLIN, J. **Reflectance properties of West African savanna trees from ground radiometer measurements. II. Classification of components**. *International Journal of Remote Sensing* (1993) **14** (6) 1081-1097

Reflectance properties in the red and near infrared of Sahelian tree species (*Acacia seyal, A. senegal, Combretum glutinosum, Balanites aegyptiaca*) in Mali were measured using a pole mounted radiometer, and classified depending on their location over the canopy. A geometrical description of patterns of shadow and sunlight on and beneath a model tree when viewed from above is given and six components defined (sunlit soil, sunlit canopy over sunlit soil, sunlit canopy over shaded soil, shaded canopy over shaded soil, shaded canopy over sunlit soil and shaded soil). The classification differs from the four component model of Li and Strahler in that presence or absence of shadow on the ground is considered. Average reflectances differ between components in the red, but in the near infrared no statistical differences were observed. Results for the red waveband suggest that presence of shadow on the ground under these fairly open canopies is important in determining reflectance of components. Average whole canopy reflectances were estimated using the geometrical model to calculate areas of different components within the canopy. Similarly, spatial average reflectance from a landscape with a known population of trees and known soil was estimated. For the three species and locations measured here it was found that tree canopies are dark in the red waveband with respect to soil, but have little or no effect on the near infrared.

382 HANSON, J.H. **Extractive economies in a historical perspective: gum arabic in West Africa. Non timber products from tropical forests: evaluation of a conservation and development strategy**. *Advances in Economic Botany* (1992) **9** 107-114

This study concerns the history of gum arabic, produced from *Acacia senegal*, in the 19th century, when intensive harvesting occurred for the world trade market. This exploitation was due to the availability of servile labour and what appeared to be an unlimited natural resource, and it is argued that commercial expansion resulted in pressures, which contributed, to increased social oppression and environmental degradation in the gum producing areas of West Africa.

383 HAQUE, S.M.S. **Nitrogen fixing trees and shrubs of Pakistan and their role in soil improvement - a review**. *Commonwealth Forestry Review* (1990) **69** (4) 345-349

Forty nitrogen fixing tree and shrub species, native or introduced to Pakistan, are discussed, and studies of the distribution and degree of nodulation of some of these (in Pakistan) are reviewed. Brief recommendations are made for planting the following species with their uses in Pakistan: *Coriaria nepalensis, Alnus sp., Casuarina equisetifolia, Robinia pseudoacacia, Leucaena leucocephala, Sesbania grandiflora, Parkinsonia aculeata, Acacia senegal, A. tortilis, A. nilotica, Albizia lebbek, Prosopis cineraria, Cassia spp. and Prosopis tamarugo.*

384 HASSAN, A.S.; STYLES, B.T. ***Acacia senegal* (*L.*) Willd. and *A. circummarginata* Chiov**. In *A Conspectus of Somali Acacias*. Oxford, UK; Oxford Forestry Institute (1990) 1-122

Detailed botanical description of *Acacia senegal*, which is widespread in Somalia in the *Acacia-Commiphora* woodland occurring on rocky limestone hills or on limestone overlain by alluvial gravels, and also along gypseous drainage lines. Occurs from 10-1500 m altitude. Somalia is the centre of diversity of this taxon, and nearly all the members of the *A. senegal* complex (18 species) occur here. Describes the variation in the species, and because of intermediates does not maintain var. *kerensis*. *A. senegal* var. *leiorhachis* is also treated as a separate species, *A. circummarginata*. Only the tree form of var. *leiorhachis* occurs in Somalia, with striking yellow peeling bark.

385 HAUKKA, K.; LINDSTROM, K.; YOUNG, J.P.W. **Diversity of partial 16S rRNA sequences among and within strains of African rhizobia isolated from *Acacia* and *Prosopis***. *Systematic and Applied Microbiology* (1996) **19** (3) 352-359

To assess the phylogenetic diversity of fast growing *Rhizobium* strains isolated from root nodules of *Acacia senegal* and *Prosopis chilensis* trees growing in Sudan and

Kenya, a 230 nucleotide segment of the 16S ribosomal RNA gene was sequenced from each of thirty strs. Twelve different sequences were found: four were identical to those of previously described species, eight were novel. Sequence comparisons indicated that one strain. belonged to the *Rhizobium huakuii* phylogenetic branch, while the rest were *SinoRhizobium,* as they were close to *S. meliloti, S. fredii, S. teranga* and *S. saheli.* Isolates from *Acacia* and *Prosopis* often had the same sequence, but the sequence type was not well correlated with the phenotypic characteristics determined previously for these strains. One isolate had two 16S rRNA sequences, differing at six positions, in approximately equal copy number. The type strain of *S. saheli* was shown to have two different sequences.

386 HAUKKA, K.; LINDSTROM, K.; YOUNG, J.P.W. **Three phylogenetic groups of nodA and nifH genes in Sino *Rhizobium* and Meso *Rhizobium* isolates from leguminous trees growing in Africa and Latin America.** *Applied and Environmental Microbiology* (1998) 64 (2) 419-426

The diversity and phylogeny of nodA and nifH genes were studied by using 52 rhizobial isolates from *Acacia senegal, Prosopis chilensis,* and related leguminous trees growing in Africa and Latin America. All of the strains had similar host ranges and belonged to the genera *SinoRhizobium* and *MesoRhizobium,* as previously determined by 16S rRNA gene sequence analysis. The restriction patterns and a sequence analysis of the nodA and nifH genes divided the strains into the following three distinct groups: *Sinorhizobia* from Africa, *Sinorhizobia* from Latin America, and *Mesorhizobia* from both regions. In a phylogenetic tree also containing previously published sequences, the nodA genes of our rhizobia formed a branch of their own, but within the branch no correlation between symbiotic genes and host trees was apparent. Within the large group of African sinorhizobia, similar symbiotic gene types were found in different chromosomal backgrounds, suggesting that transfer of symbiotic genes has occurred across species boundaries. Most strains had plasmids, and the presence of plasmid borne nifH was demonstrated by hybridization for some examples. The nodA and nifH genes of *SinoRhizobium teranga* ORS1009T grouped with the nodA and nifH genes of the other African sinorhizobia, but *SinoRhizobium saheli* ORS609T had a totally different nodA sequence, although it was closely related based on the 16S rRNA gene and nifH data. This might be because this *S. saheli* strain was originally isolated from *Sesbania* sp., which belongs to a different cross nodulation group than *Acacia* and *Prosopis* spp. The factors that appear to have influenced the evolution of rhizobial symbiotic genes vary in importance at different taxonomic levels.

387 HAYASHI, I. **A preliminary report of an experiment on vegetation recovery of drought deciduous woodland in Kitui, Kenya.** *African Journal of Ecology* (1992) **30** (1) 1-9

Vegetation and natural regeneration were investigated in savanna woodlands in a semi arid region of Kenya in 1989-90. *Commiphora africana* was the dominant tree, the wood of which is unsuitable for fuelwood. *Acacia senegal, A. mellifera* and *Terminalia brownii* are traditionally utilized for production and their densities are low. An experimental plot (300X300 m) was protected from grazing and fuelwood harvesting, and vegetational changes were compared for sub plots both inside and outside the protected plot after one year. Protection permitted some regeneration of the shrub layer and bare ground was recolonized by grasses (*Chloris roxburghiana, Digitaria macroblephara and Sporobolus fimbriatus*). The average diameter increment of the trees was 0.5 cm p.a. (s.d. 0.3 cm). The mean height of *A. mellifera* seedlings (the most abundant of the *Acacia* tree seedlings) increased from 14.7 to 23.8 cm. It is suggested that *A. mellifera, A. senegal* and *A. tortilis* are the most suitable species for planting in the Kitui region.

388 HAYASHI, I. **Five years experiment on vegetation recovery of drought deciduous woodland in Kitui, Kenya.** *Journal of Arid Environments* (1996) **34** (3) 351-361

Data are presented on the stand characteristics (including botanical composition, density, structure and natural regeneration) of unprotected plots and plots protected from grazing and fuelwood collection from 1989 to 1994 in the semiarid region of Kuwa Bonza. Increases are reported in numbers of species and individuals of shrubs and trees <2 m tall in the protected plots, while numbers of species (but not individuals) increased for trees >2 m tall in the protected plot, and numbers of tree seedlings increased in both protected and unprotected plots. Dominant tree species were *Lannea triphylla* and *Commiphora africana* in all plots, while valuable *Acacia* species were scarce except in the herb layer. From 2 selected trees of *Acacia senegal,* measured DBH and height in 1989, 1990 and 1994. Estimated 10 years to grow 1m in height for a 6 m high tree, and trunk increment of 6 cm for a tree with a DBH of 10 cm.

389 HEDBERG, I.; EDWARDS, S. **Flora of Ethiopia, Volume 3: Pittosporaceae to Araliaceae.** Addis Ababa and Asmara, Ethiopia; Uppsala, Sweden (1980) 74-82

Describes the taxonomy of *Acacia senegal* as well as the uses of the species: the source of Gum Arabic of international trade, important tree for agroforestry systems in arid and semi arid areas of Sudan and western Ethiopia. Describes the characteristics and distribution of the 3 different varieties in Ethiopia: var. *senegal,* var. *leiorhachis* and var. *kerensis.*

390 HEERMANS, J.; MINNICK, G.; POLANSKY, C. **Guide de restauration forestière et d'amenagement au Sahel Base sur les etudes de cas dans les Forêts**

Nationales de Guesselbodi et Gorou Bassounga - Niger. Niamey, Niger (1987)

391 HEITMAN **Restricted UNCTAD/GATT Report on Gum Arabic for the ITC**. (1988)

392 HELIN, W. **Tree species elimination trial. Luuq, Gedo Region, Somalia**. *Commonwealth Forestry Review* (1989) **68** (4) 273-279

A rain fed species elimination trial was started in Luuq, Somalia, in 1984, with 101 provenances (77 species, of which 23 were indigenous). Growth was evaluated after 5 yr and species/provenances given ratings of A-D (based on survival of > 75%, 50-75%, 25-49% and < 25%) or N (never outplanted from the nursery). Of the 10 best surviving provenances (all rated A), 7 were indigenous (*Acacia tortilis* var. *spirocarpa*, *Acacia reficiens* var. *misera*, *Acacia senegal*, *Acacia seyal* var. *fistula*, *Albizia anthelmintica*, '*resomagali*', and *Ziziphus hamur*), 1 was a provenance of an indigenous species (*Acacia tortilis*), and the other 2 were provenances of *Prosopis chilensis* and *Prosopis velutina*.

393 HELLINGA, G. [**Trees producing gum arabic**.] Arabische gom leverende gewassen. *Rapp. Bosbouwproefsta, Buitenzorg* (1949) No.21 1-5

Notes that experiments on the growth of exotic gum-producing *Acacia* species in Indonesia show that *A. senegal*, *A. arabica* [*A. nilotica*], *A. karroo* and *A. stenocarpa* [*A. seyal*] give good results. Their cultivation by the native population in the east of the archipelago is recommended for their multiple uses [from English summary].

394 HENDERSON, K.D.D. **The making of the modern Sudan. The life and letters of Sir Douglas Newbold, K.B.E., Governor of Kordofan 1932 - 38**. Faber & Faber (1953) 1-601

395 HENDERSON, L. **Barrier plants of Southern Africa** *Botanical Survey of South Africa Memoirs* (1987) No. 55 1-97

Presents information on 504 species of which 220 are indigenous and 96 of these are being suggested for use as barrier plants for the first time. Both varieties of *A. senegal* (vars. *rostrata* and *leiorhachis*) are recommended as thorny indigenous security hedge plants for the hot and dry regions of southern Africa. Var. *rostrata* could make an excellent framework plant, being sturdy, multi-stemmed and low-branching with fine foliage casting little shade, and has been used for security hedging. It reaches an average height of 2-3 m and a maximum of 9m, and will grow on stony, deep sand, clay, brack and calcrete soils. Variety *leiorhachis* on the other hand could be a potential tall filler, giving rise to a very sparse and slender crown, and reaches an average height of 5-8 m with a maximum of 17 m and will grow only on stony or calcrete soils.

396 HEPPER, F.N. **Pharoahs flowers. The botanical treasures of Tutankamun**. London, HMSO & Royal Botanical Gardens, Kew (1990) 1-80

397 HERLOCKER, D.J. **Implementing a forestry programme for local community development in the south-western Marsabit District of Kenya**. In *Forestry for rural communities. Proceedings of the Eighth World Forestry Congress, Jakarta, Indonesia, 16-28 October* (1978) No. FRC/4-10 1-8

Various possibilities for forestry programmes in the very arid part of north central Kenya are discussed. Trials of both exotic and indigenous species should be made under rain fed and irrigated conditions. Of the existing natural resources, *Acacia tortilis* woodland and *A. reficiens* bushland could be managed for charcoal, *A. senegal* for gum arabic and *Aloe spp.* for medicine. Reforestation of selected watersheds in the Hurri Hills might increase the usefulness of springs at lower altitudes.

398 HERLOCKER, D.J. **Implementing forestry programmes for local community development, south-western Marsabit District, Kenya**. (1979) No.D-2c 1-10

A brief review of the possibilities for species trials (rainfed or irrigated) and for the utilization of existing natural resources (*Acacia tortilis* woodlands, *A. reficiens* bushland, *A. senegal* gum arabic and *Aloe* spp.)

399 HILLIS, W.E. **Heartwood and tree exudates**. *Springer series in Wood Science*. Berlin; Springer-Verlag (1987) 1-268

400 HIPPOLYTE, I. **Glycosylated protein content of *in vitro* calluses of *Acacia senegal*. Development in relation to culture conditions and water stress**. (Protéines glycosylées de cals *in vitro* d'*Acacia senegal*. Evolution en fonction de différentes conditions de culture et au cours de stress hydriques.) In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.)*. L'Orstom, Collection colloques et séminaires, Paris, France (1998) 273-283

Acacia senegal callus cultivated *in vitro* produced glycosylated proteins, which varied in function to whether hormones were applied to the culture medium. Three types of glycosylated proteins were identified by PAGE analysis. Application of water stress to the *in vitro* culture (by adding polyethylene glycol 8000) resulted in a reduction in glycoproteins, possibly indicating their deglycosylation. A commercial sample of gum arabic

(SIGMA) was also examined by electrophoresis, and various glycosylated polypeptides identified. It remains to be seen if the *in vitro* compounds are possible precursors to the larger molecules in gum arabic.

401 HIRST, E.L. **The chemistry of plant gums and mucilages**. *Endeavour* (1951) **10** (38) 106-111

Includes reference to the structure of gum arabic, gum from *Sterculia setigera* and the mucilage of *Ulmus fulva*.

402 HOCKING, D. ***Acacia senegal***. In *Trees for dry lands*. New Delhi, India; Oxford and IBH (1993) 78-81

Written with examples mostly from the Indian subcontinent, this species treatment gives a short description, its distribution, site requirements and limitations, its propagation and management, and its uses and productivity. Seed sources in India are also given. In India it occurs in the arid regions of Punjab, Haryana, Gujarat, and Rajasthan, between 100-1000 m in altitude. Direct sowing is successful, and on rocky hilly sites seeds are sown into trenches cut along the contours. Seedlings are susceptible to frost and fire. For gum production transverse blazes 4 cm wide and 1.3 cm deep are cut every 26 cm apart on the branches in the summer and then sprayed with a solution of 50% sulphuric acid. Trees are tapped from 10 years old and are tapped continuously for 3 years before felling the trees. An excellent fuelwood it has a calorific value of about 3000 kcal/kg. Pods and leaves are used as fodder. Forty four percent of the seeds contain a green coloured fat known as khakhan, rich in lauric, myristic and palmitic acids. The dried seeds are edible, used in local medicine and in soap making. They form part of a local Jodhpur delicacy called Panchkut.

403 HOGBEN, S.J.; KIRK-GREENE, A.H.M. **The Emirates of Northern Nigeria.** Oxford, UK, Oxford University Press (1969) 1-638

404 HOPKINS, A.G. **An economic history of west Africa.** London UK, Longman (1973) 1-337

405 HOUÉROU, H.N. Le. **Planting and management methods for browse trees and shrubs**. In *Browse in Africa; the current state of knowledge (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980a) 351-359

Examines the choice of ligneous species suitable for browse throughout the world, according to ecological and especially bioclimatic conditions of the areas to be planted. Propagation techniques are discussed, by direct drilling, planting out young plants, and propagation by cuttings. Planting out practices include soil preparation, plant spacing and density, watering and irrigation, fertilization and general maintenance. Management and utilization, feed value, agricultural value and yields are also covered. Warns of the danger of too early a utilization before plants have reached the adult stage for example 4 to 8 years for *Acacia senegal*. The agricultural value of forage trees and shrub plantations as stabilizers of grazed ecosystems is universally acknowledged. In the Sudan restoring soil fertility by rotating *A. senegal* and sorghum (*Sorgum sudanense*) is a traditional agroforestry practice.

406 HOUÉROU, H.N. Le. [**Agroforestry techniques for the conservation and improvement of soil fertility in arid and semi-arid zones.**] Techniques agroforestieres pour la conservation et l'amilioration de la fertilite des sols dans les zones arides et semi-arides. In *Browse in Africa; the current state of knowledge (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980b) 433-435

Major agroforestry systems are listed including the Gum-arabic (*Acacia senegal*)- sorghum bush fallow system in the Sudan.

407 HOUÉROU, H.N. Le. **The role of browse in the Sahelian and Sudanian zones**. In *Browse in Africa (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980c) 83-100

Assesses the contributions of ligneous species to the lives of people and animals in the Sahelian and Sudanian zones. In a study of forage production of browse species found that *A. senegal* produced a mean of 0.054 kg of fruits/tree/year at Fété-Olé Senegal during 1971-77. Considers it as a main browse species in the Sahelian and Sudanian zones, and gives crude protein levels of 22%DM (13-29), Net energy of 5.8 MJ (4.8-7.6), digestible protein/FU 206 (87-305) and phosphorus 0.2 (0.1-0.3).

408 HOUÉROU, H.N. Le. **Chemical composition and nutritional value of browse in Tropical West Africa**. In *Browse in Africa, the current state of knowledge (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980d) 261-289

A review of the literature for data on the chemical composition of different parts of 105 species of browse plants from Tropical West Africa. The basic analyses include crude protein and fibre, total minerals, total fat, silica, macroelements and nitrogen free extracts (mainly carbohydrates). From these it was calculated that *Acacia senegal* is a good forage that is high in Digestible Protein (mean D.P.=17.1%), and energy (5.8 MJ) and a nutritional ratio of 206 (mean all Browse species=100 or legumes=145). Stresses the need for browse to supplement the grasses in the dry season, dry grass not being able to meet livestock requirements. For an adequate maintenance diet, a minimum of 20% browse is required.

409 HOUÉROU, H.N. Le.; CORRA, M. **Some browse plants of Ethiopia**. In *Browse in Africa, the*

current state of knowledge (edited by Houérou, H.N. le). Ethiopia; ILCA (1980e) 109-114

A study of natural plant populations in the extensive rangelands of Jijiga and Northeastern Ethiopia, divided into 9 major plant formations throughout the altitude ranges. Tabulates observations on 82 Browse plant species with *Acacia senegal* being mentioned as palatable [the leaves]. *A. senegal* occurs between 900-1600 m, common in rainfall regimes from 300-600 mm, in plant formation - mesophyllic deciduous open woodland often a co-dominant with *Commiphora* spp.

410 HOUÉROU, H.N. Le. **Gaps in knowledge and research priorities**. In *Browse in Africa, the current state of knowledge (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980f) 479-481

411 HOWES, F.N. **Vegetable gums and resins**. Massachusetts, USA; Waltham (1949) 1-188

A large book dealing vegetable gums and resins, with the first two chapters dealing with Acacia gums and resins. Describes the occurrence and origin of gum in plants around the world, their physical and chemical properties, their commercial valuation and their industrial and other uses. For the Acacia gums describes 8 producing areas including Sudan, French West Africa (Senegal, Mauritania and Niger (French Sudan)), Nigeria, East Africa (Tanzania), North Africa excluding the Nile region (Morocco, Somalia and Ethiopia), Southern Africa (South Africa, Botswana and Namibia), India and Australia. The history of gum trade, the distribution and description of the gum yielding varieties, and the marketing, bleaching and grading, and cultivation are discussed. In Sudan, the major producing area, the gum trade is discussed with reference to Blunt's monograph 1926 (see abstract). In French West Africa the trade averaged 3-6000 tons/annum in the period 1933-36, and nearly all exported to France, and principally to the port of Bordeaux. From French west Africa Senegal is by far the most important producer, and has been trading gum with Europe since the 17 th century, and reaching its zenith in latter part of the 19 th century when Sudan ceased exporting due the Madhia rebellion. Some of the best gum collecting districts lie along the north side of the Senegal river. As there are two dry seasons there are two collecting seasons, December to January and April to July. Gum from Senegal is graded into three main qualities; Gomme du bas du fleuve (best), Gomme du haut du fleuve (intermediate) and gomme friable (poorest quality). Describes the grading that takes place in Bordeaux. The gum trade in Nigeria is more recent and limited extent compared to Senegal and Sudan, averaging 521 tons/annum preceeding the second world war. Bornu province is the main producing area, and the greatest density of trees in Mobber, Geidam and Gubio districts. Most gum is collected on an add hock basis although some tapping experiments have been untaken with favourable results. Three kinds of gum are recognised; Falli (best), Marrua and Mumuye. In Tanzania, a recent export industry has developed and the last 5 years prior to the second world war an average of 800 tonns/annum were exported, mostly to India. As well as from *A. senegal,* gum also is derived from *A. drepanolobium*. Gum pickers are divided into two classes, habitual gum collectors who are mostly men and pick for long periods and the casual gum collectors who live close enough to the areas and make short excursions out. Tapping is not carried out. Access to water determines the extent of gum picking. Gum is purchased by itinerant traders, mostly Arabs who pay very low prices. Gum from North African countries, includes Morocco (trade now almost negligible) and Somaliland [Northern Somalia] and Ethiopia. In Somaliland four classes of gum are distinguished (Adad (best), Jalefan, Hobloho, Nujal) and these are usually shipped to Aden and then re-exported on to Europe (Aden gum) or to Bombay (East Indian gum). Licenses are issued to gum collectors and export duty charged on the gum. In Southern Africa, gum mainly from *A. karroo* was shipped in the last century to the European markets as Cape gum, although not much exported now because of its inferior qualities. Still consumed locally in pharmacy and as an adhesive. In India, Bombay is the main center of trade and much gum is imported cleaned and then re-exported as East Indian gum arabic. Local collections are usually mixed with many other species and also come from other local species of *Acacia* (*A. nilotica, A. catechu, A. modesta.*) In Australia some wattle gums (eg *A. decurrens*) have been exported to Britain (in 1898 168 tons were exported falling to 26 tons in 1907), and many other *Acacia* species show potential in their gum quality but have not been exploited.

412 HOWES, F.N. **Age old resins of the Mediterranean region and their uses**. *Economic Botany* (1950) **4** (4) 307-316

413 HULSE, J. **Flavours, spices and edible gums: opportunities for integrated agroforestry systems**. In *Domestication and commercialization of non-timber forest products in agroforestry systems (edited by Leakey, R.R.B.; Temu, A.B.; Melnyk, M.; Vantomme, P.). Proceedings of an international conference held in Nairobi, Kenya 19-23 February 1996. Non Wood Forest Products, FAO* (1996) No.9 86-96

Natural flavours, spices and gums are extracted from plant species; they are then processed preserved and enhanced to preserve them, which can raise their market value by up to 20 times. Demand for the polysaccharide gums is continuing to rise because of their use in processed foods, and the possibility exists for processing to an acceptable commercial quality to be done by a rural industry close to the area of production. For gum arabic, the main producing countries are Sudan, Nigeria,

Senegal and Mauritania, but none refine the gum to food commercial quality. The market for high-quality refined gum arabic is US$ 15-25/kg, 8-10 times the price paid for the crude exudate. Lists some of the main uses: coincident spray-drying encapsulates flavour, spice oils and oleoresins to produce dry particles suitable as ingredients of dry soap, sauce, dessert and cake mixes. Its gels form the bases of many varieties of pastilles, gum drops, jelly candies, cough lozenges and other confections high in sucrose. It acts as a stabilizer in marshmallows, caramels and nougats; and as a protective coating for nuts and a glaze for baked bread and cakes; in toppings and icings for cakes; foam on beer. It is also used as an emulsion stabilizer and binder in a wide assortment of lotions, emollient creams, lotions and other cosmetics.

414 HUSSEIN, S.G. **A preliminary study of soils under *Acacia senegal* (L) Willd.** *Sudan Silva* (1983) 5 (25) 125-137

415 HUSSEIN, S.E.G. **The influence of fallow under *Acacia senegal* (L.) Willd. on the C and N content of the soil**. *Beitrage zur Tropischen Landbwirtschaft und Veterinarmedizin* (1990) 28 (2) 217-222

The paper describes the origin, properties, and utilization of the Goz sands of the Sudan. Traditional bush fallow-crop systems in the past used to be 20-40 years of trees, followed by 5-10 years of cropping, but these have been reduced to 12 to 15 years of bush fallow under *Acacia senegal*, followed by a shifting cultivation system cultivation for 4 years. A comparative investigation of soil profiles showed a considerable accumulation of soil organic matter and nitrogen under fallow vegetation, restoring fertility for a further cropping cycle.

416 HUSTACHE, G.; BARNOUD, F.; JOSELEAU, J.P. **Callus formation and induction of a cell suspension culture from *Acacia senegal***. *Plant Cell Reports* (1986) **5** 365-7

Describes an *in vitro* technique for producing callus from the cambial zone of a branch of *Acacia senegal*. The medium was a basal Knop and Ball with an auxin supplement. When transferred to a Schenk and Hildebrandt medium, active growth of colonies was obtained, which later gave rise to a cell suspension culture in liquid medium. This can be regarded as a first step towards producing embryos in culture.

417 IBPGR **Forage and browse plants for arid and semi-arid Africa**. Royal Botanic Gardens, Kew; International Board for Plant Genetic Resources (1984) 17-20, 267

Information derived from the database accumulated by the Survey of Economic Plants for Arid and Semi-Arid Tropics (SEPASAT) is held on 5000 plant species occurring in arid lands for which some use has been recorded. Material on geographic distribution, uses, habitat and vernacular names are recorded, and with nutrient analyses given from Uganda and Kenya of pods, young twigs and leaves. Uses listed for *Acacia senegal* include: main source for Gum arabic (extensively exploited for this - both wild stands and plantations); Browsed by animals (protection of young plantations is essential for successful establishment); Pods are palatable and are eaten by animals in some parts of the range.

418 IBRAHIM, M.A. **Distribution and forage value of five *Acacia* species of the Artificial Insemination Centre, Afgoi (Somalia)**. *Thesis, Faculty of Agriculture, Somali National University* (1985) 1-30

A study of the synecological characteristics of the 6 *Acacia* associations found at the Centre (based on soil and topography), with data on crude protein and dry matter contents of the leaves and twigs of each species (*A. horrida*, *A. tortilis*, *A. senegal*, *A. nubica* and *A. nilotica*).

419 IDRIS, O.H.M.; WILLIAMS, P.A.; PHILLIPS, G.O. **Characterisation of gum from *Acacia senegal* trees of different age and location using multidetection gel permeation chromatography**. *Food Hydrocolloids* (1998) **12** (4) 379-388

The chemical and physico-chemical characteristics of eight authenticated *Acacia senegal* gum samples from trees of varying ages (5,10,15 and 20 years old) growing in Sudan were investigated. The samples originated from the Kordofan region in west Sudan which is the traditional source of the gum and from the new plantations established in the El Daley region in east Sudan. The monosaccharide compositions, protein and amino acid contents and optical rotation were found to be similar to values reported in the literature and there were no obvious trends observed with age or source of the tree. The molecular mass distribution was determined by gel permeation chromatography (GPC) using four different detection systems, namely, UV absorbance, refractive index, photon correlation spectroscopy (PCS) and multi-angle laser light scattering (MALLS). The weight average molecular masses obtained by GPC agreed well with the values calculated from the intrinsic viscosity and varied for the individual samples between 2 X 10^5 and 7.9 X 10^5. The highest values were obtained for samples from trees 15 years old. All samples were found to be polydisperse (Mw/Mn = 1.3-1.8) and the GPC UV elution profiles demonstrated the existence of three principal molecular mass components with molecular masses of 1.4 X 10^6, 1.5-3.0 X 10^5 and 1.8 X 10^5. The radii of gyration, Rg, and hydrodynamic radii, Rh, obtained by GPC/MALLS and GPC/PCS of all of the molecular species were found to be small relative to their molecular mass. The plot of log Rg against log molecular mass for each sample was linear with a slope of ~0.42 and the ratio of Rg/Rh was consistently about 0.8 +/-0.2 nm.

These findings were taken as evidence of a highly branched globular structure consistent with the 'wattle blossom' model proposed for arabinogalactan protein complexes generally. There were no significant differences between the gums from the two regions.

420 ITC GENEVA. **The gum arabic market and the development of production**. UNCTAD/GATT, Geneva (1983)

421 IVENS, G.W. **The effects of arboricides on East African trees and shrubs. I. *Acacia* species**. *Tropical Agriciculture, Trinidad* (1958) **35** (4) 257-271

General conclusions from the series of experiments described are that, for basal sprays in diesel oil, 2,4,5-T (n-butyl) appears to be more effective than ester formulations of 2,4-D. Concentrations of the former of 0.5% were frequently effective and increases above 1-2% gave little advantage. Frill girdling intensified the effect in the larger *A. nigrescens*, *A. senegal*, and *A. tortilis*, especially the first, which is also killed by band girdling. For such non-regenerating species any season appears suitable for spraying, and the frilling of smaller species does not appear necessary.

422 JACKSON, J.K. **Fung working plan for the period 1959/1968**. *Forest Bulletin (New Series), Forests Department, Sudan* (1959) No.3 1-114

A working plan for the forest reserves along the Blue Nile between Sennar Dam in the north and Ṛoseires in the south. The main forest species of economic importance is *Acacia nilotica* ssp. *tomentosa*, which characteristically colonizes areas that are subjected to annual or periodic inundations from floodwaters. The river is typically bounded by banks of deep silt deposits (gerf) which slope gently on their landward sides down to level basins of silt layers over clay (maya). Beyond the basins are the eroded clay slopes of the plains (kerrib). The kerrib slopes are above normal flood level and carry a vegetation similar to that of the surrounding clay plain, e.g. Acacia *senegal*, *A. seyal*, *A. nubica*, *A. mellifera* and *Balanites aegyptiaca*.

423 JACKSON, J.K.; PEAKE, F.G.G. **Forestry Research in the Sudan, 1950 to 1954**. *Memoirs of Forestry Division, Ministry of Agriculture, Sudan* (1955) No.7 1-63

In the silvicultural section, there is a section on gum arabic investigations. Gum arabic is by far the most important product and 95% of it comes from the hashab tree (*A. senegal*) and 5% from the talh tree (*A. seyal*), and between 75-80% comes from the deep wind-blown sands of Kordofan and Darfur. Records complaints from trade sources that samples of gum were not dissolving completely in water and appearing stringy. Samples of gum were collected from 6 areas, and it was found that stringiness occurred more frequently early in the season, and that a tree can produce stringy gum from one branch and not another. It was thought to possibly be an environmental effect, but the cases of stringiness were very small. Possible adulterants to gum samples was investigated and the gum from *A. laeta* which is a natural hybrid between *A. mellifera* and *A. senegal*, proved to be very stringy when tested. During the experiment yields of gum per tree were collected, and the mean yields varied from 20-580 grammes per year per site. Highest yields were 2,686 grammes from a tree 11 inches in diameter. Regeneration of *A. senegal* during the fallow period was investigated and it was found that exhausted soils would not easily be colonised by *A. senegal* but instead by *Calotropis procera*. Tried pre-treatment of seeds with conc. sulphuric acid before sowing but found better regeneration with untreated seed recommending that farmers should collect their own seed and sow directly. Better results were obtained from another experiment at Suweilinga forest, near El Fasher, were seeds pre-treated with acid for 3 mins. only and sown on small mounds 40 cm diameter and 20 cm high, with a 80% success rate. Peake notes in the Entomology section that in a survey of *A. senegal* in Kordofan found no incidence of insect attack on living trees, except occasionally sporadic defoliation by the Sara-el-Lel, the tree locust (*Anacridium wernerella*).

424 JACKSON, J.K.; SHAWKI, M.K. **Shifting cultivation in the Sudan**. *Memoirs of Forestry Division, Ministry of Agriculture, Sudan* (1950) No.2 210-222

Section on the Gum arabic gardens, describing the cycle from the sands close to the Nile north of Kosti. There are 4 periods that occur in the cycle, the cultivation period where acacia scrub is cleared from the land leaving some stunted *Balanities aegyptica*. Crops (*Pennisetum typhoideum* and *Sorghum vulgare*) are sown from 4-10 years until the soil is exhausted and infested with *Striga hermonthica*. Land is abandoned and the soil becomes colonised by *Cenchrus biflorus, Acacia seyal* and *A. senegal* which regenerate on freshly worked soil. In 3 years the acacias reach a metre in height and in 8 years are ready for tapping. This second phase moves onto the dominant phase, where trees are tapped for gum from 6-10 years. Finally the cycle enters the deterioration phase, where trees tend to die simultaneously. They do not regenerate as dense growing grasses have colonised the site. Fire is more prevalent and eventually the cultivator moves in and starts the cycle again.

425 JAMA, B.; NAIR, P.K.R.; KURIRA, P.W. **Comparative growth performance of some multipurpose trees and shrubs grown at Machakos, Kenya**. International Council of Research in Agroforestry (ICRAF). *Agroforestry Systems* (1989) **9** (1) 17-27

Data is presented on the growth rates of 29 multipurpose species or varieties, including *Acacia albida*,

grown at the ICRAF field research station at Machakos, Kenya (a sub-humid to semi-arid climatic zone) for 6 years. The study started in Oct. 1981 and used seedlings at least 6 months old. All were intercropped with maize and beans (*Phaseolus vulgaris*) twice a year, and recommended fertilizer types and rates were applied to the crops. Exotic species such as *Grevillea robusta*, *Sesbania grandiflora*, *Leucaena leucocephala*, *Cassia siamea* and *Sesbania sesban*, some of which were outside their traditional climatic zones, had larger diameters, heights and stem volumes (sometimes up to 130% more) than some of the indigenous species. Several exotic and indigenous species gave such a poor performance (either because of low ecological adaptation and/or pest and browse damage) that they were deleted from the trial and growth data are not given. These included *Acacia mellifera*, *Atriplex nummularia*, *Calliandra calothyrsus*, *Cassia alata* and *Cordeuxia edulis*. General ecological characteristics of some of the species tested are summarized in a table.

426 JAMAL, A. **Major insect pests of gum arabic trees *Acacia senegal* Willd. and *Acacia seyal* L. in Western Sudan**. *Journal of Applied Entomology* (1994) 117 (1) 10-20.

Describes a survey of insects attacking the dominant gum Acacias (*Acacia senegal* and *A. seyal*) of Kordofan province, as these were suggested as the main causal agents in the decline in gum production after a long drought during 1979-84. A survey initiated in the region in August 1986 revealed a great number of dead acacias due to drought and pest attack but mainly due to unfavourable socioeconomic conditions leading to abandoning maintenance of the gum gardens and harvesting trees for charcoal, (see Jamal & Huntsinger 1993). The main areas surveyed were the once rich markets of Barra, El Mazroub and El Khuwei and the area surrounding El Obeid. The El Damokia Forest on the Gum Belt was also visited. The most important insect pests were the buprestids *Sternocera castanea* L., *Chrysobothris sp.*, *Agrilus spp.* and *Psiloptera sp.*, the elaterids *Lanelater notodonta* Latr. and *Tetralobus cavifrons* Fairni., the cerambycid *Acanthophorus confinis* Cast, and on the seeds *Bruchus baudni* [*Bruchidius uberatus* Caill.].

427 JAMAL, A.; HUNTSINGER, L. **Deterioration of a sustainable agro silvo pastoral system in the Sudan: the gum gardens of Kordofan**. *Agroforestry Systems* (1993) **23** (1) 23-38

Describes the results of surveys undertaken in Kordofan province in 1986/7 with small-scale farmers who traditionally tapped gum arabic in the gum gardens of Western Sudan. *Acacia senegal* (hashab) and *Acacia* seyal (talh) are the two major marketable gum-producing trees found in this region. These *Acacia* spp. are grown as part of an agrosilvopastoral system that has persisted for >100 yr in Kordofan Province, where 70% of Sudan's gum arabic was once produced (as well as most of its grain and livestock products). After a lengthy drought lasting from 1979 to 1985, gum production in Sudan decreased drastically. It was reported that pest attacks and drought were major causal agents in the decline of gum production (see Jamal 1994). A survey made in northern Kordofan Province starting in August 1986 found a large number of dead acacias (some due to drought and pest attack), but from interviews with gum farmers it is concluded that the decline in gum production is largely due to unfavourable socioeconomic relations which have been exacerbated by the drought, leading to the deterioration of the agroforestry system of production. An inability to get a fair price for gum at the local level (10 US$/ton whereas export prices from Port Sudan were 2000 US$/ton) and increasing emphasis on a cash economy has led to farmers to excessive tapping (can kill the trees) and logging the trees for selling for fuelwood or charcoal. The gum gardens had long flourished with the intensive husbandry of small-scale farmers, and the trees have always been highly valued. Normally the trees naturally regenerate during the cropping cycle, and some will coppice and some sowing of the trees also occurs during the sowing of the agricultural crops. Trees can produce gum to over 40 years of age. Once these farmers were no longer able to care for them, the gum trees disappeared from the system, indicating that a lack of community stability can be fatal to even a well developed agro forestry system. However in some areas (Rashid and El Nihud) farmers managed to smuggle gum across to Chad where they received better prices. In these areas gum gardens were still maintained.

428 JAYASANKAR, S.; MOHAN KUMAR, B. **Early growth and nodulation in five *Acacia* species**. *Nitrogen Fixing Tree Research Reports* (1992a) **10** 102-105

Pot trials undertaken at Vellanikkhara, Kerala, India are reported for *A. senegal, A. nilotica, A. mangium, A. auriculiformis* and *A. catechu*, from January to August 1990. *A. senegal* and *A. nilotica* showed superior growth (measured in shoot and root dry weights and lengths) compared to the other species tested over 170 days, and *A. senegal* also presented the greatest number of nodules recorded per plant (15.6). For *A. senegal* shoot length averaged 33.54 cm and dry weight was 1.305 g/plant, and average root length was 27.70 cm and dry weight/plant was 1.309 g/plant.

429 JAYASANKAR, S.; MOHAN KUMAR, B. **Early growth and nodulation in five *Acacia* species**. *Myforest* (1992b) **28** (2) 215-220

Same results presented in the above abstract (428).

430 JHA, P.K.; NAIR, S.; BABU, C.R. **Development of an inexpensive legume-Rhizobium inoculation**

technology, which may be used in aerial seeding. *Journal of Basic Microbiology* (1994) **34** (4) 231-243

Encapsulation of seeds with alginate entrapped rhizobia (AER) bead has been developed as a new seed-applied inoculum technique for utilizing legume-Rhizobium symbiosis for the management and protection of natural ecosystems. Alginate beads trapped water and immobilized rhizobia, which ensured germination of seeds and nodulation of seedlings. Incorporation of a synthetic polymer, Jalshakti, in alginate beads did not enhance symbiotic nitrogen fixation but sufficient number of rhizobia remain viable in them even after 30 weeks of storage reflecting suitability of these materials as carriers for rhizobia. Plant cultures raised from these beads were similar to or even better than the inoculated controls in symbiotic parameters indicating the effectiveness of seed-applied inoculum technique. Pelleting of seeds with these polymers after coating with gum arabic lead to substantial reduction in symbiotic association and viability of rhizobia. Experiments involving two legume-Rhizobium associations indicated that the encapsulation of seed with AER bead is a cheap, inexpensive and effective inoculation technique which may be used in aerial seeding.

431 JINDAL, S.K.; KACKAR, N.L.; SOLANKI, K.R. **Interrelationship between shoot dry weight and components in *Acacia senegal* (L.) Willd. progeny.** *Nitrogen Fixing Tree Research Reports* (1987) **5** 16-17

The progenies of 34 plus trees of *A. senegal* selected on the basis of better growth from different parts of Rajasthan were raised in polythene bags in Feb. 1985. Root fresh weight, root dry weight, shoot length, root length, basal diameter, shoot fresh weight and shoot dry weight were measured for 3 seedlings from each plus tree at 3 month old. Genotypic and phenotypic correlation coefficients were calculated, and genotypic correlation coefficients for shoot dry weight and other characters were further partitioned into direct and indirect effects by path coefficient analysis. Genotypic correlation coefficients were higher than the corresponding phenotypic correlations. All correlation coefficients were positive and significant except for those of root length with shoot length, basal diameter and shoot dry weight. Path analysis showed that the direct effects of root dry weight and shoot fresh weight on shoot dry weight were high and positive, followed by those of shoot length and root length. Root dry weight and shoot fresh weight were also highly correlated with shoot dry weight indicating that selection could be made on these criteria. The low residual effect in the path analysis indicated that the major portion of the variability in shoot dry weight was accounted for by the 6 characters that were analysed.

432 JOHANSSON, S.G.; KAARAKKA, V.J.; MUGAH, J.O. **Growth and yield of six year old fuelwood species under irrigation in eastern Kenya. Forestry in irrigation schemes with special reference to Kenya.** *East African Agricultural and Forestry Journal* (1993) **58** Special Issue 23-34

Data on biomass production and water use efficiency are given for 10 species (*Acacia senegal, Acacia mellifera, Azadirachta indica, Casuarina equisetifolia, Eucalyptus camaldulensis* (2 provenances), *Eucalyptus microtheca, Eucalyptus tereticornis* (2 provenances), *Prosopis chilensis, Prosopis juliflora* and *Prosopis pallida*) grown under furrow irrigation in the Bura Irrigation Settlement Scheme in Kenya.

433 JOLY, H.I. [***Acacia albida* or *Faidherbia albida*? Taxonomy: the potential of isoenzymatic electrophoresis.**] *Acacia albida* ou *Faidherbia albida*? Taxonomie: potentialites de l'electrophorese isoenzymatique. *Bois et Forêts des Tropiques* (1991) No.230, 33-37

Used isozymes as genetic markers to study the anomalous taxonomic position of *Acacia albida* in relation to two other species in the genus. Polyacrylamide gel electrophoresis was used on 5-day-old cotyledons of *A. albida* (Malian provenance), *A. senegal* (Cameroonian provenance) and *A. tortilis* (provenance from Israel) and 8 isoenzyme loci were scored. Some loci varied (in number) between the 3 species (*AAP, alanine aminophosphatase; ADH, alcohol dehydrogenase;* and *GOT, glutamate oxaloacetate transaminase [aspartate aminotransferase]*); some had the same number of loci but species' profiles differed (*beta-EST, beta-esterase*; and *ME, malic enzyme*); others did not appear characteristic of any species (*ACO, aconitase; GDH, glucose dehydrogenase*; and *IDH, isocitrate dehydrogenase*).

434 JOSELEAU, J.P.; ULLMANN, G. **A relation between starch metabolism and the synthesis of gum arabic.** *Bulletin of the International Group for the Study of Mimosoideae (IGSM)* (1985) **13** 46-54

They tested two hypotheses on the biosynthesis of gum; that it could result from the molecular rearrangement of cell wall hemicelluloses (especially arabinogalactans) or that from a turnover of starch. Carbohydrate analysis of aqueous and alkaline extracts and the enzymic activity of gum producing and unproductive branches of *Acacia senegal* were compared. The nearly complete disappearance of starch in the gummiferous tissues together with the high level of amylase activity can be interpreted as strong evidence for the involvement of starch hydrolysis in the synthesis of gum arabic. This also agrees well with the use of etephon and 2,4-D, which trigger gum formation, and also induce a-amylase synthesis and starch degradation. Gummosis seems to be directly related to starch metabolism in *Acacia senegal.*

435 JOSELEAU, J.P.; ULLMANN, G. **Biochemical evidence for the site of formation of**

Gum arabic in *Acacia senegal*. *Phytochemistry* (1990) **29** (11) 3401-3405

Chemical carbohydrate analyses of the inner bark, cambial zone and the xylem of both gum producing and non-gum producing branches of a 15 year old tree of A. *senegal* were undertaken and compared to locate the area of gum production. Acidic polysaccharides, which were precipitated by hexadecyltrimethyl ammonium bromide, were abundant in the aqueous extracts from the inner bark and the cambial zone of the gum producing branch, and were absent from the non gummiferous branch. Neutral sugar and uronic acid analysis showed that the precipitated polysaccharides had the same composition as the gum produced by the same branch. These biochemical analyses (methylation analysis and 13C NMR spectroscopy) showed the presence of the gum only in the gum producing branch in the cambial zone, but the presence of gum was not restricted only to the site of tapping and gum exudation but also occurred throughout the cambial zone of the branch. The same research was carried out on a one year old plant without any presence of the gum being found, indicating that gum production from the cambial zone requires a certain maturity of the tree. This is in agreement with the local knowledge that a tree needs to be at least five to seven years old to produce reasonable amounts of gum. Also suggests that the biosynthesis of the gum must be in competition with tree growth.

436 JURASEK, P.; KOSIK, M.; PHILLIPS, G.O. **The classification of natural gums. Part II. Characterisation of the gum arabic of commerce based on a chemometric study of amino-acid compositions.** *Food Hydrocolloids* (1993a) **7** (2) 157-174

Commercial samples of gum arabic from Ethiopia, Senegal, Nigeria, Chad and Sudan have been compared with authenticated *A. senegal* (L.) Willd. specimens from Mauritania, Mali, Senegal, Ethiopia and Oman using a chemometric analysis (including Principal Component Analysis) based on their amino acid compositions. The majority of these form a cluster which encompassed both normal geographic and commercial variability. The three samples outside the cluster possess chemical features which account for their exceptional behavior. For comparison, *Acacia* gums from non-African sources (Phyllodineae Benth.) and the *Leucaena* gums from Hawaii and Mexico, which are closely related chemically and physically to gum arabic were also analysed. These gums can be identified individually and distinguished from commercial gum arabic. It is proposed that chemometric methods could provide a basis for setting commercial specifications for gum arabic, which would take account of the antecipated variability of this complex natural product and eliminate the possibility of serious adulteration by unacceptable related gums of arabinogalactan protein origin.

437 JURASEK, P.; KOSIK, M.; PHILLIPS, G.O. **A chemometric study of the Acacia (gum arabic) and related natural gums.** *Food Hydrocolloids* (1993b) **7** (1) 73-85

Used chemometric data analysis (Principal Component Analysis and Discriminent Component Analysis (DCA)) on nine physical and chemical parameters to separate *Acacia* from *Combretum* and *Albizia* gums of similar composition. *Combretum* and *Albizia* gums could be readily distinguished from each other and *Acacia*. The order of importance of properties studied were (in decreasing order) specific rotation, viscosity, rhamnose, arabinose, equivalent weight and galactose. Using DCA the two subgenera of *Acacia* could be separated on their arabino-galactan proteins, although they nearly merge at the boundaries. The authors suggest that *A. seyal* and *A. senegal* could be regarded as closely related gums even though they are from separate taxonomic subgenera. Their use of the term *Acacia senegal* complex for all the species in the subgenera Aculeiferum does not fit into taxonomic usage.

438 JURASEK, P.; PHILLIPS, G.O. **The classification of natural gums. Part IV. Identification and discrimination of Acacia, Combretum and Prosopis gum exudates.** *Food Hydrocolloids* (1993) **7** (4) 337-352

Principal Component Analysis and Discriminent Component Analysis and for classification Linear Discriminent Analysis have been used to study the relationship between the arabinogalactan proteins in *Acacia, Combretum* and *Prosopis* gum exudates. The Australian Acacia gums (series Phyllodineae) can be readily distinguished from other Acacia species (only looked at African species and not those from Americas), as can the *Combretum* and *Prosopis* gums with the exception of *P. juliflora. Prosopis juliflora* gum cannot be distinguished from *A. senegal* and others species in the series Vulgares. Two African *Acacia* species of the Gummiferae series (*A. fisheri* and *A. gerrardii)* also fell within the *Prosopis* species cluster.

439 JURASEK, P.; PHILLIPS, G.O.; VARGA, S.; CHIKAMAI, B.N.; BANKS, W.B. **The classification of natural gums: VI. Gum arabic derived from *Acacia senegal* var. *kerensis* from Kenya.** *Food Hydrocolloids* (1994) **8** (6) 567-588

Sixty-seven samples of gum from *Acacia senegal* var. *kerensis*, the main source of gum arabic in Kenya, have been evaluated using chemometric methods. The gums were collected from individual authenticated trees from four regions of northern Kenya: Marsabit (Ngurunit and Kargi), Isiolo and Turkana districts and brown samples of gum from single trees from the various districts. The gums were analysed for amino acid composition, and physical and carbohydrate parameters: specific optical rotation, viscosity, % nitrogen and composition of galactose, arabinose, rhamnose, equivalent weight and uronic acid content. The mean (alpha)-D varied from -34 to -37 degree, with individual values of -40 degrees

recorded; the average nitrogen content was 0.45%, with individual samples as high as 0.70%. On this basis the gum fell outside the proposed JECFA limits, and if this specification was implemented, the Kenyan gums would not be acceptable as commercial gum arabic. Using principal component (PCA), the Kenyan gum was compared to 65 other commercial gums arabic and authenticated *A. senegal* samples collected from a variety of countries: Sudan, Niger, Nigeria, Uganda, Oman, Mauritania, Mali, Senegal and Ethiopia. The gums were drawn from periods ranging from 1903 to the present. On the basis of amino acid analysis, all the Kenya gums formed part of an extended cluster, which embraces the gum arabic/*A. senegal* from the various countries. Gums from the Marsabit (Kargi) region, mainly contributed to a peripheral cluster characteristic of the Kenya gum. The physical and carbohydrate features also confirmed the fundamental similarity of the Kenya gum to the other gum arabic/*A. senegal* samples. Here also a distinctive cluster could be attributed to certain Kenya samples, mainly from the Turkana region. When the carbohydrate and amino acid features are combined to provide 26 features, the former patterns were evident, with the amino acid compositions exerting the major influence on the cluster patterns. Using only four of the most discriminating features: specific optical rotation, viscosity, hydroxyproline and lysine, both the distinctive nature of the Kenya gums and their broad coherence within the gum arabic family was established. Using the dominant characteristics associated with certain groups of gums, we were able, by analysis of covariance, to identify the region of origin of such local variants within the gum arabic family. On the basis of the chemometric analytical evidence, the gum arabic derived from a varietal form of *A. senegal* found in Kenya must be regarded as a legitimate and acceptable gum arabic.

440 KANANJI, B. **Exploration and seed collection of *Acacia senegal* in Sudan**. *Forest Genetic Resources* (1994) No.22 37-42

Gives an introduction to seed collecting activities at the Government Tree Seed Center in Sudan, which collects seed for some 20 species, both exotic and indigenous. The priority species for tree improvement is *Acacia senegal*. Describes the seed collection activities on *A. senegal* and details areas of major gum production in the Sudanese Gum belt [the map appears to come from Seif El Din's thesis]. Lists 14 provenances of the species from which most of them had 30 individual tree collections, and stated that gum yield was one of the selection criteria. Notes that some provenances can be made available to other research institutions.

441 KARAMALLA, K.A.; SIDDIG, N.E.; OSMAN, M.E. **Analytical data for *Acacia senegal* var. *senegal* gum samples collected between 1993 and 1995 from Sudan**. *Food Hydrocolloids* (1998) **12** (4) 373-378

Over 1500 authenticated and commercial *A. senegal* var. *senegal* gum samples were analysed to evaluate existing quality control parameters and to assess the potential of new parameters such as pH, viscosity, viscosity average molecular weight (MV) equivalent weight and total uronic acid content as additional qualifying indices. The data obtained indicate the following mean values: moisture (10.75%), ash (3.77%), nitrogen (0.328%), specific rotation (-31.3°), pH (4.66), equivalent weight (1436) and total uronic acid content (13.71%). The results also indicate wide variations in intrinsic viscosity and viscosity average molecular weight (mean values 16.4 ml/g and 9.0×10^5, respectively). Accordingly these parameters, therefore, cannot be recommended as qualifying indices. Apart from the intrinsic viscosity and viscosity average molecular weight the parameters conform to JEFCA (1990) specification.

442 KARIHALOO, J.L. **Effect of pre-treatment on germination of *Acacia* seeds**. *Seed Research* (1984) **12** (2) 112-115

Describes the effect of various pretreatments on the germination of nine *Acacia* species. Both *A. senegal* (L.) Willd and *A. lenticularis* Ham. germinated readily without pre-treatment except soaking in water at room temperature for 18 hours (control). The other seven species required pre-treatment for rapid germination. All seeds were sown within 9 months from harvesting.

443 KATHJU, S.; TEWARI, M.N. **Development of the root from the cotyledonary callus of *Acacia senegal***. *Labdev. Journal of Science and Technology* (1973) 11-B (3-4) 84-85

Describes the development of roots from callus cultured *in vitro* from excised cotyledons of *Acacia senegal*. These were cultured on modified White's medium without natural additives like coconut milk or casein hydrolysate.

444 KAUL, R.N. **An approach to provenance trial in relation to tree introduction in arid lands**. *Ann. Arid. Zone, Jodhpur* (1965) **4** (2) 164-171

Summarizes and discusses the results of experiments to discover the degree of variation within and between a number of species considered suitable for arid-zone planting in India. They fell into two distinct groups: (a) slow-growing indigenous specis (*Acacia senegal*, *Prosopis cineraria* and *Tecomella undulata*) with relatively greater variability in growth rate between species, and (b) fast-growing exotic species (4 provenances of *Eucalyptus rostrata*, *E. melanaophloia*, and *A. tortilis*) with relatively greater variability within species. The design of provenance trials with such species, and problems involved, are discussed.

445 KAUL, R.N.; CHAND, G. **Forest-tree planting in arid zones**. In *Proceedings of the UNEP*

Desertification Conference, Nairobi, Kenya, 1979. (1979) 196-202

A review of research carried out by the Central Arid Zone Research Institute at Jodhpur, India, on the development of methods for afforesting different land types in the arid zone. Local tree species are very slow growing, but the most useful are *Prosopis cineraria*, *Acacia senegal*, *Tecomella undulata*, *Albizzia lebbek*, *Salvadora oleoides* and *Azadirachta indica*. Their silvicultural characteristics are briefly described. The most promising introduced species, with a higher growth rate, are *Eucalyptus melanophloia*, *E. tessellaris*, *E. oleosa*, *E. camaldulensis* and *Acacia tortilis*. Experience with nursery techniques, and planting methods and most successful species in relation to land-types are reported.

446 KAUL, R.N.; CHERIAN, A.; DAULAY, H.S. **Micro-relief as a decisive factor in the development of vegetation in arid zones**. *La-Yaaran* (1966) **16** (4) 122-128, 170-164

The relationships between micro-relief, soil depth and plant growth were studied on an arid semi-rocky site near Jodhpur, India, having a mean annual rainfall of 354 mm and a mean annual evaporation of 4787 mm. Soil depth was highly correlated with micro-relief and with height growth and crown development of natural shrubs and planted *Prosopis juliflora* and *Acacia senegal*. It is concluded that planting should be restricted to patches with a soil depth >43.5 cm.

447 KAUL, R.N.; CHITNIS, B.K. **Kumat - the tree of rocky desert**. *Indian Farming, New Delhi* (1964) **13** (12) 9-10

A brief description of *Acacia senegal*, its habitat, distribution, wood and gum (and their uses), natural regeneration (often in clumps of *Euphorbia neriifolia*), propagation, protection (from frost, fire, goats, camels, desert rats and termites) etc. On gravely or rocky sites, plantations can be raised by direst sowing on the ridges of a ridge-and-trench contour system, with trenches 60 cm wide and 30 or 60 cm deep. For transplanting in extremely arid regions, half-filled pits 60 x 60 x 60 cm have been found suitable.

448 KAUL, R.N.; MANOHAR, M.S. **Germination studies on arid zone tree seeds. I. *Acacia senegal* Willd**. *Indian Forester* (1966) **92** (8) 499-503

Investigates the extent of seed dormancy of *Acacia senegal* (var. *senegal*) and the germination of seed of different maturities under different moisture stresses. Seeds of *A. senegal* are 'hard' and require seed scarification to obtain good germination. However, seeds collected when the pods begin to bronze in colour, 10 days after seed has filled in the green pods, require no scarification for maximum germination. Germination was found to be severely affected, irrespective of the extent of seed maturity, if moisture conditions of the seedbed fell below -600 joules/kg.

449 KAUR, K.; GUPTA, P.; VERMA, J.K.; KANT, U. ***In vitro* propagation of *Acacia senegal* (L.) Willd. from mature nodal explants**. *Advances in Plant Sciences* (1998) **11** (2) 229-233

A tissue culture method is described for the clonal multiplication of *Acacia senegal* using nodal explants from mature 'elite' trees growing in the field [in Rajasthan, India]. MS medium with BAP ([benzyladenine] 4.0 mg/litre) and NAA (0.5 mg/litre) induced maximum number of shoot buds. Addition of adenine sulfate (25.0 mg/litre), ascorbic acid (10.0 mg/litre) and glutamine (146.0 mg/litre) to the medium were beneficial. The shoot buds elongated on MS medium with lower concentrations of cytokinins (BAP and Kn [kinetin] at 1.5 mg/litre each). On this medium shoot buds developed into healthy and sturdy shoots. Rooting was best in 1/2 MS medium fortified with IAA (5.0 mg/litre).

450 KAVATHEKAR, K.Y.; PANDA, P.K.; SASTRY, T.C.S; GUPTA, R.; RETHINAM, P.; EDISON, S.; PAREEK, O.P.; SHARMA, S.; CHADHA, K.S.; MAL, B.; KOCHKAR, S.; KALLARACKAL, J.; SOMEN, C.K.; FAROOQI, M.I.H.; ABROL, I.P.; REKIB, A.; UPADHYAY, V.S.; PATHAK, P.S.; JHAMB, V.N.; BHATT, V.S. **Trees for life**. *Indian Farming* (1991) **41** (8) 1-70

Includes a section devoted to trees yielding gums and resins. Data on gums used for international trade are listed, and some important gums further discussed including gum arabic from *Acacia senegal*, tragacanth gum from *Astragalus spp.* and karaya gum from *Sterculia urens.*

451 KAZMI, S.M.A. **Some firewood species of Somalia**. *Somali Range Bulletin* (1982) No.13 12-17

Details are given of the calorific value and uses of wood of *Acacia nilotica*, *A. senegal*, *A. tortilis*, *Azadirachta indica*, *Casuarina equisetifolia*, *Gmelina arborea*, *Eucalyptus camaldulensis*, *Tamarix aphylla*, *Ziziphus mauritiana*, *Z. spina-christi* and *Conocarpus latifolia*.

452 KERKHOF, P. **Agroforestry in Africa: a Survey of Project Experience**. London UK, PANOS Institute (1990) 1-216

A survey of 21 Agroforestry projects in 11 African countries, undertaken in 1989, including the project reforestation around wells in northern Senegal, using seedlings of *Acacia senegal* (ann. rainfall 300-400mm/yr). However poor survival and little interest from local farmers and herders in growing trees resulted in the reforestation approach being abandoned.

453 KHALID, A.S.; MOHAMMED, O.H.; MAHGOUM, S.O.; KHALID, S.A. **The microflora of gum arabic and their significance to gummosis**. In *Gums and Stabilisers for the food industry 4 (edited by Phillips, G.O.; Williams, P.A., Wedlock, D.J.).* Oxford, England; IRL Press (1988) 435-441

Seventy-two specimens of gum arabic were collected from 12 trees of *A. senegal* var. *senegal* in Sudan of ages varying from 3,5,10,15,20 and 25 years old. They were screened for their microflora and its relevance to gummosis is discussed. Five genera of moulds were identified, namely *Asperigillus, Penicillium, Rhizopus, Gilocladium* and *Cladosporium*. Bacteria characterized are gram positive spore formers, gram positive non-spore formers, and gram negative rods. Morphological evidence proved that Sudanese gum arabic is free from pathogenic micro-organisms (salmonella and coliforms). Absence of the moulds from some samples suggests that they probably do not induce gummosis.

454 KHAN, H.A.; HARSH, L.N. **Quality of ethephon induced gum from** *Acacia senegal*. *Annals of Arid Zone* (1994) **33** (1) 85-86

Results are reported from trials at CAZRI, showing that ethephon induced gum exudation in *A. senegal*, and that the samples were of good quality, (see also Anderson 1990).

455 KHAN, M.I-UR-R. **Cyto-genetical studies in some species and hybrids of *Acacia* and *Larix***. *Punjab (Pakistan) For. Rec.* (1951a) **1** (1) 1-48

Acacia senegal, A. mellifera, A. modesta and *A. decurrens* all have a chromosome number of 2n=26. The apparent hybrid *A. senegal* x *A. mellifera* showed 2n=39 or 40 in the somatic nucleoli of its progeny. It is considered that all the 13-chromosome *Acacias* are secondarily balanced polyploids. *A. arabica* and *A. farnesiana* are both tetraploids. The Australian *Acacias* of the *decurrens* group have very similar chromosome morphology and are mainly diploids. The influence of cytogenetical characters on the possibility of artificial hybridization and induced polyploidy are discussed. The somatic chromosome number of *Larix laricina* was found to be 2n=24. A basic chromosome number of 6 is suggested for the genus *Larix*. On cytological grounds it is considered that *L. decidua, L. decidua* var. *polonica* and *L. sibirica* are closely related. *L. leptolepis* has larger chromosomes and is regarded as more primitive than any of the other species studies.

456 KHAN, M.I-UR-R. **Study of somatic chromosomes in some *Acacia* species and hybrids**. *Pakistan Journal of Forestry* (1951b) **1** (4) 326-341

New chromosome numbers were recorded for *Acacia senegal, A. mellifera* and *A. modesta* (2n=26 for each). Two hybrids of *A. decurrens* x *A. mollissima* also had 2n=26. An apparent hybrid *A. senegal* x *A. mellifera* showed 2n=39 or 40 in the somatic nucleoli of its progeny. No natural or artificial triploid *Acacia* has been reported so far. Of the two tetraploid species studied, *A. arabica* showed 4 pairs of nuclioli, and *A. farnesiana* only 3 pairs. The loss of a pair in the latter species is inferred to be due to mutation in the course of evolution. The Australian species of the *decurrens* group resemble each other in chromosome morphology; on the basis of relative chromosome length, *A. decurrens* appears to be the most highly evolved species and *A. dealbata* the most primitive. The scope and possibilities of artificial hybridisation and induced polyploidy are discussed.

457 KHAN, W.A.W. **Seeding and planting on clay plains**. *Pamphlet, Forestry Research Education Project, Forest Department, Sudan* (1965) No.16 1-20

Describes the ecology, climate and soil of the clay plains in the eastern half of Central Sudan. Root studies of 2 year old *Acacia senegal* plants indicated two zones of lateral root proliferation from the tap root in the first 20 cm and around 80 cm depth. Eight different soil-working techniques were tried on the clay soils at Hawata, to improve establishment and accelerate early growth of *A. senegal*. The most efficient and economical was the 'Pit Method', where 30 cm^3 of topsoil was dug out, broken up and refilled into the pits. Pits are spaced 4 m x 4 m. To ensure success with direct seeding, earliest sowing should be done in July. Nursery stock was better left to the end of July. This was found to be more successful than furrow planting. Need for 3 to 4 weedings to reduce excessive competition from grasses. Also presents drawings of *A. senegal* and *A. seyal* seedling root systems, showing both tap roots which sometimes bifurcated and many lateral roots.

458 KOKWARO, J.O. **Medicinal plants of East Africa**. Nairobi, Kenya; East African Literature Bureau (1976) 1-126

Lists a number of medicinal uses of *Acacia senegal* in Kenya, and their vernacular names. A root decoction is slightly purgative and is drunk in the case of constipation or for stomachache, and is also used in the treatment of gonorrhea. A decoction of the bark is drunk to treat diarrhea and stomach disorders.

459 KOLB, K.B.; KUNKEL, M.E. **Effect of pH and hemicellulase digestion on calcium binding by selected gums**. *Food Chemistry* (1994) **49** (4) 379-385

The following study was conducted to investigate calcium binding by locust bean gum (Loc), gum arabic (Ara) and xanthan gum (Xan) under various pH conditions and during hemicellulase digestion. Binding behavior of the gums was pH-dependent. Ara and Xan bound most Ca at neutral pH, whereas Loc bound most Ca at pH 9.5. For all three gums, binding decreased below pH 5.

Xan bound an average of 70% of added Ca in the range studied (0-3000 mu-M). Ara bound about 26% of added Ca, whereas Loc bound 5-25% of added Ca. Based on Scatchard analysis, there were two types of binding sites for Ca for Xan and Ara, and one type for Loc. Hemicellulase digestion decreased binding ability for all three gums. Ara and Loc released endogenous Ca, while Xan lost 35-45% of its Ca binding capacity after a 24 h in-vitro digestion.

460 KOLBERG, H. **Acacias of SWA/Namibia**. SWA-Herbarium P/sak 13184 P/bag, Windhoek, 9000 (1989) 1-30

Description of *Acacia senegal* in Namibia whose common names are the three-thorned *acacia*; Driedoringakasia; Dreidornakazie. Unique among SWA/Namibian *acacias*, as curved prickles are grouped in threes: two pointing towards the tip, the middle one towards the base of the twig. Distribution: a band from central to northwestern parts of Namibia.

461 KONE, O.M. **Considerations socio economiques liees au developpment du Gommier au Senegal**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, 25-28 Octobre, St Louis, Senegal* (1988) 267-272

In Senegal, gum was traditionally collected by pastoralists of the Maure tribe whilst out grazing livestock around the shores of the river Senegal. Later this has been taken up by sedentary pastoralists of the Maure and Peulh tribes, and since the droughts of the 1970's the Wolof agriculturalists as well (notably in the Louga region). Some projects have fenced off areas of *A. senegal* to protect the trees, which was not liked by the pastoralists at first, but later realised that they could use the plots as fodder reserves (especially the herbaceous layer). Found problems in the marketing of gum arabic with the middlemen pocketing nearly all the profits. With the new Forest code, forests are to be managed by the people with minimum supervision by government foresters. Land tenure is seen as problem in these community gum plantations, as is the collection of gum from the trees.

462 KULANE, M.A. **Phenology and protein content of three *Acacia* species at the Artificial Insemination Centre**. *Thesis, Faculty of Agriculture, Somali National University* (1986) 1-32

The results of a study at Afgoi, Somalia, on the relations between phenology and protein content of *Acacia nubica, A. horrida* and *A. senegal* during the wet and rainy seasons, in order to provide information on forage quality.

463 KUMAR, S. **Comparing classification and different ordinations of vegetation in the Thar desert of India with implications in resource management**. *Tropical Ecology* (1992) **33** (1) 110-131

Relative Importance Value (RIV) data for perennial vegetation were sampled in tenth hectare quadrats at 251 sites covering all the major desert habitats in Jaisalmer district, Rajasthan, and analysed for classification and ordinations. Soil analyses were also undertaken at each site. However, only the results obtained in respect of the vegetation data of the sandy undulating hummocky plain habitats are discussed here. Some 17 species were identified overall; these included trees, shrubs, undershrubs, perennial grass, browse and spiny plants. The woody species included *Calotropis procera, Capparis decidua, Ziziphus nummularia, Prosopis cineraria, Acacia senegal, Salvadora oleoides, Leptadenia pyrotechnica, Crotalaria burhia* and *Heliotropium sp.* Classification of vegetation by 2 way indicator species analysis (TWINSPAN) revealed 3 site classes and 4 species classes, both arranged along a gradient of soil texture. The 4 species classes were: (1) *Lycium barbarum/Panicum turgidum*, (2) *Salvadora oleoides/Leptadenia pyrotechnica/Lasiurus s[c]indicus*, (3) *Aerva pseudotomentosa/Capparis decidua/Ziziphus nummularia/Crotalaria burhia*, and (4) *Calotropis procera/Haloxylon salicornicum/Dipterygium glaucum*. Of the ordination analyses carried out by the methods of Polar Ordination (PO), Principal Component Analysis (PCA), Reciprocal Averaging (RA) and Detrended Correspondence Analysis (DCA), site and species classes obtained by DCA were nearest the natural situation. Moreover, the addition of 5 non existent (outlier) species with zero RIV to the main matrix either aborted the calculations or introduced noise, thus making interpretation difficult; however, such species were completely eliminated by DCA and TWINSPAN. Six site and 10 species classes, which corresponded to each other in DCA were an improvement over TWINSPAN classes. Examination of these classes for trends in 19 vegetational and 10 edaphic parameters, along with ecological status, dominance diversity curves, beta diversity and dominance concentration, provided cues for vegetation management on these sites.

464 KUMAR, S.; ULLAH, A. ***Tecomella undulata* a new host for aak grasshopper *Poekilocerus pictus* (Fabricius) (Orthoptera: Pyrgomorphidae) from Rajasthan**. *Indian Forester* (1997) **123** (11) 1081-1082

Poekilocerus pictus is primarily a defoliator of aak (*Calotropis spp.*) but has also been reported defoliating other tree species, various ornamental plants and vegetables. During 1993-96 adults and nymphs were found defoliating young trees of *Acacia nilotica* (15%), *Acacia senegal* (10%), *Prosopis cineraria* (30%), *Prosopis juliflora* (7%) and *Tecomella undulata* (60%) in and around Jodhpur District, Rajasthan. Experimental host preference tests were carried out with 4 tree species (including 3 of those above), and showed that *T. undulata* was the preferred species of these (it was completely defoliated), followed by *P. cineraria* and *A. nilotica*. *Azadirachta indica* was not attacked at all.

Control methods and the biology of the pest are briefly discussed.

465 LAJUDIE, P. De.; NEYRA, M.; DUPUY, N.; ALAZARD, D.; GILLIS, M.; DREYFUS, B. [**Diversity of *Rhizobium*, specificity of nodulation and ability of the Sahelian acacias to fix nitrogen.**] Diversite des *Rhizobium*, specificite de nodulation et aptitude a fixer l'azote chez les acacias saheliens. In *Physiologie des arbres et arbustes en zones arides et semi-arides (edited by Riedacker, A.; Dreyer, E.; Pafadma, C.; Joly, H., Bory, G.)*. Paris, France; Groupe d'Etude de l'Arbre (1991) 257-262

Acacias are nitrogen-fixing trees with great potential for arid and semi-arid zones. A review is presented of current results of studies into *Rhizobium* and *Bradyrhizobium* capable of nodulating Sahelian acacias. This is the first report of the presence of nitrogen-fixing nodules on mature trees in Senegal grown in natural conditions. Slow-growing rhizobia nodulating *Acacia albida* have been isolated at 34 m below the soil surface, at the water table level. A library of tropical *Rhizobium* strains isolated from different ecological areas in Senegal has been characterized especially in respect to their growth characteristics and their symbiotic properties (host range and nitrogen-fixing potential). These strains were compared to other known *Rhizobium* species by numerical taxonomy. Results here have confirmed that the acacias can be classed into three categories, those that associate with *Rhizobium*, those that associate with *Bradyrhizobium* and those that associate with both. *A. senegal* belongs to the first group. Tropical soils on the other hand contain mainly *Bradyrhizobia*. This research has enabled the selection of rhizobia that are highly effective in specific associations in increasing growth of the tree.

466 LAJUDIE, P. De.; WILLEMS, A.; NICK, G.; MOREIRA, F.; MOLOUBA, F.; HOSTE, B.; TORCK, U.; NEYRA, M.; COLLINS, M.D.; LINDSTROM, K.; DREYFUS, B.; GILLIS, M. **Characterization of tropical tree rhizobia and description of *MesoRhizobium plurifarium* sp. nov.** *International Journal of Systematic Bacteriology* (1998) **48** (2) 369-382

A collection of strains isolated from root nodules of *Acacia* species in *Senegal* was analysed previously by electrophoresis of total cell protein, auxanographic tests, rRNA DNA hybridization, 16S rRNA gene sequencing, DNA base composition and DNA DNA hybridization [See Int. J. Syst. Bacteriol. (1994) 44, 715-733]. Strains from *Acacia* were shown to belong to two groups, *SinoRhizobium terangae*, and a so called gel electrophoretic cluster U, which also included some reference strains from Brazil. Further taxonomic characterization of this group using the same techniques plus repetitive extragenic palindromic PCR and nodulation tests is presented in this paper. Reference strains from Sudan and a number of new rhizobia isolated from nodules of *Acacia senegal*, *Acacia tortilis* subsp. *raddiana* and *Prosopis juliflora* in *Senegal* were included. As a result of this polyphasic approach, the creation of a new species, *MesoRhizobium plurifarium*, is proposed for a genotypically and phenotypically distinct group corresponding to the former cluster U and containing strains isolated from *Acacia, Leucaena, Prosopis* and *Chamaecrista* in West Africa (Senegal), East Africa (Sudan) and South America (Brazil). The type strain of *MesoRhizobium plurifarium* ORS 1032 has been deposited in the LMG collection as LMG 11892.

467 LAMERS, J.P.A.; MICHELS, K.; VANDENBELDT, R.J. **Trees and windbreaks in the Sahel: establishment, growth, nutritive, and calorific values.** ***Agroforestry Systems*** (1994) **26** (3) 171-184

Tree and windbreak species considered for the Southern Sahelian Zone (SSZ) of West Africa have to be evaluated following multiple criteria such as fast establishment, shelter efficiency, production of feed for livestock, and fuelwood. An on station experiment was conducted on a sandy soil at ICRISAT's experimental station at Sadore, SW Niger between 1988 and 1993 to assess the establishment, growth, nutritive, and calorific values of 7 species considered for windbreaks: *Andropogon gayanus* (a perennial grass), *Bauhinia rufescens, Acacia holosericea, Acacia nilotica* var. *adansonii, Acacia senegal, Faidherbia albida*, and *Azadirachta indica*. Mortality and stem diameter (10 cm above soil surface) were monitored twice a year. From 20 months after planting (MAP) onwards, species were trimmed annually to 2 m height and to 1 m sidewards of the main stem. Fresh and dry weight of leaves, twigs, wood, and fruits were recorded. Leaves were analysed for crude (CP) and metabolizable energy (ME) content. Wood was analysed for its gross calorific value and its ash content. At 56 MAP, all species had less than 5% mortality, except for *Acacia holosericea*, which had a mortality rate of 15.9%. *Azadirachta indica, Acacia holosericea* and *A. senegal* showed the highest stem diameter among the woody species with 12.2, 11.8 and 9.3cm, respectively, at 56 MAP. *A. senegal* had the highest dry matter production with 22.3 t/ha at 56 MAP, followed by *Azadirachta indica* (12.0 t/ha), *Acacia holosericea* (11.7 t/ha) and *B. rufescens* (11.2 t/h). Only *A. senegal* (6.4 t/h) and *Azadirachta indica* (5.1 t/ha) had a significant wood production. Leaves of *Acacia senegal* and *Azadirachta indica* had the highest CP contents (258 and 214 g/kg, respectively). The leaves of all species except *Andropogon gayanus* had a higher CP:ME ratio than natural pasture in the region. The calorific values of fuelwood did not differ significantly among species, and for *A. senegal* was 18.9 MJ/kg of dry matter. Concluded that for the establishment, growth and fodder value of windbreaks, *A. senegal* and *B. rufescens* showed the greatest potential. Taking into account the total calorific values, *A. senegal* and *A. indica* scored best, and including the Fuelwood value index *A. indica* showed the best

firewood potential. Further research should be directed towards cost benefit analyses, land tenure, and property rights, in combination with surveys on local knowledge of rural people.

468 LAMPREY, H.F.; HERLOCKER, D.J.; FIELD, C.R. **Report on the state of knowledge on browse in East Africa in 1980.** In *Browse in Africa, the current state of knowledge (edited by Houérou, H.N. le.).* Ethiopia; ILCA (1980) 33-54

Area covered in report comprises Kenya, Tanzania, and Uganda; plant species included are those of the sub humid, semi-arid and arid wooded savanna ecosystems. Sources of information fall mainly into two categories: 1. Information of woody plants which are browsed by wild and domestic herbivores (or are otherwise important to browsers) on plant communities in which they occur; 2. Information on the diets of browsing animals. 150 browse species are included in the report including 2 observations relating to *Acacia senegal*: 1. parts browsed- young twigs and leaves; animal- impala; place- Mara; date- October 1962; Composition of parts browsed in %DM: ash- 6.79, crude protein- 20.26, ether extract- 2.56, crude fibre- 27.72, nitrogen free extract- 42.67, silica- 0.19, silica free ash- 6.60, Ca- 1.40, P- 0.165, Na- 0.025, K- 0.96. 2. parts browsed- young twigs and leaves; animal- giraffe; place- Mara; date- November 1962; Composition of parts browsed in %DM: ash- 8.26, crude protein- 20.51, ether extract- 2.20, crude fibre- 27.74, nitrogen free extract- 41.29, silica- 0.65, silica free ash- 7.61, Ca- 1.37, P- 0.238, Na- 0.37, K- 1.36.

469 LANGE, W. **Exudates from trees: minor forest products (1).** [Exsudate von baumen erzeugnisse der forstlichen nebennutzung (1).] *Holz Zentralblatt* (1998) 124 (22) 334

An account is given of the harvesting, chemical composition and uses of gums from *Acacia senegal* (gum arabic), *Acacia seyal* (gum talha), *Astragalus* spp. (tragacanth), *Sterculia* spp. (karaya gum), *Cochlospermum gossypium* (kutira gum), and *Anogeissus latifolia* (ghatti gum).

470 LARSEN, E. **Germination response of *Acacia* seeds to boiling.** *Aust. For. Res.* (1964) **1** (1) 51-3

Tabulates the results of tests on 43 *Acacia* spp. in which the seeds were placed in ca. 10 times their volume of boiling water, which was then immediately left to cool. With the possible exception of 3 species (*A. cambagei*, *A. senegal* and *A. lineata*) the method is safe and results in greatly improved germination percentages.

471 LARSON, B.A.; BROMLEY, D.W. **Property rights, externalities, and resource degradation: Locating the tragedy.** *Journal of Development Economics* (1990) **33** 235-262

472 LARSON, B.A.; BROMLEY, D.W. **Natural resource prices, export policies, and deforestation: the case of Sudan.** *World Development Oxford* (1991) **19** (10) 1289-1297

Environmental destruction is often the result of price policies for primary commodities that determine how individuals will use and abuse natural resources. This paper analyses how domestic policies under colonial and independent governments in Sudan contributed to *Acacia senegal* deforestation and the demise of the international gum arabic trade. They give an historical perspective on the gum arabic trade, and then describe the effects of Sahel drought of the early 1970's and the flawed pricing policies of the Gum Arabic Company that brought fundamental changes to the domestic and international gum market. With the declining export market for gum arabic poor farmers had to increase agricultural production, by reducing fallow periods and clearing more trees for planting and selling for fuelwood.

473 LARSSON, H. **Linear regressions for canopy cover estimation in *Acacia* woodlands using Landsat TM, MSS and SPOT HRV XS data.** *International Journal of Remote Sensing* (1993) **14** (11) 2129-2136

The aim of the study was to establish remote sensing models for the estimation of canopy cover in *Acacia* woodlands. The models were established using Landsat TM and MSS data and SPOT HRV XS data and based on field data from the Rawashda forest reserve (dominated by *Acacia seyal, A. senegal* and *A. mellifera*), eastern Sudan. Models were derived using the Reduced Major Axis (RMA) method. Correlation coefficients between NDVI and canopy cover are for Landsat TM 0.552, for Landsat MSS 0.698 and for SPOT HRV XS 0.718. Confidence intervals of predicted canopy cover are also presented.

474 LAURIE, A.P. **Materials of the painter's craft in Europe and Egypt from earliest times to the end of the 17th Century.** London UK; Foulis TN (1910) 1-444

475 LAWTON, R.M. **Some indigenous economic plants of the sultanate of Oman.** In *Plants for arid lands (edited by Wickens, G.E.; Goodin, J.R.; Field, D.V.).* London, UK; George Allen & Unwin (1985) 267-275

A. senegal forms one of the main browse species (particularly for goats and camels) in the rangelands of Oman. Details two analyses of the plant from Oman, the latter figures being old leaves; Ash% 15.3 and 11.6; Crude protein % 21.2 and 17.43; Phosphorus % 0.11 and 0.12 and Potassium % 0.9 and 0.82.

476 LELY, H.V. **The useful trees of Northern Nigeria.** London, UK; Crown Agents (1925) 1-128

An illustrated book of 120 tree species from the savannas of Northern Nigeria, with their descriptions. *Acacia senegal* or Dakwora (Hausa) is a small tree 15-20 ft high, found especially in Sokoto where it grows in dense thickets. Its wood is white but because of its small dimensions it is not utilised, but the bark of the roots are twisted into strong ropes. It flowers from May to July (observations between 9-14 degrees latitude North).

477 LENNE, J.M. **Diseases of multipurpose woody legumes in the tropics: a review**. *Nitrogen Fixing Tree Research Reports* (1992)**10**, 13-29

Reviews the common, serious, and potentially important diseases of eight woody legume genera including *Acacia*. These included leaf spots, rusts, mildews, stem cankers and rots, shoot and twig blights, wilts, and root, collar and heart rots. While some of the references include diseases on *A. senegal,* it is not referred to specifically in the text. The review is complemented by brief sections on control strategies.

478 LINDLEY, D.K.; DEANS, J.D. ***Acacia* tree fallows in Senegal**. Annual report (1991) to the Overseas Development Administration. Institute of Terrestrial Ecology, NERC, UK (1992) 1-20

The objectives of the project were to determine the rate of improvement in soil fertility under *Acacia senegal* tree fallow system, and identify the factors limiting the rate of increase under these trees, and determine the rate of soil degradation under a cereal cropping system. Five plantation sites with tree spacing of 7-10 m, ranging from 3-17 years old were identified as suitable for estimating tree growth and soil amelioration. The best predictor of above-ground biomass was a quadratic regression fitted to stem diameter. The average above-ground biomass of a 17 year old tree was 100 kg (about 75% of the total biomass), with an initial estimate of fine root biomass of 3.9 kg/tree. Chemical analysis (N, P and K) showed that a 17 year old tree contained about 1 kg of nitrogen, of which about 400 g were contained in woody tissues greater than 2 cm in diameter. In the same aged tree, total levels of potassium were also around 400 g and phosphorus 40 g. Preliminary analyses of the soils found that nutrients were greatest adjacent to the tree stems, and then declined systematically the further away from the stems one goes. These red brown sandy soils of northern Senegal had very low nitrogen levels (0.0098%) and the soil organic matter content was extremely low (0.94%). [see Lindley *et al.* (1997) & Deans *et al.* (1999)]

479 LINDLEY, D.K.; DIAGNE, O.; DEANS, J.D.; DIONE, M. **Nutrient budgets in a chronosequence of *Acacia senegal* plantations in a Sahelian savannah**. Special issue on agroforestry modeling: selected papers from a workshop held in Edinburgh, 28-30 May 1997 *Agroforestry Forum* (1997) **8** (2) 27-30

Nutrient budgets in a chronosequence of 3 to 18 year old *Acacia senegal* plantations were assessed in northern Senegal. Total amounts of N, P, and K in tissues were determined from regression relationships based on stem basal area. Soil organic matter (SOM, assessed as loss on ignition) and plant nutrients (N, P and K) in the soil were determined to 1 m depth beneath tree canopies and in the open. These data enabled a series of 'field usable' polynomial equations based on plantation age and tree spacing to be developed, thus enabling prediction of site nutrient capital at different ages of 'tree fallow'. By age 18, each tree contained about 0.95, 0.04 and 0.42 kg of N, P and K respectively and N in the top 10 cm of soil had increased by about 360 kg/ha with an inter tree spacing of 7 m. Estimated loss of N caused by complete harvesting of the yearly production of leaves and fruits was 20% of the total tree N, while clear felling and harvesting of all wood >2 cm in diameter at the same age would remove only 30% of N. Regular harvesting of fodder, therefore, poses a greater risk to site nutrient budgets than timber harvesting at the end of the rotation, especially since in practice, the thorny nature of the branches means that these also are removed with leaves and fruits for fodder, thus increasing nutrient losses to the same level as in final timber harvesting.

480 LITTLE, E.L. ***Acacia senegal***. In *Common fuelwood crops*. Morgantown, West Virginia, USA; Comm. Tech. Associates (1983) 28-31

Compilation of data from various sources, gives a description, common names, distribution climate and soils and other uses of *A. senegal*. It is a commonly used fuelwood in the semi arid regions, and planted as well as for gum production for sand dune fixation and wind-erosion control. The wood is whitish, hard and heavy, and is locally the preferred firewood and also used in charcoal production.

481 LOCK, J.M. **Legumes of Africa. A check-list**. *Royal Botanic Gardens, Kew* (1989) 1-619

A check-list of all legume species prepared from collections held in the Kew Herbarium and material cited in floras or monographs, summarized by species including nomenclature, characteristics, economic importance to man, habitat and geographical distribution in Africa. *A. senegal* is listed from 25 countries and island states in Africa out of a possible 51, and also occurs in Asia. The varieties in the species are not listed.

482 LOCK, J.M.; SIMPSON, K. ***Legumes of West Asia. A check-list.*** *Royal Botanic Gardens, Kew* (1991) 1-263

A check-list of all legume species prepared from collections held in the Kew Herbarium and material cited in floras or monographs, summarized by species including nomenclature, characteristics, economic importance

to man, habitat and geographical distribution in Africa. *A. senegal* is listed from Oman in west Asia and India and Pakistan in south Asia as well as in Africa. The varieties in the species are not listed, but they likely belong to var. *senegal*. A wide range of uses are noted, mainly derived from Miller & Morris (1988).

483 LOUVET, A. **Etude sur la production de la gomme arabique pendant plusiers voyages dans les forêts gommiers**. *Journal de Pharmacopee et de Chimie, Paris* (1876) **XXIV** 447-476

484 LUCA, Y. de Cataloque **des metazoaires parasites et predateurs de bruchides (Coleoptera).** *Journal of Stored Products Research* (1965) **1** 51-98

485 LUCAS, A. **Ancient Egyptian materials and industries**. London, UK; E. Arnold Publishers, (1962) 4th edition 1-523

486 LUNA, R.K. ***Acacia senegal*(L.) Willd**. In *Plantation trees*. Dehra Dun, India; International Book Distributors (1996) 61-64

Details the general silvicultural characteristics, site factors and uses of the tree with data mostly from India. The tree is indigenous to the arid zone of India, south-east Punjab, parts of Gujarat (Saurashtra, Kutch) mainly on the dry and rocky hills of Aravallis (hill slopes ascending to 700m) and the sandy tracts of the west of Aravallis. Also occurs on the plains south of Punjab and western Rajasthan. Annual rainfall is erratic and can be as low as 600 mm, with 8-11 dry months. The seedlings are frost tender, but the tree frost hardy sometimes withstanding temperature falls a few degrees below zero. It coppices well, up to 30-40 years of age, with a stool percentage as high as 92. However the rate of growth (above ground) is slow. The plants can be sown by planting out one year old nursery stock or by direct sowing although the latter is susceptible to die back in the drier regions such as Rajasthan. Nursery raised seedlings are often planted in 30 cm^3 pits which are half filled with soil and half made to heap on the lower side of the slope. Height growth is slow, on average 40-45 cm/yr. White ants are said to attack seedlings. Apart from being used as a fodder tree, the fuelwood is excellent (3200 kcal/kg). Gum arabic has not been tapped on a commercial scale in India, although experiments at Jodhpur reveal that higher yields are obtained from tree grown on the sandy plains rather than the rocky hills. The best period for tapping in India is May-June (the hot season). In India the species is used for reclamation of sand dune sites.

487 LUTZ, L. [**The progressive degeneration of the anatomical elements of wood by the action of lignicolous fungi. *Acacia verek* Guill. et Perr. and *Polyporus hispidus*.**] Sur la dégénerescence progressive des éléments anatomiques du bois par les champignons lignicoles. L'*Acacia verek* Guill. et Perr. et le polypore hispide. *C.R.Acad. Agric. Fr.* (1946) No.32 369-370

Wood specimens from *Acacia verek* (*A. senegal*) were soaked in water and inoculated with *Polyporus hispidus* in order to compare the gum resulting from the degradation of the wood with the natural soluble gum. The process of disorganization was (with slight differences) similar to that of Beech exposed to *Daidalea quercina*. The resulting gum was insoluble in both cases. The author concludes that the solubility of gums is conditioned, not by the nature of the tree itself, but by the parasitic fungi.

488 MACDICKEN, K.; BREWBAKER, J.L. **Descriptive summaries of economically important nitrogen fixing trees.** *Nitrogen Fixing Tree Research Reports* (1984) **2** 46-54

Descriptive information from NFTA database for selected species. *Acacia senegal* (L.) Willd. has a poor tree form. Produces fuelwood, forage (pods & leaves), gum and has a wood volume of 1-5 m^3/ha/yr. It can survive in areas with an annual rainfall as low as 200 mm with an extended dry season.

489 MACDONALD, K.R. **The gum arabic industry in Bornu Province**. *Farm and Forest* (1941) 13-16

While *Acacia senegal*, which produces the highest quality gum arabic, occurs throughout the Dry Thorn Forests of Northern Nigeria, it is only in Bornu Province between parallels 12°N and 13°N, that concentrations sufficient for gum exploitation are available. Since 1928 steps have been taken to promote trade in this product in Nigeria and while progress was slow at first the industry now appears to be established. Annual yields of over 2000 tons of gum were estimated for the province; however in the last six years, 1935-41, average yields of only 550 tons/annum have been exported from the province, and about 70% of this was brought by Nigerian traders across the border in Niger. In southern Bornu, gum purchased is a mixture from three common *Acacia* species; *A. seyal, A. camplyacantha [A. polyacantha spp. camplyacantha]* and *A. senegal*. This is sold at a much lower price. Better cleaning, marketing and tapping as used in Sudan is recommended to improve this new fledgling industry.

490 MACDONALD, L.H. **Agroforestry in the African humid tropics**. *Proceedings of a workshop held in Ibadan, Nigeria, 27 April - 1 May 1981*. (1982) 1-163

Provides introductory material on the principles of agroforestry, traditional agroforestry systems and prospects for their development. Discusses the taungya system from biological and production viewpoints and the

current agroforestry activities in the African humid tropics. Outlines the future development of agroforestry emphasizing the role of trees in the production and consumption systems and presents reports of the working groups.

491 MADSEN, J. [**Complex problems in the Sahel.**] Komplekse problemer i Sahel. *Vaekst* (1986) **107** (2) 22-27

The article is based on work undertaken in Senegal during 1984/85. The area studied used to be able to feed its population of nomads and farmers, who benefited from one another, but is now a barren desert because of intensive groundnut cultivation which has impoverished the soil, overgrazing, and young trees being gnawed by animals or cut down. Sweden has financed two planting projects that were developed through area chiefs. Container-grown *Acacia senegal* and *Prosopis juliflora* were planted, hedged round with *Acacia albida*. Single trees were also planted to provide a good microclimate. Now advice will be needed to preserve the trees.

492 MALCOLM, D.W. **Report on Gum and Gum arabic.** Tanganyika Territory (Tanzania); Government Printer, Dar-es-Salaam. (1936) 1-59

A study assessing the possibilities of large-scale production and marketing of gum arabic in Tanzania, drawing on detailed data from Sudan and specifically the Kordofan gum marketing system. Many gum yielding species occur in both countries including *A. senegal.*

493 MANNICHE, L. **An ancient Egyptian herbal.** London, UK; British Museum Publications Ltd. (1989) 1-176

494 MANOJ MEHTA; SEN, D.N.; MEHTA, M. **Water inhibition and hard seed coated ness of some arid tree species.** *Annals of Arid Zone* (1994) **33** (1) 89-90

Germination studies on seeds of *Acacia senegal*, *Prosopis cineraria* and *Mimosa hamata.*

495 MARSHALL, R.C. **Forestry in the Northern territories of the Gold Coast.** Accra Ghana; Government Printing Department (1945) 1-13

The Northern Territories of the Gold Coast lie roughly between 8 °N and 11 °N latitude and are thus wholly within the tropics. The total area is 41,063 sq. miles, with a population of over a million. The vegetation is savanna forest of varying density and composition, with close fringing forest along many of the streams and rivers. The protectorate is essentially a forest-and-agricultural community with practically no export money crop. Trypanosomiasis is endemic and the effect of vegetation on the incidence of tsetse flies has to be borne in mind. The function of forestry falls into two main divisions: indirect utility in the conservation of water supplies, prevention of erosion, shelterbelts, etc., and direct utility in the supply of fuelwood, poles, and possibly the production of limited amounts of sawn timber which now has to be imported from Ashanti. The headwaters of rivers should be maintained under forest. In some cases reafforestation is indicated, but many such areas are now under cultivation. Evergreen shelterbelts oriented in a general N.W.-S.E. direction are needed to reduce the effects of dry winds. They should, wherever possible, be supplemented by rows of trees round farms. Apart from firewood, the main timber requirement is for round building poles used in the construction (particularly of the roofs) of compound houses. A surprising number of poles are used in the construction of flat roofs. To provide for the above, an extensive system of forest reserves, supplemented by plantations and farm woodlots, is required. Reserves should be selected to protect the headwaters of all major streams. In Navrongo District the sources of 5 major streams were examined. In each case the slopes above the stream had been denuded of practically all vegetation by farming and the grazing of stock. To aid in selecting reserves, aerial surveys and mapping would be most valuable. After the laying out of headwaters reserves has been completed, attention should be directed to linking them up with shelterbelt reserves. It is anticipated that great difficulty will be encountered in the densely populated, heavily farmed areas, i.e. just where shelterbelts would be most desirable. Silvicultural research on both native and exotic species is essential before large-scale plantation work is embarked on. The silvicultural characters of the following native species at least should be investigated: *Acacia senegal*, *A. albida*, *A. arabica*, *A. polyacantha* ssp. *campylacantha*, *A. macrothyrsa*, *A. seyal*, *A. mellifera*, *A. ataxacantha*, *A. rehmanniana*, *A. sieberiana*, *Anogeissus schimperi*, *Afzelia africana*, *Burkea africana*, *Bombax buonopozense*, *Butyrospermum parkii*, *Detarium senegalense*, *Daniellia oliveri*, *Parkia filicoidea*, *Pseudocedrela kotschyi*, *Pterocarpus erinaceus*, *Khaya senegalensis*, *Isoberlinia doka*, and *Tamarindus indica*; and the following exotic species: *Cassia siamea*, *Dalbergia sissoo*, *Azadirachta indica*, *Tectona grandis* and *Eucalyptus* spp. Notes on distribution, habit and utilization of all the above species are given in an appendix. Recommendations are made for a proposed forestry staff to carry out the above proposals.

496 MASAMBA, C.; MAGHEMBE, J.A. **Presowing seed treatments on four African *Acacia* species: appropriate technology for use in forestry for rural development.** Special Issue: Agroforestry research in the African miombo ecozone. Proceedings of a regional conference on agroforestry research in the African miombo ecozone held in Lilongwe, Malawi, 16-22 June 1991. *Forest Ecology and Management* (1994) **64** (23) 105-109

Studies were undertaken on the seeds of 4 *Acacia* species (*Acacia albida* [*Faidherbia albida*], *Acacia senegal*, *Acacia tortilis* and *Acacia nilotica*) considered to be important for dry land afforestation. Seed dormancy caused by an impermeable seed coat is the main problem to overcome if planting programmes for these species are to be successful. Twelve provenances (5 of *F. albida*, 3 of *A. senegal*, 3 of *A. tortilis* and 1 of *A. nilotica)* of the 4 species were used in this study that involved presowing treatments in cold water, hot water, sulfuric acid and a hot wire scarifier. Seed coat dormancy was observed in three of the four species but no dormancy was evident in the three provenances of *A. senegal*. The duration of water treatments used did not appreciably increase germination, but both the sulfuric acid and the hot wire treatments increased germination to 80% and above in all provenances. The hot-wire treatment showed clear evidence of an optimum treatment duration of between 5 and 10 s for nearly all the provenances. It is concluded that hot wire presowing treatment is worth considering as an alternative to sulfuric acid because of safety problems associated with handling the acid. The hot wire as a prototype requires some modifications to enable more seeds to be pretreated at a time [see also Stubsgaard 1986].

497 MASSON, J.L. **The Management and Utilization of Sudan Savanna of Northern Nigeria with a special reference to Bornue Province.** *Special subject. Department of Forestry, University of Oxford.* (1953) 1-17

Describes the vegetation zones that occur in this northern province of Nigeria, and *A. senegal* woodland is given a separate vegetation type. *A. senegal* also occurs in the *A. tortilis/Commiphora africana* scrub woodland in the Sahel thorn forest. Gives a section on gum arabic in the minor forest products section, and describes the tapping methods used on *A. senegal*. Care is needed not to damage the cambial layer when the native axe is pushed under the bark, then a sharp twist of the axe will break a bark strip which is pulled off by hand. Gum is collected 5-8 weeks after tapping. Based on local knowledge, the best time to tap is when the leaves fall like rain when the tree is hit with an axe, which is said to be a few weeks after the end of the rains.

498 MASUTHA, T.H.; MUOFHE, M.L.; DAKORA, F.D. **Evaluation of N2 fixation and agroforestry potential in selected tree legumes for sustainable use in South Africa**. International Symposium. Sustainable agriculture for the tropics: the role of biological nitrogen fixation, Angra dos Reis, Rio de Janeiro, Brazil, 26 November -1 December 1995. *Soil Biology and Biochemistry* (1997) **29** (5-6) 993-998

Seven tree legumes with agroforestry potential were tested for their capacity to nodulate with indigenous rhizobia or bradyrhizobia in soils collected from different ecological zones in South Africa. The findings show that all the tested species, except *Acacia senegal*, could effectively nodulate with root nodule bacteria native to Venda and Klipspruit soils. Since *Acacia seyal, Acacia galpinii. Albizia lebbeck* and *Acacia auriculiformis* exhibited, in that order, a greater level of growth and symbiotic performance, they manifest themselves as suitable species for agroforestry programs in Venda and Klipspruit soils. The other three species tested were *Acacia erioloba, Acacia senegal* and *Dalbergia sissoo.* Another indigenous species, *Acacia ataxacantha*, was assessed to be a non nodulating legume even when inoculated with a promiscuous strain of *Rhizobium* NGR234.

499 MATEY, J. **Les insects xylophages des *Acacia* dans la regions saheriennes**. *Imprensa Portuguesa*, Porto (1975) 1-714

Comprehensive account of the Coleoptera (and of their associated insects) boring into 5 species of *Acacia*; *A. senegal, A. raddiana [A. tortilis ssp. raddiana], A. flava [A. ehrenbergiana], A. scorpiodes [A. nilotica* ssp. *nilotica]* and *A. seyal.*

500 MAURITANIAN FOREST SERVICE. **[Annual report of the forest service of Mauritania for 1949.]** Service forestier du territoire de la Mauritanie: Rapport pour l'annee 1949. *Bois et Forêts des Tropiques* (1950) No.15 295-296

Plots of *Acacia senegal* were tapped at different dates to determine the effect of season of tapping on yield of gum. Differences were not significant, but the yield appears to decrease slightly as the tapping is done later in the season. In general the amount of gum collected by tapping is negligible (ca. 1.5% of total) compared with that obtained from natural exudation. The total quantity of gum collected increases with frequency of collection; weekly collections in one stand gave a total yield 65% in excess of that from a similar stand collected monthly. Annual rainfall appears to have a marked influence on the yield of gum in the following year; rainfall was 314 mm in 1947 and 88.6 mm in 1948, and the gum yield in 1949 was only half that of 1948. Maximum yield is obtained from trees of 56-75 cm diameter.

501 MAYDELL, H.J. Von. **Agroforestry to combat desertification - a case study of the Sahel**. Hamburg; Institute for World Forestry, Federal Research Centre for Forestry and Forestry Products (1974) 1-16

The forestry situation in the Sahel and its contribution to combat desertification is discussed. Desertification in the Sahel, the demands of the local rural people and the different ways to avoid the widening gap between demand and supply are reviewed. Selected agroforestry projects in the Sahel and its neighbouring region of Sudan savanna are described. Emphasis is given to the importance of *Acacia albida* and *Acacia senegal* in some agroforestry practices.

502 MAYDELL, H.J. Von. **Tree and shrub species for agroforestry systems in the Sahelian zone of Africa**. *Plant Research and Development* (1978) **7** 44-49

An outline is given of the criteria that should be applied in selecting species for the area, emphasizing; the local demands of the community, the establishment of fuel, pasture or shelter; adaptability to site conditions; and ecological constraints. There is a need for genetic improvement of local species, and for more information on their site requirements. Brief accounts are given of the characteristics and potential of some promising local and exotic species, including *Acacia albida*, *A. senegal*, *A. seyal*, *A. nilotica*, *A. tortilis*, *Eucalyptus camaldulensis*, *Prosopis juliflora*, *Azadirachta indica* and *Pinus eldarica*.

503 MAYDELL, H.J. Von. [**Forestry in Senegal - problems and development programmes.**] Forstwirtschaft in *Senegal* - Probleme und Entwicklungsaufgaben. *Forstarchiv* (1980) **51** (7) 129-135

A review of general topics (forest vegetation zones, condition of forests, forestry goals, government forestry administration, forestry training, and afforestation programmes) and of a joint W. German-*Senegal*ese project, 'Afforestation of deep well sites in N. Senegal (Ferlo region)', designed to develop a stable agro-sylvopastoral system under the pressures of natural and man-induced desertification. The project includes afforestation with *Acacia senegal* for production of gum arabic.

504 MAYDELL, H.J. Von. **Forestry in *Senegal* - problems and prospects for development**. *Plant Res. Dev.* (1981) **14** 7-20

Problems and prospects for development of forestry in Senegal are discussed. The vegetation is described and the problems resulting from drought and overuse are discussed. Analyses the challenges of forestry in solving some of these problems and describes the German-Senegalese project on afforestation, which aims at developing agrosilvopastoral, creating permanent gum arabic, improvement of regional bush fires protection and improve forestry services. The tasks for forestry research are also highlighted.

505 MAYDELL, H.J. Von. **Trees and shrubs of the Sahel-their characteristics and uses**. *Schriftenreihe der* G.T.Z., Eschborn (1986) No.196 1-525

A revised updated English edition of *Schriftenreihe der G.T.Z.* No. 147, 'Arbres et arbustes du Sahel', published in 1983. Describes 114 species of trees and shrubs, both exotic and native, which grow in the Sahel region of Africa, with notes on their characteristics, silviculture, distribution and uses. This handbook has useful photographs of habit, seeds, fruits and flowers. Appendices list vernacular names in 9 different West African languages, French names, site requirements for each species, scientific names and synonyms. *Acacia senegal* var. *senegal* is a typical tree from the Sahel from Senegal to the Red sea coast, limited between 11 and 16° latitudes north in this region, in areas with an annual rainfall of 100-800mm, mainly between 300-400mm, with an 8-11 month dry period. It prefers sandy soils, such as fossil dunes, but also grows on loamy soils, on sandstone and even on skeletal soils (lithosols). Generally well drained soils, it also occurs on heavy clay soils in eastern Sudan. Natural regeneration is rarely observed in old stands but occurs on open ground. Gives details of gum yields from trees that can vary considerably from year to year and tree to tree. On average 250g/tree in Kordofan is estimated which will drop to 100 g. in western part of the Sahel. Gives details of the excellent fodder value of the tree, and the importance in soil stabilisation and soil improver. Recommended for promoting in agroforestry systems, as it has proved in Sudan and northern Senegal.

506 MAYUS, M. **Millet growth in windbreak shielded fields in the Sahel: experiment and model**. *Tropical Resource Management Papers* (1998) No.21 1-259 [also published as Thesis, Wageningen Agricultural University]

In the Sahel, wind erosion contributes significantly to impoverishment of sandy soils and land degradation. A possible control measure is the implementation of windbreaks that may additionally ameliorate crop microclimate. However, windbreaks also compete with crops for limited resources (water, nutrient and light). Assessment of competitive effects is complicated, due to difficulties in determining below ground competition and interference with other tree crop interactions. This thesis is in 2 parts and presents both experimental data and a model, which both address these competitive effects. The field experiments, at the ICRISAT Sahelian Center at Sadore, SW Niger, analysed the effects of windbreaks of 5 native tree species (*Bauhinia rufescens*, *Faidherbia albida*, *Azadirachta indica*, *Acacia nilotica* subsp. *adstringens*, *Acacia senegal*), one exotic tree species (*Acacia holosericea*) and a grass (*Andropogon gayanus*) on growth of pearl millet (*Pennisetum glaucum*) sown to the west of each windbreak. The tree windbreaks were in a staggered 2-row configuration at 3X1.5 m spacing established in 1988, and were pruned to 2 m tall and 1 m sideways before each rainy season. Windbreaks were 30 m apart. Detailed microclimatic and soil measurements were confined to the *Bauhinia* windbreak. The model was developed to investigate tree crop interactions in relation to spatial and temporal heterogeneity. Both the field data and the model analysis showed that yields were reduced in the vicinity of the windbreak, due to competitive use of resources. Water competition between trees and crops is likely to occur early in the growing season, when available soil water is restricted to the upper horizons and transpiration of the windbreak is higher than that of the crop. Neither horizontal flow nor reduced evaporation could

compensate for tree water use. Under moderate water stress, light reduction was of similar or major importance. The field experiment showed a slight increase in overall yields of the windbreak protected crop, probably due to protection against wind erosion, improved water availability and small microclimate modifications in the center of the fields.

507 MBAYE, I. **Situation et organisation du commerce international de la Gomme Arabique**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 247-255

Gives an overview of the international gum arabic market and trade, and the situation in Senegal. Apart from the usual uses of the gum notes that pharmaceutical companies discovered that helps to reduce the doses of insulin for diabetics and cholesterol. In Senegal two types of gum arabic from *A. senegal* are exported; 'du bas du fleuve' and 'ferlo'. The majority is exported to France, and in the best years up to 9,000 tons/annum are exported. Since 1986 all government restrictions to exportation have been removed.

508 MCDOUGAL, F.J. **Studies on gum exudates, with particular reference to gum arabic (*Acacia senegal*) and other *Acacia* species**. *Ph.D. Theses, Edinburgh, U.K.* (1987) [from thesis summary]

Two commercial samples of gum arabic were characterised. The first, 'gum arabic (old)', corresponded to analytical parameters for *Acacia senegal* gum. The other, 'gum arabic (new)', was suspected to contain 10% *of Acacia seyal* gum. A series of studies on laboratory rats were carried out involving gum arabic (new). At a level of 15% of the diet, gum arabic was found to cause caecal enlargement within 72 hours, mainly due to an increase in the % moisture content of the caecum. Caecal enlargement was reversible, again within 72 hours. Heat-treated gum arabic caused a similar response. Treatment of rats, receiving 15% gum arabic, with Metronidazole had no discernible effect. An antibiotic cocktail of Bacitracin, Neomycin Sulphate and Streptomycin greatly affected the digestion of gum arabic. Caecal enlargement was greatly increased. This increase appeared due to remnants of gum arabic in the caecal contents. Some bacterial populations in the caecum were eliminated, volatile fatty acid (V.F.A.) concentrations also diminished, indicating that fermentation of gum arabic to V.F.A.'s in the caecum had been prevented. Solutions of gum arabic (new) were subjected to autohydrolysis, mild acidic hydrolysis and ultraviolet irradiation. In each case, three products were isolated: - an insoluble, highly proteinaceous precipitate; a degraded proteinaceous gum polysaccharide; and a diffusate. The results confirm the lability of some of the arabinose, rhamnose and galactose, and establish that some amino acids in gum arabic are more labile than others. Data are presented for the amino acid and sugar compositions of gum arabic (old) and its four Smith-degradation products (0.34, 0.56, 0.87, 0.90 and 0.85%N respectively). The proteinaceous enrichment of the branched, galactan core largely involves serine, threonine and proline; this correlates well with previous degradative studies. Serine, threonine and proline are commonly encountered in sugar-amino acid linkages. Gums must now be regarded as proteoglycans and the amino acids must be taken into account. Sixteen gum exudates of the Series Phyllodineae, Gummiferae and Vulgares were analysed for their polysaccharide and amino acid parameters. A further nine, previously characterised *Acacia* gum exudates, were analysed for their amino acid contents. It appears likely that the proteinaceous component is of structural importance even in those species with very low nitrogen contents. Solutions of the gums from *Acacia gerrardii, A. goetzei, A. eriopoda and A. tumida* have been subjected to mild acidic hydrolysis; *A. eriopoda* was also subjected to ultraviolet irradiation. Data are presented for the sugar and amino acid compositions of the three products obtained from each gum. As in gum arabic, some amino acids are more labile than others; high proportions of serine and hydroxyproline in the natural gums become even higher in the degraded gums. Amino acid data are presented for gum exudates from four *Combretum* species and for the degradation products of *Combretum nigricans* and *Prosopis alba* when subjected to mild acidic hydrolysis and ultraviolet irradiation. The results for the *Prosopis* gum (but not for the *Combretum* gum), closely resemble those of the *Acacia* gums. Such gums are not permitted, worldwide, as food additives or ingredients and this data will facilitate their detection for legal purposes.

509 MEILLASSOUX, C. **The development of indigenous trade and markets in Africa**. International African Institute, Oxford University Press (1971) 1-444

510 MENZIES, A.R. **Characterisation of gum arabic using physical, chemical and immunochemical techniques**. *Ph.D. Thesis, Salford, U.K.* (1992) [from thesis summary]

Gum arabic is defined as 'dried exudation obtained from the stems and branches of *Acacia senegal* (L) Willdenow or closely related species.' (FAO, 1990). Currently an array of chemical techniques is required to identify *A. senegal* gum from other gum species within the genus *Acacia.* The aim of this study was to investigate the physicochemical characteristics of the gum and to develop an immunoassay capable of identifying gum from *A. senegal.* The gum arabic samples used were characterised by optical rotation, molecular mass distribution, determination of arabinose, galactose, rhamnose and glucuronic acid contents and estimation of protein content. Antisera directed against *A. senegal* gum were raised by intramuscular injection in rabbits. Purification of the

antisera by affinity chromatography on EAH-Sepharose yielded anti-gum arabic antibodies that were used to develop an enzyme-linked immunosorbent assay (indirect competitive ELISA). The specificity of the ELISA was investigated by assessing the extent of cross reaction with commercial gum arabic samples, authentic *Acacia* gums from different species, other *non-Acacia* gum exudates, degraded samples of *A. senegal* gum and by hapten inhibition experiments. The interaction of fractions of *A. senegal* gum prepared by size exclusion chromatography (FPLC) and by hydrophobic interaction chromatography (HIC) in the ELISA was also determined. FPLC showed that gum arabic was composed of primarily three molecular mass fractions (designated peaks A, B and C). These have been termed an arabinogalactan-protein (AGP), arabinogalactan (AG) and glycoprotein(s) (GP) respectively. It was found that the ELISA could detect *A. senegal* gum and commercial samples of gum arabic. Some cross reaction occurred with gums from other *Acacia* species and in hapten inhibition tests D-glucuronic acid and galacturonic acid interacted. Peaks C (especially) and A were detected in the ELISA. The *Acacia* gums which cross reacted all contained peak C and the HIC fractions rich in peaks A and C interacted strongly in the ELISA. Amino acid analysis of the HIC fractions showed that hydroxyproline, serine, aspartic acid, leucine and threonine were the predominant amino acids.

511 MENZIES, A.R.; OSMAN, M.E.; MALIK, A.A.; BALDWIN, T.C. **A comparison of the physicochemical and immunological properties of the plant gum exudates of *Acacia senegal* (gum arabic) and *Acacia* seyal (gum tahla)**. *Food Additives and Contaminants* (1996) **13** (8) 991-999

The physico-chemical and immunological properties of 3 Sudanese gum arabic samples and four gum tahla samples (2 Sudanese, one West African and one Tanzanian of *Acacia seyal* var. *seyal*) were compared. The optical rotation (ca.-30°) and contents of rhamnose (12-14%), arabinose (24-29%), galactose (36-42%), glucuronic acid (16-17%), nitrogen (0.327-0.365%) and protein (2.16-2.41%) of the gum arabic samples were consistent with the FAO (1990) specification for *Acacia* gum. In contrast, the gum tahla samples had positive [alpha]-D values (45-54°), lower rhamnose (3-4%) and higher arabinose (41-45%) contents, and lower nitrogen (0.147-0.175%), and hence protein (0.97-1.15%), contents. All of the gum arabic samples precipitated with beta glucosyl Yariv reagent and hence contained arabinogalactan protein(s) (AGPs), whereas in all but one of the gum tahla samples AGPs were not detected. The strong interaction of gum tahla with a monoclonal antibody known to recognize arabinose residues present in AGPs and arabinogalactans (AGs) was consistent with the observed higher levels of arabinose present in the gum tahla samples relative to the gum arabic samples. The data presented confirm that there are a number of physicochemical and structural differences between gum arabic and gum tahla, and that a quick and simple immunological technique (immunodot blots) using an antiAGP/AG monoclonal antibody (MAC 207) could be used to screen for the presence of gum tahla in gum arabic consignments [from authors summary].

512 MERTIA, R.S. **Potential of top feed species for increasing primary and secondary productivity on arid sandy rangelands in Thar desert**. *Journal of Tropical Forestry* (1996) **12** (4) 174-182

Grazing land management studies which have been carried out in the Thar desert of India are reviewed, with particular emphasis on the potential of top feed species (fodder trees and shrubs) for increasing the primary and secondary productivity of these arid and sandy rangelands. The discussion is supplemented by tabulated data (from published work) on (1) the extent of the major grassland types in the desert district of Jaisalmer (Rajasthan) and their forage yields, carrying capacity, and livestock (heifer) weight gain in relation to grazing management, and (2) the growth performance of 4 top feed species (*Prosopis cineraria, Ziziphus mauritiana, Colophospermum mopane, Dichrostachys nutans*), and the effects of 4 other top feed species (*Acacia senegal, Acacia tortilis, Prosopis cineraria, Tecomella undulata*) on the populations and forage production of dominant grass species.

513 MHINZI, G.S.; MOSHA, D.M.S. **Some physico-chemical properties of Tanzanian commercial *Acacia* gums (gum arabic)**. *Journal of Food Science and Technology, Mysore* (1995) **32** (6) 510-512

Properties are described for Tanzanian gum arabic, which is derived mainly from *Acacia senegal* and *Acacia seyal*, and compared with commercial gum samples from Sudan. Ash and alkaline earth metal contents were lower, and the average viscosity (at 100g/l) was also half that of the Sudanese sample.

514 MHINZI, G.S.; MOSHA, D.M.S. **Studies on Tanzanian *Acacia* gums, Part 1. Some properties of gum exudates from *Acacia drepanolobium* and *Acacia* seyal var. seyal**. *Discovery and Innovation* (1996) **8** (4) 361-364

Data are presented on some physicochemical properties of gum exudates from *Acacia drepanolobium* and *Acacia seyal* var. *seyal* in natural stands in central Tanzania, and these are compared with the properties of commercial *Acacia* gum samples from Sudan (used in the food and pharmaceutical industries). The properties of *A. seyal* var. *seyal* gum from Tanzania were found to be similar to those of Sudanese 'tahl' grade gum arabic (also from A. *seyal* var. *seyal*). The solubility of *A. drepanolobium* gum was similar to that of Sudanese 'cleaned' grade gum arabic, although its viscosity and alkaline earth metal content were lower.

515 MHINZI, G.S.; MROSSO, H.D.J. **Studies on Tanzanian *Acacia* gums. Part 3. Some properties of gum exudates from the series Vulgares and Gummiferae**. *Food Chemistry* (1995) **54** (3) 261-264

Some properties of gum exudates from Tanzanian *Acacia senegal* var. *leiorhachis*, *A. polyacantha* subsp. *campylacantha* and *A. tortilis* subsp. *spirocarpa* are presented, and compared with Sudanese commercial *Acacia* gums. Some properties of the gum exudates from *A. senegal* var. *leiorhachis* and *A. polyacantha* showed significant differences from Sudanese *Acacia* gums in having a higher proportion of insoluble gel fraction, lower magnesium content and higher viscosity. Furthermore, the methoxyl content of *A. polyacantha* gum is higher than previously reported. The viscosity of *A. tortilis* gum, on the other hand, was similar to that of Sudanese *Acacia* gums at the same concentration. However, the nitrogen content is higher, whereas its alkaline earth metal content is lower.

516 MICHON, P. [**Gum arabic trees in Chad.**] Les Gommiers au Tchad. *Bois et Forêts des Tropiques* (1968) No.117, 27-30

A short account of the geographical distribution of *Acacia senegal* and *A. laeta* in Chad, which occurs in the 250 to 450 mm rainfall zone. In the west, gum trees grow slowly on sandy soils and nomadic shepherds gather naturally secreted gum. In the east, where growth is best, the trees are tapped by settled farmers. Official records have less than 60 tons of gum exported in 1956-7, and over 850 tons in 1965-6. In good years Sudanian merchants also cross the border to buy the gum. Potential production of gum arabic is estimated at 1500 metric tons/year.

517 MIETTINEN, P.; KARSISTO, M.; MUSA, M.G. **Nodulation of nine nitrogen fixing tree species grown in central Sudan**. *Forest Ecology and Management* (1992) **48** 107-119

Formation of root nodules *on A senegal, A. seyal* var. *seyal* and *Prosopis chilensis* seedlings was studied for a period of 12 weeks at a forest nursery in Um Hager, Tendelti (13°01'N, 32°53'E) and all species rapidly formed root nodules with *Rhizobium* spp., which occurred naturally in the different local soil mixtures of sand, clay and compost. However, nodulation was irregular in the *A. senegal* seedlings, with percentage nodulated varying from 50-83% depending on the soil mixture. A mixture of coarse compost and clay significantly induced more nodules, but this was not reflected in the biomass production after 12 weeks. Suggested that the high salinity of irrigation water which may have inhibited nodule formation and/or nitrogen fixation, and recommended inoculation of an effective salt-tolerant Rhizobium strain for use at Um Hager nursery.

518 MIETTINEN, P.; LUUKKANEN, O.; JOHANSSON, S.; EKLUND, E.; MULATYA, J. **Rhizobium nodulation in *Prosopis juliflora* seedlings at different irrigation levels in eastern Kenya**. *Plant and Soil* (1988) **112** (2) 233-238

In field trials in the Bura region of E. Kenya the pattern of nodulation in 500 *P. juliflora* seedlings grown in Mar.-July 1986 at irrigation levels corresponding to 1500, 1000, 500 or 0 mm annual rainfall was investigated. The mortality of root nodules was 40.4, 69.3, 74.9 and 98.4, respectively. Some trees lacked viable root nodules, especially in non-irrigated plots. Eight Rhizobium strains isolated from the sample trees were capable of nodulating indigenous *Acacia senegal.*

519 MILLER, A.G.; MORRIS, M. ***Acacia senegal* (L.) Willd. Plants of Dhofar, the southern region of Oman. Traditional, Economic and Medicinal Uses**. Oman; Office of the Advisor for Conservation of the Environment (1988) 180-181, 320-321

In Arabia, *A. senegal* is found in Dhofar, where it is common on the lower slopes of the escarpment hills, especially by watercourses where it will grow to medium sized trees. Also forms a low stunted shrub in the dry valleys behind Raysut and in the drier areas to the east and west. It is one of the most important trees of Dhofar, with many traditional uses listed by the Dhofari and Jibbali tribes. Apart from their importance in constructing livestock pens, a highly valued fodder, and flexible branches for making fish traps, the medicinal uses from the bark and resin are well recorded. The jibbali tribe have a wealth of names for each of the phenological stages of the plant, indicating their importance in livestock and bee forage. Its pods are traditionally valued for feeding to sickly, delicate or parturient livestock, increasing milk yields in the latter. Also notes its human food value in other parts of Africa, and suggests that as little as 6 ounces (170 g) is sufficient to support an adult from 24 hours [see Grieve 1931].

520 MILLER, J.T.; GRIMES, J.W.; MURPHY, D.J.; BAYER, R.J.; LADIGES, P.Y. **A phylogenetic analysis of the Acacieae and Ingeae (Mimosoideae:Fabaceae) based on trnK, matK, psbA-trnH, and trnL/trnF Sequence Data.** *Systematic Botany* (2003) **28** (3) 558-566

The results support other recent molecular studies in showing that neither the tribe Ingeae nor the tribe Acacieae is monophyletic. Some subgenera of Acacia, specifically subgenera Acacia and Phyllodineae are monophyletic, however subgenus Aculeiferum and the Ingeae are paraphyletic.

521 MISRA, C.M.; SINGH, S.L. **Suitable tapping technique of gum from *Acacia nilotica* (babool)**. *Van Vigyan* (1985) **23** (1/2) 10-12

A study of the effects of applying acid, alkali and mud solutions to blazes produced by tapping the bark, to stimulate gum exudation in natural stands of *A. nilotica*

in Uttar Pradesh, India. Greater gum exudation was obtained with the alkali (NaOH) solutions, and in a second experiment the optimal concentration of NaOH was found to be N/20. It is suggested that tapping at breast height should be done in the summer and the gum collected at the end of the rainy season (Sept./Oct.) provided the blaze is protected from rain with a tin shade.

522 M'KHATORAT, M.S.O. **La Gomme en Mauritanie.** *Memoire de Stage a l'Ecole Nationale de la France d'Outre-Mer* (1959)

523 MOCAK, J.; JURASEK, P.; PHILLIPS, G.O.; VARGA, S.; CASADEI, E.; CHIKAMAI, B.N. **The classification of natural gums. X. Chemometric characterization of exudate gums that conform to the revised specification of the gum arabic for food use, and the identification of adulterants.** *Food Hydrocolloids* (1998) **12** (2) 141-150

Fifty-four individual authenticated or commercial exudate gums were collected from the gum arabic producing countries of Africa as part of an FAO project to clarify the factors which influence the specification of gum arabic additive (*Acacia* gum INS 414) used in food. Seven analytical parameters were measured for each gum: specific optical rotation, intrinsic viscosity, content of nitrogen (and hence protein), arabinose, rhamnose, galactose and uronic acids. Using various chemometric methods, all gums could be distinguished as belonging to the *Acacia senegal (A. laeta* included in this group) or *Acacia* seyal (including *A. karroo* and species closely related) groups, and those outside these categories (*A. polyacantha* and gums from other genera). Thus it is possible to identify those gums that conform to the revised (1997) FAO/WHO Joint Expert Committee for Food Additives (JECFA) specification (which in part are based on this study) and those, which would be adulterants in food use. They decided from the analyses that the *A. seyal* group is closely related to *A. senegal* and should be called gum arabic. This was later debated at the JEFCA meeting and referred back to further review!

524 MOHAN, V.; VERMA, N.; NAIR, K.S.S.; SHARMA, J.K.; VARMA, R.V. **Interaction of VA mycorrhizal fungi with rhizosphere and rhizoplane mycoflora of forest tree species in arid and semi arid regions. Impact of diseases and insect pests in tropical forests.** *Proceedings of the IUFRO Symposium, Peechi, India, 23-26 November 1993* (1996) 222-231

Vesicular arbuscular mycorrhiza (VAM) fungi, ubiquitous in nature, are found in most ecosystems including arid and semi arid region. It is well known that the mycorrhizal fungi protect plants against soil and root borne pathogens thereby improving plant growth and vigour. In the present study, a mixed inoculum of VAM fungi was inoculated to selected tree species which are of economic importance in arid and semi arid regions of India, viz. *Acacia nilotica, A. senegal, A. tortilis* and *Prosopis cineraria.* The maximum percentage of VAM infection was in VAM inoculated plants compared with that of uninoculated controls. The rhizosphere and rhizoplane mycoflora of both VAM inoculated and uninoculated plants were assessed for their effect on mycorrhizal fungi. The mycoflora of the rhizosphere and rhizoplane were found to be very much reduced in inoculated plants as compared with uninoculated plants of all the tree species. Most of the pathogenic fungi were suppressed or completely eliminated in VAM inoculated plant roots and rhizosphere soil.

525 MOLLARD, A.; JOSELEAU, J.P. **Extracellular xyloglucans from *Rosa glauca* and *Acacia senegal* suspension cultured cells.** *Food Hydrocolloids* (1991) **5** (1-2) 177-178

526 MOLLARD, A.; JOSELEAU, J.P. ***Acacia senegal* cells cultured in suspension secrete a hydroxyproline deficient arabinogalactan protein.** *Plant Physiology and Biochemistry, Paris* (1994) **32** (5) 703-709

Describes an arabinogalatan protein produced from the culture medium of suspension cultured cells of *Acacia senegal*, which was purified by DEAE cellulose chromatography. The water soluble polysaccharide contained arabinose and galactose as the major constituents plus rhamnose, glucuronic acid and 4 O methyl glucuronic acid, and had a protein content of 11%. Structural determination by methylation analysis and 13C NMR spectroscopy of the fraction and of its carboxyl reduced form showed a highly branched structure. On the other hand, the amino acid composition revealed that this arabinogalactan protein (AGP) belongs to the newly reported class of hydroxyproline poor AGPs. The absence of hydroxyproline and the presence of glucose differs notably from the arabinogalactan protein of true gum arabic, and at present it is not possible to culture gum arabic *in vitro.*

527 MONTGOLFIER-KOUÉVI, C. De.; HOUÉROU, H.N. Le. [**Study on the economic viability of browse plantations in Africa.**] Etude de la viabilite economique des plantations de fourrages ligneux en Afrique. In *Browse in Africa; the current state of knowledge (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980) 449-464

A study was made in order to assess the economic feasibility of planting browse trees and shrubs as feed resources, and further to evaluate the cost price of the animal feed which could be produced under relatively extensive conditions (using a minimum of inputs). The price of livestock feeds depend generally upon their energy values (measured in forage units) and their digestible protein

content per kg of feed. The main plantation objective in plantations of *Acacia senegal* is gum arabic. Forage output is low, the tree only being available for browse outside the gum collection period, in other words at the beginning of the rainy and dry seasons, giving only a marginal value to the forage as a supplementary source of feed supplies during drought periods. Gum production is estimated at 250g/tree (155kg/ha) from the fifth year onwards and over a period of 35 years, at the end of which the plantation has to be completely renewed. The trees are then cut down and sold in bulk. Browse production consisting of leaves can be estimated at 200 FU/ha with a DP content of 200g/FU. *Acacia senegal* plantations appear to offer only a very marginal interest in terms of browse production. Establishment costs are calculated, according to whether barbed wire fences or thorny hedges are used.

528 MOURET, M. **Gummosis of Acacias: current histological research**. *Bulletin of the International Group for the Study of Mimosoideae* (1985)**13**, 38-45

The study dealt with four African *Acacia* species, including *Acacia senegal* and eight Australian *Acacia* species. Part of the branches used for the tests were scarified and gummiferous and the rest were control samples producing no gum, branch lengths varied from 20 to 60 cm. Previous studies on gummosis were described and the present results divided in three sections: Gum potentiality, the pectic content of tissues is conspicuous near the cambial zone even in seedling stages; which may indicate that it is under genetic control; main stages of gummosis, the most important modifications caused by gummosis are observed in the phloem and consist, at first, of thickenings and chemical modifications of cell walls of the pholem; and gum lacunae, these lacunae characterize the final term of gummosis preceding gum exudation. Lacunae have been observed only in gummiferous branches and near exudation points. On a chemical basis, gummosis in Acacia could be linked to degradation of starch (see also Joseleau & Ullmann 1985).

529 MOURET, M. **Les Acacias gommiers**. *Docteur de 3 ème cycle thesis, Universite Paul Sabatier de Toulouse (Sciences), Toulouse, France* (1987) 1-184 (Ph.D. thesis supervised by J.Vassal.)

The introduction discusses the problem of the production of gum arabic with statistics for gum arabic production from the Republic of Sudan (1974 to 1982). Gives botanical descriptions and distributions of many Acacia species that produce gum, describes the ecology, exploitation of the gum and trade figures for the EEC (1970-1981), the physico-chemical features of the gum, industrial utilisation and management. A histological study was then undertaken on *Acacia senegal* and other species of African and Australian species to study gummosis.[see Mouret 1985 & Vassal and Mouret 1993 for published work from this thesis].

530 MOURGUES, G. [**Nomadism and deforestation in the Sahel regions of French West Africa.**] Le nomadisme et le déboisement dans les régions sahéliennes de l'Afrique Occidentale Francaise. *Comptes Rendus, 1 ere Conference Internationale des Africanistes de l'Quest, Paris* Published by the Librairie d'Amerique et d'Orient Adrien-Maisonneuve, 11 rue Saint-Sulpice, Paris, 6e. Sponsored by the Institut Francais d'Afrique Noire, Dakar. (1950) 1 139-67

Discusses causes of the destruction of vegetation in the Sahel with particular reference to nomads and overgrazing; considers the possibilities of reforestation and some of the natural and human obstacles that would hinder the implementation of a successful reforestation scheme; describes the results of some attempts to protect vegetation and offers some suggestions for the protection of *Acacia* and for reforestation with *Acacia senegal*.

531 MUGEDO, J.Z.A.; WATERMAN, P.G. **Sources of tannin: alternatives to wattle (*Acacia mearnsii*) among indigenous Kenyan species**. *Economic Botany* (1992) **46** (1) 55-63

The quantity and quality of tannins from commercial wattle (*Acacia mearnsii*) were compared with those from 9 other Kenyan species: *A. hockii, A. kirkii, A. mellifera, A. nilotica, A. polyacantha, A. sayel [A. seyal], A. senegal, A. sieberiana* and *A. xanthophloea* using three different assay procedures including the official hide-powder method employed by the leather trade. The extract from *Acacia senegal* produced the highest tannin content but also had the highest astringency value compared to wattle which prevents poor penetration into the leather prior to binding resulting in poor quality leather. But when mixed with weakly astringent bark extracts from *Acacia nilotica* the resulting mixture gave a similar protein precipitating profile to that of wattle.

532 MUKHERJEE, S.; SHARMA, A.K. **In situ nuclear DNA content in perennial fast and slow growing acacias from arid zones**. *Cytobios* (1993) **75** 33-36

In situ DNA content estimations were carried out on 17 species of Acacia growing at CAZRI, Jodhpur, India to determine the relationship between DNA content, polyploidy, adaptation and growth. The nuclear DNA content values per cell varied from 4.795 pg in *Acacia nilotica* (2n=26) to 8.221 pg in *A. tortilis* (2n=78), with *A. senegal* having 6.027 (2n=26). The interspecific variations of nuclear DNA content are less than a factor of two, and this narrow range has probably favoured adaptation to extreme climatic and water stress conditions. The faster growing diploid acacia species (including *A. senegal*) had a statistically lower 4C DNA contents per cell compared to the slow growing species, whereas the polyploid species were not significantly different. In fact the polyploid species had a reduction in the DNA content per genome.

533 MULLER, D. **Gum arabic, a natural product for the year 2000?** [La gomme arabique produit naturel de l'an 2000?] *Flamboyant* (1995) No.34 14-18

A brief account is given of production and trade in gum arabic. The product is classified into two broad categories, 'hard' and 'soft' gums, the hard gums being the best from *Acacia senegal,* and the soft from *A. seyal.* Three grades of *A. senegal* gum are described based on the size of the gum nodules. The market for gum arabic is currently poor, and has been in decline; some suggestions are made, including eco certification, for reinvigorating trade in this product of semi arid zones of Africa. A table at the end shows the proportion of the gum arabic market that the different properties and uses occupy, the greatest amount being used in the confectionary industry (40%).

534 MUTHANA, K.D. **Gum arabic - the backbone of the Kordofan region, Sudan.** *Myforest* (1988) **24** (2) 95-98

A brief account of the production of gum arabic from *Acacia senegal* from the Kordofan region (SW of Khartoum), and its role in the balanced agricultural practices and the socio-economics of the region. Procedures for seed collection, nursery seedling production and transplanting, and the periods and methods of tapping and gum collection are described. The various uses of gum arabic are listed. The trees are raised in plantations (known as gum gardens when they are on farmers' fields) in the 'gum belt' of Kordofan. The farmers in the area receive free food from the World Food Programme during the land preparation and planting season (May-Sep.), which coincides with the period of food shortage. Increased payments for the gum by the Gum Producers Association have encouraged the extension of gum gardens. Charcoal produced from the trees also fetches a good price. Describes a new gum-tapping tool, the Sunki, used on branches having more than 2.5 cm diameter, around mid to end of October when leaf shedding occurs. Average gum yields are 100 kg per hectare of 500 mature trees, and per tree 0.225 g. Seeds collected by farmers are sold at 100 Sudanese pounds per 45 kg (one kantar).

535 MUTHANA, K.D.; ARORA, G.D.; GIANCHAND **Comparative performance of indigenous trees in arid zone under different soil working techniques.** *Annals of Arid Zone* (1976) **15** (1/2) 67-76

A report of trials during 1960-72 with *Prosopis cineraria, Albizzia lebbek, Acacia senegal* and *Tecomella undulata* at Jodhpur, Rajasthan. Five types of soil working (on a deep sand with a kankar pan [caliche] at 120 cm) were compared; each species was both sown direct and transplanted as 1-yr-old seedlings. The best results were obtained with transplanted seedlings, planted in 60 cm^3 pits refilled with weathered soil. Height growth was best in *A. lebbek*, but mortality due to termite attack was high in this species.

536 MUTHANA, K.D.; GYANCHAND; ARORA, G.D. **Silvical studies on indigenous and exotic tree species in Rajasthan Desert.** In *Arid zone research and development (edited by Mann, H.S.).* Jodhpur, India; Scientific Publishers (1980) 339-343

Between 1958 and 1976, 112 species of *Eucalyptus*, 65 species of *Acacia* and 82 miscellaneous species from both indigenous and exotic sources were investigated in trials at Jodhpur and Pali, India. The most promising species are listed and some of their characteristics briefly described. The *Acacia* species that gave the most favourable results were, in order of performance: *A. tortilis* [*A. tortilis* ssp. *tortilis*], *A. raddiana* [*A. tortilis* ssp. *raddiana*], *A. senegal, A. planifrons, A. ciliata, A. aneura, A. karroo, A. leucophloia* [*leucophloea*], *A. saligna, A. nilotica* and *A. catechu.*

537 MUTHANA, K.D.; MEENA, G.L.; BHATIA, N.S.; BHATIA, O.P. **Root system of desert tree species.** *Myforest* (1984) **20** (1) 27-38

Root systems were excavated of 6 species growing on sandy soils at (or near) Jodhpur: *Prosopis cineraria, Acacia senegal, Tecomella undulata* and *Albizia lebbek* (all 20 yr old); *Eucalyptus camaldulensis* (13 yr old); and *Acacia tortilis*, 5, 10 and 14 yr old. Trees were felled 15-20 cm above ground before excavation started. The root systems are described in detail for each tree with drawings, and data are tabulated on soil profiles, tree ht. and d.b.h. and crown diameter as well as on root spread and numbers and tap root length.

538 NATIONAL ACADEMY OF SCIENCES. **Gums.** In *Tropical legumes: resources for the future.* Washington, USA; National Academy of Sciences (1979) 278-291

Briefly reviews the most important gum producing taxa in the Leguminosae, their trade and vast variety of uses, with a principal section on *Acacia senegal.* Gum arabic has an important international trade, and has been used since biblical times by Egyptians in medicine and ceramic pottery, and imported from Sudan and Arabia, hence its name. An average annual gum yield per tree is 250 grams, but yields can vary from a few grams to about 10 kilograms. Shows a photo of the remarkable excavated root system of a large tree, with several tap roots, and some widespread lateral roots which extend over 30 feet from the base. Suggest where further research is needed, especially the causes and physiology of gum production. Increasing gum yields can only be achieved when the causal factors for gum production are understood.

539 NATIONAL ACADEMY OF SCIENCES. ***Acacia senegal.*** In *Firewood crops.* Washington, USA; National Academy of Sciences (1980) 102-103

Acacia senegal is described as an excellent fuelwood species (one headload of wood 22.5 kg is found to

be equal to 72,000 kcal.); one of the few plants to survive and grow in very dry and adverse conditions, besides being the source of gum arabic, the bark exudate that has been commercialized for over 4,000 years. It is a small thorny tree, up to 13 m tall with a life-span of 25-30 years. It is characteristic of the drier parts of the Sahara and has many geographical races being important for the economy of Sudan, which supplies 80% of the world's gum arabic with large plantations in this country and in Senegal. It is also cultivated in India, Pakistan and Nigeria. The tree coppices well and produces an average of 5 m^3 of wood per ha. at close spacing. Other uses are poles and agricultural implements, root fibers used for rope, fishnets and also lining wells; foliage and pods are fodder rich in proteins, eaten by camels, sheep and goats; seed also eaten as vegetables by humans; has benefits of soil improvement by nitrogen fixation, sand-dune fixation, and control of wind erosion. It is suitable for agroforestry systems. It can be easily propagated from seeds which should be soaked overnight and requires weeding over the two first years after planting. Young plants can be damaged by overgrazing, pods can be heavily predated by insects. It can become invasive. It grows in Sudan at average temperatures between 14 and 43 degrees; in India -4 to 48; An altitude from 100 to 1,700m in east Africa; grows best conditions between 300 and 450 mm of annual rainfall but it can grow as low as 200 mm. Does not withstand waterlogging. Notes that it could become a serious weed, and both South Africa and Australia have policies to eradicate it.

540 NAVILLE, E. **The Temple of Deir-el-Bahari**. *Egypt Exploration fund memoir, London* No.12 (1894) 1-32

541 NEWBURY, C.W. **Prices and profitability in early nineteenth century west African trade.** In *The development of indigenous trade and markets in Africa* (edited by Meillassoux, C) International African Institute, Oxford University Press (1971) 93-106

542 N'DIAYE, I.; BADJI, S.; GESLOT, A.; MERLIN, G.; NEVILLE, P. [**Research into favourable rooting conditions of cuttings of *Acacia senegal* (L.) Willd.**] Recherché de conditions favorables à l'enracinement de boutures d'Acacia *senegal* (L.) Willd. In *Physiologie des Arbes et Arbustes en zones arides et semi-arides. Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadma, C.; Joly, H., Bory, G.).* (1993a) 315-322

Studied the effect of auxin (IBA) and various rooting mediums on the rooting ability of herbaceous cuttings of shoots harvested from five year old plants of Acacia *senegal grown* in a green-house. IBA (at 2 or 4%) increased the rooting rate and numbers of the cuttings, and depressed the shoot growth. Best results were with IBA at 2% in sand, compost or 1/1 compost vermiculite medium, and when rooted transferred to a compost/vermiculite medium without IBA.

543 N'DIAYE, I.; GUINDO, H.; GESLOT, A.; MAIRONE, Y.; NEVILLE, P. **Greffe d'Acacia *senegal* (L.) Willd. adulte sur jeune et son influence rajeunissante exprimée par l'aptitude rhizogène de boutures provenant du greffon**. In *Physiologie des Arbes et Arbustes en zones arides et semi-arides. Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadma,. C.; Joly, H., Bory, G.).* (1993b) 309-313

Grafts and cuttings of growing shoots from 15 year old trees of *Acacia senegal* were produced in Mali. The grafts were made on 8-12 month old seedlings of *Acacia senegal*. There was a high rooting rate of the cuttings, but rapid shoot elongation was not observed which normally occurs with the rooting cuttings of young plants. While grafted cuttings can be made from adult trees, the inhibition of their shoot growth needs to be overcome.

544 NDOUR, P.; DANTHU, P. **Effects of water and salt stress on the germination of some African acacias**. [Effet des contraintes hydrique et saline sur la germination de quelques acacias africains.] In *L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.).* L'Orstom, Collection colloques et séminaires, Paris, France (1998) 105-122, 453-454

Seeds of eight species of *Acacia* from contrasting biogeographic zones in West Africa were scarified, and water stress or saline conditions were simulated using sodium chloride (0 to 40 g/litre osmotic pressure from 0 to 2.4 MPa), polyethylene glycol (PEG, 0 to 2.1 MPa) or mannitol (0 to 1.7 MPa). The species (approximate rainfall range added in brackets) were: *Acacia ehrenbergiana* (<100-200 mm), *A. raddiana* (<100-400 mm), *A. nilotica* subsp. *adstringens* (200-600 mm), *A. senegal* (200-600 mm), *Faidherbia albida* (200-800 mm), *A. nilotica* subsp. *tomentosa* (200-800 mm), *A. seyal* (400-800 mm), *A. sieberiana* (600-1200 mm), and *A. dudgeoni* (800-1500 mm). Results are tabulated for the effects of both stress factors on seed germination. Generally, *A. nilotica* (both varieties) was the most susceptible to salt stress, and *A. senegal, A. albida, A. dudgeoni, A. erhenbergiana* and *A raddiana [A. tortilis* ssp. *raddiana]* were the most tolerant. The most susceptible species to water stress also was *A. nilotica* (both varieties), and the most tolerant were *A. raddiana, A. senegal* and *A. sieberana* (-1.7 or -1.8 MPa). In natural conditions *A. dudgeoni* (the least drought tolerant species) and *A. ehrenbergiana* (the most drought tolerant species) exhibited the same level of tolerance to the imposed stress conditions: this finding suggests that seed germination under stress conditions is not a good indicator of tree ecophysiology.

545 NDOYE, I.; GUEYE, M.; DANSO, S.K.A.; DREYFUS, B. **Nitrogen fixation in *Faidherbia albida*, *Acacia raddiana*, *Acacia senegal* and *Acacia* seyal estimated using the 15N isotope dilution technique**. *Plant and Soil* (1995) **172** (2) 175-180

A pot experiment was conducted in a greenhouse using the 15N isotope dilution method and two reference plants, *Parkia biglobosa* and *Tamarindus indica*, to estimate nitrogen fixed in four *Acacia* species: *A. raddiana*, *A. senegal*, *A. seyal* and *Faidherbia albida*. For the reference plants, the 15N enrichments in leaves, stems and roots were similar. With the nitrogen fixing plants, leaves and stems had similar 15N enrichments; they were higher than the 15N enrichment of roots. The amounts of nitrogen fixed at 5 months after planting were similar using either reference plant. Estimates of the percentage of N derived from fixation (%Ndfa) for the above ground parts, in contrast to %Ndfa in roots, were similar to those for the whole plant. However, none of the individual plant parts estimated accurately total N fixed in the whole plant, and excluding the roots resulted in at least 30% underestimation of the amounts of N fixed. Between species, differences in N2 fixation were observed, both for %Ndfa and total N fixed. For %Ndfa, the best values were for *A. seyal* (average, 63%) and *A. raddiana* (average, 62%), compared to the %Ndfa in *A. senegal* (average, 34%) and *F albida* (average, 37%). Because of its very high N content, *A. seyal* was clearly the best in total N fixed, fixing 1.62 g N/plant compared with an average of 0.48 g N/plant for the other *Acacia* species. Growth rates were 300% more in *A. seyal* compared with the other three species, which meant higher values of total N. The results show the wide variability existing between *Acacia* species in terms of both %Ndfa and total N fixed: *A. seyal* was classified as having a high N2 fixing potential (NFP) while the other species had a low NFP.

546 NEW, T.R. **A biology of Acacias: a new source book and bibliography for biologists and naturalists**. Melbourne, Australia; Oxford University Press (1984) 1-153

A useful reference book, reviewing the literature on the biology and ecology of the genus *Acacia* up until 1982.

547 NGE'THE, J.C.; BOX, T.W. **Botanical composition of eland and goat diets on an *Acacia* - grassland community in Kenya**. *Journal of Range Management* (1976) **29** (4) 290-293

The consumption of various plant species by eland (*Taurotragus oryx*), a common game species with potential for domestication, and by domestic Galla goats, was studied in *Acacia tortilis/Commiphora riparia* savanna at the Kiboko Range Research Station, 164 km south of Nairobi. Although 63 plant species appeared in the diet of eland, the chief food plants for both eland and goats were the grass *Digitaria milanjiana* (the most important), *A. tortilis*, *A. senegal*, *Disperma kilimandscharica*, and 2 other grasses. *Themeda triandra*, the most abundant pasture species, was a minor dietary component. Goats consumed more browse (49% of the total diet) then eland (30%). The diets for both species were more diverse in the growing season (Feb-May) than in the dry season (July-Oct). The dietary intake of eland appears to be largely regulated by availability.

548 NICHOLSON, S.E.; KIM, J.; HOOPINGARNER, J. **Atlas of African Rainfall and its interannual variability.** Florida, USA; Florida State University, Dept. of Meteorology (1988) 1-237

Rainfall atlas of the continent, emphasising rainfall variability as well as mean rainfall data from over 1300 individual stations.

549 NIGERIAN FOREST SERVICE. [**Annual report of the forest service of French Niger Colony for 1949**.] Service forestier du Niger: rapport pour l'annee 1949] Bois *et Forêts des Tropiques* (1950) No.15 295

Broadcast sowing of *Acacia senegal* followed by hoeing was very successful even in a very dry year (136 mm of rain), whereas spot sowing was a failure.

550 NJITI, C.F.; GALIANA, A. **Symbiotic properties and *Rhizobium* requirements for effective nodulation of five tropical dry zone acacias**. *Agroforestry Systems* (1996) **34** (3) 265-275

Four day old seedlings of 5 tropical dry zone acacias (four native to Africa and one Australian exotic) were inoculated with 3 fast growing *Rhizobium* strains and 4 slow growing *BradyRhizobium* strains (culture collections from the CIRAD-Foret laboratory, Paris). After 2 months of growth in the greenhouse, the plants were harvested and their shoot height and dry weight, nodule number and dry weight, acetylene reduction activity, and total shoot nitrogen were determined. The results showed that: (1) *Acacia polyacantha* (being evaluated for the first time) was promiscuous, nodulating indiscriminately with *Rhizobium* and *BradyRhizobium* strains; (2) *Faidherbia albida* and *Acacia holosericea* (that were previously known to nodulate with *BradyRhizobium* strains only) nodulated with *Rhizobium* strains as well; and (3) *Acacia senegal* and *Acacia nilotica* that were previously known to be nodulated exclusively by *Rhizobium* strains only were nodulated with both genera. While most strains produced nodulation on *A. senegal* they had no positive effect on plant growth and were classified as moderately effective.

551 NOEL, J.C.; SAAD, Z.A.; BUNDERSON, W.T. **Planning for agroforestry research in western Sudan: approaches, issues and lessons learned the**

evolution of a management approach. In *Planning for agroforestry. Selected contributions from an international symposium held at Washington State University, Pullman, Washington, on 24-27 April 1989 (edited by Budd, W.W.; Duchhart, I. ; Hardesty, L.H.; Steiner, F.).* Amsterdam, Netherlands; Elsevier Science Publishers (1990) 203-226

Describes the activities of the Western Sudan Agricultural Research Project (WSARP), which established an agricultural research network in the four western provinces of Sudan. The research programme functions in concert with its parent organization, the national Agricultural Research Corporation, to plan and implement research leading to sustainable improvements in agricultural production and productivity for the farmers and pastoralists of the regions. Describes three broad ecological zones in western Sudan, the qoz sands and gardud non-cracking clays in the north and west, the Nuba mountain complex in the south-central region, and the broad clay plains in the south. and *A. senegal* is dominant in the former (qoz sands). Three major types of production systems were identified in the area: the first sedentary farming systems dominated by crops (cotton and sorghum) but including some livestock/poultry and carried out in areas clearing *Acacia seyal* (sometimes tapped for gum), and then regenerates after a 5- 7 yr copping cycle when crop production declines. They retained *Balanites aegytica* and *A. albida* within the system. The second transhumant pastoralist systems, which utilize *Acacia senegal* (for gum arabic and fodder) and *Balanites* and *A. albida* (for fodder). The third and true nomadic pastoral systems also gathers gum arabic and uses perennial species for fodder. Within the context of a systems oriented research approach (i.e. production systems or farming systems approaches), the WSARP developed a strategy, policies and procedures, and carried out research and planning efforts in which agroforestry development of the existing production systems figured prominently. Specific WSARP technical agroforestry activities and results are included in a separate paper from this conference (Bunderson *et al.*, 1990).

552 NONGONIERMA, A. [**Contribution to a biosystematic study of the genus *Acacia* Miller in West Africa. II. Characters of the inflorescences and flowers**.] Contribution à l'étude du genre *Acacia* Miller en Afrique occidentale. I. Caracteres des inflorescences et des fleurs. *Bulletin de l'Institut Française d'Afrique Noire, Série A* (1976) **38** (3) 487-657

A detailed biosystematic study of the floral characters of the West African *Acacias,* illustrated with detailed drawings, and correlates them with phenological, cytological and biogeographic information. For *A. senegal*, two varieties are given in West Africa, var. *senegal* and var. *samoryana*, and quotes a chromosome determination for the former as 2n=26 while the latter is undetermined. The average number of seeds per pod is 4.5 and 4.6, and their seed weights are 71.9 g and 73.4 g/1000 seeds respectively. Both varieties commonly occur in the Sahelian and Sudanian zones. Proposes the formation of the monotypic genus *Faidherbia* A. Chev., with two subspecies *F. albida* (Del.) A. Chev. ssp. *albida* and *F. albida* (Del.) A. Chev. ssp. *senegalensis* Benth., and with subspecies *senegalensis* having 3 varieties. *F. albida* is anomalous in many of the characters studied including stamen glands absent, only species with filaments partly joined at the base, only species with a spicate inflorescence and having indehiscent pods, and these points are illustrated with detailed drawings. It also flowers much later than other *Acacias*, most flowering between 1-3 years whereas it first flowered in the 7th year after planting.

553 NONGONIERMA, A. [**Contribution to a biosystematic study of the genus *Acacia* Miller in West Africa. III. Edaphology**.] Contribution à l'étude du genre *Acacia* Miller en Afrique occidentale. III. Édaphologie. *Bulletin de l'Institut Française d'Afrique Noire, Série A* (1977) **39** (1) 23-74

A study of 54 sub groups of soils taken from 613 soil profiles from Upper Volta, Mali, Mauritania, Niger and Senegal and compares them with the distribution of 27 *Acacia* taxa growing there. Most of the *Acacia* species grew on wide range of soil types and different climatic conditions, widespread in the Sahelian, Sudanian, Sudanian-Guinean zones of West Africa. *A. senegal* var. *samoryana* was recorded from the south Sahelian/ Sudanian zone and var. *senegal* reaching further north in the Sahelian and north Sudanian zone. Most *Acacia* taxa were found to be calcifuges, growing in a wide variety of soils with a low mean exchangeable calcium content (0-5.2% in milliequivalents), and *A. senegal var. samoryana and var. senegal* are grouped as preferential calcifuges having 4.5% and 3.7% in m.e. respectively. In fact most of the 54 sub groups of soils fitted into this low category. Variety *samoryana* occurred in 23 of the 54 sub groups of soils and var. *senegal* in 27. Analyses of the soils where the species commonly occurs indicated neutral to more basic soils (a pH of 6 or above). The 54 soils were divided into 12 classes, and it was only in one class that *A. senegal* was not found, the ferrallitic soils which occur in the Sudanian and Guinean zones.

554 OBEID, M.; EL DIN, A.S. **Ecological studies of the vegetation of the Sudan. I. *Acacia senegal* (L.) Willd. and its natural regeneration**. *Journal of Applied Ecology* (1970) **7** (3) 507-518

A study of the size, age and density of stocking of *A. senegal* in a series of plots in Kordofan showed that the species is still capable of maintaining itself by natural regeneration over many parts of the former Gum belt of the Sudan, where the average annual rainfall is 300-450 mm, provided that the local system of land use is favourable. The present failure of *A. senegal* to regenerate over parts of the belt is apparently attributable to

changes in the distribution and density of the population and the consequent changes in the lengths of the cropping and bush-fallow stages of the usual agricultural cultivation cycle. A shortening of the bush fallow and lengthening of the cropping stage are inimical to the persistence and regeneration of *A. senegal*. Where soil deterioration has led to the abandonment of cultivation, recolonization by *A. senegal* is slower and more hazardous than formerly, because of the smaller number of seed parents available, increased grazing pressure and greater frequency of grass fires. Maintenance of stocks of the species by planting or raising seedlings at appropriate stages of the cultivation cycle is suggested. The silvicultural characteristics of *A. senegal*, which behaves like a pioneer woody species rather then a major component of closed stable forest, are discussed in relation to its survival.

555 OBEID, M.; EL DIN, A.S. **Ecological studies of the Sudan. III. The effect of simulated rainfall distribution at different isohyets on the regeneration of *Acacia senegal* (L.) Willd. on clay and sandy soils.** *Journal of Applied Ecology* (1971) **8** (1) 203-9

Describes an experiment in which simulated June rainfalls of 200-500 mm. were applied on sandy soils, and of 300-600 mm. on clay soils. Results showed that the germination % of *A. senegal* is a direct function of the amount of simulated rainfall, and that the soil type and frequency and intensity of rains also affect germination. In clay soils seeds require higher rainfall to give the same performance as on sands.

556 OBUNGA, E.O. **A study of genetic systems of four African species of Acacia.** DPhil. Thesis, School of Biological Sciences, University of Sussex (1995) 1-142

The thesis consists of a series of studies on the genetic systems of four Acacia species: *A. senegal* (L.) Willd., *A. nilotica* (L.) Willd. ex Del, *A. tortilis* (Forssk.) Hayne and *A. albida* (now *Faidherbia albida* (Del.) A. Chev. native to the African continent. Investigations were made on breeding systems, genetic variation and cytogenetics. Investigation of the breeding systems indicated that *A. nilotica, A. senegal* and *A. tortilis* were self-incompatible. No seed formed after self-pollinations while low seed set occurred on open–pollinated inflorescences. Cytological examination of pollen tube growth, the first among these African acacias, indicated that incompatible pollen tubes reached the embryo sac. It is suggested that self-incompatibility in these species could be either a pre-fertilization failure within the embryo sac or a post-fertilisation event. In an attempt to investigate the genetic variation within and between *A. nilotica, A. senegal* and *A. tortilis,* the trnL intron of chloroplast DNA of the three species was amplified using polymerase chain reaction (PCR). The PCR products were sequenced using an Automated Applied Biosystems, Model 370A, DNA sequencer. Universal primers designed by Taberlet *et al.* (1991) were used. Estimates of nucleotide divergence (genetic distances) showed considerable genetic differentiation within and between the species and indicated closer taxonomic affinity between *A. nilotica* and *A. tortilis*. Mitotic chromosome counts were provided. Diploidy (2n=2x=26) was confirmed for *F. albida* and *A. senegal* and a polyploid series, tetraploidy (2n=4x=52) and octoploidy (2n=8x=104) for *A. tortilis* and *A.nilotica* [from thesis summary].

557 OGIGIRIGI, M.A. **An approach to development of the forest resources of the Sudano-Sahelian zone of Nigeria.** In *Proceedings, 15th Annual Conference of the Forestry Association of Nigeria, Yola, 25-29 November, 1985 (edited by Okojie, J.A.; Okoro, O.O.).* Forestry Association of Nigeria (1985) 18-31

A review is presented of current forestry development programmes in Nigeria, which concentrate on fuelwood and pole plantations, shelterbelts, and the production of tannin from *Acacia nilotica* and gum arabic from *A. senegal*. Some prospective areas of development are the domestication of wild fruits, production of vegetable oils and cultivation of forage species. Suitable species are noted, and implementation strategies are discussed.

558 OJO, G. **Thoughts on tree improvement programmes for some savanna plantation species.** *Research Paper Savanna Series, Federal Department of Forest Research, Nigeria* (1974) No.35 1-4

Briefly discusses possibilities of improvement for *Tectona grandis, Gmelina arborea, Azadirachta indica, Acacia nilotica, A. senegal, Pinus caribaea, P. oocarpa,* and several *Eucalyptus spp.* (all used or potentially useful in savanna planting in Nigeria).

559 OLEGHE, P.E.; AKINNIFESI, F.K. **Gum yield of *Acacia senegal* as affected by soil water potential and season of tapping.** *Nitrogen Fixing Tree Research Reports* (1992) **10** 106-109

Studies undertaken with 5 yr old trees at the Mafoni Forest Reserve (11.1°N 13.5°E), Borno State, Nigeria, indicated that gum yields were higher in the summer months (mean of 60.6g/tree in April) than the winter (mean 25.4g in December). Noted that trees tapped early during the dry warm season and late during the dry cold season produced darker gum arabic. Gum yields were increased by irrigation to a state where plants were only moderately stressed (soil water potential of 0.5 MPa in the summer and 0.8MPa in the winter) compared with the control plot of 1.5 MPa. Irrigated plots tended to have lighter gum that those not irrigated.

560 OLSSON, K. **Remote sensing for fuelwood resources and land degradation studies in Kordofan,**

the Sudan. Meddelanden Fran Lunds Universitets, Geografiska Institution, Auhandlingar 100, Sweden (1985) 1-182

Based on studies from the project "Monitoring wood resources and land degradation in Kordofan, Sudan", which is in the gum arabic belt (*Acacia senegal* var. *senegal*). A methodology for quantitative assessment of woody biomass, based on remote sensing technology is described, and an investigation into patterns of fuelwood use both historically and during the project period (1981-82). The estimation of woody biomass from measurements of crown diameter, tree height, and collar diameter for 12 species (including *A. senegal*) in the area were investigated and a reliable predictor of biomass (fresh wt.) was found to be the crown diameter squared. Canopy cover and woody biomass were possible to relate to Landisat MSS data. Average fuelwood consumption was 1.035 tons/person/year and no severe supply problems were found within the area. Discusses the role of *A. senegal* in gum arabic production, its distribution and the gum cultivation/fallow cycle. The most serious threat to the woody vegetation in the area is a reduction in fallow period with increased risks of wind erosion.

561 OMER, H.M. The **effect of burning on the viability of seeds of five *Acacia* species**. *Sudan Silva* (1975) **3** (20) 20-22

Investigates the effect of two intensities of burning on the viability of seed of five *Acacia* species dominant in the Sudan, including *A. senegal*, *A. campylacantha*, *A. seyal*, *A. nubica* and *A. fistula*; sown at a depth of about 1 cm. 'Heavy' burning, (148°C at 1 cm depth) did not significantly affect the viability of the *A. senegal* seeds on clay or sandy soils, and light burning appeared to stimulate more seeds to emerge.

562 OSMAN, A.H. [**Identification of various *acacias* from seeds and seedlings**.] Identificazione di alcune acacee attraverso il seme e la plantula. *Thesis, Facolta di Agraria, Universita Nazionale Somala* (1982) 1-48

After an introduction describing the ecology and uses of *Acacia* in Somalia, studies are reported on 5 species: *A. nubica*, *A. nilotica*, *A. senegal*, *A. tortilis* and *A. horrida*. Descriptions are given of the morphological characteristics of seeds and seedlings, germination, seedling growth characteristics, and phenology, with data on the nutritive value of foliage and pods.

563 OSMAN, M.E.; MENZIES, A.R.; MARTIN, B.A.; WILLIAMS, P.A.; PHILLIPS, G.O.; BALDWIN, T.C. **Characterization of gum arabic fractions obtained by anion exchange chromatography**. *Phytochemistry* (1995) **38** (2) 409-417

Two samples of authentic gum arabic (A and B) were fractionated by anion exchange chromatography on DEAE cellulose. Fractions were isolated by a stepwise increase in ionic strength of the elution buffer. Samples A and B yielded five and six fractions, respectively. All fractions isolated were polydisperse containing varying proportions of the different Mr species associated with whole gum. Carbohydrate composition of all fractions remained relatively constant with each containing similar proportions of galactose, arabinose, rhamnose and glucuronic acid. Protein content of fractions varied slightly (0.31 - 2.8%). For sample A, protein content decreased in the order F2>F1>F3>F5>F4; for sample B, F1>F6>F3>F2>F4>F5. Whereas Hyp and Ser were the principal amino acids for whole gums and the majority of fractions isolated, two fractions from sample A had Asp, Ser and Glu as their principal components. Interaction of fractions from both samples with an artificial carbohydrate antigen (Yariv reagent) indicated that they all contained arabinogalactan proteins (AGP). In addition, immuno dot blots of these fractions screened against a panel of anti AGP monoclonal antibodies demonstrated that they all contained epitopes recognized by one or more of these antibodies. Results demonstrate the molecular complexity of this natural product, and in combination with other separation procedures may provide the key to eventual elucidation of its biochemical synthesis.

564 OSMAN, M.E.; MENZIES, A.R.; WILLIAMS, P.A.; PHILLIPS, G.O.; BALDWIN, T.C. **The molecular characterisation of the polysaccharide gum from *Acacia senegal***. *Carbohydrate Research* (1993) **246** 303-318

A study on gum Arabic structure and composition providing novel data on the molecular complexity of this gum. Gum arabic (from *Acacia senegal*) was fractioned by hydrophobic interaction chromatography on Phenyl-Sepharose CL-4B and yielded four fractions of similar carbohydrate composition, whilst differing in protein content, amino acid composition, and molecular mass distribution. All four fractions interacted with an array of anti-arabinogalactan-protein (AGP) monoclonal antibodies via anti-carbohydrate epitopes and were precipitated by Yariv's reagent, suggesting that they were all AGPs. Further characterisation using SDS-PAGE and Western blotting showed that all fractions contained proteins of molecular mass 30 000 - 45 000 with at least one protein unique to each fraction. The fractions were subjected to enzymatic (with pronase) and alkaline hydrolysis, and the molecular mass distribution of the products was monitored by gel permeation chromatography. The fractions showed various degrees of resistance to hydrolysis, thus illustrating differences in their macromolecular structure.

565 OSMAN, M.E.; WILLIAMS, P.A.; MENZIES, A.R.; PHILLIPS, G.O. **Characterization of commercial samples of gum arabic**. *Journal of Agricultural and Food Chemistry* (1993) **41** 71-77

Six commercial gum arabic samples and authenticated samples from *Acacia senegal* (from Sudan, Chad, Senegal and Ethiopia) and *Acacia seyal* (Sudan) have been characterized using a range of chemical and physiochemical techniques including determination of specific rotation, sugar composition, nitrogen and amino acid content, and molecular mass distribution. Although some of the gums have slight different chemical and physicochemical characteristics, gel permeation chromatography shows that each consists of essentially three molecular mass fractions classified as an arabinogalactan, an arabinogalactan-protein complex, and a glycoprotein. The proportions of each varied for the individual samples. The gums were tested using a specifically developed enzyme-linked immunosorbent assay (ELISA), which can identify gum from *A. senegal* and chemically related species. Their interaction with the antibody could be correlated with differences observed in their molecular compositions. Such evidence will assist in their chemotaxonomic classification. Even between two different subgenera of Acacia, such as Gummiferae (*A. seyal*) and Vulgares (*A. senegal*), there are significant points of chemical similarity, although there are clear differences as well. Both appear to contain similar and discrete molecular mass fractions indicative of a common taxonomic origin.

566 PALGRAVE, K.C. **Trees of Southern Africa**. 2nd Edition. Cape Town, South Africa; Struik Publishers (1988) 250-251

Describes briefly the taxonomy of *Acacia senegal* in Southern Africa, with particular reference to the bark, flowers and fruit. Describes the 2 varieties that extend south of the Zambezi River - var. *rostrata* Brenan and var. *leiorhachis* Brenan, the most widespread being var. *rostrata* Brenan.

567 PALMA, B.; VOGT, G.; NEVILLE, P. **Comparison of root pruning systems of seedlings and plantlets of *Acacia senegal* (L.) Willd**. *Phyton, Buenos Aires* (1994) **55** (1) 137-146

Comparative studies were made of the root systems of seedlings, and of plantlets raised *in vitro* from 2 month old seedlings grown under axenic conditions. The plantlets were subjected to 2 treatments: all adventitious roots retained, and only one adventitious root retained. Root pruning (as a simulation of the type of damage that can occur on transplanting) was performed by cutting 4 cm from the neck (seedlings) or at the level of insertion into the stem (plantlets). Subsequent root growth was studied for 24 days after transfer to minirhizotrons. The root system architecture of *A. senegal,* like the majority of woody plants, develops from an orthogravitropic taproot which elongates rapidly and indefinitely describes small oscillations around the vertical. Lateral roots appear in an acropetal sequence 8 days after germination, 6cm below the soil level. The axes of the lateral roots are either short and horizontal or longer and inclined. The main root grows at 2-3.5 cm/day (3.8 cm/day in the first 6 days decreasing to 2 cm/day from 6-23 days). The results indicated that for the multi rooted plantlet treatment the rate of growth of the main root may exceed that of the seedling tap root, thus suggesting that plantlets had a greater capacity for growth after transplanting than seedlings.

568 PALMA, B.; VOGT, G.; NEVILLE, P. **Endogenous factors that limit seed germination of *Acacia senegal* Willd**. *Phyton, Buenos Aires* (1995a) **57** (2) 97-102

Seeds of *Acacia senegal* was studied to determine whether there are inherent characteristics that limit germination. The age, role of the integuments and capacity of imbibition were analysed using three types of seeds: normal, scarified (with conc. sulphuric acid for 14 mins) and naked embryos. The source of seeds was a 12 yr old plantation in Kayes, Mali. The water content of the seeds is very low at 5.6%, which preserves the seeds for many years. In seeds 3 or more years old the germination percentage diminishes with increased latency times. Imbibition time is short (4 to 5 h) in scarified seeds and, conversely, the presence of integuments delays water entrance. The scarified seeds increase by 180% in weight due to imbibition, and imbibition rate is the same regardless of temperature. Chemical scarification does not adversely affect seed viability, so that seed can be scarified and stored. It is concluded that there are no obstacles to seed germination at the embryo level, as once the integuments are removed, germination rate is 100%.

569 PALMA, B.; VOGT, G.; NEVILLE, P. **Environmental factors that influence germination of seeds of *A. senegal*, Willd**. *Phyton, Buenos Aires* (1995b) **57** (2) 103-112

A study was conducted to determine optimal temperature for seed germination, seed tolerance to water stress, and the effect of light on germination, using normal and scarified (conc. sulphuric acid) *Acacia senegal* seeds, and naked embryos. In the present study, optimal germination for normal seeds was 25°C. Naked embryos and scarified seed germinated best at 30°C. A slight positive photoblasty was detected when the integuments remained intact. Two types of seed were identified, those with fast and those with slow germination. At osmotic potentials of 0.7 and 0.9 MPa there was still seed germination of up to 70%, but with a considerable increase in lag time, to 24 and 50 hours respectively. Seeds had an excellent tolerance to water stress up to 1.1 MPa with germination percentages over 50%. These results show that the seed of *A. senegal* is tolerant of high water potentials and resistant to dry conditions.

570 PALMA, B.; VOGT, G.; NEVILLE, P. **A combined in vitro/in vivo method for improved grafting of *Acacia senegal* (L.) Willd**. *Journal of Horticultural Science* (1996) **71** (3) 379-381

A procedure for grafting microcuttings onto 3 month old rootstocks obtained in vivo has been developed and has led to 40% successful grafts. This procedure constitutes a great improvement for propagating tree species with economic potential such as *A. senegal* on a larger scale. Normal apices grafted under the same conditions did not give successful results.

571 PALMA, B.; VOGT, G.; NEVILLE, P. **Micro grafting, an answer to *in vitro* multiplication of *Acacia senegal*?** [La microgreffe, une solution pour la multiplication *in vitro* de l'*Acacia senegal* (L.) Willd.?] *Annales des Sciences Forestieres* (1997) **54** (2) 203-210

In order to investigate means of improving gum arabic production in *Acacia senegal* plantations, productive 5 yr old trees in a seed orchard (established with seeds from a plantation in Kayes, Mali) were used in propagation trials. Apex and microcutting techniques with scions and explants from rootstock shoots were tested. These procedures were satisfactory, as 23 and 60% of successful grafts were obtained, respectively, when the grafting was carried out onto epicotyls of *in vitro* raised, 3 week old, dark grown seedlings. Microscopic analysis of graft union structures is described, and the importance of correct light levels noted.

572 PALMA, B.; VOGT, G.; SPINELLI, S.; NEVILLE, P. **Effects of several factors on seed germination of *Acacia senegal*** (L.) Willd. [Influence de differentes facteurs sur la germination des semences d'un vegetal d'interet economique l'*Acacia senegal* (L.) Willd.] *Proceedings of the Fourth International Workshop on Seeds: basic and applied aspects of seed biology, Angers, France, 20 24 July, 1992.* (edited by Come, D. & Corbineau, F.) (1993) **2** 423-428

573 PALMER, E.; PITMAN, N. **Trees of southern Africa.** Cape Town, South Africa; A.A.Q. Balkema (1972) **2** 1-1497

Lists the two varieties of *A. senegal* that occur in southern Africa, namely var. *leiorhachis* Brenan and var. *rostrata* Brenan. The gomdoring or var. *leiorhachis* grows in south Africa in the dry bush in eastern and northern Transvaal, while the geelhaak or var. *rostrata* grows widely in scrub and bush from Mozambique, Swaziland and Zululand, westwards to Namibia and north to Zimbabwe. It is fairly common in the eastern, northern, and central Transvaal, and in parts of the Waterberg is encroaching rapidly and becoming a problem to farmers. Both varieties can be distinguished by habit, and the leaf rachis (*leiorhachis* means smooth rachis) and pod shape (*rostrata* means beaked or slender tip).

574 PANCHOLY, A. **Studies on the status of indigenous soil rhizobia associated with certain arid zone legume trees.** *Nitrogen Fixing Tree Research Reports* (1991) **9** 9-10

Seeds of 5 species (*Prosopis cineraria, Prosopis juliflora, Acacia tortilis, Acacia senegal*, and *Albizia lebbek*) were sown in polybags with two soil treatments, soil with or without Farm Yard Manure, to see the effect on nodulation in the arid zone of India. Seeds were uninnoculated and after 5 months only seedlings of *A. senegal* and *P. juliflora* remained unnodulated in either treatment.

575 PANCHOLY, A.; JINDAL, S.K.; SOLANKI, K.R. **Effect of gamma radiations on germination and seedling growth of certain arid zone trees.** *Annals of Arid Zone* (1993) **32** (3) 203-204

Results are summarized and discussed for 3 multipurpose tree species: *Acacia senegal, Acacia tortilis* and *Hardwickia bipinata.*

576 PANDIT, B.R. **An ordination of plant communities in a reserved forest near Bhavnagar.** *Indian Journal of Forestry* (1996) **19** (3) 278-282

No ecological study has so far been made on the reserved forest of Victoria Park, near Bhavnagar, Gujarat. This paper reports an investigation of the composition, structure and growth characteristics of the forest vegetation, which was dominated by *Acacia senegal* and *Prosopis juliflora.* Nine types of plant communities (associations) were defined based on statistical analyses of density, basal cover, frequency, and tree height. The communities were further defined by (1) coefficient of variation (cv) in density (a measure of homogeneity), with the species having a cv <1.5 being designated the characteristic species in any block (a cv of <1.0 indicated normal dispersion, cv 1-1.2 hypo dispersion, and cv 1.2-1.5 hyper dispersion), and (2) relative growth index (RGI).

577 PANDYA, S.M.; SIDHA, V.K. **Structure and composition of forest vegetation of Kutch (Gujarat state).** *Indian Forester* (1985) **111** (8) 583-595

The structural components of the Kutch forest, which contains about 695 species of flowering plants and is classified under tropical thorn forest, were studied. The soils, climate and vegetation are described in general. Four forest associations are recognized, viz. *Prosopis juliflora solidus Salvadora persica, Acacia nilotica solidus Prosopis cineraria, Euphorbia commiphora solidus Acacia senegal* and *Acacia senegal solidus Prosopis cineraria.* Their locations, component species, mean density, mean cover, relative growth index and maximum height are given.

578 PARAMESWARAN, N.; SCHULTZE, R. **Fine structure of chambered crystalliferous cells in the bark of *Acacia senegal*.** *Zeitschrift für Pflanzenphysiologie* (1974) **1** 90-93

Describes the ultra-structure of the cells that occur at the periphery of bast-fibre groups in the bark.

579 PARIHAR, D.R. **Field evaluation of natural resistance of timber and fuel wood against termite attack**. *Annals of Arid Zone* (1997) **36** (1) 61-64

The resistance of timber wood (*Tectona grandis, Dalbergia sissoo, Acacia nilotica, Shorea robusta, Mangifera indica, Pinus longifolia [Pinus roxburghii], Tecomella undulata*) and fuel wood (*Acacia tortilis, A. senegal, Prosopis cineraria, P. juliflora, Leucaena leucocephala, Eucalyptus camaldulensis, Albizia lebbeck*) species to termite attack (*Microtermes, Eremotermes* and *Odontotermes* spp.) was assessed. Most damage was observed in *Leucaena leucocephala* (74.6 ± 2.6% weight loss) and least in *Dalbergia sissoo* (15.0 ± 7.8% weight loss).

580 PARIHAR, D.R.; SINGH, M.P. **Insects associated with kumat (*Acacia senegal* Willd) in the arid regions of western Rajasthan**. *Annals of Arid Zone* (1998) **37** (1) 89-95

The arthropod spectrum of *Acacia senegal* in the arid tracts encompassed 22 species of pest insects, 15 species of flower visitors, 3 species of parasitoids and 7 species of predators (including 4 spider species). Important injurious insects were *Oxycarenus sp., Holotrichia sp.*, bruchids and *Acmaeodera aurifera*. The flower visitors included *Apis florea, Halictus sp., Camponotus sp.*, and *Xylocopa sp.* The parasitoids were of hymenopteran lineage, while the predators were of Acarine and Coleopteran origin.

581 PARSA, A. **Flore de l'Iran**. Iran, Mazaheri Teheran (1948) **2** 491

Botanical description of *A. senegal* Willd. (syn. *A. rupestris* Stocks). It is recorded from Balouchestan, where the type specimen of *A. rupestris* Stocks was collected (Stocks 502 at Kew Herbarium).

582 PATEL, A.K.; BOHRA, H.C.; KAUSHISK, S.K. **Effect of supplementation on comparative weight gain of certain goat breeds in arid zone**. *Indian Journal of Small Ruminants* (1998) **4** (2) 91-93

The body weights and percentage weight gains of Jhakrana, Jamnapari, Parbatsar and Marwari goats (9 animals of each breed) were measured at fortnightly intervals. The animals were kept at the Central Research Farm, Jodhpur (India) and allowed to browse for 5-6 h/day. The principal plant species available were *Prosopis* cineraria, *Acacia senegal, Acacia tortilis, Tecomella undulata, Ziziphus nummularia* and *Cenchrus ciliaris*. Between October and June the animals were given pelleted concentrated feed (18% crude protein, 200 g/day). At the start of the experiment the Marwari goats had the highest body weight. A significant (P<0.01) increase in body weight was observed for all 4 breeds by the end of the period of supplementation. The gain in body weight was significantly (P<0.01) lower for Marwari goats than for the other breeds.

583 PATRICK, H.N.; LOWTHER, W.L. **Influence of the number of rhizobia on the nodulation and establishment of** *Trifolium ambiguum*. *Soil Biology and Biochemistry* (1995) **27** (4-5) 717-720

Rhizobium leguminosarum bv. *trifolii* in New Zealand soils is ineffective on *Trifolium ambiguum* and inoculation with an effective strain of rhizobia is essential for nodulation. We investigated the effect of inoculation on the establishment of over sown *T. ambiguum* (cv. Monaro) in different tussock grassland environments. Peat-based inoculant was applied to seed at a range of rates, in a gum arabic-lime pellet, and when sown 1 day after inoculation the number of rhizobia ranged from 0.2 times 10-3 to 260 times 10-3 seed-1. Over the 9 sites, seedling nodulation progressively increased from 5% up to 66% as the number of rhizobia seed-1 increased. Seedling establishment at the end of the first year was directly related to nodulation. These results have important practical implications in improving the establishment of this legume, as the number of rhizobia required to maximize nodulation is higher than that obtained by inoculation at the recommended rate.

584 PATTEN, R.S.; ELLIS, J.E. **Patterns of species and community distributions related to environmental gradients in an arid tropical ecosystem**. *Vegetatio* (1995) **117** (1) 69-79

The heterogeneous vegetation mosaic of the South Turkana region of north Kenya is associated with diversity in the region's physical environment. The abundance and distribution of the dominant species are related to gradients in those abiotic factors that influence water availability, including precipitation, soil texture, and topographic relief. Research focused on three *Acacia* species that are a major component of the Turkana vegetation: *A. tortilis, A. senegal* and *A. reficiens*. These species each exhibit a different response to variations in abiotic factors. Consequently, species abundance varies independently across the landscape, creating a continuum of intergrading populations. Community types can be identified within the mosaic of intergrading populations. Although community borders are not discrete due to continual change in species abundance, types are identifiable and are repeated in areas with similar environmental conditions. The landscape patterns are representative of Whittaker's (1953) climax as pattern, with communities created by individual patterns of populations responding to environmental gradients, creating a continuum of community change across the landscape.

585 PEAKE, F.G.G. **A Bruchid seed-borer in *Acacia arabica***. *Memoirs of Research Division, Ministry of Agriculture, Sudan* (1952) No.29 317-324

Names two Bruchid pests of *Acacia albida*; *Pachymerus pallidus* Pic. (also found occasionally on *A. arabica*) and *Pachymerus pallidus* Ol. (also found on *Medicago* sp., *Terminalia*, *A. verek* [*A. senegal*], and *A. arabica*). For *A. senegal* also recorded *Bruchus submaculatus* Fhs. and *Bruchus albosparsus* Fhs..

586 PEARCE, D.W. **Natural resource management and anti- desertification policy in the Sahel - Sudan zone**. *Geojournal* (1988) **17** 349-355

587 PELLEW, R.A. **The production and consumption of *Acacia* browse and its potential for animal protein production**. In *Browse in Africa (edited by Houérou, H.N. le)* Ethiopia; ILCA (1980) 223-233

Based on browse yield data from the *Acacia* dominated woodlands in the Serengeti National Park, Tanzania. The nutritional quality of browse from 6 *Acacia* species are tabulated, and *A. senegal* is shown to have the highest crude protein levels of all the species, the flushing shoots having a mean crude protein content of 33.5% with a maximum recorded figure of 37.7%. This browse persists only for a few days and then the shoots harden off and lignify, and the crude protein levels drop to about 22% in older leaves. This level is still high and the species is strongly selected for in the diet of both giraffe and elephants. Shoot growth occurs in growth spurts, but these are not synchronised and the proportion of flushing shoots is probably under 5% at any time. Productivity rates can be very high in *Acacia* browse, and records 1725 kg/ha/annum of new shoots and leaves from the ridge-top *Acacia* regeneration thicket (of which *A. senegal* forms 17% in species composition).

588 PELTIER, R. [**Trees in rural areas (of sub-Saharan Africa)**.] L'arbre dans les terroirs villageois. Savanes d'Afrique, terres fertiles? *Proceedings of a conference held at Montpellier, France, 10-14 December 1990*. Paris, France; Ministere de la Cooperation et du Developpement (1991) 507-530

Different agroforestry systems are briefly described, and recent research, particularly into improvements in tree productivity, is summarized. Included are details on planting live fences of *Acacia nilotica* on clay soils, *A. senegal* on sandy soils and *A. polyacantha* on ferruginous soils. Some problems encountered in the introduction of new methods are discussed; such as the resistance of farmers to the planting of shelterbelts (to prevent soil erosion and provide timber, fuelwood and forage) when traditionally the small size of cultivated plots and their proximity to woodland or fallow land provided adequate crop protection.

589 PERROT, E. [**Gum arabic**.] Gomme arabique. In *Ou en est l'Afrique Occidentale Francaise?* Mission en Cote d'Ivoire, Haute Guinee, Senegal (1939) 138-139

Gives export figures of gum arabic from Senegal, Mauritania and Niger as increasing since 1935 (4,062 tons) to between 4,083-5,537 tons in 1936. These figures could increase further, but for the decimation of the gum trees by the Peulh pasturalists, who cut the branches down so that their goats have access to the forage. By protecting 70,000 hectares in the area of Goundam from this indiscriminate lopping an annual production of 500 tons has been collected, which was divided between the pasturalists and traders.

590 PETERS, C.R.; O'BRIEN, E.M.; DRUMMOND, R.B. **Edible wild plants of sub-Saharan Africa**. Royal Botanic Gardens, Kew (1992) 1-239

Compiled from references a checklist of plants from sub-Saharan Africa, which have been recorded being eaten by primates, and divided into humans, chimpanzees and baboons. For *Acacia senegal*, humans eat the gum and baboons eat the young fruits, young leaves, flower buds and blossom.

591 PETRIE, W.M.F. **Medum**. Egypt Exploration Fund, London (1892) 1-52

592 PETRIE, W.M.F. **Abydos, part 1**. Egypt Exploration Fund, Memoir No 22, London (1902) 1-51

593 PHILIPS, S.; DEWAN, A.; NANDU, K.; GUPTA, S.C. **Optimization of *in vitro* seed germination and seedling growth of *Acacia* species**. *Forest, Farm, and Community Tree Research Reports* (1998) **3** 26-28

Data are reported from seed pretreatment tests with *Acacia nilotica* subsp. *indica*, *A. senegal* and *A. tortilis*, involving scarification at the chalazal end, soaking in distilled water for 2-12 hours at room temperature, or scarification followed by soaking. Soaking alone was the least effective treatment (promoting no germination at all in *A. nilotica*), and scarification followed by soaking the most effective treatment. The best seed germination and seedling growth was with scarification + 6 h soaking for *A. nilotica* subsp. *indica* and *A. senegal* and scarification + 4 h soaking for *A. tortilis*.

594 PHILLIPS, G.O. ***Acacia* gum (gum arabic): a nutritional fibre\metabolism and calorific value**. *Food Additives and Contaminants* (1998) 15 (3) 251-264

This paper reviews the metabolism of gum arabic and the relevance of this information in the formulation of an energy value.

595 PHILLIP, M.S. **Gum arabic and *Acacia senegal***. *Nigeria Forest Information Bulletin (New Series)*

Federal Department of Forestry, Ibadan (1975) No.29 1-12

A report on the future prospects for *Acacia senegal* plantations and gum arabic production in the north-eastern state of Nigeria. Nigeria produced 10% of the world production (data from Awonda 1973). Describes the silviculture, marketing and uses of the tree. In N. Nigeria plantations are established from nursery stock and survival was greater than 50%. Even though being browsed 5 year old plantations at Gajiram were ready for tapping gum, being over 2 m tall and 7 cm in diameter at the soil surface. Concluded that *A. senegal* plantations should be encouraged for reafforestation in Northern Nigeria.

596 PINTO, G.L. DE; MARTINEZ, M.; CLAMENS, C.; VERA, A. **Potential use of *Enterolobium cyclocarpum* gum.** [Uso potencial de la goma de *Enterolobium cyclocarpum.*] *Revista de la Facultad de Agronomia La Plata* (1996) **101** (1) 51-56

Describes the potential use of *E. cyclocarpum* gum, known as "caro caro" in Venezuela, which has some similar properties to gum arabic and could have industrial applications. The productivity of 2 watered specimens was relatively high (11-13 g/month/specimen). The gum contained galactose (49%), arabinose (20%), rhamnose (10%) and uronic acids (21%). The viscosity limit (100 ml/g) was higher than that reported for *Acacia senegal* gum ("gum arabic") (20 ml/g), and it was water soluble. Comparison of analytical data of the hydrocolloid in different conditions (crude, pure, stored for 6 months and heated at 100°C) does not show any significant difference. The cationic composition of the ash from the gum showed high contents of Ca, Mg and Na. The presence of heavy metals (Pb, Cd, and Co) was not found.

597 PIOT, J.; NEBOUT, J.P.; NANOT, R.; TOUTAIN, B. **[Utilisation of the Sahelian woody perennials by domestic herbivores. Quantitative study in the southern zone of the Mare d'Oursi (Upper Volta).]** Utilisation des ligneux sahéliens par les herbivores domestiques. Étude quantitative dans la zone sud de la mare d'Oursi (Haute Volta). Centre Technique Forestier Tropical, Institut d'Élevage et de Médicine Vétérinaire des Pays Tropicaux (1980) 1-304

Describes the phenology, ecology, biological production and use as animal fodder for 22 forage tree species, including *Acacia senegal.*

598 PLANT PROTECTION RESEARCH INSTITUTE, SOUTH AFRICA. **Checklist of insects on forest trees and shrubs in South Africa.** *Entomology Memoir, No.21, Department of Agricultural Technical Services, Pretoria* (1970) 1-81

A checklist of insects, mainly from the orders Coleoptera and Lepidoptera, found attacking trees and shrubs growing in South Africa. Many insect species are listed for the genus *Acacia* and one was also specifically noted for *Acacia senegal* as *Titoceres jaspideus* (Cerambycidae - Coleoptera), a larval borer.

599 PLAYFORD, J.; APPELS, R.; BAUM, B.R. **The 5S DNA units of *Acacia* species (*Mimosaceae*).** *Plant Systematics and Evolution* (1992) **183** (3-4) 235-247

The DNA sequence structure of 5S DNA units in *Acacia* species, including representatives from the three subgenera of *Acacia*, have been determined for the first time. The data were interpreted to suggest that at least three lineages of 5S DNA sequences exist in *Acacia* and the proposal was made that the lineages be named 5S Dna-1, 5S Dna-2, and 5S Dna-3. The 5S Dna-1 lineage was represented by units from *A. bidwillii*, (subgenus *Acacia*), the 5S Dna-2 lineage by units from *A. melanoxylon*, *A. pycnantha*, *A. ulicifolia*, (all subgenus *Phyllodineae) A. boliviana*, *A. bidwillii*, and *A. albida* (subgenus *Acacia)*, and the 5S Dna-3 lineage by units from *A. bidwilli, A. boliviana,* and *A. senegal* (subgenus *Aculeiferum*). Based on this interpretation of the sequence data, the Australian species of subgenus *Phyllodineae* grouped together as a cluster, quite separate from the subgenera *Aculeiferum* and *Acacia*, which were very similar for this character. As expected from the analyses of morphological characters, the 5S DNA units from *A. albida* (syn. *F. albida*) were quite separate from the other *Acacia spp.*, further support to it belonging to the monotypic genus *Faidherbia.* It is interesting to note that the existence of NA lineages, implies that the 5SDNA-2 must have evolved or been amplified before the break up of Gondwanaland, as it is in species endemic to the 3 continents.

600 PLAYFORD, J.; APPELS, R.; BAUM, B.R. **The 5S DNA units of *Acacia* species (*Mimosaceae*).** *Bulletin of the International Group for the study of the Mimosoideae* (1997) **20** 19-20

The same results reported in the above abstract Playford *et al.* (1992).

601 POHJONEN, V. **White Nile reforestation. Ten years of the Sudan-Finland forestry programme.** *Development Journal* (launch issue) (1990) 16-17

General article highlighting the Sudan-Finland forestry programme in the White Nile province by a FINNIDA forestry advisor. This area is one of the important gum arabic producing areas of Sudan, which is collected from privately owned gum gardens or natural stands of *Acacia senegal.* Unfortunately since the 1970's a series of factors (such as growing populations and increased demand for cereals) have reduced the fallow period of seven to ten years in the gum gardens which was sufficient for the acacias to regenerate and soil to regain its fertility. Deforestation resulted with increased

fuel wood shortages, exasperated by ever increasing demands for charcoal in Khartoum. Desertification followed with loss of topsoil from wind blow, and ever declining cereal yields forced the farmers to migrate. The main objective of the programme was to increase reforestation using *A. senegal* and *Prosopis juliflora*. By 1988 four million seedlings had been raised and 5,400 ha planted although droughts in some years had produced failures. Found that seedlings grown in improved pot-tray method could be planted two to four times faster than the traditional polythene tube seedlings. There is also a critical period in the planting season (15 July-15 August), which coincides with the peak labour demand in agriculture. Survival of seedlings was found to be best at the top of the ploughing ridge and not at the bottom of the furrow. Points to the need for increasing gum gardens where *A. senegal* is planted and more research on alley cropping such as *Prosopis* with sesame or karkadeh.

602 POLLATH, W. [**Gum arabic from the Sudan.**] *Zeitschrift für Wirtschaftsgeographie* (1972) **16** (7) 220-221

Sudan is the world's major producer of gum arabic, from *Acacia senegal* and *A. seyal*, mainly in Kordofan province; 56,000 tons were exported in 1966.

603 POPOV, G. **Some notes on injurious Acrididae (Orthoptera) in the Sudan-Chad area**. *Ent. mon. Mag.* (1959) **95** 1139

Includes a note on the tree locust *Anacridium melanorhodon melanorhodon* found principally on species of *Acacia*, *Balanites* and *Zizyphus*. Damage to trees, particularly *Balanites* spp., *A. mellifera* and *A. senegal*, was considerable and the insect, which appears to be increasing, is considered a serious threat to agriculture. It appeared to be largely confined to the denser parts of *Acacia*/short-grass savanna and mixed deciduous woodland zones.

604 POULSEN, G. **The non wood products of African Forests**. *Unasylva* (1982) **34** (137) 15-21

605 POUPON, H. [**Biomass partitioning during the growth of *Acacia senegal* in a Sahelian savanna (Senegal).**] La Biomasse et l'evolution de sa repartition au cours de la croissance d'*Acacia senegal* dans une savane sahelienne (Senegal). *Bois et Forêts des Tropiques* (1976) No.166 23-28

Biomass and net primary production (dry weight) of *A. senegal* were determined in savanana within the Sahelian zone at Ferlo, N. Senegal, and the structure of the population was studied in a 25-ha quadrat comprising five types of relief. The population studied had an inverted J distribution, and 70% of all individuals were less than 10 cm circumference. An attempt is made to establish the relation between number of growth rings and girth at the butt. The changes that occur in above-ground and underground biomass as a function of tree age are demonstrated, although he failed to confirm experimentally that the growth rings were annual. Young trees quickly develop a large root system. In an adult tree, the root system represents 40% by weight of the total biomass, while the above-ground biomass is equally distributed among the tree components: stem, main branches, and secondary branches. An estimate is given of the production of deciduous material (leaves, flowers and fruit) for 1973. An initial calculation of foliar productivity shows that, during the years when leaf efficiency is highest and the tree at its most vigorous (21-30 growth rings which he correlates as "years old"), dry-matter production amounts to 729 g/year per m^2.

606 POUPON, H. [***Acacia senegal* dry matter production in a Sahelian savanna in *Senegal*.**] Production de matière sèche d'*Acacia senegal* (L.) Willd. dans une savanne sahélienne au Sénégal. *Geo-Eco-Trop* (1977) **1** (3) 209-228

The biomass and net primary productivity of *A. senegal* were measured in a 25-ha plot of 292 trees at Ferlo, N. Senegal (8 trees felled for biomass determination). Regression equations relating the biomass of stems, branches and roots to the number of annual rings were developed. Over the first 20 years of growth a large root system develops, while the aerial parts develop more slowly. At age 16-40 yrs, aboveground biomass increases more quickly than underground biomass, with its max. m.a.i. at 30-40 yrs, coinciding with the max. foliar production. The older the tree becomes, the greater the flower production, with max. fruit production between 30 to 40 yrs. After this point, flower production continues to rise, but fruit production decreases.

607 POUPON, H.; BILLE, J.C. [**Ecological research on a Sahelian savanna of northern Ferlo, Senegal: effect of the drought in 1972-73 on the trees.**] *Terre et la Vie* (1974) **28** (1) 49-75

Describes the effect of the 1972 drought on the tree canopy of the IBP study site in Senegal. Compared with the usual pattern, trees came into leaf later, leaf production was less, and leaves were retained for a shorter time. Fruit and seed production were very low or nil. The commonest species (comprising 98% of the trees) varied in their resistance to drought in the order *Boscia senegalensis* (0.2% mortality); *Grewia bicolor* (1%); *Balanites aegyptiaca* (5.5%); *Commiphora africana* (7.9%); *Acacia senegal* (53%) and *Guiera senegalensis* (63%).

608 PRATT, D.J. **Bush-control studies in the drier areas of Kenya. I. Preliminary work with the Holt machines**. *Empire Journal of Experimental Agriculture* (1964) **32** (125) 18-25

An experiment in Baringo District, Kenya, tested the efficiency of two machines from the Holt Weed Breaker range in controlling regeneration *Acacia/Tarchonanthus* bush. The species studied were *A. brevispica*, *A. nilotica* ssp. *subalata*, *A. senegal*, *A. seyal* var. *seyal*, and *T. camphoratus*. The effects of (a) the Holt VIa and (b) the Holt VIIIb, both pulled by a Fordson Major tractor were compared with two controls, i.e. (c) the tractor without extra machinery and (d) no treatment. The machine tended to flatten the trees. Neither (a) nor (b) had a significant killing effect, but in the case of *A. nilotica* there may have been a slight killing effect in the 5-10 ft height class. The natural rate of regeneration was doubled as a result of soil disturbance. *A. brevispica* and *T. camphoratus* contributed little but the other *Acacia* species increased by 140-300% following (a) and (b) compared with 75-120% for (c) and (d). It is concluded that, although the machines are useful in flattening the bush, their use requires follow-up treatment if a useful kill of the thicket-forming species is to be achieved. It appears that the machines by themselves would be of greatest use on denuded grazing lands where their use encourages regeneration. On grasslands better control of the woody species could probably be achieved by burning.

609 PRATT, D.J. **Bush control studies in the drier areas of Kenya. VI. Effects of fenuron (3-phenyl-l, l-dimethyl urea).** *Journal of Applied Ecology* (1971) **8** 239-245

In field trials with the arboricide fenuron the best results were achieved when the pellets were placed on the ground immediately at the bases of the stems. *Commiphora* spp. and the broadleaf shrubs *Maytenus putterlickioides*, *Premna oligotricha* and *Tarchonanthus camphoratus* were generally tolerant of the recommended dosage of 7 g active ingredient. However, *Dichrostachys cinerea* and most *Acacia* spp. were sensitive to treatment. The chemical was particularly effective against *A. mellifera* ssp. *mellifera* and *A. reficiens* ssp. *misera* under arid conditions where 100% mortality was achieved, but *A. nilotica* ssp. *subalata* and *A. senegal* var. *senegal* were semi-tolerant to treatment. It is suggested that subsequent burning may be effective in increasing the percentage kill of some species. From author's summary.

610 PRATT, D.J.; KNIGHT, J. **Bush control studies in the drier areas of Kenya. V. Effects of controlled burning and grazing management on *Tarchonanthus /Acacia* thicket.** *Journal of Applied Ecology* (1971) **8** (1) 217-237

A combination of burning, use of goats and preliminary slashing in two management systems is described to control bush encroachment, which is appropriate to traditional cattle husbandry. It is suggested that the *T. camphoratus/ A. brevispica* thicket association is a fire climax. Noted that *Acacia nilotica* ssp. *subalata* was tolerant of burning increasing seedling regeneration from 17 to 82 plants/ha in slashed areas, and might form an important constituent with *A.seyal*, of the woodland or wooded grassland that could be expected to develop if the thicket components of vegetation (esp. *A. brevispica*) were removed. *A. senegal* var. *senegal* was generally tolerant of burning (unlike *A. gerrardii* var. *gerrardii*) and goats grazing prevented a 100% increase in population, which occurred in their absence. Goats also reduced the natural regeneration of *A. nilotica* and *A. seyal*.

611 PRIN, Y.; GALIANA, A.; DUCOUSSO, M.; DUPUY, B.; LAJUDIE, P. De.; NEYRA, M. **Rhizobia of *Acacia* spp.: biodiversity and taxonomy. Les *Rhizobium* s d'Acacia: biodiversite et taxonomie.** *Bois et Forêts des Tropiques* (1993) No.238 5-20

In the first part of the article, the authors review the concepts of taxonomy, genus, species, isolate, biotype, strain, and species diversity of root nodulating bacteria (*Rhizobium* spp. and *BradyRhizobium* spp.). The second part discusses the importance of identifying rhizobial species, particularly in the context of field inoculation trials and the utilization of strains. Research in two laboratories into root nodulation of the genus *Acacia* is outlined: that at the ORSTOM/ISRA laboratory in Dakar, Senegal, has concentrated on the diversity of rhizobia in dry zone acacias (*A. senegal*, *A. raddiana* and *A. seyal*); research at the ORSTOM/CIRAD laboratory near Paris, France, has been investigating nodules in humid zone acacias (e.g. *A. mangium*).

612 PRINCE, S.D. **Measurement of canopy interception of solar radiation by stands of trees in sparsely wooded savanna.** *International Journal of Remote Sensing* (1987) **8** (12) 1747-1766

A 3-dimensional tree canopy model is described for savanna-type vegetation comprising a discontinuous tree layer and a continuous field layer. Hemispherical canopy photographs were used to measure three parameters for the model: direct solar radiation; diffuse sky radiation; and emission of reflected radiation from vegetation. Frequency distribution of tree canopy diameters, measured from the ground or on aerial photographs, provides input for the model. Measurements made in Sudan showed that canopy cover measured in the traditional way (treating canopy as opaque) over-estimates interception by about half. Comparisons between *Acacia senegal* and *Acacia mellifera*, *Albizia amara*, *Balanites aegyptiaca*, *Bauhinia reticulata* and *Combretum cordofanum* show significant differences in transmission characteristics between species.

613 PRIOR, J.; TUOHY, J.; WHITING, J. **Interrelationships between aspects of nitrogen metabolism and solute accumulation and the distribution of subtropical woody plants in southeast Africa.** *New Phytologist* (1987) **107** 427-439

Leaf samples from 59 species in 5 savanna areas of southeastern Africa, collected during the dry season were used in a preliminary investigation into physiological adaptations caused by environmental stress. Basal and induced nitrate reductase activity and basal concentrations of proline, quaternary ammonium compounds and condensed tannins were analysed. In *Acacia senegal* leaves proline and quaternary ammonium compounds (examples of stress metabolites) were found, but no tannins.

614 PROT, J.C. [**Susceptibility of seven leguminous trees to the root-knot nematodes *Meloidogyne javanica, M. incognita, Scutellonema cavenessi* and *Dolichorhynchus elegans***.] Sensibilité de sept légumineuses arborescentes aux nématodes *Meloidogyne javanica, M. incognita, Scutellonema cavenessi* et *Dolichorhynchus elegans*. *Revue de Nématologie* (1986) **9** (4) 416-418

Seven tree species (six *Acacia* spp. and *Prosopis juliflora*) proposed for reforestation of the Sahelian zone of Senegal were tested for susceptibility to infestation with four root-knot nematodes common in Senegal. All the tree species were more or less susceptible to *Meloidogyne javanica* and *M. incognita*, with *Prosopis juliflora* as the best host for both. *Acacia raddiana* (*A. tortilis* ssp. *raddiana*), *A. nilotica*, *A. senegal* and *A. tumida* were poor hosts, only maintaining the initial population inoculated, whereas *A. albida* and *A. holosericea* were good hosts. Weak reproduction of *Scutellonema cavenessi* took place only in *A. holosericea* and *P. juliflora*, and *Dolichorhynchus elegans* reproduced only in *A. holosericea*.

615 PURI, D.; MUTHANA, K.D.; HANDA, D.P. **Studies on the comparative growth and establishment of *Acacia tortilis* (Forsk) and *Acacia senegal* in rocky habitats**. *Annals of Arid Zone* (1973) **12** (3/4) 167-171

Compares direct sowing and planting of 1-year-old nursery-grown seedlings of *Acacia tortilis* from Israel (a) and *A. senegal* from a local source (b) on a rocky site in W. Rajasthan. Data for height growth, over a 5-year-period, indicated that in all cases (a) was substantially superior to (b). Height growth was greater with planting than with direct sowing in both species, but even direct sowing of (a) was superior to planting of (b).

616 QI, W.; FONG, C.; LAMPORT, D.T.A. **Gum arabic is a twisty hairy rope.** *Plant Physiology* (1991) **96** 848-855

617 RAEBILD, A.; GRAUDAL, L.; OUEDRAOGO, L.G. **Evaluation of a provenance trial of *Acacia senegal* at Dori, Burkina Faso.** *Results and Documentation Series, Danida Forest Seed Centre, Humlebaek, Denmark* (2003a) No. 3 1-36 (available from www.dfsk.dk)

Results of a trial established in 1988 at Dori Burkina Faso, of seven provenances of *A. senegal*, and vegetative and growth characters assessed after 5 years in 1993. Gum production was not measured. Seedlings were established at 4 x 4m spacing, in an area of 400-600 mm mean annual rainfall. Survival varied between 60-90%, and the average heights were around 1.5 m although not significant between provenances. The fastest growing provenances produced approx. 3 t/ha after 5 years, or 0.6 t/ha/yr.

618 RAEBILD, A.; GRAUDAL, L.; OUEDRAOGO, L.G. **Evaluation of a provenance trial of *Acacia senegal* at Gonsé, Burkina Faso.** *Results and Documentation Series, Danida Forest Seed Centre, Humlebaek, Denmark* (2003b) No. 5 1-26 (available from www.dfsk.dk)

Results of a trial established in 1988 at Gonsé Burkina Faso, of ten provenances of *A. senegal*, and vegetative and growth characters assessed after 5 years in 1993. Provenances came Burkina Faso, Senegal, Sudan and Pakistan. Seedlings were established at 4 x 4m spacing, in an area of 600-800 mm mean annual rainfall. Gum production was not measured although gum was being produced naturally. Highly significant differences were found between provenances, the two Pakistani provenances performed poorly, and the best provenances were from Senegal and Burkina Faso. The fastest growing provenances produced almost 2 t/ha/yr of above ground dry biomass, with the best provenance from Burkina with individuals weighing 15 kg/tree.

619 RAHEJA, P.C. **Influence of climatic changes on the vegetation of the arid zone in India**. *Ann. Arid Zone, Jodhpur* (1965) **4** (1) 64-73

Describes the geological history of W. Rajasthan, recent climatic changes, and the vegetation of four climatic zones (arid, semi-arid, transitional and sub-humid). *Acacia senegal* var. *senegal* grew successfully on rocky areas, on semi-rocky and gravely areas, on sandy soils but not on consolidated loam.

620 RAINA, A. K. **Acacia for arid zones**. *Nitrogen Fixing Tree Research Reports* (1984) **2** 9-10

Over 60 Acacia species were tried in trials at 5 x 5 m spacing in the hot arid zone of Jodhpur, Western Rajasthan, India, which has an annual rainfall of 320 mm. Nine species with promising performance were taken up for multilocational trials. For *Acacia senegal* (Kenyan provenance) 14 year growth data is presented. On sandy soil overlying a kamkar pan heights of 5.8 m were recorded with a DBH of 9.8 cm. On a rocky site trees measured 3.3 m high.

621 RAMSAY, D. McC. **The forest ecology of central Darfur**. *Forest Bulletins (New Series), Forests Department, Sudan* (1958) No.1 1-84

A publication in three parts: (a) General description of Darfur and the major environmental factors; (b) The vegetation of Darfur, and its correlation with the vegetation in other areas of Africa; and (c) Detailed description of the vegetation of central Darfur. *Acacia adansonii* [*A. nilotica* ssp. *adstringens*] occurs on hard soils in several climatic associations of the region: Thorn forest formation: *Acacia mellifera, Commiphora africana, Acacia nubica, Acacia tortilis* association, located between 300 mm and 500 mm isohyets. *Albizia sericocephala, Acacia seyal, Acacia senegal, Acacia mellifera* association, located between 450 mm and 650 mm isohyets. Savanna woodland formation: *Annogeissus schimperi, Acacia seyal, Lannea humilis, Albizia sericocephala* association between 600 mm and 800 mm isohyets. The abundance of *A. adansonii* in these associations does not exceed 2.4% of total stocking. The species is also found in the edaphic associations of riparian vegetation Riparian thorn land formation: *Acacia mellifera, Boscia senegalensis, Acacia nubica, Balanites aegyptiaca* association. Riparian thorn forest formation: *Acacia albida, Acacia tortilis, Ziziphus mucronata, and Balanites aegyptiaca* association. The association, which includes *Acacia nilotica* ssp. *nilotica* is found on sandy silt soils of wadi banks and flood plains.

622 RASANEN, L.A.; LINDSTROM, K. **The effect of heat stress on the symbiotic interaction between Sino- *Rhizobium* sp. and *Acacia senegal*.** *FEMS Microbiology Ecology* (1999) **28** (1) 63-74

Sino-*Rhizobium* sp. strain HAMBI 2180, marked with the beta glucuronidase (GUS) encoding gus A gene, was used for studying the effect of heat stress on the symbiotic interaction between *Acacia senegal* seedlings and Sino-*Rhizobium* sp. in growth cabinet conditions. The infection process, observed during 18 days after inoculation, was delayed at a root temperature of 40°C compared to a root temperature of 38°C, but nodulation was retarded already at 38°C. At 42°C no nodules were formed. At this root temperature the development of lateral roots and root hairs was one week delayed. Although the roots had normally deformed root hairs in addition to abnormally deformed ones, only disintegrated infection threads were present. However, the ability to form symbiosis was reversible. Nitrogen fixing nodules developed on those parts of the roots, which were formed after completion of the thermal stress at 42°C. A root temperature of 42°C did not affect the numbers of culturable rhizobia in the *A. senegal* rhizosphere.

623 RASHID, A. **New weapon to beat drought.** *South* (1986) 127-128

Experiments in Sudan, with a new generation of synthetic water absorbing polymers have proved successful in the battle to save drought prone parts of Africa. Trials dealt with 4 economically important trees including *Acacia senegal*, source of gum arabic and fuel; covering stages in tree production from germination through nursery growth to transplantation. Results suggest that a technique with so much impact on tree survival should more than pay its way.

624 RASPLUS, J.Y. [**New Afro tropical species of the genus Entedon Dalman and notes on their biology.**] Nouvelles especes afrotropicales du genre *Entedon* Dalman et notes sur leur biologie. *Bulletin de la Societe Entomologique de France* (1990) **94** (7-8) 223-245

Six new species of the genus *Entedon* are described from the Ivory Coast. These include *E. albizia* rum sp. nov. and *E. vuattouxi* sp. nov. from larvae of *Bruchidius albizziarum* in seeds of *Albizia adianthifolia, A. ferruginea* and *A. zygia*, and *A. adianthifolia* and *A. zygia*, resp., *E. bouceki* sp. nov. from larvae of *B. lamtoensis* in seeds of *Entada scelerata, Entedon bruchivorus* sp. nov. from larvae of bruchids attacking Mimosaceae and Caesalpiniiaceae and *E. omnivorus* sp. nov. from larvae of *B. uberatus* on seeds of *Acacia nilotica*. Also, *E. pterocarpi* sp. nov. is described from an apionid in grains of *Pterocarpus angolensis* in Zaire, *E. senegalensis* sp. nov. from the apionid *Piezotrachelus* various on seeds of *Vigna unguiculata* in Senegal and *E. delvarei* sp. nov. from bruchids on *A. senegal*, also in Senegal. A description of *E. apionidis*, a parasitoid of *Apion xanthostylum* on cotton, is also given. A key to the females of Afrotropical species is provided.

625 RATHGEB, R. **The promotion of Gum Arabic.** Restricted Report Proj. No SUD/24/59 ITC/DTC/89/1061 (1989)

626 RAVEN, P.H.; AXELROD, D.I. **Angiosperm biogeography and past continental movements.** *Annals of the Missouri Botanic Garden* (1974) 61 (3) 539-673

627 RAVEN, P.H.; POLHILL, R.M. **Biogeography of the Leguminosae.** In: *Advances in Legume Systematics Part 1 (edited by Polhill, R.M. & Raven, P.H.), Royal Botanic Gardens, Kew, UK* (1981) 27-34

628 RAY, A.K.; BIRD, P.B.; IACOBUCCI, G.A.; CLARK, B.C. Jr. **Functionality of gum arabic: Fractionation, characterization and evaluation of gum fractions in citrus oil emulsions and model beverages.** *Food Hydrocolloids* (1995) **9** (2) 123-131

Gum arabic, the exudate from *Acacia senegal*, has been fractionated by size exclusion chromatography (SEC) and by hydrophobic interaction chromatography (HIC). The data support a picture of gum arabic as a very complex, polydisperse glycoprotein, polydisperse in mol. wt and particularly in protein composition. Gum

arabic, an excellent emulsifier, is endowed with a particularly good combination of many molecular species differing in size and composition.

629 REDDELL, P.; WARREN, R. **Inoculation of *Acacias* with mycorrhizal fungi: potential benefits**. In *Australian Acacias in developing countries. ACIAR Proceedings, Australian Centre for International Research* (1987) No.16 50-53

Reviews the potential for using mycorrhizal fungi to improve the survival, establishment and growth of hardwood species in tropical plantations. Both ecto and VA mycorrhizal types have been found in the roots of *Acacia* species, which increase plant growth by enhancing the absorption of nutrients, and may reduce the effects of drought and transplantation stresses. In the African species of Acacia (such as *A. albida*, *A. nilotica*, *A. senegal* and *A. tortilis* ssp. *raddiana*) only VA mycorrhizas have been found .

630 REHMAN, S.; HARRIS, P.J.C.; BOURNE, W.F. **The effect of hardening on the salinity tolerance of *Acacia* seeds** . *Seed Science and Technology* (1998) **26** (3) 743-754

Seeds of *Acacia, A. bivenosa, A. coriacea, A. elata, A. farnesiana, A. nilotica, A. salicina, A. saligna, A. senegal, A. tortilis* and *A. tumida* were hardened by soaking in distilled water (DW) for 10 h and drying before germination. Depending on species, final germination in DW was either reduced or unaffected by hardening while germination in NaCl, at the LD50 concentration for each species, was reduced, unaffected or increased. Similarly, germination rate was reduced, unaffected or increased in DW and NaCl by hardening. Hardened seeds of species such as *A. tortilis* which had high initial viability and germination rate and lower leakage of K^+ and Ca^{2+} into water showed increased rate of germination in DW and NaCl and increased final germination in NaCl. In contrast, *A. elata*, with low initial viability and germination rate and higher leakage of K^+ and Ca^{2+} showed reduced germination and germination rate in DW and in NaCl as a result of hardening. It is unclear to what extent the response to hardening reflects differences between species rather than differences in the viability and vigour of particular seed batches. Hardening may have considerable value for increasing the final germination and germination rate of seeds in saline soils.

631 REHMAN, S.; HARRIS, P.J.C.; BOURNE, W.F.; WILKIN, J. **The effect of sodium chloride on germination and the potassium and calcium contents of *Acacia* seeds**. *Seed Science and Technology* (1997) **25** (1) 45-57

Acacia bivenosa, A. coriacea, A. elata, A. farnesiana, A. nilotica, A. salicina, A. saligna, A. senegal, A. tortilis and *A. tumida* were screened for their salt tolerance during seed germination in the presence of NaCl. The uptake of water, and the levels of Na^+, K^+ and Ca^{2+} of *A. coriacea* (salt sensitive), *A. nilotica* (intermediate) and *A. tortilis* (salt tolerant), before and after imbibition, were measured to ascertain the contributions of ionic and osmotic factors to the observed differences in response to salt stress. Imbibition by seeds incubated on NaCl solutions was reduced by only approximately 1% for each 100 mol/m^3 increase in NaCl concentration. The relationship between Na^+ concentration applied to the seeds and the Na^+ concentration of the solution imbibed did not differ significantly among the species and there was no indication that selective uptake or exclusion of Na^+ contributed to the differences in salinity tolerance. *A. tortilis* seeds had significantly lower initial K^+ concentration and lost significantly less K^+ in response to Na^+ uptake than did either *A. nilotica* or *A. coriacea*. In contrast, the initial concentration of Ca^{2+} was significantly higher in *A. tortilis* than in the other two species, and the loss of Ca^{2+} in response to Na+ was higher in *A. tortilis* than in *A. coriacea*. The adverse effects of NaCl on seed germination, observed in this study, appear to result from internal osmotic or ion toxicity effects rather than from a restriction of imbibition.

632 REHMAN, S.; HARRIS, P.J.C.; BOURNE, W.F.; WILKIN, J. **The relationship between ions, vigour and salinity tolerance of *Acacia* seeds**. *Plant and Soil* (2000) **220** (1/2) 229-233

Experiments carried out to determine whether seed ion contents and leakage, and seed germination percentage and rate, could be used to predict salt tolerance at the germination stage of a range of *Acacia* species including *A. senegal*. Seeds of the *Acacia* species were tested for their final germination percentage in distilled water (DW) and in 25-400 mol/m^3 NaCl, germination rate, Ca and K concentrations, the leakage of these ions when soaked for 24 h in DW and in 250 mol/m^3 NaCl. Linear regressions revealed significant positive relationships between salinity tolerance, final germination percentage, Ca/K concentration and Ca/K leakage when soaked in 250 mol/m^3 NaCl. Multiple regressions were developed to predict I50 (the concentration of NaCl required to reduce final germination to 50% of the control value in DM) from the above parameters. The best fitting equation, accounting for 93% of the variation, was I50 = 108 + 422 Rate - 1.32 K (K concentration) + 16.3 Ca leakage in DW- 5.4 K leakage in DW + 71.6 K/Ca leakage in DW. This equation provides a screening test for the salt tolerance of *Acacia* seeds.

633 REHMAN, S.; HUSSAIN, A.; AMEEN, S. **Results of early selection of *Acacia* and *Prosopis* species/seed sources**. *Pakistan Journal of Forestry* (1988) **38** (2) 109-117

Survival and height growth of a number of indigenous and exotic species of *Acacia* (*A. tortilis, A. albida, A. aneura, A. holosericea, A. cowleana, A. nilotica* and

A. senegal) and *Prosopis* (*P. tamarugo*, *P. chilensis* and *P. cineraria*) in the nursery at Peshawar gave significant differences among sources, indicating the possibilities for selection of the best seed sources for afforestation in Pakistan. Further scope for improvement of the species is discussed. Recommends using hot water treatment (5 mins in water which has boiled before sowing) for *A. senegal*. Seed from 6 provenances of *Acacia senegal* were tried in the nursery, and survival rates after 3 months varied from 39-53%, and seedling heights 21-26 cm high.

634 RELWANI, L.L.; LAHANE, B.N.; GANDHE, A.M. **Performance of nitrogen fixing MPTS on mountainous wastelands in low rainfall areas. Multipurpose tree species for small farm use**. *Proceedings of an international workshop held November 2-5, 1987 in Pattaya, Thailand (edited by Withington, D.; MacDicken, K.G.; Sastry, C.B.; Adams, N.R.)*. Co-published with the International Development Research Centre, Canada. Arlington, Virginia, USA; Winrock International Institute for Agricultural Development (1988) 105-113

The introduction to this paper summarizes the results of highly successful earlier trials on fodder and wood production by *Leucaena leucocephala* carried out at the BAIF Central Research Campus on the mountainous Deccan wastelands of India. The most successful provenances were the Hawaiian Giants K8, K29, K67 and K72. The rest of the paper describes the results of the current trials with a large number of other nitrogen fixing and dry zone multipurpose tree species (MPTS) under rain fed, irrigated, and hand watering systems, with an annual rainfall of 350-400 mm over the experimental period (1982-87). Under rain fed conditions, *L. leucocephala* achieved the best growth, followed by *Acacia tortilis* and *Acacia senegal*.

635 REYNDERS, M.I. **Depth of sowing trial with *Acacia senegal***. *Pamphlet, Forestry Research Education Project, Forest Department, Sudan* (1965) No.7 1-8

Best germination and survival resulted, in a nursery trial, from sowing at a depth of 0.5-1 cm; 80% of the seeds germinated within 15 days of sowing without any pre-treatment (seed 6 months old).

636 RIEDACKER, A.; DREYER, E.; PAFADNAM, C.; JOLY, H.I.; BORY, G. **Physiologie des arbres et arbustes en zones arides et semi arides** [Physiology of trees and shrubs of arid and semiarid zones.] *Proceedings of a seminar held at Nancy and Paris, France, 20 March 6 April 1990*. Montrouge, France; John Libbey Eurotext (1993) 1-489

Papers are presented from a seminar held under the aegis of Groupe d'Etude de l'Arbre (the Tree Study Group) and Observatoire du Sahara et du Sahel (the Sahara and Sahel Observatory). Participants were mainly from research organizations and universities in France, and from countries (French speaking) in the Sahel and Sahara regions of Africa. There are 8 chapters. Chapter 1, Adaptation of forest trees to drought, has 9 papers, covering in situ measurement techniques, effects of drought on physiological processes, and one paper giving preliminary results of tests on the water relations of four exotic species used for afforestation in N. Cameroon. Chapter 2, Trees in plantations: competition and installation, has 3 papers examining the ecophysiology of trees, or interactions between trees and other plant species, and includes reports of trials into the establishment, growth and suitability of 33 multipurpose tree species for use as living fences in Burkina Faso including *A. senegal* at Gonse (survival was 100% for nursery sown stock of *A. senegal* and 11% for direct sown. Chapter 3, Root symbioses in semiarid zones, contains 6 papers, covering mycorrhizas of *Acacia* spp., nitrogen fixing bacteria (including a paper on *A. senegal* covered separately in this bibliography) and *Casuarina* spp., and *A. holosericea* and multiple symbionts. Chapter 4, Physiology of a multiple use species, *Acacia albida* (*Faidherbia albida*) has 5 papers on phenology, genetic variation, architectural development, *Rhizobium* spp. diversity, and vesicular/arbuscular mycorrhizas (VAM) and their interactions with *BradyRhizobium* sp. Chapter 5, Gummosis and optimizing management of *Acacia senegal*, comprises 7 papers (all covered separately here) addressing histological studies, induction of gummosis, and *in vitro* tissue culture and vegetative propagation techniques. Chapter 6, The contribution of the physiology of date palms to the regeneration of palm groves. Chapter 7, Physiology of afforestation species, contains 11 papers on arganier (*Argania spinosa*, 2 papers), *Acacia raddiana*, *Balanites aegyptiaca*, carob (*Ceratonia siliqua*), shea nut tree (*Butryospermum paradoxum* [*Vitellaria paradoxa*]), *Moringa spp. (M. oleifera* and *M. stenopetala*), Aleppo pine (*Pinus halepensis*), *Tamarix aphylla*, yeheb (*Cordeauxia edulis*), and *Pistacia atlantica*. Chapter 8 briefly summarizes conclusions and future recommendations reached by the participants, and for *A. senegal* recommendations to use clonal material to remove the genetic variables in gummosis studies.

637 ROBERTS, H. **Forest insects of Nigeria with notes on their biology and distribution**. *Institute Paper, Commonwealth Forestry Institute, University of Oxford* (1969) No.44 1-206

Gives details of the activities of: (a) insects attacking living trees; (b) insects attacking felled and dying trees and lumber; (c) insect parasites, predators and commensals. The following has been found on *Acacia senegal*:- Order ORTHOPTERA, Family ACRIDIDAE, *Anacridium melanorhodon melanorhodon* Walker- the Sahel Tree Locust which feeds on the foliage of trees in contrast to the other locusts occasionally seen in swarms in Nigeria which feed on agricultural crops. In the Bornu area, *A. senegal* is one of its favoured food trees. There is no recorded damage to any forest plantations.

638 ROBBERTSE, P.J. **The genus *Acacia* Miller in South Africa. The genus *Acacia* Miller in south Africa V. with special reference to the seedling structure as a taxonomic characteristic**. *Mitt. Bot. Staatssamml. Munchen* (1971) **10** 170-177

The seedlings of the genus can be divided into two main categories, namely those of which the cotyledons are sessile and those with petiolated cotyledons including *A. senegal*. Ten groups of species were made from the external morphology of the seedlings and *A. senegal* var. *leiorhachis* belonged to group 6 which has its first leaf pinnate and the second leaf bipinnate with four jugae. *A. senegal* var. *rostrata* belonged to group 8a, which has its first leaf pinnate and the second leaf bipinnate with two jugae.

639 ROBBERTSE, P.J. **The genus *Acacia* in South Africa. II. With special reference to the morphology of the flower and inflorescences**. *Phytomorphology* (1974a) **24** (1/2) 1-15

With this investigation the term 'flowering system' is introduced to describe the branch system on which inflorescences are produced. The South African *Acacia* species are divided into several groups based on the flowering system. The relationship between the type of flowering system, and the time of flowering of the different species is discussed. The possible origin of the involucel of the *Gummiferae* species and the importance of this phenomenon as a taxonomic criterion is discussed. Sketches of the flowers of all the investigated species are given to emphasize the presence of a cuplike disc in the flowers of the Vulgares species, the structure and the appendages of the ovary and the indumentum of the calyx as taxonomic criteria. Suggests that the paniculate flowering system, the spicate inflorescence, pedicelled flowers, presence of a cup-like disc and a pedicellate ovary are all primitive characteristics found in the Vulgares section (includes *A. senegal*).

640 ROBBERTSE, P.J. **A scanning electron microscopic investigation of the pollen of South African *Acacia* species**. *Journal of South African Botany* (1974b) **40** (2) 91-99

Uses SEM and light microscopic techniques to gain further details on the surface structures of pollen of South African *Acacia* species, and briefly discusses the taxonomic position of *A. albida* and *A. giraffae* [*A. erioloba*]. *A. albida* is distinct in that (1) unlike all S. African acacias it has no glandular appendages on its anthers, (2) it has polyads with ungrooved monads like the *Acacias* in the series *Vulgares* [which include *A. senegal*], which all have 16 cell polyads but (3) it has up to 32 cells in the polyad (4) 2 peripheral monads on each lateral side of the polyad undergo a single division to form a double layer (unlike all others except *A. giraffae*). Concludes that *A. giraffae* and A. *albida* must be relicts of the parental stock of the African *Acacia* species, and *A. albida* should not be separated into *Faidherbia*.

641 ROBBERTSE, P.J. **The genus *Acacia* Miller in South Africa. I. Stipules and spines**. *Bothalia* II (1975a) **4** 473-479

A large number of seedlings and young twigs of South African *Acacia* species were sectioned and the vascularization of the nodes and internodes studied. In the Gummiferae species and *Acacia albida* the spines are modified stipules. The nodes of all the species examined are trilacunate, and as in the stipules of the Vulgares species, stipules of Gummiferae species are supplied by vascular tissue branching from the lateral leaf traces. The stipules of the Vulgares species including *A. senegal* var. *leiorhachis* and var. *rostrata* are membranous. The prickles contain no vascular tissue are found at the nodes and in some species also on the internodes of the Vulgares species. These prickles always occur on the ridges formed on the stem by leaf traces.

642 ROBBERTSE, P.J. **The genus *Acacia* in South Africa. IV. The morphology of the mature pod**. *Bothalia* II (1975b) **4** 481-489

The external morphology and anatomy of the pods of all the South African *Acacia* species are discussed, including the inner and outer epidermis, the mesophyll of the pericarp, the parenchymatous and sclereid strata, the fibre stratum, and the orientation of seeds within the pods. It was found that these species can be grouped into a number of distinct categories on the basis of the anatomy of their pods, of which there is quite a marked difference between those of the series Vulgares and those of the series Gummiferae. According to a classification based upon the anatomy of the pod, *Acacia albida* belongs to the series Vulgares, since its pericarp contains both longitudinal as well as latitudinal fibres (Gummiferae have fibre stratum with or without longitudinal fibres only). *A. senegal* (var. *leiorhachis* and *rostrata*) also have a fibre stratum with longitudinal and latitudinal fibres, and a fibre stratum with layers of stone cells not extending up to the vascular bundles.

643 ROBBERTSE, P.J. **The genus *Acacia* Miller in South Africa. VI. The morphology of the leaf**. *Boissiera* (1975c) **24** 263-270

The author has studied the morphology and anatomy of the heterophyllous (proximal and distal) leaves of 40 South African *Acacia* species. The pinnules have been found to be anatomically different in section *Vulgares* than in section *Gummiferae*. The petiole anatomy is also found to be different between the two sections, except that *A. polyacantha (Vulgares)* fits in a group of species belonging to section *Gummiferae*, and *A. albida* differs from all the other species and merits to be treated as being a separate, in the monotypic genus, *Faidherbia*. *A. senegal* is grouped with *A. ataxacantha, A. caffra, A. erubescens* and *A. montis-usti*.

644 ROBBERTSE, P.J.; VENTER, G.; RENSBURG, H.J. VAN. **The wood anatomy of the South African *Acacias***. *IAWA Bulletin* (1980) **1** (3) 93-103

Wood specimens of 37 different *Acacia species* were studied. Of the many wood characters investigated, only 9 were found useful for principal component analysis to differentiate between the different species. Width and, to a lesser extent, ht. of the rays gave the best results. The rays in the wood of the subgenus *Acacia* are 1-3 seriate, while those of the subgenus Aculeiferum are multiseriate. A significant negative correlation was found between latitude and ray ht. of *A. karroo* wood specimens collected in different parts of South Africa. They found the presence of growth rings in most species of the subgenus Aculeiferum and only in a few species of subgenus Acacia. They presented 10 wood characters for all the species and including the two varieties of *Acacia senegal* (vars. *rostrata* and *leiorhachis*) that occur in Southern Africa. The averages values of the wood characters in var. *leiorhachis* and var *rostrata* (with the mean value for the subgenus Aculeiferum in brackets) were: Rays width (no. of cells in widest part of ray) 3.8 and 4.2 (3.4); Rays height (μm) 273 and 420 (296); Number of rays (per mm-cross section) 6 and 5.9 (5.7); Number of rays (per mm^2-in tangential section) 33 and 18.4 (27.6); Parenchyma number of crystals cells per mm^2 in tangential section 7.9 and 12.2 (12.3); Diameter of pores (μm) 96 and 89 (105); both had solitary and multiple pores; the number of pores (per mm^2) was 5.1 and 11.6 (9.8); Growth rings were noted in var. *rostrata* and not var. *leiorhachis* and var. *leiorhachis* had banded axial parenchyma whilst var. *rostrata* had confluent axial parenchyma.

645 ROBBINS, S.R.J. **A review of recent trends in selected markets for water soluble gums**. *Overseas Development Natural Resources Institute, Bulletin No.2, Overseas Development Administration, London* (1988)

646 ROBERTSON, B.K.; DREYFUS, B.; ALEXANDER, M. **Ecology of stem nodulating *Rhizobium* and *AzoRhizobium* in four vegetation zones of Senegal**. *Microbial Ecology* (1995) **29** (1) 71-81

The occurrence and distribution of *AzoRhizobium* and *Rhizobium* strains that induce stem nodulation of *Sesbania rostrata* were determined in 4 vegetation zones in *Senegal*. Based on tests with 16 *Rhizobium* and 10 *AzoRhizobium* strains nodulating *S. rostrata*, a method was devised to distinguish among the strains. In all vegetation zones, members of both genera were more abundant in rhizosphere than nonrhizosphere soil under *S. rostrata*, *Cassia obtusifolia*, *Acacia senegal*, and *Hystic sauveolens* [?*Hystrix suaveolens*], and *Rhizobium* was present at higher densities than *AzoRhizobium*. *AzoRhizobium* was more abundant on the leaves and stems than *Rhizobium* in 3 of the vegetation zones, and the density of *AzoRhizobium* but not *Rhizobium* was far greater on the leaves of *S. rostrata* than the 3 non-host species in all 4 zones. Approximately 90% of the stem nodules and 39-48% of the root nodules on *S. rostrata* in all 4 zones were formed by *AzoRhizobium*.

647 ROBERTSON, W.H. **Modelling soil nitrogen levels under acacia/sorghum rotations**. *Agroforestry Systems* (1994) **27** (3) 283-292

A mathematical model is formulated and implemented for the nitrogen (N) cycle, on a yearly time scale, in an arid zone fallow system. By combining data from a number of sources in the Sahel, the behaviour of the model is investigated for a generic *Sorghum bicolor/Acacia senegal* system. The model is generally applicable to such systems, and aims to predict the effects of rotation length on soil nitrogen levels and crop production. The model reproduced such observed effects as the initial fall in soil N early in the *A. senegal* rotation, and provides support for the hypothesis that the N fixing potential of the roots of *A. senegal* is less important than their ability to take up otherwise inaccessible mineral N through deep roots. Model predicts peak N mineralisation rates of 2.7g/m^2/yr slightly lower than mean rates of 3-15 g/m^2/yr in Bernhard-Reversat & Poupon (1980).

648 ROBINSON, A.P. **Charcoal-making in Somalia: a look at the Bay method**. *Unasylva* (1988) **40** (1) 42-49

An illustrated description of the production method used in the Bay Region, which supplies the national capital and largest city, Mogadishu, 300-350 km away. Good quality charcoal with yields in excess of 40% (oven-dry basis) are achieved. The main and preferred timber species is *Acacia bussei*; *A. senegal* provides far smaller quantities. In 1983, over 42,000 tons of charcoal was recorded entering the city.

649 ROBINSON, P.J. **Trees as fodder crops**. In *Attributes of trees as crop plants* (edited by Cannell, M.G.R. & Jackson, J.E.) Institute of Terrestrial Ecology, UK (1985) 281-300

650 ROSS, J.H. ***Acacia senegal* (L.) Willd. in Africa, with particular reference to Natal**. *Bol. Soc. Broteriana (Ser 2)* (1968) No.42 207-240

Discusses the distribution, variation, taxonomy of the species from a southern African aspect. In Natal, populations of *A. senegal* var. *rostrata* stretch from Mozambique border in the north to a little south of Tugela river mouth (distribution map). Growth forms vary from shrubs to small trees. The tree can form thickets and is greatly relished by black rhinoceros in the game reserves. Bark varies from pale to dark yellowish or grey-brown, and typically flaking. The outer layers can exfoliate revealing powdery, sulphur coloured inner bark. Maintains the four varieties of the species, but notes intermediates between them all and that further studies in the horn of Africa are needed to clarify this variation.

651 ROSS, J.H. **The *Acacia senegal* complex**. *Bothalia* (1975a) **11** (4) 453-462

Presents a taxonomic account of present knowledge of the species in this group, and draws attention to the taxonomic difficulties encountered within it. Botanical descriptions are given of the 16 species concerned (*A. senegal* (L.) Willd., *A. asak* (Forsk.) Willd., *A. hamulosa* Benth., *A. oliveri* Vatke, A. *somalensis* Vatke, A. *hunteri* Oliv., *A. dudgeoni* Craib ex Holl., *A. thomasii* Harms, *A. condyloclada* Chiov., *A. ogadensis* Chiov., *A. caraniana* Chiov., *A. cheilanthifolia* Chiov., *A. zizyphispina* Chiov., and *A. ankokib* Chiov.), with a key for their identification. The group is defined as all *Acacia* species having spicate inflorescences and armed at or near the nodes with prickles either in threes, with the central one typically hooked downwards and the two laterals curved upwards or at times spreading laterally, or else solitary, the two laterals being absent.

652 ROSS, J.H. **The typification of *Acacia senegal*.** *Bothalia* (1975b) **11** (4) 449-451

Analysis of the protologue (species description) by Linnaeus in Species Plantarum ed. 1 :521 (1753) showed an absence of a type specimen or existence of an illustration. Therefore Ross selected a neotype (Adanson 16899) to preserve the name *Mimosa senegal* (basionym of *A. senegal* (L.) Willd.).

653 ROSS, J.H. **A conspectus of the African *Acacia* species.** *Memoirs of the Botanical Survey of South Africa* (1979) No.44 1-155

A conspectus is presented of the *Acacia* species (Fabaceae) which occur indigenously (including *A. farnesiana* which is doubtfully indigenous) in the continent of Africa west of Suez. The characters traditionally employed to divide the African species into two main groups are reviewed and the advantages of using these characters are discussed. The findings of workers in a number of diverse fields such as pollen, seedling and chromosome morphology, phytochemistry and the amino acid content of seeds are correlated with general morphology to provide a more comprehensive overall picture, and the infrageneric classification of the African species down to the rank of section is provided. Brief notes are given on pollen morphology and pollination, seed production, predation and dispersal, hybridization, and the origin and distribution of the African species. The morphological characters employed in the keys to identification are outlined and keys to the identification of the African species are provided. A brief description of each species is given together with synonymy, bibliographic references and a selection of representative specimens.

654 ROSS, J.H.; BRENAN, J.P.M. **Notes on Mimosoideae: X.** *Kew Bulletin* (1967) **21** (1) 67-73

Botanical description of various African *Acacia* species. *Acacia delagoensis* is reduced to *A. welwitschii* ssp *delagoensis* stat. nov., and *A. circummarginata* to *A. senegal* var. *leiorhachis*. Lists 6 points from which they conclude that *A. circummarginata* is not specifically separable from *A. senegal*. *A. reficiens* is maintained, with ssp. *reficiens* (incl. *A. uncinata*) and *misera*; *A. luederitzii* is also maintained, with vars. *leuderitzii* (incl. *A. goeringii*) and *retinens* stat. nov. (*A. retinens*, *A. gillettiae*).

655 RUBIN, S. **Medieval English medicine**. David and Charles, Newton Abbot, London, U.K. (1974) 1-232

656 RUESS, R.W.; HALTER, F.L. **The impact of large herbivores on the Seronera woodlands, Serengeti National Park, Tanzania.** *African Journal of Ecology* (1990) **28** (4) 259-275

Species composition, stand structure and type and extent of browsing damage were recorded in 1982 in 22 open woodlands dominated by *Acacia tortilis* in association with *Commiphora trothae, A. clavigera, A. senegal* or *Albizia harveyi* (tree density ranged from 32 to 363/ha) and 8 riverine forest stands dominated by *Acacia xanthophloea* (tree density ranged from 17 to 118/ha). In 22 sites the relative frequency of *A. senegal* varied from 1.3-35%. Frequency of damaged trees was related to species composition and population structure but not stand density. *A. senegal* was significantly preferred and *C. trothae* and *A. clavigera* were significantly avoided. Damage by elephants and giraffes have significantly reduced the proportion of mature trees in the past 2 decades. During the 10 year period prior to 1982, the frequency of mature *A. tortilis* and *A. senegal* trees greater than 5 m in height decreased by 70% and 89% respectively, and during the same period there was a 72% increase in frequency of trees of *A. senegal* below 2 m high. The sites with the highest frequency of *A. senegal* had the greatest damage, and there was a low regeneration frequency. This species is a highly favoured forage. With a recent reduction in elephant numbers (through poaching), future woodland change is likely to be affected most by frequency and intensity of fire, and browsing pressure by giraffes.

657 RUSSELL, F.C. **The use and misuse of shrubs and trees as Fodder**. *Imperial Agriculture Bureaux, Joint Publication* (1947) No.10 1-231

A review of the present state of knowledge of fodder shrubs and trees in the world, with the emphasis of these plants as protectors of the soil in critical environments. *Acacia senegal (A. verek)* in the Acacia/Grass savanna in the Sudan provides winter feed for camels. It is also mentioned as a fodder source in the Sind, India. It is not included in the table of crude chemical composition and nutritive value of 894 samples of edible parts from fodder trees and shrubs around the world. The importance of browse is summed up by the statement

"It is a humbling fact for grass pasture experts to realise that probably more animals feed on shrubs and trees, or on associations in which shrubs and trees play an important part, than on true grass-legume pastures."

658 RUTLEDGE, L.C.; GUPTA, R.K.; MEHR, Z.A.; BUESCHER, M.D.; REIFENRATH, W.G. **Evaluation of controlled-release mosquito repellent formulations**. *Journal of the American Mosquito Control Association* (1996) **12** (1) 39-44

Research into the possible use of gum arabic in mosquito repellent formulations. Eight polymer and 9 microcapsule formulations of deet (mosquito repellent) were tested on laboratory rabbits against the mosquitos *Aedes aegypti* and *Anopheles albimanus*. Several formulations were significantly more effective than simple (unformulated) deet at the same strength for periods up to 24 h. Best results were obtained with a polymer formulation containing a high molecular weight fatty acid and 3 microcapsule formulations containing lanolin, gum arabic, gelatin, tannic acid, stearic acid, polypropylene glycol, water, and a commercial lotion in the microcapsule and carrier fractions.

659 SAAD, Z.A. **Nitrogen dynamics of the *Acacia senegal* Agroforestry system in the Sudan.** PhD Thesis, Old Dominion University, Norfolk, Virginia, USA. (1991) 1-167 [from thesis summary]

This study investigated the climatic, edaphic and biotic interactions of the *Acacia senegal* agroforestry system that govern the nutrient dynamics, mainly N, and biomass. The effects of limited resources of soil, space and photoperiod of biomass, nodulation and the rate of N fixation were investigated. Genetic differences among populations were studied. Progenies of the selected high yielding gum trees were compared. Seed from various localities were grown on different soils to test the variation in nodulation potentials. Nodule ultrastructure was also examined. Seedlings raised on clay soil yielded more nodules and biomass than those on sand. Nodule extracts used to infect seedlings raised on sterile soil gave inconsistent nodule numbers. Nodulation was affected by phenological condition. The functional nodule peak period was eight weeks, extending the period to 13 weeks resulted in less red nodules. Competition intensity correlated negatively with the individual plant biomass and nodule numbers. Site potential expressed as total biomass was realised irrespective of plant number. Seed, leaves and twigs contained the highest nitrogen concentration. Iron and phosphorus concentrations were variable among tissues. The bush fallow rotation phase increased soil N, P and pH. Long period of fallow caused more accumulation and better soil improvement. Agricultural crops drastically drained soil N. The marked acidity of Aldubeibat sand was probably due to leaching of basic cations caused by rainfall which was higher than that of El Obeid where sand was at near neutral pH. Acidity impacted nodulation. The variation in soil types and rainfall regime and geographic isolation resulted in genetically different populations. Artificial selection of high yielding mother trees resulted in locating and identifying superior gum trees. They are recommended to be treated as seed stands for dissemination of high quality seed. Low gum producers yielded more biomass than high gum yielders, their effects on nutrient dynamics was insignificant.

660 SAARAINEN, T.; LUUKKANEN, O.; BISHAY, E. (ed.); DREGNE, H. **Afforestation experiments on multipurpose tree species in the Central Sudan. Desert development Part 1: desert agriculture, ecology and biology**. Proceedings of the Second International Desert Development Conference, 25-31 January 1987, Cairo, Egypt. Chur, Switzerland; Harwood Academic Publishers (1991) 435-447

The results are reported of nursery and establishment phase field trials carried out with *Acacia senegal* and *Prosopis chilensis* from 1983 to 1986 as part of a FINNIDA supported forestry project at Tendelti, White Nile Province, Sudan. Various silvicultural recommendations are made and a brief account given of a socio-economic survey carried out of attitudes to tree planting (which are becoming more positive).

661 SAHARIA, G.S.; SHARMA, M. **Chemical examination of *Acacia senegal* Willd**. *Indian Journal of Forestry* (1981) **4** (1) 63

Chromatographic studies of alcoholic extracts from the bark and fruits of *Acacia senegal* showed the presence of β-amyrin, β-sitosterol and β-D-sitosterol glucoside in both the bark and fruits; other compounds identified were erythrodiol and sucrose in the bark, and kaempferol and quercetin in the fruit.

662 SAHNI, K.C. **Important trees of the Northern Sudan**. Forestry Research and Education Centre, Khartoum, Sudan UNDP/FAO (1968) 40-41

A botanical description of *Acacia senegal* (L.) Willd. var. *senegal*, with details of distribution and utilization in the Sudan. The spot characters are a small tree with an eventually flattened crown. Flowers are creamy white in cylindrical spikes usually longer than the leaves. Pods are usually fawn or pale brown in colour, flat, papery, usually around 9 cm long, rounded to acuminate, venose.

663 SALEEM, M.; AHMAD, M.; AHMAD, A. **Chemistry of the medicinal plants of genus Acacia**. *Hamdard Medicus* (1998) **41** (1) 63-67

The medicinal uses and chemical composition of 11 *Acacia* species are described: *A. albida* [*Faidherbia*

albida], A. arabica [A. nilotica], A. catechu, A. farnesiana, A. leucophloea, A. mellifera, A. modesta, A. senegal, A. seyal, A. sieberiana and *A. tortilis*. The bark, gum and roots are the main parts used. Most of the extracts are used as astringents to treat gastrointestinal disorders, as a gum wash to stop bleeding, as a clarifying agent and flavouring in the production of spirits from sugar and palm juice, or as demulcents and emollients.

664 SALEY, H. [**Research work on *Acacia senegal* undertaken in Niger.**] Quelques travaux effectues sur *Acacia senegal* au Niger. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 33-44

Summarises research undertaken on *A. senegal* in Niger in the last two to three decades. The species is distributed between the 11-15° N parallel, with the denser stands found around Manga (Diffa department). Commercialisation has been undertaken by COPRO-Niger as a monopoly since 1969. Gives the production figures from 1973-1979, which varies from 644-112 tons/annum. Lists various conservation projects in Niger, provenance and species trials undertaken, and a study of the root systems. Found that the species has a spreading root system in the upper horizon and tap roots down to 6 m deep. Provenance trials started in 1987 at Ndouga with 11 provenances (6 from Niger) found that three of the exotic provenances (two Malian, Dialaka and Aite, and a Sudanian, Northern Kordofan) performed best in terms of survival and height growth (data not given).

665 SALIH, A.A.; MUSTFA, A.F. **Phosphorus and water use efficiency of *Acacia senegal* (L.) Willd provenances in Sudan. Nuclear techniques in soil plant studies for sustainable agriculture and environment preservation**. Proceedings of a symposium, Vienna, Austria, 17-21 October 1994, jointly organized by IAEA and FAO. Paper No. IAEA SM 334 28. Publication No. STI PUB 947 (1995) 529-534

Thirteen provenances collected from within the gum arabic belt were screened for combined high water use efficiency (WUE) and high phosphorus use efficiency (PUE). Seedlings were grown in a field naturally containing 22.1 kg/ha P. An additional 21.5 kg/ha P was applied to half the seedlings. Irrigation was applied when 75% of available water was depleted. There was no significant response to applied P, but the provenances differed widely in response to limited water supply, with those from clayey soils having a higher WUE than those from sandy sites.

666 SAMYN, J.M.; ZONGO, A. [**Agroforestry: A potential solution to major problems of Burkina Faso.**] L'agroforestierie face aux grands problemes du Burkina Fasso. *Intercooperation Suisse* (1984) 1-26

Presents the disastrous effects of 3 factors of degradation on the woodland savanna on Burkina Faso. The cited factors and analyses are increased population, methods of cultivation and the need for fuel wood. The traditional agroforestry methods, the necessity for soil improvement and their potential contribution towards an integrated rural environment are discussed. *Acacia senegal, A. albida, A. nilotica, Tamarindus indica, Balanites aegyptiaca, Prosopis chilensis*, and *P. juliflora* are mentioned for planting in the Sahelian zone as forage species.

667 SANGINGA, N.; VANLAUWE, B.; DANSO, S.K.A. **Management of biological N2 fixation in alley cropping systems: estimation and contribution to N balance. Management of biological nitrogen fixation for the development of more productive and sustainable agricultural systems**. *Plant and Soil* (1995) **174** (1-2) 119-141

Fast growth and Nitrogen (N) yield of most trees used as hedgerows in alley cropping is due greatly to their ability to fix N2 symbiotically with *Rhizobium*. Measurements of biological N2 fixation (BNF) in alley cropping systems show that some tree species such as *Leucaena leucocephala, Gliricidia sepium* and *Acacia mangium* can derive between 100 and 300 kg N ha^{-1} yr^{-1} from atmospheric N2, while species such as *Faidherbia albida* and *Acacia senegal* might fix less than 20 kg N ha^{-1} yr^{-1}. Other tree species such as *Senna siamea* [*Cassia siamea*] and *S. spectabilis* [*C. spectabilis*] are also used in alley cropping, although they do not nodulate and, therefore, do not fix N2. The long term evaluation of the potential or actual amounts of N2 fixed in trees however, poses problems that are associated with the perennial nature and massive size, the great difficulty in obtaining representative samples and applying reliable methodologies for measuring N2 fixed. Strategies for obtaining representative samples (as against the whole tree or destructive plant sampling), the application of 15N procedures and the selection criteria for appropriate reference plants are all discussed. Little is known about the effect of environmental factors and management practices such as tree cutting or pruning and residue management on BNF and eventually their N contribution in alley cropping. Data using the 15N labeling techniques have indicated that up to 50% or more of the tree's N may be below ground after pruning. In this case, quantification of N2 fixed that disregards roots, nodules and crowns would result in serious errors and the amount of N2 fixed may be largely underestimated. Large quantities of N are harvested with hedgerow prunings (>300 kg N ha^{-1} yr^{-1}) but N contribution to crops is commonly in the range of 40-70 kg N ha^{-1} season. This represents about 30% of N applied as prunings; however, N recoveries as low as 5-10% have been reported. The low N recovery in maize (*Zea mays*) is partly caused by lack of synchronization between N release by the hedgerow trees and the associated food crop N demand. The N not taken up by the

associated crop can be immobilized in soil organic matter or assimilated by the hedgerow trees and thus remain in the system. This N can also be lost from the system through denitrification, volatilization or leaching beyond the rooting zone. Below ground contribution (from root turnover and nodule decay) to an associated food crop in alley cropping is estimated at about 25-102 kg N ha^{-1} $season^{-1}$. Timing and severity of pruning may allow for some management of underground transfer of fixed N2 to associated crops. However many aspects of root dynamics in alley cropping systems are poorly understood. Current research projects based on 15N labelling techniques or 15N natural abundance measurements are outlined. These would lead to estimates of N2 fixation and N saving resulting from the management of N2 fixation in alley cropping systems.

668 SARY, H.; SOME, L.M. **Attacks by spermatophagous insects on the seed of three *Acacias* -*A. albida*, *A. nilotica* var. *adansonii* and *A. senegal***. In *Tropical Tree Seed Research. Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Queensland, Australia, 21-24 August 1989 (edited by Turnbull, J.W.). ACIAR Proceedings Series* (1990) **28** 21-23

Studies were made of 25 fruits from each of the upper, middle and lower crown levels of 5 specimens of *Acacia nilotica* var. *adstringens* and 10 each of *Faidherbia albida* and *A. senegal* from different sites in Burkina Faso. The endosperm of seeds of *F. albida* was parasitized by adults and larvae of Bruchidae. Caterpillars of *Chilades cleusis* were observed in unripe fruits of *A. nilotica* var. *adstringens*, while dry fruits were attacked by larvae and adults of several bruchid species, including *Callosobruchus maculatus*. Fruits of *A. senegal* showed holes in valves, malformation of seeds, and evidence of parasitism by bruchid larvae and adults, although no insects were found.

669 SAWER, T. **The agricultural problem in the Anglo Egyptian Sudan**. In *Pump Irrigation in Northern Sudan. Central Research Farm Bulletin* No.1 (1915)

670 SAXENA, S.K.; SINGH, S. **Some observations on the sand dunes and vegetation of Bikaner district in western Rajasthan**. *Annals of Arid Zone* (1974) **15** (4) 313-322

Descriptions are given of the morphology (shown schematically in figures) and vegetation of 5 types of dunes: parabolic, longitudinal, transverse, barchan (crescent-shaped, and formed in the direction of the wind) and shrub-coppice (formed against fences, shrubs and bushy vegetation). The first 3 types are stabilized, and support a mixed xeromorphic thorn forest (with *Acacia jacquemontii*, *A. senegal*, *Calotropis procera*, *Lycium barbatum*, *Maytenus emarginatus*, *Prosopis cineraria* and *Ziziphus nummularia* as important species) or, in regions of lower rainfall, a psammophytic scrub desert vegetation. The other 2 types of dune are still active, and almost bare of vegetation. It is suggested that the smaller (0.9-2.5 m high) dunes of these 2 types should be levelled by bulldozing, and that the larger ones (up to 10 m high) should be stabilized by planting indigenous psammophytic species.

671 SCHOLTE, P.T. **Leaf litter and *Acacia* pods as feed for livestock during the dry season in *Acacia - Commiphora* bushland, Kenya**. *Journal of Arid Environments* (1992) **22** (3) 271-276

The composition of the dry season diets of cattle and goats in an area of deciduous *Acacia-Commiphora* bushland in the Eastern Province of Kenya was determined in 1985. Leaf litter was >80% of the diet at the beginning of the dry season, and between the start of the dry season and halfway through the next rainy season it provided 22% and 29% of the diets of goats and cattle, respectively. Leaf litter came mainly from *Commiphora africana*, *Sterculia rhynchocarpa* and *Terminalia spp*. Later in the dry season, animal diets were mainly *Acacia senegal* and *A. tortilis* pods; *Acacia* pods provided 37 and 30% of the diets of goats and cattle, respectively, over the whole study period. A short period of protein deficiency occurred at the start of the dry season, but later in the dry season and in the early wet season the replacement of protein poor leaf litter in the diet by protein rich *Acacia* pods and browse gave a more balanced diet, especially in goats.

672 SCHULTZ, E.; THERON, G.K.; HOWEN, W. VAN **The vegetation and identification of management units of the Imberbe Game Lodge in the mixed bushveld of the north western Transvaal**. *South African Journal of Botany* (1994) **60** (2) 85-93

An analysis of the vegetation of the Imberbe Game Lodge in the mixed bushveld of the NW Transvaal is presented. Data were compiled in 39 stratified random sample plots. Four distinct plant communities were identified by Braun Blanquet procedures. These were *Peltophorum africanum-Stipagrostis uniplumis* open woodland, *Grewia flava-Pupalia lappacea* open shrubland, *Acacia nigrescens-Aristida rhiniochloa* open woodland and *Acacia grandicornuta- Acacia senegal* closed woodland. The data were ordinated using detrended correspondence analysis to investigate possible relationships and gradients in and between plant communities. Three management units were determined by means of a vegetation ordination. A hierarchical classification, description and ecological interpretation of the plant communities as well as a description of the management units are presented.

673 SEN, D.N.; BANSAL, R.P. **Food plant resources of the Indian Desert**. In *Arid land plant*

resources (edited by Goodin, J.R.; Northington, D.K.). Lubbock; Texas International Centre for Arid and Semi-arid Land Studies (1979) 357-370

The paper lists the food plant resources of the Indian desert in a number of classifications: grains and seeds; vegetables; fruits; and gums and oils. *Acacia senegal* is classified as 1. a vegetable: locally known as "Kumbhitia" occurring as a tree in hilly tracts; it flowers and fruits in July and November; fresh fruits are collected, dried, preserved and used later as vegetables. and 2. under gums and oils: the peoples of the Indian desert consider gum as a very strength giving part of their diet and the gum from *A. senegal* as of a very high quality; the gum is dried, made into small pieces and fried in fat to make puffs, which are supposed to be a very nutritive food, ground gum mixed with fried wheat flour and sugar is given to women after child delivery. The seeds and fruits of *Acacia senegal* are especially noteworthy, as they do not rot when made into a vegetable and keep for many days without any refrigeration.

674 SENE, A. [**Gum arabic in the colonial economy of St Louis, Senegal (18 to 19th centuries).**] La Gomme Arabique dans l'Economie Coloniale de St Louis du Senegal (18ème - 19ème siècle). In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 257-265

The European market for gum arabic was disputed between England, France and Holland in the 18-19 centuries, and gum arabic was the major trade article from St Louis. This was later replaced by the trade in groundnuts. He describes the exploitation of gum, the organisation of trade, the crisis of the trade and the fallout effect on the economy and society of St. Louis.

675 SENE, A. **Recherches sur la productivité gommière d'*Acacia senegal* dans le Nord-Ferlo (Sénégal).** These de doctorat 3ème cycle, Université P. Sabatier, Toulouse. (1988) 1-243

676 SENE, E.H. **Trees, food production and the struggle against desertification**. *Unasylva* (1985) **37** 19-26

677 SERRIER, J.B. [**Tree secretions** 1] Les sécrétions s'Arbres (1). *Bois et Forêts des Tropiques* (1986) **213** (3) 33-39

General article on tree secretions from rubber, gums, resins to name a few, their uses and possible synthetic substitutes. Gum arabic is listed as one of the principal gums with a molecular weight (250,000 - 300,000. Used both in food processing and industrial uses (dying and printing). Given a fall in annual production (10,000 tons in 1986 from 60-70,000 in the 1970's), suggests possible substitutes for the industrial uses (carboxy-methyl-cellulose, hydroxyl-methyl-cellulose and l'alcool polyvinylique) but has none for the food uses.

678 SERVICE DES EAUX ET FORÊTS. [**Synthetic growth regulators and gum secretion in *A. senegal*.**] Hormones synthetiques et secretion de gomme sur *Acacia senegal. Service des Eaux et Forêts, Dakar* (1960) 1-5

Experiments in spraying *A. senegal* with various formulations of 2,4-D, 2,4,5-T, and MCPA, showed that all exercised a temporarily depressing effect on gum yield. In the case of one formulation, however, (200 g. 2,4,5-T + 400 g. 2,4-D in 1 litre water) the depressing effect slowly wore off, and at the end of the season gum yield of treated trees was double that of controls.

679 SHANKARNARAVAN, K.A. **Impact of overgrazing on the grasslands**. *Annals of Arid Zone* (1977) **16** (3) 279-394

Excessive grazing and browsing is indicated in Rajasthan by a predominance in the vegetation of *Butea monosperma, Holarrhena antidysenterica, Cassia auriculata, Capparis decidua, Ziziphus mauritiana, Calatropis procera* or *Adhatoda vasica*, species avoided by cattle. Excessive browsing markedly affects the growth form of trees: *Ziziphus nummularia* and *Salvadora oleoides* assume a bush form, and *Prosopis cineraria, Anogeissus pendula* and *Acacia senegal*, a cushion form.

680 SHARAWI, H.A. ***Acacia senegal* in the Gum Belt of Western Sudan: a cost benefit analysis**. *M.Sc. Thesis, Wales, Bangor, U.K.* (1987) [From thesis summary.]

This study is intended to examine the evaluation *of Acacia senegal* plantations in the gum belt of Western Sudan. The tree is known to have a major role in desertification control in the marginal lands, besides its provision of fuelwood for local consumption and gum arabic for exporting. The study is directed to fulfill three distinct objectives: the first concerns the evaluation of the bush-fallow system as presently managed in the area; the second concerns the evaluation of a proposed more organised rational system in the same area. The last objective is to evaluate returns from *A. senegal* in irrigated schemes. The techniques of cost-benefit analysis as recommended by the OECD approach was used at the financial, economic and social levels. Using this approach and the net present value criterion (NPV) in our analysis, the proposed bush-fallow system showed a positive NPV per feddan (NPV/F) substantially above that of the present situation at both farmer and national levels. The economic analysis also gave a positive NPV/F but lower than that realised in the present situation. In the social analysis the NPV/F was negative.

Irrigated *A. senegal* showed a positive NPV/F only under the financial analysis both at the farmer and national levels. The indirect benefits of the tree were not evaluated quantitatively due to lack of scientific data.

681 SHARMA, A.K.; BHATTACHARYYA, N.K. **Structure and behaviour of chromosomes of species of *Acacia*.** *Phyton, Buenos Aires* (1958) 111-122

Covers 6 species with the following 2n chromosome numbers: *A. moniliformis*, *A. catechu* and *A. senegal*, 26; *A. farnesiana* and *A. leucophloea*, 52; and *A. arabica*, 44; including a detailed karyotype analysis and a discussion of polyploidy as a factor in species evolution.

682 SHARMA, B.D.; GUPTA, I.C. **Effect of trees cover on soil fertility in western Rajasthan.** *Indian Forester* (1989a) **115** (5) 348-354

Thirty-two surface soil samples were collected from 3 sites in Rajasthan which included barren sand dunes, and sand dunes with 6 different types of tree cover: afforested with *Prosopis juliflora*, *Acacia tortilis* or *P. cineraria*, or with natural cover of *P. cineraria*, *Balanites aegyptiaca*, *A. senegal* or *Capparis decidua*. Data are tabulated on the physico-chemical properties of each. The overall fertility of the soils under tree cover was improved, with the greatest overall improvement generally found under *P. cineraria* and the least under *P. juliflora*. Under *P. cineraria*, organic carbon increased from 0.03 (in barren dunes) to 0.47%, total nitrogen from 0.007 to 0.043%, available nitrogen from 87.50 to 227.0 kg/ha and available P_2O_5 from 14.95 to 33.68 kg/ha. The soil pH decreased from 8.58 to 8.34 under *P. cineraria*, but greater decreases occurred under *A. senegal* (7.85) and *C. decidua* (7.55).

683 SHARMA, B.D.; GUPTA, I.C. **Stabilising sand dunes with tree cover.** *Indian Farming* (1989b) **38** (12) 19, 21-22

A brief account of work by CAZRI in Rajasthan, started in 1958 at Udairamsar (Bikaner), in 1965 at Srikolayatji and in 1967 at Palsana (Sikar). The afforestation technique used involved (1) fencing to protect against biotic interference, (2) the establishment of micro-windbreaks on the windward side of the dune in parallel strips of 3-5 m in a 5-m chess board pattern, and (3) sowing grasses and transplanting (at the onset of the monsoon) trees and shrubs raised in earthen bricks on the leeward side of the micro-windbreaks. There was no supplemental irrigation. Species used included *Prosopis juliflora*, *Acacia tortilis* and *A. senegal* and some natural vegetation already present (e.g. *P. cineraria*, *Capparis decidua* and *Balanites aegyptica*). Data are tabulated showing the changes in soil physical and chemical properties under these 6 species, in comparison with those of barren sand dunes.

684 SHARMA, B.M. **Foliar and soil nutrient status of some common plants of rocky areas at Ajmer, Rajasthan.** *Van Vigyan* (1988) **26** (1-2) 20-23

The dominant plants of this area are *Euphorbia caducifolia* (which has a fleshy cylindrical phyllocladous stem) and *Acacia senegal*. Analyses were made of the nutrient contents of the stems and leaves of the former, and the leaves of the latter, using specimens collected from 4 sites (2 rocky areas and 2 on hilly terrain). Surface soil samples of the shallow soils were collected from near the plants and analysed. The soils were alkaline (pH 7.8-8.2) and predominantly sandy with a low CEC and poor nutrient content. There was some variation between sites. *E. caducifolia* grew well on sites that were poor in Na, but rich in Ca, Mg and Cl. The plants had a high foliar and stem ash content, and nutrients such as Ca and P were higher in the leaves than in the stem. The leaves of *A. senegal* were rich in ash content and Ca.

685 SHARMA, S.K.; SHANKAR, V. **Gradient analysis of the catchment vegetation of Kailana in the Thar Desert, India.** *Tropical Ecology* (1990) **31** (2) 104-111

Vegetation habitat studies were done in 10 catchments at Kailana west of Jodhpur, Rajasthan, with slopes between 3.6 and 25.0%. Nine of the catchments were in the protected afforested area of the Central Arid Zone Research Institute, and the tenth was in an adjacent unprotected area. Soil depth in the GS (gentle slope, 5.4%) and MS (moderate slope, 9.5%) group of watersheds was 0-100 cm. The watersheds in the SS (steep slope, 19.5%) group were almost devoid of soil cover. Soil texture in the GS group was sand to loamy sand, while in the MS and SS groups on middle and upper slopes it was fine sand to silty clay loam and rich in organic carbon content. Distribution data are given for trees/shrubs and herbs in the different slope groups, indicating their presence on the basal, middle or upper slopes. *Euphorbia caducifolia, Grewia tenax* and *Barleria acanthoides* were most common woody species recorded from all the watersheds. The presence of different species groups in various habitats (such as *Aerva persica, Fagonia cretica*, and *Justicia vahlii* in hummocky habitats, and *Grewia tenax, Euphorbia caducifolia* and *Acacia senegal* in rocky habitats) confirmed the complexity of the vegetation habitat relationship in the Kailana catchment area.

686 SHARMA, S.K.; VERMA, C.M.; AHUJA, L.D. **Production of ground storey (grass component) in afforested areas in arid regions of India.** *Annals of Arid Zone* (1980) **19** (3) 283-287

An evaluation of forage production under 12 year old plantations of *Prosopis cineraria*, *Albizzia lebbek* and *Acacia senegal* at Jodphur, India, sampled from 1972-1976. The average total forage yield (dry matter) was highest under *P. cineraria* (1.15 t/ha air dry) and *A. lebbek* (1.12 t/ha) and significantly lower under *A. senegal* (0.68 t/ha). Perennial grasses were separately

measured, contributing over 70% to these total figures. Monthly rainfall figures are given, which is compared with the forage yields.

687 SHAWKI, M.K. **Sudan Forests, 1950 to 1954.** *Memoirs of Forestry Division, Ministry of Agriculture, Sudan* (1955) No.10 1-27

Gives details on the vegetation, values of Sudan's forests and Forest policy, administration and management. A section on gum arabic mentions the trade, and grading of gum. Three grades are mentioned the best being bleached gum which is almost transparent, the lowest grade being gum that has got wet (it becoming brittle and less sticky) and medium grade which is a mixture of the two. Most of the gum comes from gum gardens, which are natural except for some experimental areas started 15 years previously. Tapping is started at the end of the rainy season (October).

688 SHEPHERD, G. **The reality of the commons: answering Hardin from Somalia.** *Development Policy Review* (1989) 7 (1) 51-63

Against the background of Hardin's 'tragedy of the commons', the article reports on work undertaken in the Bay Region of Southern Somalia between January and April 1988. During this time it became clear that the assertion and denial of common property rights to bushland were at the heart of the energy issue which was the original field of study. It also describes the early stages of research aimed at returning common property rights to rural people who have lost them, and thereby ensuring the survival of resources which would otherwise be lost as well. People in the Bay Region survive by the complementarity of the low-risk trees-and-livestock component of their economy practiced on sandy soils, and high-risk sorghum cropping on clay soils. The Region is also the main source of charcoal (300 t per day) for the capital, Mogadishu. Fieldwork indicates intensive conflict over trees, particularly disappearance of species suitable for building materials: *Acacia bussei*, *Acacia senegal*, *Acacia tortilis* and *Terminalia spp.*. Fodder species are also being used as fuel (*Grewia spp.*, *Cordia spp.*, and *Commiphora spp.*). However, communal land rights were as much of an issue as trees. Villagers proposed solutions to the common property rights' problem, including reserving rights of groups to portions of woodland, improved control of use of trees for poles, legal rights to control charcoal burners, and new land management arrangements. These issues were discussed at a national seminar.

689 SHIVA, M.P.; SINGH, N.P.; THAKUR, F.R. **Newly designed improved gum tapping tools.** *MFP News* (1994) **4** (1) 8-11

For use with commercially important gum yielding species like *Sterculia urens, S. villosa* (gum karaya), *Anogeissus latifolia* (gatti gum), *Lannea coromandelica* (jhingan gum), *Bauhinia retusa* (semla gum) and *Acacia senegal* (true gum arabic).

690 SIBLY, E. **A herbal of foreign plants being a supplement to Culpeper's British Herbal.** Reprint of the 6th edition of 1820 Published by Llanerch Enterprises (1988 edition, original 1792) 1-116

691 SIM, B.L. **The genetic base of *Acacia mangium* Willd. in Sabah.** In *Provenance and genetic tree improvement strategies in tropical forest trees* (edited by Barnes, RD & Gibson, GL) Commonwealth Forestry Institute Oxford and Forest Research Centre, Harare (1984) 597-603

692 SINA, S. **Synthese des resultats de quelques travaux sur *Acacia senegal* au Burkina Faso.** In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 9-24

A synthesis of research undertaken by the CNSF on the natural stands of *A. senegal* in Burkina Faso. Describes the natural distribution of the species, which occur between longitudes 13° and 14°30'N and between latitudes 1°and 4° W. Lists the definition of provenance selection and the seed collection strategies (1 kg lot has around 12,000 seeds). Tried a series of pretreatments but found no significant differences in germination between the pretreatments (acid for 5 mins, manual scarification) and the control (92%). Fast growth of 30 cm high plants recorded in 10 weeks in the nursery. Gives results on their tree improvement work, including provenance trials of 14 provenances tried in 3 areas (Djibo, Dori and Gonsé). After 3 years no significant differences were recorded in height between provenances. Notes the need for a regional plan for tree improvement of the species. Presents 2 maps showing the phytogeographic regions and zones of concentration of the tree populations.

693 SINGER, C.; HOLMYARD, E.; HALL, A.; WILLIAMS, T. **A history of technology, Vol II, the Mediterranean Civilization and the Middle Ages.** Oxford; Clarendon Press (1956) 1-802

694 SINGH, H.S. **Study on biodiversity on Hingolgadh Nature Education Sanctuary.** *Special issue: Focus on wildlife. Indian Forester* (1998) **124** (10) 825-832

The vegetation of Hingolgadh Nature Education Sanctuary, Gujarat (India) is of the dry deciduous thorn scrub and dry savanna type. A remote sensing study of the vegetation cover showed that canopy density has improved progressively since a severe drought in 1987, due to fair regeneration of *Acacia senegal*. The small

area is exceptionally rich in flora and fauna. The indigenous flora of the sanctuary is represented by 63 families, 189 genera and 286 species. The sanctuary also supports a high diversity (212 species) and very high density (1967 birds/km^2) of birds, along with other fauna. *Commiphora wightii*, an endangered species, and other locally threatened species have started recovering due to improvement of the habitats. The rarity and threat level for various species in the sanctuary are assessed.

695 SINGH, J. **Attempts to combat wind erosion in Punjab**. In *Proceedings of the Tenth Silvicultural Conference, Dehra Dun, 15-20 and 22-25 November, 1961,* Vol. I. Delhi, India; Manager of Publications (1966) 523-528

The entire area of the Punjab plains is affected by wind erosion to varying degrees. The southern districts, which make up 30% of the area, are the worst affected, whereas the central districts suffer from the formation of localized deserts owing to storm winds invading from the south west. Extremes of climate, low rainfall, fierce and strong winds, clearing of vegetation and over-grazing are the common causes of local wind erosion, but the extension of irrigation is helping to contain the problem. During the First and Second Five-Year Plans reclamation work was implemented consisting of the formation of green belts between hills to reduce the impact of winds from Rajasthan, fixation of sand dunes, and establishment of plantations, wind breaks and shelter belts. Experiments showed that shifting dunes could be fixed within two years by planting tufts of *Saccharum munja* and sowing seeds of *Aerua avanica*, *Calligonum polygonoides*, *Calotropis procera*, *Citrullus colocynthis*, *Cyperus arenarius*, *Leptadenia partium*, and *Ricinus communis*. On fixed dunes, or in hollows or depressions, it was possible to establish *Acacia arabica* [*A. nilotica*], *A. senegal*, *A. modesta*, *Albizia lebbek*, *Balanites roxhurghii*, *Cercidium tarryanum*, *Prosopis juliflora* and *Zizyphus jujuba*.

696 SINGHAL, P.C.; JOSHI, L.D. **Role of gum arabica and gum catechu in glycemia and cholesterolemia**. *Current Science, India* (1984) **53** (2) 91

In tests on normal albino rats gum arabic [from *Acacia senegal*] was shown to be hypoglycaemic and normocholesterolaemic, and gum catechu [from *A. catechu*] normoglycaemic and hypercholesterolaemic.

697 SINHA, S.C. **Floral morphology of Acacias**. *Caribbean Journal of Science* (1971) **11** (3/4) 137-153

Presents a study of the morphology and development of the flowers of *Acacia nilotica* compared with the floral anatomy of *Acacia senegal* Willd. and 4 other *Acacia* spp. Surrounding the leaf base of *A. senegal* are three brown coloured stout spines; unlike other species, the middle one is recurved and situated just below the leaf base; not receiving any vascular supply and is entirely non-vascular. The lateral spines are stipular in nature, receiving their vascular supply from the lateral leaf traces.

698 SIRAG, A.A. **Land use systems in Sudan**. Report for ICRAF, Nairobi (1987) Mimeo, 1-6

In Sudan cultivated land is divided into 1.6 million hectares under irrigation, 2.2 million hectares under rain fed mechanised farming and 6.6 million hectares under traditional shifting cultivation, the latter including the gum arabic cycle in western Sudan. In 1970 the government central Forestry association changed from planting *A. seyal* trees on reserved forest land to dividing the land for farmers to grow a taungya system, cropping for two years and then planting *Acacia senegal* and moving on, but this did not happen and now all old *A. seyal* forests have been cleared. Shelterbelts and borderlines of trees of *A. senegal* and *A. mellifera* were also tried with limited success. Also details an agroforestry demonstration plot at Wad Awad (eastern Sudan) on deep cracking black clay soils, with Acacias planted with Sorghum and sesame crops, which failed due to poor rainfall (428 mm) and late planting of tree seedlings.

699 SIVASANKARAN, D.; VENKITASWAMY, R.; CHINNUSAMY, C.; SHANMUGASUNDARAM, V.S. **A sustainable integrated farming system for dry lands**. *Madras Agricultural Journal* (1995) **82** (6-8) 458-460

Field experiments were conducted at the Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore during 1988-93 to study the economics of the integrated farming system (IFS) in a 1.0 ha area of dryland. The treatments in IFS were: sorghum + cowpeas for grain/seed or fodder; *Leucaena leucocephala* + *Cenchrus ciliaris* for fodder; *Acacia senegal* or *Prosopis cineraria* + grass (not specified) for fodder. The animal component included 5 female goats and 1 male goat during the first year. The goats were stall-fed. This system was compared with a conventional cropping system (CCS) of sorghum + cowpeas for seed/grain. The net returns were significantly greater from IFS than CCS. IFS also generated additional employment of 113 man days/ha annually.

700 SKERMAN, P.J.; CAMERON, D.G.; RIVEROS, F. **Tropical forage legumes**. Rome, Italy; FAO Plant Production and Protection Series, (2nd edition) (1988) No. 2 1-692

Several aspects of Leguminous browse are discussed, and then gives lists and descriptions of browse species such as *Acacia senegal*. A botanical description of *A. senegal* is given, a deciduous tree which drops the leaves in November in Sudan. The leaf fall is mineralized and builds up the fertility of sandy soils for ensuing

crops of groundnut, sorghum, bulrush, millet and sesame. Strips of bark are also slashed from the branches in November, and in January the gum exudate is collected and sold as gum arabic. Camels and goats browse it, but are usually excluded from gum-bearing groves as they browse back the trees and reduce gum production.

701 SMIT, N. **Guide to the Acacias of South Africa**. Briza, South Africa. (1999) 90-197

An identification guide to the Acacias of South Africa, richly illustrated with colour plates. Describes the two varieties of *A. senegal*, var. *rostrata* and var. *leiorhachis*, which are clearly distinct in this area. Variety *rostrata* is commonly a low shrub with a flattened crown and horizontal spread which can often well exceed its height, whereas var. *leiorhachis* is a spindly tree with long irregular straggling branches. Variety *rostrata* flowers from Nov. to Jan. whereas var. *leiorhachis* from August to October. Wood is slightly denser in var. *rostrata* (990 kg/m^3 air dry) compared with var. *leiorhachis* (930 kg/m^3).

702 SMITH, J. **Distribution of tree species in the Sudan in relation to rainfall and soil texture**. Bulletin No 4, Ministry of Agriculture, Sudan (1950) 1-64

Describes the geography, soils and climate in Sudan, which have a strong influence on plant distributions. *Acacia senegal* occurs in three major ecological formations, Acacia desert scrub, Acacia short grass country on sandy soils, and Acacia tall grass communities on clay soils. Shows the distribution of the species as 2 belt axes on a map of Sudan, the western axis on sandy soils with 400 mm annual rain, and the eastern axis on clay with 600 mm annual rain. Also notes that outside of the two belts it can occur up to 1400 mm rainfall on the sheet erosion slopes at Nimule in association with *A. mellifera.*

703 SOLANKI, K.R.; JINDAL, S.K.; MUTHANA, K.D.; KACKAR, N.L. **Performance of *Acacia senegal* and *Prosopis cineraria* in western Rajasthan**. *Nitrogen Fixing Tree Research Reports* (1984) **2** 13-14

Data is given on growth measurements of 20 trees of each species growing at the Central Arid Zone Research Institute, Jodhpur, India. The area had an annual rainfall of 317 mm. Observations diameter, height, canopy diameter and volume on 20 trees were recorded on 22 years-old plantations giving an average diameter at breast height of 9.3 cm, ranging from 6.6 to 16.0 cm, height of 5.1 m, ranging from 3.6 to 6.3 m and canopy diameter 5.6 m (4.1-7.0 m). The growth performance of *A. senegal* was better compared to *Prosopis cineraria*. The presence of more fibrous roots of *A. senegal* in the first 40 cm of soil compared with those of *P. cineraria* was considered an advantage. *A. senegal* was taller and had a greater volume than *P. cineraria.*

704 SOLANKI, K.R.; JINDAL, S.K.; MUTHANA, K.D.; KACKAR, N.L. **Performance of *Acacia senegal* and *Prosopis cineraria* in western Rajasthan**. *Nitrogen Fixing Tree Research Reports* (1985) **3** 27-28

Data is tabulated on average height, basal diameter, d.b.h., canopy diameter and volume of trees in a 22 year old plantation at Jodhpur, India. In general, parameters were greater in *A. senegal* than in *P. cineraria.* Essentially the same data given in above abstract Solanki *et al.* (1984.)

705 SONI, P.L. **Some commercially important Indian gum exudates**. *Indian Forester* (1995) **121** (8) 754 -759

Gum exudates are important food additives besides being used in medicines, textiles, adhesives, etc. The commercial applications of such gums depends upon their overall molecular structure and properties; they are facing a stiff challenge from modified starch or fermentation products. Also, food safety regulations have contributed to restricted use of gum exudates in the food industry. Six important Indian gums, which have a place in the market, are described and discussed in this paper. They are gum karaya (from *Sterculia spp.*), gum arabic from *Acacia* spp. (mainly true gum arabic from *A. senegal*, and khair gum from *A. catechu*), gum tragacanth (from *Astragalus spp.*), gum ghatti (from *Anogeissus latifolia*), leucaena gum (from *Leucaena leucocephala*). Other important gums and gum resins commonly available on the Indian market are listed.

706 SOUTHGATE, B.J. **A preliminary list of *Acacia* species and the Bruchid beetles associated with them**. *International Group for the Study of the Mimosoideae* (1975) Bulletin No.3 31-32

List of species from either literature references or from data attached in museum collections. Identifications of the host have to rely on the integrity of the author. Listed for *A. senegal* are *Bruchus silaceus* FAHR., *Bruchus subuniformis* PIC, *Bruchus centromaculatus* All. and *Caryedon pallidus* Ol.

707 SOUTHGATE, B.J. **Handbook on seed insects of *Acacia* species**. Food and Agriculture Organisation, Rome (1983) 1-30

While not specifically mentioning *A. senegal*, this book provides a review of the current knowledge concerning insect species and levels of infestation suffered by the genus *Acacia*, and gives guidelines for further investigation. Four main groups feed upon the seeds of the family Leguminosae in arid and semi-arid zones; Coleoptera (beetles), Heminoptera (plant bugs), Lepidoptera (moths and butterflies) and Hymenoptera (Phytophagus wasps). Of these, the Coleoptera are by far the most important, containing the group Bruchidae. The basic fundamentals of their life cycle (esp.

Callosobruchus maculatus) and taxonomic position are outlined, as well as an account of their effects on seed collection (including preventive measures and the examination of harvested seed). Chemical control methods and the equipment for their application are also detailed. The identification and storage of collected and bred insect material and a glossary are dealt with in an appendix.

708 SPEECE, M. **Economic policy and desertification in arid and semi-arid developing countries**. *Pakistan Development Review* (1997) **36** (2) 191-201

Environmental degradation in arid and semi arid regions of developing countries often results from trade offs between immediate and long term needs. Ecological (and ultimately economic) benefits of restrained, sustainable resource use are well understood by scientists, and are usually apparent to local farmers and herders as well. However, immediate economic needs often conflict, and excessive exploitation of resources may be necessary to subsistence producers' survival. Such issues are illustrated in a variety of settings (rangeland degradation in the Sahel; declining traditional agriculture in southern Arabia; deforestation of *Acacia senegal* in Sudan; salinization in Egypt and Pakistan). Solutions to problems containing important economic components require appropriate economic policies, as well as technical action. Long term sustainable resource utilization rather than short term exploitation must be made more attractive to local producers in their daily lives.

709 SPEEDY, A.; PUGLIESE, P. (eds.) **Legume trees and other fodder trees as protein sources for livestock**. *FAO Animal Production and Health Paper* (1992) No.102 1-339

710 SPINAGE, C.A.; GUINNESS, F.E. **Tree survival in the absence of elephants in the Akagera National Park, Rwanda**. *Journal of Applied Ecology* (1971) **8** (3) 723-728

Presents data showing that tall trees (mostly *Acacia senegal*) are very susceptible to windthrow in this high altitude national park, and that lightning often causes damage to branches and crowns. It is suggested that, in other areas, damage caused by these factors may be erroneously attributed to elephants.

711 SRIVASTAVA, H.P.; CHANDEL, S.; KAUSHAL, S.; RAM REDDY, S. **Arbuscular mycorrhizal fungi occurring in vegetated sand dunes of Indian Thar Desert**. *Microbial biotechnology. "Professor K. S. Bilgrami Commemoration Volume". (edited by* Reddy, S.M.; Srivastava, H.P.; Purohit, D.K.) *PB.* Jodphur, India; Scientific Publishers (1997) 87-96

The vegetation on the dunes of the title area is sparse due to poor rainfall, high wind velocity, and sandy texture of soil with poor water holding capacity and nutrient deficiencies. Examination of periodically collected root and soil samples showed that most of the species growing on and around the sand dunes develop mycorrhizas of vesicular arbuscular type under natural ecosystems. Perennating spores of the arbuscular mycorrhizal fungi (AMF) belonging to genera *Glomus*, *Gigaspora* and *Acaulospora* were recovered from the mycorrhizosphere soil/root samples of *Acacia jacquemontii, A. nilotica, A. senegal, Aerva persica, Aristida adscensionis, Calotropis procera, Capparis decidua, Cenchrus biflorus, C. ciliaris, C. prieurii, C. setigerus, Crotalaria burhia, Lasiurus scindicus, Maytenus, Panicum turgidum, Prosopis cineraria, Tephrosia purpurea* and *Ziziphus nummularia*. The isolates of AMF symbionts were cultured in pots on the living roots of *Cenchrus ciliaris* and identified on the basis of developmental structures of the spores. *Glomus fasciculatum* invariably dominated over *G. aggregatum, G. macrocarpum, Gigaspora gigantea* and *Acaulospora elegans*.

712 STEPHEN, A.M. **Structure and properties of exudate gums**. In *Gums and stabilizers for the food industry (edited by Phillips, G.O.; Williams, P.A.; Wedlock, D.J.)*. Oxford, UK; Oxford University Press (1990) 5-16

Describes the analytical procedures that led to the formulation of the molecular structures of Acacia gums and then a discussion of the physical properties of the gums and their application in food products. Gum arabic is shown to be highly versatile as a hydrocolloid in a wide range of products in the food industry. It is extremely soluble, and most of its useful functions in foods depend on its viscosity, which causes stabilisation and affects texture. In summary it is used in bakery mixes (thickener[a], emulsifier[b], stabiliser[c]); icings (adhesive[e], crystallisation inhibitor[f], encapsulating agent[g]); meringues (c, water binding agent[d]); flavourings (b,g); beverages (b,c,g, competitive interaction[h]); confections (a-g); and processed meats (h.) The low calorific values of gum arabic are also important from the dietetic point of view, and it is also used in vitamin supplements.

713 STEWART, R.R. **An annotated catalogue of the vascular plants of West Pakistan and Kashmir.** In *Flora of west Pakistan (edited by Nasir, E & Ali, S.I.)* Pakistan: Fakhri Printing Press, Karachi. (1972) 380

An annotated checklist of the vascular plants from western Pakistan and Kashmir. *A. senegal* is recorded from the districts of Karachi, Dadu, Sukkur, Tharparkar and Lasbela.

714 STILES, D. **Arid lands plants for economic development and desertification control**. *Desertification Control Bulletin* (1988) No.17 18-21

Dry land *Acacia/Commiphora* bush in the Sudano-Sahelian region (and similar regions elsewhere in Africa) has been and is being degraded by activities of man, aggravated by drought. Possibilities are discussed for the economic development of these areas using arid land plants whose products are of economic value (gums, resins, oils, etc.). Species considered include *Acacia senegal*, *A. mellifera*, *Commiphora myrrha*, *C. hortziana*, *Boswellia neglecta*, *Sesbania sesban*, *Vernonia galamensis*, *Astragalus* sp., *Lawsonia* sp., and *Sterculia* sp.

715 STONE, G.N.; WILLMER, P.; ROWE, J.A. **Partitioning of pollinators during flowering in an African *Acacia* community**. *Ecology* (1998) **79** (8) 2808-2827

Competition for pollination is an important factor structuring flowering in many plant communities. Mechanisms reducing interspecific pollen flow were examined in plant communities on different soil types with a total of 10 *Acacia* species (*Acacia brevispica, A. drepanolobium, A. etbaica, A. nilotica, A. reficiens, A. tortilis, A. zanzibarica, A. senegal, A. thomasii* and *A. bussei*) in a highly seasonal savanna habitat at Mkomazi game reserve, Tanzania. Partitioning was achieved, in part, through separation of flowering in space and seasons, and through interspecific differences in pollinator guilds. Flowers in both subgenera are typically protandrous and last a single day. In Mkomazi (Tanzania) mass flowering in *A. senegal* occurred in December and January, following the autumn rains, when up to eight Acacia species were flowering concurrently, although slight scattered flowering could occur in other months. The flowers open in mid to late morning, and anther dehiscence followed immediately, giving peak availability during the middle of the day. The pattern of flower opening is correlated with decreasing relative humidity at the microsite. Nectar availability was greatest at the onset of dehiscence, and nectar foragers consistently made up a high proportion of all visits to this species. Honeybees were the most important visitors, followed by nymphalid, papilionid, and pierid butterflies, anthophorine and megachilid solitary bees, pepsid spider wasps and sunbirds (*Nectarinia hunteri* and *A. venusta*). Even the large nectar feeding butterflies, wasps and sunbirds are considered efficient pollen vectors. Nevertheless, co flowering *Acacia* species shared several pollinators; this meant that interspecific pollen transfer is possible. Daily patterns of pollinator activity and pollen release were analysed in 10 *Acacia* assemblages containing a total of 10 *Acacia* species. Pollinator activity was scored using counts at flowers over constant time intervals throughout the day. Pollen availability was assessed using a simple method, which allows quantification of pollen exposed on the surface of the *Acacia* inflorescence. Sympatric co-flowering *Acacia* species each show high intraspecific synchrony but released their pollen at different times of day. Pollinators rapidly harvest available pollen and move from one *Acacia* species to the next, following the daily sequence of pollen release. The activity of shared pollinators was structured throughout the day as a result of temporal patterns of pollen release across *Acacia* species. The observed temporal structuring of pollen release was compatible with patterns predicted to result from competitive displacement. Additional support for a competition based explanation for this patterning came from the observation that an *Acacia* species flowering without competitors shows no synchronized peak of pollen availability at any time of day.

716 STUBSGAARD, F. **Pretreatment of *Acacia* and *Prosopis* seed. Two mechanical methods.** *Technical note, DANIDA Forest Seed Centre, Denmark* (1986) No. 27 1-8

Describes, with drawings, two practical mechanical methods for pretreating *Acacia* and *Prosopis* seed. (1) The home-made impaction scarifier or 'seed gun' slings seed against a concrete drum and allows large quantities of seed to be treated (1 kg in 10 seconds). It proved most successful for the six Prosopis species, whereas for the acacias (*A. caven, A. farnesiana, A. nilotica, A. tortilis* and *A. senegal*) effectiveness varied with the speed. (2) Burning the seed coat with a glow brander proved the best method for small quantities of seed (100 seeds/2 mins). The best results were achieved when the filament was red hot and placed within the areole of the seed for the shortest possible time.

717 STUTH, J.W.; KAMAU, P.N. **Influence of woody plant cover on dietary selection by goats in an *Acacia senegal* savanna of East Africa**. *Small Ruminant Research* (1990) **3** (3) 211-225

Seasonal effects of woody plant cover on dietary selection and nutrition of goats were evaluated in an *Acacia senegal* savanna in Kenya during the dry season and wet season in 1982. Treatment paddocks were established in light, moderate, and heavy woody plant densities with 13, 31 and 47% total canopy cover, respectively. Grass and grass-like species, particularly *Cenchrus ciliaris*, *Sporobolus pellucides*, *Eragrostis caespitosa*, *Digitaria macroblepharia* and *Chloris roxburghiana* dominated goat diets in the early dry season. Browse, particularly *Solanum incanum*, *Grewia bicolor*, *Acacia mellifera*, *Acacia senegal* and *Commiphora africana*, were abundant in the diets of goats from August to November in the moderate and heavy woody covered paddocks. *A. senegal* pods were the major source of feed for goats in July and August. Crude protein concentration exceeded requirements of goats throughout the period of study. Organic matter digestibility of the goat diets was lowest in moderate and heavy woody plant conditions in the late dry season. When contemplating bush removal of woody plants (e.g. for tsetse fly control), consideration should be given

to the role that large *Acacia* trees can play in stabilizing protein intake of goats and other domestic or wild browsers. By giving goats simultaneous access to protein-rich, pod-producing areas and also high-energy grassland areas, pastoralists can diversify diet selection and stabilize nutrient intake. Cutting large *Acacia* trees for fuelwood and charcoal is particularly detrimental to the nutritional ecology of goats and perhaps other browsing herbivores.

718 SUDAN, FOREST DEPARTMENT. **Gum Arabic**. *Rep. For. Dep. Sudan, 1949* (1950) 33-34

Gum yields from the western Division of 22,700 tons for the 1948-49 season showed a drop of 5,800 tons from the previous year. This is attributed to lower prices and the poor 1948 rainfall was followed by exceptionally cold weather. The direct effect of low rainfall on the tree is probably not so important as the effect on movement of the tappers later in the season, such as shortage of water and possibly food for them and their animals. The season started well in November/December with record production which later tailed off with the colder weather, reduced prices and scarcity of water. Gives tonnage figures recorded in both eastern and western divisions and the export tonnage of 31,998 tons of hashab, 1,826 tons of talh gum, 88 tons of bleached gum and 4 tons of gum dust.

719 SUDAN, FOREST DEPARTMENT. **Gum Forests**. *Rep. For. Dep. Sudan, 1950/51* (1952) 45

Notes that during a trip by the entomologist throughout the Kordofan gum Arabic forests, no insects were encountered attacking the trees of *Acacia senegal* even though wounded by the gum tappers, showing how hardy this species is. Also notes that the Talh borer attacks *A. seyal* once the tree has been felled and is dead. Stacking logs vertically and de barking also discourages attack.

720 SUDAN, FOREST DEPARTMENT. **Gum arabic investigation**. *Rep. For. Dep. Sudan, 1951/52* (1953) 36-38

In order to determine the origin of 'stringy gum', an investigation was made on gum from 5 different plots of *Acacia senegal* all in Kordofan province. Results (tabulated) indicate that the stringiness is most general in samples collected early in the season and diminishes with later collections. No evidence was found of correlation with locality, size of tree, or weight of gum produced.

721 SUDAN, FOREST DEPARTMENT. **Gum Arabic "stringiness" investigation**. *Rep. For. Dep. Sudan, 1952/53* (1954a) 35-36

More gum samples were collected from the 5 localities in Kordofan (see report for 1951/52), as well as one from Fung district of the Blue Nile province and the other from Gedaref district, Kassala province. In the latter two areas, *A. senegal* occurs on clay soils with a higher rainfall of 500-800 mm in contrast to the sandy soils of Kordofan which have lower rainfall. In these areas the tree occurs in belts or scattered with associated trees of *A. seyal, Balanities aegyptica, A. mellifera* and with grass species such as *Hyparrhenia pseudocymbaria, Cymbopogon nervatus* and *Sorghum purpureosericeum*. One objective was to divide the samples collected into two parts, analysing one immediately for stringiness and the other six months later. However out of 295 samples analysed only one had 15% stringiness and three had 5% stringiness so the second part of the experiment was abandoned. The reason for low stringiness was not clear, it may be due to climatic factors although the widely different sites and rainfall regimes showed little difference.

722 SUDAN, FOREST DEPARTMENT. **Gum Arabic: Factors affecting yields and harvesting**. *Rep. For. Dep. Sudan, 1952/53* (1954b) 59-61

In the Western Division gum production and prices remained steady, which was a stabilising factor. Climate was favourable and exudation generally good, even though it was feared that the failure of the melon crop might substantially reduce production, as melons in western Kordofan are a source of food and water for the gum tappers and their animals. Less gum was harvested in the west, but was not as great as could be expected and offset by increased production in the northern and eastern districts. The final production figure of 25,288 tons (up to 29/6/1953) for the west was the second highest on record. Gives comparative figures for the previous 5 seasons. In the eastern Division there was a decrease in amount of hashab and talh gum collected except west of the White Nile where yields were exceptionally high. Prices for talh gum rose above those for hashab, with increased sales of talh gum especially in the Gedaref district. Opening of roads and the provision of water stimulated gum tapping. Gives total production figures for the area and export tonnages from the country as a whole.

723 SUDAN, FOREST DEPARTMENT. **Gum Arabic "stringiness" investigation**. *Rep. For. Dep. Sudan, 1953/54* (1955a) 38-39

Further gums of *A. senegal* were collected from 2 sites west of Um Ruwaba on typical Kordofan sands and one from El Khwei on alkaline sands from a depression west of El Obeid to test for stringiness. The incidence of stringiness tended to be higher earliest in the tapping season, with some exceptions from Daggag. One tree with two stems at Daggag produced 15% stringiness from one and the other stem was only slightly stringy (results of analyses tabulated). Yields of gum were low this season, due to late prolongation of the rains in 1953 and a cold winter. Average yields per tree/yr were 181, 80 and 45 grams from the 3 sites.

724 SUDAN, FOREST DEPARTMENT. **Gum Arabic: Factors affecting yields and harvesting**. *Rep. For. Dep. Sudan, 1953/54* (1955b) 55-56

Details the gum Arabic production figures for the 1953/54 season. In the western division rains finished late and were followed with four months of exceptionally cold weather, producing poor exudation from the first tappings. By March production was little more than half what it had been during the previous year, and trade prices rose rapidly to about double the previous years price. Gum sales from March to June were all-time records in the El Obeid market. The final production figures were 22,246 tons at 4/7/1954, only 3,000 tons short of the previous year. In the eastern Division, gum prices increased for hashab from £E 28,600 to £E 66,000 m/ms. and talh from £E 24,860 to £E35,200 m/ms. at the end of the season. Gum collections increased from the southern Fung circle, due to opening new roads and the provision of water. Dinder National Park was also opened up for gum collectors and consequently more talh gum was collected there. Gum production figures for the eastern Division are given of both Hashab (6,874 down from 11,636 tons in the previous year) and Talh (2,261 up from 1,986 tons in the previous year) gums.

725 SUDAN, FOREST DEPARTMENT. **Experiments with Hashab (*Acacia senegal*)**. Rep. For. Dep. Sudan, 1954/55 (1956a) 47-48

Details results of an experiment carried out in 1954 at Umm Ruwaba comparing broadcast sowing with seed sown by a digging stick with seed untreated or pre-treated with conc. sulphuric acid. Seed was also sown at two dates, in May before the onset of the first rains and June during the rains. Germination was relatively low (9-22%) although sufficient for restocking the species. In May untreated seed gave significantly better results than the treated seed, and the digging stick method was significantly better than broadcast sowing. In June there was no significant differences between pre-treatments, and again the digging stick proved a better sowing method. Results of experimental sowings of *Acacia senegal* at Sweilinga near El Fasher in 1954 obtained an 80% success rate. Seed was sown on small mounds about 40 cm in diameter by 2 cm high, and pre-treated for 3 min with acid.

726 SUDAN, FOREST DEPARTMENT. **Gum arabic**. *Rep. For. Dep. Sudan, 1954/55* (1956b) 49

Notes that a further 241 samples of gum were submitted for analysis in continuation into the causes of "stringiness", a formation of a gummy deposit after dissolving the gum. The British Pharmacopoeia and exporters specify that Acacia gum should be free from this phenomenon. Observations confirm previous findings that "stringiness" in gum from a particular tree decreases during the picking season and the smaller the yield the greater the "stringiness".

727 SUDAN, FOREST DEPARTMENT. **Gum Arabic: Factors affecting yield and harvesting**. *Rep. For. Dep. Sudan, 1954/55* (1956c) 52-53

Details gum production figures for both the Eastern and Western Divisions. Production in the West was an all time record of 31,258 tons; the lateness of the rains (and thereby a longer dry season) increased the duration of active exudation and helped to keep the quality of gum very high. In the East, gum hashab (*A. senegal*) increased production from the previous year from 6,874 to 11,367 tons and gum talh (*A. seyal*) decreased from 2,494 to 1,775. This was in part due to increasing prices from Hashab gum and decreasing prices for Talh gum. Also details export figures from Sudan (tonnage and price) for the last seven years.

728 SUDAN, FOREST DEPARTMENT. **Tapping methods [for *Acacia senegal*.]** *Rep. For. Dep. Sudan, 1958/59* (1960a) 84

Experiments made with the tools used in rubber tapping showed such short-handled tools to be impracticable firstly because the *Acacia* tree, with its mush branched crown and thorny branchlets, will not permit their use with any comfort, and secondly because the bark is tough. The established method of using a small axe appears to be the best. In some areas there is an alternative method in which the local hoe, similar to the Dutch hoe, is used to scrape the bark instead of tearing off a strip.

729 SUDAN, FOREST DEPARTMENT. **Seed germination of *Acacia senegal***. *Rep. For. Dep. Sudan, 1958/59* (1960b) 85

A characteristic of the seed of this species is that about half will, on being wetted, germinate within 48 hrs, while the other half will remain for up to 15 days before germination. This difference is found not only in seed from the same tree but also in seed from the same pod. It is a natural provision for a species growing in a region of low and variable rainfall.

730 SUDAN, FOREST DEPARTMENT. **Water requirement of seedlings [of *Acacia senegal*.]** *Rep. For. Dep. Sudan, 1958/59* (1960c) 85

Experience has shown that watering does not have a beneficial effect if continued during the dry season. The *Acacia* seedling sends down a long tap-root (seedlings 2 months old had roots 5 ft long), and the few lateral roots that develop in the early stages probably cease to function as the topsoil dries out. The seedling then draws its water from the lower moist soil layer through other side roots sent out by the taproot. In sandy soils, watering may even be harmful. Heavy mortality in El Obeid nursery during Jan-Feb 1959 was attributed to a 'damping-off' effect, the topsoil being damp, and the tap-root in this region not being able to absorb the water.

731 SUDAN, FOREST DEPARTMENT. **Pests and diseases**. *Rep. For. Dep. Sudan, 1959/60* (1961)

In December 1959, reported dying trees of *A. senegal* were being attacked by unidentified *Coleopterus* larvae in an area of 100 feddans near El Obeid. In the same area millipede damage was stopped by applying Agrocide 3 BHC.

732 SUNDARARAJ, R.; MURUGESAN, S. **Occurrence of *Acaudaleyrodes rachipora* (Singh) (Aleyrodidae: Homoptera) as a pest of some important forest trees in Jodhpur (India)**. *Indian Journal of Forestry* (1996) **19** (3) 247-248

Nymphs and adults of the babul (*Acacia nilotica*) whitefly, *Acaudaleyrodes rachipora*, were observed infesting the leaves of a variety of important arid and semiarid (multipurpose) forest tree species around Jodhpur, Rajasthan in December 1993. Subsequently, a survey of nurseries and plantations showed maximum infestation on *Prosopis juliflora* (778.32 nymphs/leaf) and *Acacia senegal* (540.60 nymphs/leaf). The infestation was low on *Acacia nilotica, Albizia lebbeck, Dalbergia sissoo, Leucaena leucocephala* and *Prosopis cineraria*.

733 SUNDARARAJ, R.; MURUGESAN, S.; AHMED, S.I. **Differential impact of NSKP extracts on nutrition and reproduction of Taragama siva Lefebvre (Lepidoptera: Lasiocampidae)**. *Entomon.* (1995) **20** (3-4) 257-261

The antagonistic effect of neem seed kernel powder (NSKP) (particularly acetone and methanol extracts) on growth rate and nutritional indices such as CI, AD, ECD and ECI in larvae of *Taragama siva* [*Streblote siva*] were evaluated. Host leaves of *Prosopis juliflora, Acacia senegal* and *P. cineraria* treated with 0.05, 0.01 and 0.005% of the extracts were evaluated and analysed in order to assess growth disruption activity. The adverse effect of NSKP extracts on reproductive potential was also estimated. Of the extracts tested against *T. siva*, the 0.05% methanol extract of NSKP gave considerable reductions in survival, growth and egg production.

734 SUNDARARAJ, R.; MURUGESAN, S.; MISHRA, R.N. **Efficacy of neem seed oil against the babul whitefly *Acaudaleyrodes rachipora* (Singh) (Aleyrodidae: Homoptera)**. *Special issue: neem gift of the gods. Indian Forester* (1995) **121** (11) 1077-1080

Laboratory experiments were conducted to study the efficacy of neem (*Azadirachta indica*) seed oil and some conventional insecticides against the babul whitefly (*Acaudaleyrodes rachipora*) on *Acacia senegal*. Neem seed oil at 0.5, 0.3 and even at 0.1% concentrations were very active and suppressed the development of the whitefly significantly, while 0.1% monocrotophos, endosulfan and teepol were not effective.

735 SWAIN, N. **Note on the grazing behaviour of sheep and goat on natural degraded semi-arid rangeland**. *Indian Journal of Animal Science* (1982) **52** (9) 829-830

This study deals with the time spent by native sheep and goat (Malpura) under free range grazing/browsing management in semi-arid regions of Rajasthan, India. The study-area consisted of natural degraded rangeland having undulated topography and many shallow dry watercourses. The vegetation was dominated by short grasses and forbs having a 5.4% cover. The tree layer of the rangeland was predominantly *Acacia senegal* and *Maytenus emarginatus*. There were 294 trees and 430 shrubs per ha producing 5.8 q of fodder (sun dry) estimated through complete lopping. Goats prefer *A. senegal, Maytenus emarginatus, Ziziphus nummularia, Bauhinia purpuria* and *Lacicum barbarum* in the order of preference and spent 3.43 hours/day browsing on *A. senegal* (about 90% of total browsing).

736 SYLLA GAYE, C. **Comportement de *Acacia senegal* en plantation et dans la nature du Sahel sénégalais. Perspectives d'avenir des reboisements gommiers**. In *SYGGA III, Troisiemme Symposium sur le Gommier et la Gomme Arabique, St Louis, Senegal, 25-28 Octobre* (1988) 139-169

737 TANDON, R.; SHIVANNA, K.R. **Pollination Biology and breeding system of *Acacia senegal.*** Botanical *Journal of the Linnean Society* (2001) **135** 251-262

Phenology, pollination biology and breeding system were investigated in three populations of *Acacia senegal* located in Delhi and Rajasthan. Flowers emit a mild fragrance and produce a minute quantity of nectar. The stigma is wet non-papillate, cup-shaped and generally accommodates one polyad with 16 pollen grains. The style is solid. The mass effect created by the brush type of blossoms attracts a wide variety of insects, of which the giant Asian honeybee, *Apis dorsata*, is the most effective pollinator. Manual *in vivo* pollination studies have shown that the species is self-incompatible. Self-incompatibility appears to operate inside the embryo sac. Under natural conditions fruit set is as low as 0.36%, and this is thought to be due to insufficient pollination. Manual xenogamous pollinations substantially improve fruit set to 30%.

738 TCHIE, N.A.; GAKAHU, G.C. **Responses of important woody species of Kenya's rangeland to a prescribed burning**. *African Journal of Ecology* (1989) **27** (2) 119-128

Plants of *Acacia senegal, A. tortilis, A. mellifera, Balanites aegyptiaca, Grewia villosa, Hermania* [*Hermannia*] *alhensis* and *Solanum incanum* of 2 height classes (above and below 1.8 m, except for the last two species) were tagged in 2 adjacent paddocks, one of

which was then burnt. Fire killed plants of most species, irrespective of height. Overall, canopy area and height were reduced for most woody species and density of herbaceous species increased.

739 TEEL, W. **A pocket directory of trees and seeds in Kenya** . Kenya Energy Non-Governmental Organisations (KENGO), Nairobi (1990) 1-150

A very useful guide to tree planting in Kenya, with a large section of 90 tree species profiles both indigenous and exotic. For *Acacia senegal* lists its common names in Kenya, its uses, its preferred climate type, seed information and seed sources (nearly all based in northern Kenya.) It is classified as a desert plant, growing well in the Magadi/Garba Tula and Wajir climate types (these climate types were derived from the Agroclimatic zone map of Kenya). This species produces gum in northern Kenya.

740 TEKETAY, D. **Germination ecology of twelve indigenous and eight exotic multipurpose leguminous species from Ethiopia**. *Forest Ecology and Management* (1996) **80** (1-3) 209-223

The germination requirements of seeds of 20 leguminous species were studied in three experiments undertaken at Alemaya University, Ethiopia. In the first experiment, seeds were subjected to mechanical scarification, sulphuric acid and boiling water treatments. In the second experiment, they were treated with dry heat at 60, 80 and 100°C. In the third experiment, seeds were placed at different temperature regimes (10, 15, 20, 25 and 30°C) on a thermogradient. Sulphuric acid treatment improved germination in all the species while mechanical scarification improved germination in 18 out of 20 species. Boiling water treatment improved germination in 15 species but proved to be lethal to five species. Similarly, germination was significantly improved in 11 out of 16 species treated with dry heat. Germination was faster and higher at both 25°C and 30°C and the optimum temperature for germination was between 20°C and 30°C for all species. Mechanical scarification, sulphuric acid and boiling water treatments as well as dry heat were effective to overcome seed coat imposed dormancy in the species studied. It was not possible to recommend a treatment, which is equally effective for all the species. However, boiling water is a practical method for achieving rapid, uniform and high germination except in five of the species for which it proved to be lethal (*Acacia seyal, Caesalpinia decapetala, Acacia tortilis, C. spinosa* and *A. senegal*). In the latter case, either mechanical scarification or sulfuric acid treatment should be used. Seeds of *Millettia ferruginea* should be sown when they are fresh to get high germination, as they tend to lose their viability during storage. It is demonstrated that once the dormancy in leguminous species with hard seed coats is broken, the seeds germinate in wide ranges of temperature. Other species tested were: (indigenous species) *Faidherbia albida; A. brevispica; Acacia nilotica* subsp. *indica; A. oerfota; A. seyal; A. sieberiana; A. schimperiana; Cadia purpurea; Entada abyssinica* and *Millettia ferruginea*; and (exotic species) *Albizia lebbeck; Delonix regia; Erythrina lysistemon; Leucaena leucocephala; Parkinsonia aculeata* and *Prosopis juliflora.*

741 TEWARI, M.N.; RATHORE, L.S. **Changes in the level of ascorbic acid in germinating seeds of *Acacia senegal* Willd.** *Biochemie und Physiologie der Pflanzen* (1973) **164** 103-106

Shows the changes in the concentration of ascorbic acid (vitamin C) in germinating seeds of *Acacia senegal* collected from Rajasthan, India. Highest concentrations were found in the embryonic tissues, especially the epicotyl, and low concentrations in the cotyledons (no statistical analysis).

742 THOMASSET, J.P. **Le Gommier. *Acacia senegal* (L.) Willd.** *Special issue: trees of the month. (Special arbres du mois.) Flamboyant* (1993) No.27 19-22

One of 13 short (2-3 pages) guides to important trees of the Sahel and Sudanian/ Guinean zones of Africa. [first published in October 1991 in the same journal]. Brief notes are given on botanical synonyms, vernacular names in West Africa, distribution and ecology. Its root system is both a deep taproot and a lateral root system that may cover 500 m^2. Describes the traditional agroforestry system practiced in Kordofan, and its silviculture. Sowing direct or in the nursery is practiced and repotting thinned seedlings is not very successful. Growth of seedlings is rapid in the nursery and within 10 weeks the seedlings can be 30 cm high and ready for planting out. Under the best conditions the plant reach 2 meters in 30 months, but normally 50-60 cm/yr. Also describes the uses and marketing of gum Arabic.

743 THOMASSEY, J.P. [**Natural resources in Chad.**] La situation des resources naturelles du Tchad. *Bois et Forêts des Tropiques* (1991) No. 228 49-62

An account of the natural vegetation and wildlife resources (including fisheries) of Chad, in the context of the prolonged drought from 1973 to 1982. This has resulted in extensive desertification; it is estimated that the major bioclimatic zones (from N. to S., Saharan, Sahelian, and Sudanian) have shifted 150 to 300 km southwards, and that the northern limit of vegetation, which was at latitude 15°30'N in 1964-66, was at 14°N in 1988. *A. senegal* naturally occurs in the Sahelian zone, from 200-600 mm of rainfall. A combination of drought and war has also resulted in a southward movement of population towards the more fertile Sudano-Guinean zone. Forest types within this zone are briefly described. Recent actions to improve Chad's forest resources are

outlined; these include the provision of fast growing and/or multipurpose tree species (*Azadirachta indica, Khaya senegal*ensis for shade trees or in rows, and *Eucalyptus camaldulensis, Prosopis juliflora* and *Parkinsonia aculeata* for shelterbelts and live fences). More recently, attempts have been made to provide seedlings of indigenous species (preferred by many local farmers and pastoralists) such as *Acacia nilotica, A. albida, A. senegal* and *Balanites aegyptiaca*. These species are perceived as resisting climatic extremes (flooding as well as drought) better than exotics. Brief information on natural regeneration in the different bioclimatic zones is also given. In 1987 and 1988 rainfall was plentiful, and regeneration of *A. senegal* and *A. seyal* was proceeding, although stands are susceptible to over browsing or cutting for fuelwood, and, in the case of *A. senegal*, the collection of gum arabic. Two measures introduced in 1989 by the Chad government a Forest Code and an Anti desertification Plan are also briefly noted.

744 THORNDIKE, L. **Science and thought in the 15th century. Studies in the History of Medicine and Surgery**. New York; Hafner Publ. Co. (1963) 1-387

745 THULIN, M.; TARDELLI, M. **A new species of *Acacia* (*Leguminosae, Mimosoideae*) from Somalia**. *Willdenowia* (1988) **17** (1-2) 125-128

A. moggii, a Somali endemic and a member of the *A. senegal* complex, is described for the first time from the Hiram region of central Somalia.

746 THULIN, M. **New and noteworthy species of Leguminosae in NE tropical Africa.** *Nordic Journal of Botany* (1989) 8 (5) 457-488

Describes 20 new legume species from NE tropical Africa including *A. densispina* Thulin, a rare Somali endemic from central Somalia and *A. flagellaris* Thulin, characteristic of the limestone escarpments in the Bari region of northern Somalia, both belonging to the *A. senegal* complex.

747 THULIN, M. ***Acacia ochracea* (Leguminosae-Mimosoideae), a new species from Somalia.** *Nordic Journal of Botany* (1990) 10 (5) 477-479

Acacia ochracea, a new species in the *A. senegal* complex, is described and illustrated. It is a conspicuous tree over large areas in the western Bay region and in the Gedo region in SW Somalia.

748 THULIN, M. **Flora of Somalia. Volume 1 Pteridophyta; Gynospermae; Angiospermae (Annonaceae-Fabaceae)** Kew, UK: Royal Botanic Gardens (1993) **1** 1-857

Taxonomic description of the Acacia species native to Somalia, including *Acacia senegal* (L.) Willd. and *A. circummarginata* Chiov. and other members of the *A. senegal* complex. *Acacia senegal* is normally a small tree or shrub growing to 10 m high, occurring in *Acacia-Commiphora* bushland and dry scrub from 0-1340 m altitude. *A. circummarginata* Chiov. is a tree 5 – 10 m high tree in Somalia, and when growing with *A. senegal* is easily distinguished by being larger with yellowish papery peeling bark, glabrous purplish brown branchlets with long internodes and a glabrous inflorescence axis. Occurs in *Acacia-Commiphora* bushland between 230-490 m of altitude.

749 THULIN, M.; AL-GIFRI, A.N. **Two new species of Acacia (Leguminosae-Mimosoideae) from Yemen.** *Nordic Journal of Botany* (2000) **20** (6) 691-696

Description of two new species of Acacia from the Yemen, including *A. mahrana* Thulin & Gifri, a member of the *A. senegal* complex, and a restricted endemic from the Mahra region of eastern Yemen.

750 THURSTON, M.I.; BONWICK, G.A.; WILLIAMS, P.A.; WILLIAMS, J.H.H.; CRONK, Q.C.B.; DEWEY, F.M. **Detection of gum from *Acacia seyal* and species of *Combretum* in admixtures with *A. senegal* using monoclonal antibodies**. *Food and Agricultural Immunology* (1998) **10** (3) 237-247

Describes the development of monoclonal antibody immunoassays to detect possible adulterant gum from *Acacia seyal* and *Combretum* gum in commercial gum arabic (*A. senegal*). Eight hybridoma cell lines were raised to gum from *A. seyal* that secrete monoclonal antibodies (MAbs) that recognize, by ELISA, gum from *A. seyal* but not gum from *A. senegal*; one of these antibodies (SY JIA1) also recognizes *Combretum* gum. All the antibodies belong to the immunoglobulin class IgM. Plate trapped antigen-ELISA (PTA-ELISA) tests of heat, periodate, pronase and trypsin treated gums indicate that they all recognize heat stable carbohydrate epitopes. Two of these MAbs, SY HH3 and SY JIA1, have been identified as suitable for the detection of gum from *A. seyal* (from the Kordofan region, Sudan) or *Combretum* gum (from the Sokoto region, Nigeria), in mixtures with gum from *A. senegal* (also from the Kordofan region, Sudan). The limit of detection of *seyal* gum in mixtures using SY HH3 in PTA-ELISAs was 0.5% and the limit of detection of *Combretum* gum in mixtures using SY JIA1 in competition Elisa's was 0.1%. The sensitivity of these immunoassays for the gum from *A. seyal* or *Combretum* gum in mixtures is 10 to 100 times greater than that of any of the procedures currently in use.

751 THURSTON, M.I.; BONWICK, G.A.; WILLIAMS, P.A.; WILLIAMS, J.H.H.; DEWEY, F.M.;

AMOS, A.; CRONK, Q.C.B. **Effect of heat and pH on the Carbohydrate Epitopes of gum from *A. senegal* recognised by monoclonal antibodies**. *Food and Agricultural Immunology* (1999) **11** 145-153

In previous papers (Dewey *et al.* 1997, Thurston *et al.* 1998) a set of monoclonal antibodies (Mabs) were raised to detect gum from *A. senegal* and differentiate it from the gums of *A. seyal* and *Combretum* spp. which can occur as adulterants in gum arabic. In order to determine the usefulness of these Mabs in immunoassays for the detection and quantification of gums used in food processing, it was deemed necessary to know how the epitopes recognised by the individual Mabs are effected by exposure to heat and changes in pH both during food processing and in the final product. The Mabs have now been divided into three groups based on their response to mild hydrolysis and elimination (neutral hydrolysis) when heated in buffers at different pH values. They also investigated the binding of these antibodies to three fractions of gum arabic separated by hydrophobic interaction chromatography. Of the three categories of Mabs, two have distinctive and easily reproducible responses to treatment of the gum and would therefore be suitable for investigation of *Acacia* gums, which have been subjected to food preparation procedures. These Mabs could also prove useful for investigating the molecular structure of the gum.

752 THURSTON, M.I.; DEWEY, F.M.; CRONK, Q.C.B. **TEM imaging of native *Acacia senegal* gum by rotary shadowing**. *Microscopy and Analysis* (1999) 13

The gum arabic images obtained from untreated gum show masses of amorphous material, the smallest units varying in size between 30-100 nm. These represent single gum molecules, which vary in size as gum consists of several heterogeneous fractions. When hydrated, the gum probably resembles balls of cotton wool. In the ELISA well the gum will be coated more heavily, resembling jam.

753 TIETEMA, T.; MERKESDAL, E.; SCHROTEN, J. **Seed germination of indigenous trees in Botswana**. *ACTS, BUN and Initiatives Research, Dry lands Research Series No 4, African Center for Technology Studies, Nairobi, Kenya* (1992) 1-106

Describes the practical methods used in seed collection, germination and raising tree seedlings, gives their vernacular names in Botswana, and the results of germination pre-treatments for each of the 67 tree species indigenous to Botswana. *A. senegal* [var. *rostrata*] occurs in sandy soils, slightly alluvial or calcium-rich, and not in wet depressions. The 100 seed weight varies from 10.0-14.5 grams. Soaking in cold water provided up to 50% germination after 1 month, whereas pretreating with cold sulphuric acid for 15 minutes gave 8% germination after 1 month. It should be noted that details on the temperature, quality of the seed batch tested, provenance and age of the seeds, time of year and numbers of seeds are not given.

754 TIMBERLAKE, J. **Handbook of Botswana Acacias**. Botswana; Division of Land Utilization, Ministry of Agriculture (1980) 1-119

Describes 32 *Acacia* species that occur in Botswana and gives keys for the species, general descriptions of the plants, their distribution and habitat, and vernacular names. *Acacia senegal* var. *rostrata* is found in Botswana in tree and bush savannas in sandveld regions on slightly alluvial or calcium-rich soils. In the hardveld it is associated with calcrete outcrops, but not in wet depressions. It is never very common and rather localised in distribution. Variety *leiorhachis* has also been recorded from SE Botswana, in the Bobonong area and northern Tuli Block on stony soils, sometimes with mopane. This variety flowers around September, as opposed to var. *rostrata* which flowers November to December.

755 TIMBERLAKE, J.; FAGG, C.W.; BARNES, R.D. **Field guide to the acacias of Zimbabwe**. Harare, Zimbabwe; CBC Publishing (1999) 1-160

This field guide provides botanical and habit drawings, distribution maps and descriptions of the 44 taxa in the genus *Acacia* that are indigenous to Zimbabwe. Also included are notes on the distribution and ecology of each of the species, and 16 boxes that describe the status, features, attributes and uses of the genus as a whole. The two varieties of *Acacia senegal* (var. *rostrata* and var. *leiorhachis*) are included in the book, with full description and illustrations. In Zimbabwe, the var. *leiorhachis* grows as a distinctive spindly tree commonly on shallow basalt lithosols, especially found on stony ridges and gravely slopes, and more rarely on gneissic and shallow sandy soils. Variety *rostrata* grows as an obconical shrub only on calcareous soils (sometimes with calcium nodules) of alluvial origin associated with the Shashe, Limpopo and tributaries and Save rivers. In Sentinel ranch in southwestern Zimbabwe possible hybids between *A. senegal* var. *leiorhachis* and *A. mellifera* have been repeatedly found.

756 TINDALE, M.D.; ROUX, D.G. **Phytochemical studies on the heartwoods and barks of African and Australian species of *Acacia***. *Boissiera* (1975) **24** 299-305

Studies on the phytochemistry of heartwoods of 10 indigenous southern African *Acacias*, which were correlated with similar studies on Australian *Acacias*. In the series Gummiferae, *A. nilotica* ssp. *kraussiana* has mollisacacidin flavinoids in the heartwood whereas *A. senegal* var. *leiorhachis* and var. *rostrata* (in the Vulgares series) has flavanoids of the pyrogallol A ring type (melacacidin and teracacidin). In *A. nilotica* ssp. *indica*, native in Asia, mollisacacidin-melacacidin was recorded in the heartwood. All these 5-deoxyflavanoids occur in *Acacia* species in Australia.

757 TONDER, S.J. Van. **The systematics of some South Africa *Acacia*-inhabiting Bruchidae (Coleoptera).** *M.Sc. Thesis, University of the Orange Free State, Bloemfontein, South Africa* (1981) 1-125

A study of the seed attacking insects found in the pods of 41 Acacia species growing in South Africa. A total of 3,300 bruchids were studied, and 23 species are described, 7 of them new. No bruchids were found in *A. exuvalis*, *A. swazica* & *A. newbrownii* and small numbers from *A. mellifera*, *A. arenaria*, *A. tenuispina* and *A. albida*. For *Acacia senegal* the species *Bruchidius petechialis* (Gyllenhal) comb. nov. was identified.

758 TONDER, S.J. Van. **Annotated records of southern African Bruchidae (Coleoptera) associated with Acacias, with a description of a new species.** *Phytophylactica,* Pretoria (1985) **17** 143-148

Results published from the M.Sc. thesis, see above abstract. 16 species of bruchid beetles are recorded from southern Africa with their *Acacia* host species. One new species of Bruchidae, *Bruchidius montisustis*, is described from *Acacia montis-usti*. A table 37 species of southern African acacias and their associated bruchids are provided, noting 2 undetermined species on *A. albida*. For *A. senegal* var. *rostrata* found *Bruchidius petechialis* (Gyllenhal) comb. nov., and an undetermined *Bruchidius sp.*

759 TORRES, S.B. **Influence of seed size of *Acacia senegal* on seedling development**. [Influencia do tamanho das sementes de *Acacia* gomifera no desenvolvimento das mudas.] *Agropecuaria Catarinense* (1994) **7** (3) 5

760 TORRES, S.B.; BARBOSA DOS SANTOS, D.S. **Dormancy break in seeds of *Acacia senegal* and *Parkinsonia aculeata* (Superação de dormencia em sementes de *Acacia senegal* (L.) Willd. e *Parkinsonia aculeata* (L.).)** *Revista Brasileira de Sementes* (1994) **16** (1) 54-57

The seed of *Acacia senegal* (L.) Willd. came from an experimental planting at the EMBRAPA semi arid station at Petrolina, PE, Brazil. Various pre-treatments were tried on the seeds, from manual scarification, immersion in hot water at intervals from 3-7 seconds, in ambient temperature from 12 - 24 hours, and in 96% sulphuric acid in intervals from 1-6 mins. For *A. senegal* all treatments had germination percentages between 84 - 90% with no significant differences between treatments. But in the germination speed index, the sulphuric acid treatment for 3 mins was significantly faster.

761 TOTHILL, J.D. **Agriculture in the Sudan.** London; Oxford University Press (1948) 1-973

Before reaching its limiting altitude, *Acacia albida* exists only as dwarf trees or bushes on the upper slopes of Jebel Marra, with a dominant but scarce *Olea chrysophylla* Lam. In Darfur Province, and along the Upper Nile Province, soft volcanic dusts are deposited as excellent riverine soils to form the 'harãz' (*Acacia albida*) of Zalingeri. As an animal foodstuff, young shoots and fruits are eaten with relish by camels. In Kordofan Province, uncultivated 'qöz' soil (undulating, sandy) generally supports a thin covering of grass and herbs, and a fair stand of light to medium bush, the commonest varieties being *A. senegal* (hashab), *A. raddiana* (seyal), *Acacia albida* (harãz), *Balanites aegyptiaca* (heglïg), *Adansonia digitata* (tebeldi) and *Zizyphus* spp. (s_dr).

762 TOUPET, C. [**Regeneration of the natural environment in the Sahel- example from Mauritania.**] La regeneration des milieux naturels dans le domaine Sahelien: l'exemple Mauritanien. In *Le Developpement Rural en Questions - Paysages, Espaces Ruraux, Systemes Agraires (edited by Blanc-Pamard, C.; Bonnemaison, J.; Boutrais, J.).* Paris, France; ORSTOM & CNRS-EHESS (1984) 75-87

Regeneration of the natural environment in the Sahelian area is one of the three priorities of the Mauritanian government. It requires an understanding of the causes of this degradation or desertification. There have been large mortalities of *A. senegal* populations between Boutilimit (100 mm isohyet) and lake Rkiz, in Brakna, Gorgol, Guidimakha, Ássaba and Hodh meridional. The serious reduction in rainfall, with the isohyets moving south, is only one factor in environmental degradation. The pastoralist population helps decimate the environment by using fire, lopping trees for browse, overgrazing with increasing human populations and high livestock numbers (average 1.9 cows/person). In the large settlements there is also a great demand for charcoal, with the consequent deforestation. Attempts to improve the situation have included fencing off areas for natural regeneration, fixing the sand dunes by reforestation, controlling use of fire and lopping and creating a green belt of 700 hectares around Nouakchott (mainly *Prosopis* species and *Euphorbia balsamifera*). The regeneration of the gum tree populations is a priority, and in the 1960's 5% of worlds gum arabic production came from Mauritania. There are estimated 170,000 km^2 of gum populations. The authorities intend to reforest 40,000 hectares, and as a pilot project regenerate 1,500 hectares.

763 TROUP, R.S. **The silviculture of Indian Trees Vol IV Leguminosae.** (Revised and enlarged by the Editorial Board, Forest Research Institute and Colleges, Dehra Dun). India: Dehli, Government of India Press (1983) 76-80

Gives a useful description, distribution, and silvicultural characteristics of *Acacia senegal* in India, with details of its ecology, uses, management, growth and protection

there. It occurs in the arid regions of India (Rajasthan, south-east Punjab, and parts of Gujarat) and Pakistan (Sind). The climatic factors for the species in India are: maximum shade temperatures may rise to 48.3°C and absolute minimum -2.5 to -5°C. The mean daily temperatures vary from 37.5 to 45°C in May (summer) and 20 to 30°C in January (winter), and the mean minimum temperature in the coldest month (January) varies from 4.4 to 10°C. Annual rainfall is erratic and varies from 250 to 600 mm, with long periods in the year without rain. Generally sown by direct seeding for afforestation of the driest areas of India, it is managed under a coppice-with-standards system, with a coppice rotation of 30-40 years. One or two weedings are necessary in the first year of sowing. The wood is hard and heavy (865-913 kg/m^3), the sapwood being yellowish white and the heartwood nearly black. It is durable and not attacked by white ants. Gives coppice rotation figures from the Ajmer-Merwara Forest Division in India, where on a rotation of 30 years 82% of the stools gave coppice shoots, and on a 40 year rotation 92% gave coppice shoots.

764 TROUPIN, G. **Flore des plantes ligneuses du Rwanda Annals serie.** In *Sciences Economiques No.12, Musee Royal de l'Afrique Central, Tervuren, Belgium* (1982) 421

Botanical description of *A. senegal* which occurs between 1300 and 1700 m. in Rwanda, in savanna woodland, especially frequent in the Akagera National Park.

765 TYBIRK, K. **Regeneration of Woody Legumes in Sahel.** *Botanical Institute, University of Aarhus, Denmark, AAU Reports* (1991) No 27 1-81

Book describes the four main aspects of regeneration of woody legumes found in the Sahel, namely seed dispersal, seed predation, germination of hard-seeded legumes and seedling growth. *Acacia senegal* has a dehiscent pod that is dispersed by wind and possibly secondary dispersal by ungulates. Seeds are flat and rather small, 3-4.5/pod, 55-83g/1000 seeds. Up to 15-38% of stored seeds have been infested, primarily by bruchid beetles. In the field up to 2/3 of the seeds are damaged by beetles, rodents and millipedes before germination. Fresh green seeds show two types of germination response, some imbibe readily and germinate while others have delayed germination. In 3 weeks 47-83% untreated seeds germinated, while 63-78% germinated while scarified. Shoot cuttings are possible, and seedling growth relatively slow (30-40 cm/yr) but roots may reach >100 cm in 3 months. Seedlings appear abundantly after rain, but suffer severely from damage from fungi, insects, rodents, browsing ungulates and fire. Some grass or mulch cover seems optimal for establishment of seedlings and cultivation seems beneficial. Concludes that the prerequisite of good regeneration (good seed crop, low seed predation and good rains occurring together) in the Sahel is rare.

766 TYBIRK, K. **Pollination, breeding system and seed abortion in some African acacias.** *Botanical Journal of the Linnean Society* (1993) **112** (2) 107-137

Studies of flower visitors on 4 species of *Acacia (Acacia albida* [*Faidherbia albida*], *A. nilotica, A. tortilis* and *A. senegal)* in Senegal and Kenya showed that they were visited by a high diversity of insects. One hundred and eighteen taxa of insects, mainly Hymenoptera, Lepidoptera, Coleoptera and Diptera were collected on all four species. For *A. senegal* 45 wasps in 14 taxa, 24 bees in 7 taxa, 24 beetles in 10 taxa, 48 butterflies in 12 taxa and 8 flies in 2 taxa were collected. Of these the most important pollen vectors were bees from the families Megachilidae and Halictidae, and wasps from the families Scoliidae and Mutellidae. Beetles, flies and butterflies were secondary pollen vectors. Sunbirds (*Nectarinia pulchella*) also commonly visited *A. senegal* flowers for nectar. *A. senegal* flowers were much more frequently visited, with 60 insect visits per inflorescence per hour, while *A. tortilis* and *A. albida* had only 6 and 10. Diversity and frequency of flower visitors of species with floral nectar (*A. senegal* and *A. albida*) were not clearly different from species without floral nectar (*A. tortilis* and *A. nilotica*). *A. tortilis* was almost exclusively out crossed (Index of Self Incompatibility = 0.2), with 5.5% of the inflorescences (0.13% of the flowers) developing fruits. The number of seeds per pod was positively correlated with dispersal type. Wind dispersed species, such as *A. senegal* and *A. polyacantha*, had fewer seeds per pod than animal dispersed species, but they set more pods per tree resulting in comparable levels of total seed production/tree in all species. About 5% of the seeds were aborted in *A. tortilis* and *A. nilotica*, while 22-48% of the seeds were aborted in *A. senegal* (and also two other species, *A. ataxacantha* and *A. polyacantha*). Most abortions in the latter three species occurred in the proximal end of the pods, indicating selective seed abortion. In *A. senegal* the mean number of seeds per pod was 3, ovules/ovary 10.88, and seed:ovule ratio of 0.28. Average pod production was 4,600 and seed production was 13,800 per tree. Pollination in *A. senegal* was high with 52% of the stigmas pollinated but even so there was a low seed:ovule ratio. The low seed numbers per pod was found to be typical of wind dispersed species, while ungulate dispersed species had much higher numbers and bird dispersed species between the two.

767 TYBIRK, K. **Reproductive biology and evolution of the genus *Acacia*.** *International Group for the Study of Mimosoideae* (1997) Bulletin No.20 45-53

Describes the main factors influencing the reproductive success of the genus *Acacia*, with emphasis on the movement of pollen, the selection of progeny and the dispersal of seeds. The small reduced flowers are united in dense inflorescences to attract a wide range of insect pollinators. The occurrence of nectar is only found in one of the subgenera of the family, namely subgenus Aculeiferum (which includes *A. senegal*), and appears

not to give much benefit as the same wide range of pollinators visit the flowers of the other subgenera. The pollination is efficient, with between 30-60% of all stigmas receiving polyads. The grouping of pollen grains into a polyad, equivalent in number to the number of ovules, allows for high seed set to ovule ratio although the fruit set per flower is low (less than 1%). In the wind dispersed acacias such as *A. senegal* seed set is less than half the ovule number, although in animal dispersed acacias have a higher seed to ovule ratio. Seed predation by bruchid species has evolved into a degree of host specificity. Flower abortions due to competition in the inflorescence and seed predation are major factors which limit the survival of the seeds.

768 TYBIRK, K.; JORGENSEN, A. **Floral biology and pollination of some African Acacias and *Faidherbia albida*.** In *Plants for the people Proceedings of the XIII th Plenary meeting of AETFAT, Zomba, Malawi, 2-11 April 1991 (edited by Seyani J.H.; Chikuni, A.C.).* National Herbarium and Botanic Gardens of Malawi, Box 528, Zomba, Malawi (1994) **1** 589-602

Data is presented on pollinator attraction, floral morphology and pollination of *Acacia senegal*, *A. mellifera*, *A. polyacantha*, *A. ataxacantha*, *A. nilotica*, *A. tortilis* and *A. seyal* and compared to that in *Faidherbia albida*. The flowers in the spicate inflorescence of *F. albida* and *A. senegal* usually progressively open from the proximal end and individual flowers open during 24-48 hours. The inflorescence may have open flowers over a period of 3 days. The presence of sweet nectar was noted in *A. senegal*. A wide range of insects from the *Lepidoptera, Coleoptera, Hymenoptera* and *Diptera* were found visiting the flowers of all species. The mean number of flowers per inflorescence varied from 117-92, and the mean number of pollen grains available per inflorescence was estimated between 1.2 -1.5 million in *Acacia senegal* (measurements from Senegal and Kenya respectively). The pollen to ovule ratio varied from 1.47-1.42 for *A. senegal*. Supports the separation of *F. albida* from *Acacia*. *F. albida* differs in reproductive characters from the African Acacias in timing of flowering; different flower smell; larger polyads; occurrence of 2 polyads on a stigma (in 6.3% of pollinated stigmas studied); higher number of ovules/ovary correlated with number of pollen grains; and lacking an anther gland.

769 TYBIRK, K.; SCHMIDT, L.H.; HAUSER, T. **Notes on soil seed banks of African acacias. Notes and Records.** *African Journal of Ecology* (1994) **32** 327-330

The dynamics of soil seed banks of tropical ecosystems are poorly known but they are important in a consideration of the degradation and resilience of African savannas. Seeds of African Acacia species have hard coats and are long-lived with seed dormancy well adapted to a strategy of seed dispersal over time. These studies of Acacia soil seed banks were carried out in Senegal, Kenya and Zambia. The upper 3-5 cm of soil in plots beneath the crown of the trees was sifted or hand sorted. Whereas high numbers of seeds of *A. mellifera, A. seyal*, and *A. hockii* (from 810 to 2439 seeds m^2) were found in Kenya, far fewer seeds were recorded in *A. tortilis* and *A. nilotica* inside a fenced area with restricted grazing in Senegal and none found underneath the crowns of *A. senegal* and *A. seyal* there. The seed bank of African acacias is influenced by annual seed production, dispersal, predation and germination. African acacias produce from a few hundred to several million seeds on a large tree of *A. albida* but mostly 5,000-100,000 per tree. *A. senegal* is typically wind-dispersed. Bruchid beetles destroy large quantities of seeds (up to 100%) in many African species. Fire also affects the soil seed bank by breaking the seed coat. The contrasting findings here give rise to the question: what really happens to the large annual seed production of *A. senegal*, for example, when the seeds are not found in the soil seed bank?

770 UCHIMURA, E. **Green shelterbelts and afforestation in semiarid zones - a case study of Nigeria.** *Tropical Forestry* (1986) No.5 42-51

The general conditions of various areas of Nigeria are described and the establishment of shelterbelts is discussed. For semiarid areas, the species recommended include *Acacia albida, A. nilotica, A. senegal, Azadirachta indica, Cassia siamea* and *Eucalyptus camaldulensis*. For each of these species the conditions required and notes on its cultivation in shelterbelts are given. The wider range of species available for use in less arid areas is also discussed.

771 ULLMANN, G. **Etude de la structure et de la biosynthese d'un exudat naturel de plante d'importance industrielle: la Gomme Arabique d'*Acacia senegal*.** These Dr Ing. Univ. de Grenoble (1983)

Work published in Joseleau & Ullmann 1985 and 1990.

772 ULLMANN, I. [**Diurnal courses of transpiration and stomatal conductance of Sahelian and Saharian *Acacias* in the dry season.**] Tagesgänge von-transpiration und stomatärer leitfähigkeit Sahelischer und Saharischer Akazien in der Trockenzeit. *Flora (Jena)* (1985) **176** (5/6) 383-409

A study of water relations, and stomatal movements in leaves of 8 species of African *Acacias*, in the middle of the dry season in the Sahelian and southern Sahara zones. Daily leaf diffusion conductance, transpiration rate under porometer conditions, leaf temperature and leaf microclimate were measured in *Acacia albida, A. erythrocalyx, A. ehrenbergiana, A. laeta, A. nilotica* ssp. *tomentosa, A. tortilis* ssp. *raddiana, A. senegal* var. *senegal* and *A. seyal* growing either in the region of

Niamey (Sahel) or Kori Teloua (Sahara). Deciduous *Acacias* were found to have high transpiration rates, with a maximum around noon. Despite accentuated drought conditions during the measuring period in spring 1983, little change was detected in water loss, probably due to rooting into the ground water table. A drought response was noted in some shrubs of *A. ehrenbergiana*, growing in granite foothills, where there was a decrease in maximal stomatal conductance and a restriction of water loss [from authors summary].

773 UMOH, B.I.; HALILU, S.A.D. **Effect of concentrate supplementation to browsing on performance of growing rams in a semi arid environment**. *Small Ruminant Research* (1992) **9** (2) 173-180

Balami rams about 17 kg were given an all concentrate diet or given concentrates to provide 75, 50, 25 or 0% of their feed intake, for the remainder of their feed they were allowed to browse species native to Northern Nigeria. Mean ambient temperature was 41°C and relative humidity at noon was 23.5%. Browsed plants included *Acacia albida, Acacia senegal, Trifolium sp., Gmelina sp., Piliostigma reticulatum, Oldenlandia sp., Hibiscus sp., Sorghum bicolor, Zizyphus mauritiana* and *Z. spina christi*. Average daily gains (kg/day) were 0.160, 0.20, 0.130, 0.06 and 0.04 kg for rams on the 5 diets, respectively. Gains and average daily gain were significantly increased for rams on the 75% supplement compared with control (0%) or 25% supplement. Least square means obtained for rib eye muscle area did not show significant differences. Dressing percentage was decreased with low levels of supplementation ($P < 0.05$). The diet with 75% of feed intake as concentrates was the most economic.

774 URQUIDI, R.L. **Gums for food uses - a review**. *Flavours, Food, Additives* (1978) **9** (2) 73-76

775 VAN DEN BERGH, J. **The aim of Aidgum**. *African Farming and Food Processing* (1987) January/February, 39, 44

The resurgence of gum production in Mali is described, noting the decisive role played by the Malian government. Increased political encouragement for the private sector led to gum exports averaging 300 t/year between 1973-77. An export of 2000 t is forecast for 1987. Productivity and planning of harvest on a large plantation, created in 1975 by the International Association for Natural Gum Development (Aidgum), is discussed.

776 VAN DEN BERGH, J. **L'*Acacia senegal*, un arbre sur lequel mettre la gomme**. *Spore* (1990) No.25 5

General article describing *Acacia senegal*, its uses and value, and how well it is adapted to the Sahelian region. However it disappeared in many areas during the droughts of the 1970's, partly due to overgrazing. But plantations, particularly in Mali, have not provided expected gum yields, which vary considerably between trees. Suggests that the Sudanese gum garden model, where natural regeneration is protected in the fields is the best option.

777 VAN WYK, B.; VAN WYK, P. **Field Guide to Trees of Southern Africa** *South Africa: Struik Publishers, Cape Town* (1997) 1-536

Richly illustrated field guide to more than 1000 tree species, classified into groups based on easy to observe vegetative features. *A. senegal* or three-hook thorn has two varieties in southern Africa, a shrub or small tree (var. *rostrata*) or a slender, upright spindly tree (var. *leiorhachis*). Browsed by game, especially black rhino.

778 VAN WYK, P. **Trees of the Kruger National Park**. South Africa; Purnell & Sons, Cape Town (1972) **1** 1-284

Detailed descriptive treatment of the trees of the Kruger National Park, in northern South Africa. Both *A. senegal* var. *leiorhachis* and var. *rostrata* occur in the park, and detailed descriptions of the morphology and distributions are given and illustrated with colour photographs. Variety *leiorhachis* flowers in August September on leafless twigs, and pods ripen November/December, whereas var. *rostrata* flowers in November/December on leafy twigs and fruits ripen February/March. Very different in stature, only var. *rostrata* produces sizable logs, whose timber is off-white, without heartwood, hard and heavy (990 kg/m^3). It has fairly noticeable pale brown annual rings and large pores. Trees are often frequently damaged by borers.

779 VASSAL, J. [**The morphology of young seedlings of *Acacia*: African *Acacias***.] *Trav. Lab. For. Toulouse* (1969) Tome1 **8** (3) 1-57

On the basis of a study of the morphology of young seedlings of *Acacias* of the sections Vulgares and Gummiferae, the author confirms the status of the section Gummiferae, but finds the section Vulgares to be heterogeneous, comprising (1) species of the group *pennata*, (2) *A. ataxacantha* and (3) a group comprising *A. caffra*, *A. galpinii*, *A. laeta*, *A. nigrescens*, *A. polyacantha* ssp. *campylacantha*, and *A. senegal*.

780 VASSAL, J. [**Gum Acacias and gummosis**.] Acacias gummiferes et gommose. In *Gommes et colloides végétaux naturels hydrosolubles, Quatrieme symposium International, 5-8 Novembre 1976*. (1978) 67-79

Describes the three main subgenera of *Acacia*, and the position of the principle gum Acacias that occur in the sahelian regions of Africa. These species are then briefly

described, notably *A. senegal* and its complex, *A. laeta* and *A. seyal* and its complex, and to a lesser extent *A. tortilis* and *A. nilotica*. The process of gummosis is then detailed histologically into three main phases. The first is a chemical modification of the cell membranes of the cambium, the second the thickening of the lignin fibres and cell walls filling with a gum mass. The third phase is the formation of gum lacunae, and the appearance of gum in the xylem vessels. There are various conditions which favour gum exudation during the dry season, such as the previous years rainfall, influence of hot dry winds during December and January, and damage done to the bark by man, his animals and sand storms. Discusses the possibility that gummosis is a reaction to infection by parasites or microorganisms, but more recent thinking suggests that it is a physiological phenomenon and not a pathological one. Concludes that there is still much to be studied in the systematics of the gum Acacias and the physiological processes of gummosis.

781 VASSAL, J. **Tribe 4. *Acacieae* Benth (1842) Nom. conserv. prop.** In *Advances in Legume Systematics (edited by Polhill, R.M.; Raven, P.H.).* (1981) Part 1 169-171

Taxonomic review of the tribe, including the genus *Acacia* and its three subgenera.

782 VASSAL, J. **Gummiferous *Acacias* and Gum Productivity. Some Aspects of Current Research.** *International Group for the Study of Mimosoideae* (1985) Bulletin No.13 30-37

Outlines 3 fields of research undergone at the University P. Sabatier in Toulouse; general data on the biology and distribution of the gum species (apart from *A. senegal* includes *A. laeta, A. mellifera, A. polyacantha, A. ehrenbergiana, A. nilotica, A. seyal, A. sieberana, A. tortilis, A. drepanolobium, A. hockii, A. karroo, A. kirkii, A. nubica* and *A. xanthophloea*), improvement of gum productivity through selection and factors involved inducing gum production. Gum is produced by stress and is dependant on various factors such as rainfall, microsite in the population, and production in the previous year. The main producer is the Republic of Sudan responsible for 83 to 88% of the world production from 1970 to 1983. In that country *A. senegal* regenerates quite well on abandoned cultivated areas. *A. senegal* accounts for about 90% of production and exudes the best commercial grade of gum: tasteless, odorless and viscous, giving pale yellow or colourless solutions. Yields vary considerably (a few grams to 1 kg or more/tree/year). Notes that provenance trials of the species have been undertaken in Sudan, Senegal and Mali, but to date no high yielding varieties are available. Also details the experimental plantation of Australian Acacias undertaken in Corsica to study growth and gum production.

783 VASSAL, J. **Etat des connaissances sur l'induction de gommose chez *Acacia senegal*.** In *Physiologie des Arbes et Arbustes en zones arides et semi-arides. Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadnam, C.; Joly, H.; Bory, G.)* (1993) 271-276

A review of research carried out on factors which induce gummosis. Gummosis in *Acacia senegal* is very probably induced by several factors. It is favored by wounding at the beginning of the dry season when the trees have lost around 2/3 of their foliage. It also seems to be induced by water stress and increased gummosis is correlated with decreased air humidity. He notes that the regular relationships between the tree vigour and their ability to exude gum and the contingent role of pathogenic organisms in the induction of gummosis is still ignored. Suggests further ecophysiological research into the water balance conditions in the tree at the optimum stage of gummosis induction.

784 VASSAL, J. **Progress of experimental research on the gum arabic tree *Acacia senegal* (L.) Willd. in northern Senegal.** *International Group for the Study of Mimosoideae* (1997) Bulletin No.20 8-9

An abstract which presents results on a multidisciplinary programme of research on the gum arabic tree from 1989 to 1991 at the experimental plantation of M'Biddi in northern Senegal. The research surveyed 280 trees within 7 plots in 3 different sites of old sand dunes. Concluded that the volume of gum exuded depends on the amount of rainfall, which seems optimum between 300 to 500 mm. The sharp drop of hygrometry and the increase in temperatures in October/November could cause water stress favoring the induction of gummosis. Gummosis is enhanced on the dune tops where water shortage happens very early at the beginning of the dry season (early and parallel leaf fall). Tapping is more successful on the dune tops in October/November than in the hollows where the water store is higher. Physiologically speaking the beginning of the dry season seems the more appropriate period for exudation, as late tapping in the hollows remains poor.

785 VASSAL, J. **Acacias in *Senegal*. Taxonomy, ecology, and importance.** [Les acacias au Senegal. Taxonomie, écologie, principaux interets.] *In L'Acacia au Senegal (edited by Campa, C.; Grignon, C.; Gueye, M.; Hamon, S.).* L'Orstom, Collection colloques et séminaires, Paris, France (1998) 15-33, 449

A key to the species of *Acacia* and *Faidherbia* is presented, and nomenclature and taxonomic changes are noted. Brief details are also included on the geographical distribution in the country, and main uses of wood and non wood products. The species are: *Faidherbia albida, Acacia kamerunensis, A. ataxacantha, A. macrostachya, A. polyacantha* subsp. *campylacantha, A. dudgeoni, A. senegal* var. *senegal, A. farnesiana* (an introduced species), *A. sieberana* var. *sieberana, A. sieberana* var. *villosa, A. nilotica* subsp. *tomentosa, A. nilotica* subsp.

adstringens, *A. tortilis* subsp. *raddiana*, *A. seyal* var. *seyal* and *A. ehrenbergiana*. *A. senegal* prefers an annual rainfall of 200-600 mm. in the Sahelian domain on deep sandy soils. Describes briefly the uses and production of gum arabic, and up to 30,000 tonnes produced in Senegal at the end of the 1980's. Notes that the experimental plantation of gum trees at M'Biddi forest research station (ISRA) will allow further research into rational exploitation of the gum arabic tree.

786 VASSAL, J.; COSSALTER, C. **Projet de recherches sur les gommiers pour une relance de la production de gomme vegetale au Mali**. CTFT (1984) 1-103

787 VASSAL, J.; GROSSO, B. ***Acacia senegal***. Fiche Technique, Publication AIDGUM (1987) 1-2

788 VASSAL, J.; MOURET, M. **Etapes histologiques du processus de gommose chez *Acacia senegal***. In *Physiologie des Arbes et Arbustes en zones arides et semi-arides. Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadnam, C.; Joly, H.; Bory, G.)* (1993) 277-281

An anatomical study of the branches of *Acacia senegal* (2-6 cm circumference), to study the processes of gummosis. Gum lacunae arise from the large tanniferous cells of the subcambial phloem, which are progressively dislocated (by intercellular secretion), and broken down by lysis. These lacunae become enlarged tangentially and grow out radially after alteration and engulfment of fiber strata and phloem rays. Some of the xylem vessels are filled in with a gummy substance. Gum appears to be synthesized from starch grains which are abundant in the xylem parenchyma.

789 VENAULT, G. [**Gum arabic in the Chad region**.] La gomme arabique dans la region du Tchad. *L'Agronomie Tropicale* (1946) **1** (3/4) 179-181

Considerable stands of *Acacia senegal* exist in the neighbourhood of Lake Chad in the borders of Niger (Maine-Sorsa) and Nigeria (Gueidam). In Chad the dominant stands occur in the regions of Rig-Rig, d'Ati and d'Abecher. Gives the gum yields in the Goure circle (Niger) as 127 tons in 1938 and 256 tons in 1939. In Niger and Chad only wild gum is collected by nomadic tribes. Tapping was tried in 1940 around Fort Lamy but without much success. In Nigeria the natives regularly tap the trees for gum, which are not plentiful except in areas with an average annual rainfall of less than 500 mm. Notes are given on attempts at artificial regeneration of *A. senegal* in Maidugari, and on the conditions of the trade in gum. The principal obstacle to the trade in the Chad region is the lack of transport infrastructure.

790 VERINUMBE, I.; JARVIS, P.G. **Agroforestry development in northeastern Nigeria**. *Special issue. Agroforestry: principles and practices. Proceedings of an international conference 23-28 July 1989, University of Edinburgh, Edinburgh, UK. Forest Ecology and Management* (1991) **45** (1-4) 309-317

Some results of recent agroforestry development efforts and research in northeastern Nigeria are summarized, and briefly discussed. An initial diagnostic survey of farms and local markets indicated local agroforestry practices used in arable farming, livestock rearing, fishing and forestry, and identified promising indigenous tree species. Some 26 of these are listed in a table, indicating their local uses and the extent of seed infestation by insects (which averaged 28%). *Acacia albida* and *Ziziphus* spp. were particularly popular among farmers. Nursery studies on the indigenous species indicated poor germination and seedling survival. Plantations of 7 tree species (*Leucaena leucocephala*, *A. nilotica*, *Khaya senegalensis*, *A. senegal*, *Azadirachta indica*, *Prosopis juliflora* and *Eucalyptus camaldulensis*) raised through the taungya system recorded >75% survival and 4.08 cm annual mean girth increment over the first 4 yr. *Acacia albida* increased the soil nutrient content under its canopy, and the yield of 3 crops (maize, sorghum and groundnuts) was increased about 5X by growing them in soil taken from under 12 yr old plantations of *Azadirachta indica*, *P. juliflora* or *E. camaldulensis*; soil from the surrounding field was used as the control. Work in progress to develop agroforestry systems on (difficult) vertisol soils, and plans to investigate the social and economic prospects of alternative agroforestry systems among farmers in the region, are also outlined.

791 VERMA, S.K. **The ecology of the *Anogeissus pendula* forests of Rajasthan, central India**. *Bois et Forêts des Tropiques* (1972) **144** 17-28

Describes the species composition and ecology of these dry deciduous forests, which represent the climax vegetation of the area. Pure stands of *Acacia pendula* are common. In the central part of the areas, *A. senegal* is common, while in the south, *Anogeissus latifolia* occurs. The stands, whose mean height is 8 m and maximum height 12 m, have been much degraded by over-exploitation, illicit felling, burning, grazing, browsing, lopping and shifting cultivation, but their retrogression can still be checked, or even reversed, by control of these practices.

792 VIDAL HALL, M.P. **Note sur l'*Acacia senegal* avec reference particuliere a sa regeneration**. *FAO - Centre de perfectionnement sur les techniques de boisement en savanne. pro. Special FAO d'education et de formation en Afrique* (1963) 1-5

Describes the problems associated with the natural regeneration of *A. senegal* in the Kordofan province of Sudan and the experiments undertaken there to

determine the better and most economical method for its artificial regeneration. The artificial regeneration can be undertaken by government plantations or by increasing the gum gardens by private owners. Three methods were studied, direct seeding, or producing cuttings or seedlings in the nursery and then planting out in the field. The most efficient method was found to be direct seeding, in the taungya method in the following way. After preliminary clearing the soil is disc ploughed twice after the first rains. Seeds of *A. senegal* are planted in lines every 4 meters, and the seeds sown in the lines every 8-15 cm, at the same time as sowing the agricultural crop (often sorghum). The final spacing of the trees is 4 x 4 m (recommendations from the Umm Ruaba research station). Replanting in some lines may be necessary the year after. Weeding for two to three years is necessary close to the seedlings. Sowing with crops appears not to adversely affect production, as the roots of *A. senegal* penetrate well below the upper soil horizon in which Sorghum develops. The actual density of trees in the gum gardens is around 45/feddan, and if the 4 x 4m spacing is followed the density would increase to 250 trees/feddan. The farmer can also just plant the seeds in the last year of cropping. Nursery grown seedlings which are planted out produce gum a year earlier than direct sown plants. Also notes that wind breaks of *A. senegal* could be used on the wide flat clay plains in Kassala and the Blue Nile provinces where mechanised agriculture is undertaken, and which are devoid of trees.

793 VINCENT, M. **Voyage d'exploration dans l'Adrar**. *Revue Algerienne et Coloniale, October* (1860) 447

794 VIR, S. **Bruchid infestation of leguminous trees in the Thar Desert**. *Tropical Science* (1996) **36** (1) 11-13

Bruchids, attacking fruits of the leguminous trees *Prosopis cineraria, Prosopis juliflora, Acacia tortilis, Acacia senegal* and *Albizia lebbeck* (the major component of afforestation programmes and sand dune stabilization works) in different regions of the Thar desert, India, are reported. No damaged seeds from any species germinated.

795 VIR, S.; PARIHAR, D.R. **Insect pests of *Acacia senegal* (L.) Willd. and *Acacia tortilis* (Forssk.) Hayne in the Thar desert of Karnataka**. *Myforest* (1993) 29 (2) 105-111

The 2 *Acacia* spp. are the major multipurpose tree species used in plantation forestry programmes related to waste land development, sand dune stabilization, and fuelwood and fodder production in this arid tract. Since very little was known about the insect pests of the species a 4 yr study was initiated in 1989 at the Central Research Farm at Jodhpur (and nearby) in Rajasthan where the trees grow abundantly. A table is included of the 37 pest species recorded, indicating their common names (types) and pest status. Most of the pests were not a major problem. Exceptions were white grubs (Scarabaeidae) and termites (Isoptera) at the nursery stage, defoliators *Indarbela guadrinota [I. quadrinotata], Beralade similis [Chilena similis]* and sap suckers (*Oxyrachis tarandus*) on plantation trees, borers on old/felled timber (Buprestidae and Bostrichidae), and bruchids on pods and seeds. Natural enemies (beneficial insects) found (parasites and predators) are also listed, and a control schedule is suggested.

796 VISSER, N.; VAN HOVEN, W.; THERON, G.K. **The vegetation and identification of management units of the Honnet Nature Reserve, Northern Province, South Africa**. *Koedoe* (1996) **39** (1) 25-42

An analysis is presented of the vegetation of the Honnet Nature Reserve. Releves were compiled in 56 stratified random sample plots. The Braun Blanquet procedure revealed 12 distinct plant communities and 4 sub communities (*Sclerocarrya birrea* high closed woodland; *Colophospermum mopane/Terminalia prunioides* high open woodland with 2 subtypes; low open woodland 6 types, one with 2 subtypes, with the main diagnostic woody species *Sesamothamnus lugardii, Catophractes alexandri, Acacia nilotica, A. senegal, T. prunioides, Ehretia amoena, Grewia hexamita, Commiphora mollis, A. tortilis, Indigofera melanadenia*; low closed woodland 2 types, diagnostic woody species *Commiphora glandulosa, Gardenia resiniflua, A. borleae; Boscia foetida* low sparse shrubland; and open forbland with no woody species). The Variable Quadrant Plot Method was used in the structural analysis of the communities and management units. The data were ordinated using Detrended Correspondence Analysis (DECORANA) to determine possible relations and gradients between and in the plant communities. Six management units were identified by means of the vegetation ordination, plant communities and the physical environment. A hierarchical classification, description and ecological interpretation of the vegetation units and a description of the management units are presented.

797 VOGT, G.; LOUESSE, S.; HOHMANN, V.; LAURENT, C. **Cultures in vitro de tissues et de cellules d'*Acacia senegal* (L.) Willd., en vue de la production de metabolites secondaires**. In *Physiologie des Arbes et Arbustes en zones arides et semi-arides. Seminaire, Paris-Nancy, 20/3-6/4/1990 (edited by Riedacker, A.; Dreyer, E.; Pafadnam, C.; Joly, H.; Bory, G.)* (1993) 289-302

Details experiments on tissue culture of bark explants of 4 year old green-house grown plants of *A. senegal*. Various variants were identified based on the consistency and colour of these subcultures. Some variants produced secondary metabolites (polysaccharides).

798 VOGT, G.; PALMA, B. **Influence of some sterilizing agents on the ability of *Acacia senegal* seeds to imbibe water role of different parts of the seed coat.** [Influence de quelques produits desinfectants sur le pouvoir d'imibition des graines d'*Acacia senegal* role des differentes parties du tegument.] *Phyton Horn.* (1991) **31** (1) 97-109; 23

Morphological study on the effects of disinfectants on the permeability of the seed coat of *A. senegal*. These disinfectants used for the decontamination of *in vitro* treated seeds (such as ethanol, sodium hypochlorite, calcium hypochlorite and concentrated sulfuric acid), could modify the ability of seeds to imbibe water during germination, and thereby the vigor of the developing plant. It was shown that the seeds immersed for 15 mins. in concentrated sulfuric acid (at temperatures from 4-40°C) enhanced the ability of *A. senegal* seeds to absorb water (100% absorption) without harming the embryo. The results of the experiments suggested the presence of 3 strata in the testa; a cuticle, below this a palisade epidermis, and finally the rest of the testa. It is proposed that each of these has a specific physiological role in water absorption.

799 VYAS, M.B.; SHARMA, K.C. **Spermoderm patterns in some Mimosaceae.** *Feddes Repertorium* (1998) **109** (1-2) 67-72

Presents scanning electron microscopic photomicrographs of the seed surfaces of *Acacia catechu, A. leucophloea, A. senegal, Albizia lebbeck, Dichrostachys cinerea, Leucaena leucocephala* and *Pithecellobium dulce*. These all show a rugulate type of spermoderm pattern, although each species has its own characteristic pattern.

800 WAHBA KHALIL, S.K.; ELKHEIR, Y.M. **Dimethyltryptamine from the leaves of certain *Acacia* species of Northern Sudan.** *Lloydia* (1975) **38** (2) 176-177

Reports on a study looking for alkaloids in the leaves of 11 Sudanese Acacia taxa, including *Acacia albida*. An alkaloid was identified by TLC and GLC chromatography as dimethyltryptamine in only three species, *Acacia polyacantha, A. nubica* [*A. oerfota*] and *A. senegal*.

801 WANG WEIPING, P.; ANDERSON, D.M.W. **Non food applications of tree gum exudates.** *Chemistry and Industry of Forest Products* (1994) **14** (3) 67-76

This review outlines the major commercial applications of the most widely used tree gum exudates, viz. gum arabic from *Acacia senegal*, gum tragacanth from *Astragalus* species, gum karaya from *Sterculia* species, and gum ghatti from *Anogeissus* species. The applications listed include pharmaceuticals, cosmetics, and technological applications in textiles, lithography and other non food industries.

802 WAPNIR, R.A.; TEICHBERG, S.; GO, J.T.; WINGERTZAHN, M.; HARPER, R.G. **Oral rehydration solutions: Enhanced sodium absorption with gum arabic.** *Journal of the American College of Nutrition* (1996) **15** (4) 377-382

The objective was to assess whether adding gum arabic (GA) to oral rehydration solutions (ORS) of either 60 or 90 mM sodium enhances net water and sodium absorption in rats. A soluble fiber such as GA appears to enhance sodium absorption from ORS when tested in the experimental animals, and net water absorption was unaffected.

803 WARBURG, G.R. **Egypt and the Sudan: studies in history and politics.** London UK; Frank Cass (1985) 1-253

804 WATA, I. **Regression de la gommeraie et desertification au Manga.** *Environnement Africain, Cahiers d'Etude du Millieu et d'Amenagement du Territoire* (1979) No.37 1-18

Describes the problems of desertification around Manga in the Sahelian zone of Niger, and the disappearance of the populations of *Acacia senegal*. Presents a map of the region, with the present limits of the gum populations and the approximate limits from 1930-50 (further North). The principle causes of desertification are attributed to the action of man, the use of bush fires, overgrazing and indiscriminate lopping of trees for fodder, and clearing for cultivation. Three state forests are described which have *A. senegal* as one of the main tree species. Lists the commercial yields of gum arabic which are exported through the port of Lagos (Nigeria). Tonnages in the late 1940's averaged 900-1000 tons/annum, but since 1972 tonnages declined from 835 to 91 tons/annum in 1977. One of the problems is that the species is a valuable forage especially at the end of the dry season, when it can be overgrazed (drastically reducing natural regeneration) and lopped indiscriminately. Describes a project, funded by the World Bank, to protect 5,186 hectares of gum populations, which are tabulated from 3 regions, aiming to selectively thin them to about 200-250 trees/ha and surround them by fire breaks. Indicates the importance of community involvement, and ideally that the trees are owned by members who will manage and exploit them.

805 WATT, J.M.; BREYER-BRANDWIJK, M.G. ***Acacia senegal.*** In *The medicinal and poisonous plants of southern and eastern Africa.* Edinburgh and London; E. & S. Livingstone Ltd. (1962) 1-550

A review of the literature on the composition and medicinal uses of obtained from the gum, root, bark, leaf and seed of *Acacia senegal*. Apart from the gum properties and uses, the root is listed as being used as a gonorrhoea remedy, and the bark and leaf as an astringent like other Acacias.

806 WATTENDORFF, J. **Ultrahistochemical reactions of the suberized cell walls in *Acorus*, *Acacia* and *Larix*.** *Zeitschrift für Pflanzenphusiologie* (1974a) **73** (3) 214-225

Reports an electron-microscope study in which suberized cell walls of twigs of *Acacia senegal* were found to have a non-periodate-reactive suberinic layer between the strongly reactive primary and tertiary wall layers. This type of suberized cell wall contrasts with that of *Picea* and *Larix* where wall formation ends with the deposition of non-periodate-reactive filling cork.

807 WATTENDORFF, J. **The formation of cork cells in the periderm of *Acacia senegal* Willd.** *Zeitschrift für Pflanzenphysiologie* (1974b) **72** 119-134

Ultrastructure studies undertaken of young twigs of *A. senegal* using an electron microscope. Cork cells of *Acacia senegal* that have been fixed during their suberization can be recognized by the fact that they do not yet have tertiary walls. If the suberinic wall layer consists of only few lamellae, suberization is in full progress. As such cells are few in number, suberization must be rapid. During this process, the endoplasmic reticulum is arranged in one to several long cisternae parallel to the cell wall, but this applies also to cells before and after suberin deposition. Highly contrasted material with myelin figures appears in the cells during suberization. It seems to be more abundant in cells with a separation of the cytoplasm into a ribosome-rich and a ribosome-free phase; these cells are possibly damaged. Similar material sometimes appears in small quantities in the plastids and maybe in mitochondria even before suberization. The lamella period of the myelin figures is different from that of cork lamellae. The Golgi activity is high during primary wall formation, restricted during suberin deposition, and seems to be taken up again before the tertiary wall is laid down.

808 WEBB, D.B.; WOOD, P.K.; SMITH, J.P.; SIAN HENMAN, G. **A guide to species selection for tropical and subtropical plantations.** *Oxford Forestry Institute, University of Oxford, Tropical Forestry Papers* No.15 (1984) 1-256

Gives datasheets for 173 tropical and subtropical species, covering climatic, ecological and silvicultural characteristics. *Acacia senegal* is described from the Sahelian zone of Africa only, being an aggressive colonizer, light demanding species, which coppices and is used in dune fixation, anti-erosion and agroforestry. Number of seeds per kilogram varies from 7000-12000. Somewhat optimistic wood volume production of 4-7 m^3/ha/yr is reported.

809 WEBB, J.L.A. Jr. **Shifting sands: an economic history of the Mauritanian Sahara 1500-1850** . *Ph.D. Thesis, Johns Hopkins University* (1983)

810 WEBB, J.L.A. Jr. **The trade in gum arabic: prelude to French conquest in Senegal.** *Journal of African History* (1985) ***26*** 145-168

From the late seventeenth century until the 1870s gum arabic from the southwestern corner of the Sahara was the most important trade good exported to Europe from Mauritania and Senegal. This article discusses the dynamics of the gum trading system based at Saint Louis du Sénégal, and details the commercial crisis in which the French colony was mired in the late 1830s and 1840s. Pressure from the French capital and from Faidherbe's military forces secured the dominance of the import-export houses, as African river traders and desert gum merchants lost the advantages of their market positions. By the 1870s the importance of the gum trade had been eclipsed by the rapid expansion of peanut cultivation.

811 WEBER, F.R. **Reforestation in arid lands.Appropriate Technologies for Development.** Peace Corps (1977) 173-174

Gives a general description of *A. senegal* with its vernacular names in west Africa. *Acacia albida* and *A. raddiana* need 10-14 weeks in plastic pots prior to transplanting whereas *A. nilotica* and *A. senegal* needed 14-18 weeks (8 cm diam. x 30 cm deep). *Acacia senegal* can also seeded directly. Its planting requirements are sandy soils or stabilised dunes on dry sites (350 mm m.a.r.).

812 WEIR, A.H.W. **Report on Gum Arabic in Bornu Province.** Nigeria, Lagos Government Report (1930) 1-24

Describes the history of the Bornu gum trade, distribution of the species (north of the Potiskum-Maiduguri road), regeneration and possible gum yields, and recommendations for development of a gum industry there.

813 WELLS, M.J.; BALSINHAS, A.A.; JOFFE, A.; ENGELBRECHT, V.M.; HARDING, G.; STIRTON, C.H. **A catalogue of problem plants in Southern Africa.** *Memoirs of the Botanical Survey of South Africa* (1986) No.53 49-50

Information listed on 1653 taxa, including 711 naturalised exotics, which have been shown to be weedy in certain situations in southern Africa. 45 *Acacia* taxa (mostly indigenous) are described, including

A. senegal (L.) Willd. var. *leiorhachis* Brenan. It is included in the National Weed List having the undesirable characteristics of being competitive (for space, light, water, nutriment), replacing preferred vegetation (grass), thorny (plant). It is cultivated as an agricultural, horticultural crop, and is ornamental. Also includes *A. senegal* (L.) Willd. var *rostrata* Brenan. It is included in the National Weed List having the undesirable characteristics of being competitive (for space, light, water, nutriment), thorny (plant), and obstructing access. It is as a declared invader.

814 WHISTLER, R.L.; BeMILLER, J.N. **Industrial gums. Polysaccharides and their derivatives**. New York; Academic Press (1959) 1-766

815 WHITE, F. **Forest Flora of Northern Rhodesia (Zambia)**. London; Oxford University Press (1962) 82

Botanical description of *A.sp.*1, which he states was erroneously cited in Kew Bulletin (1953) as *A. senegal* var. *leiorhachis* Brenan. It is a straggly tree 3-4.5 m tall from the Victoria Falls area. States that Brenan now feels that it belongs to *A. circummarginata* [although Brenan (1970) in Flora Zambesiaca changed his mind again and treated it as *A. senegal* var. *leiorhachis.*].

816 WHITE, F. **The vegetation of Africa**. *Natural Resources Research, UNESCO* (1983) **20** 1-356

A descriptive memoir to accompany the UNESCO/AETFST/UNSO Vegetation Map of Africa (3 sheets and legend; scale 1:5,000,000). In Part One, brief introductory chapters deal with environment, land use and conservation. Part Two describes regional framework, classification and mapping units. Part Three, comprising the greater part of the text, describes the vegetation of the main floristic regions individually in 22 chapters; for each region, the salient features of the flora, geology and climate are also described. A geographical index to the bibliography and a species index are provided. *Acacia senegal* is widespread throughout the drier areas of Africa and is mentioned as being dominant or an associate in 6 major floristic zones (phytochoria): (1) Sudanian regional centre of endemism, in the drier northern parts of the Sudanian region in Sudanian woodland with *A. nilotica* subsp. *adstringens* and *A. macrostachya* (both Sudanian endemics); (2) Somali-Masai regional centre of endemism, common in the *Acacia/Commiphora* deciduous wooded grassland, semi desert annual grassland, semi desert dwarf scrubland, deciduous bushland and stunted deciduous bushland; (3) Lake Victoria regional mosaic, in evergreen and semi evergreen bushland and thicket derived communities; (4) Zanzibar-Inhambane regional mosaic, in Zanxibar Inhambane secondary grassland and wooded grassland; (5) Tongaland-Pondoland evergreen and semi evergreen bushland and thicket, in the northern area with *A. nilotica;* and the (6) Sahel regional transition zone. In the Sahel it occurs in Sahel wooded grassland (widespread in the southern Sahel) often forming pure stands, frequently following cultivation and as a secondary species, in the Sahel semi desert grassland, found where rainfall is over 100 mm/yr, in the Jebble Mara Basement Complex peneplain, and Kordofan in wooded grassland with crops. In sand dune areas it is normally restricted to interdune hollows. Forms part of the gum crop cultivation cycle, and helps to suppress *Striga hermonthica* during the fallow period of the cycle. Can be found in dune areas as low as 200 mm/yr where *A. tortilis* and *A. senegal* occur with *Aristida sieberana* (grass species).

817 WHITEHEAD, E.E.; HUTCHINSON, C.F.; TIMMERMANN, B.; VARDY, R. (eds.) **Arid lands: today and tomorrow**. *Proceedings of an International research and development conference, Tuscon, Arizona, USA, October 20 - 25, 1985.* (1985)

818 WICKENS, G.E. **A study of *Acacia albida* Del. (*Mimosoideae*)**. *Kew Bulletin* (1969) **23** (2) 181-202

A detailed study of distribution of *Acacia albida*, and a taxonomic discussion, with a review of pollen, anatomy, ecology, pests and diseases and its economic significance (timber properties, chemical composition, fodder value and agricultural importance). In E. and S. Africa, it is a constituent of well defined riparian community, but in W. Africa it also occurs away from riverbanks. Often found in association with *A. senegal* (Darfur) and *A. tortilis* (Uganda, Rhodesia).

819 WICKENS, G.E. **Alternative uses of browse species**. In *Browse in Africa; the current state of knowledge (edited by Houérou, H.N. le).* Ethiopia; ILCA (1980) 155-182

The gum of *A. senegal* is edible. The species is also recorded as having various medicinal purposes; the bark, leaves and gum are used for diarrhoea, opthalmia, colds, haemorrhages and as an emollient and astringent, and is also used as an aphrodisiac. In farming the species is used as a soil stabilizer, to improve fertility and fallow period, and to reduce *Striga* infestation. It is used for fuel and charcoal. Its timber is used for throwing sticks, well linings and tool handles. For domestic economy the roots and bark are used for cordage and the gum as the gum arabic of commerce.

820 WICKENS, G.E.; GOODIN, J.R.; FIELD, D.V. **Plants for arid lands**. London; Allen & Unwin (1984) 1-452

821 WICKENS, G.E.; SIEF EL DIN, A.G.; SITA, G.; NAHAL, I. **Role of *Acacia* species in the rural**

economy of dry Africa and the Near East. *FAO-Conservation-Guide* (1995) No.27 1-56

This paper reviews the literature on the role of *Acacia* spp. in the rural economy of the drier regions of Africa and the Near East from the eastern Mediterranean and Red Sea to the Indian Desert. In these drier regions where cropping is unpredictable, greater value is placed on the perennial vegetation and the dominant genera such as *Acacia*. The livestock industry in these areas depends on browse, especially from Acacias, to provide supplement grasses and herbs particularly in the dry season (up to 30%). There are five main parts to the paper: (1) *Acacia* in the ecosystem; (2) The uses of *Acacia* in the rural economy; (3) The role of *Acacia* in the rural economy (by country); (4) Selected species (*Acacia nilotica, Acacia senegal, Acacia tortilis, Faidherbia albida* and exotics); and (5) Multipurpose management of *Acacia* formations. These are followed by references and an extensive compilation of tables and other annexes. *A. senegal* is included among 160 *Acacia* species native to Africa and the Near East, in the drier regions of which 78 (97 taxa) are reported to be utilized for fuel, timber, forage, gum, tannins, fibre, medicine, food, handicrafts, domestic utensils, environmental protection, soil fertility, shade and shelter, game refuge, amenity and ornamental plantings, and agroforestry. Information on these uses is provided by the tables. *A. senegal* is one of the four most important species to be treated separately. Varieties *senegal* and *kerensis* occur in deciduous wooded grassland, deciduous bushland and dry scrub (120-1680m), variety *leiorhachis* in woodland and bushland (460-910 m), and var. *rostrata* in woodland, wooded grassland and bushland (0-600m.). The species is the main source of gum arabic, fór which it is planted throughout the Sahel. *A. senegal* is used for **firewood** - important source of firewood and charcoal; **timber** - has dark hard termite resistant wood, which is used in construction timber, tools and implement handles, fence posts and weavers shuttles; **browse** - foliage (2.5kg DW of litter/tree/yr from a 7 year old tree in Kordofan), pods and gum exudates eaten by camels and goats (livestock excluded from the gum gardens in the Sudan as browsing reduces yield of gum), browsed by giraffe and impala; young foliage, flower buds and flowers eaten by baboons; **bee**; flowers a good bee forage, honey amber coloured, very mild aroma, granulates rapidly, within 2 weeks; **gum**; notes all 4 varieties produce gum, marketed in Africa and India; **tannins**; none; **fibre**; root fibres woven into ropes in the Sahel, those of lateral roots making the strongest ropes suitable for well ropes and fishing nets; **medicine;** *gum* - emollient - inflammation, angina,-demulcent- opthalmia, whitlow, colds; - bechnic- diarrhoea, otitis, aphrodisiac; - diuretic-haemorrage; *gum + bark* - angina, inflammation; *bark* - astringent, colds, opthalmia, haemorrage; *leaves* - astringent - colds, opthalmia, diarrhea, hemorrhage; **food** - seeds dried and preserved for human consumption, gum edible (both Africa and India). Nodulation recorded in varieties *leiorhachis, rostrata* and *senegal*. Lists uses in different geographical regions.

822 WIELAND, R.G. **Native legumes in south-western Somalia of potential economic value.** *Nitrogen Fixing Tree Research Reports* (1985) **3** 39-41

Notes are given on the habitat, habit, nursery performance and uses by refugees (who subsist as nomadic pastoralists) of 6 species of *Acacia, Albizia anthelmintica, Dalbergia commiphoroides* and *Delonix baccal. Acacia senegal* is divided into three variants, which grow on separate habitats around Luuq. The gypsum variant grows on the gypseous plains, is a small tree with a 2-3 m diameter crown, a slender stem that divides about 1 m above ground. It is a slow grower, but performed well in the nursery. There is also an alluvium variant, which is medium sized and shrubby, and prefers alluvium near gullies, depressions or drainage ways. It is less common than the other two, performs excellently in the nursery and is particularly thorny (good for live fencing). There is also a limestone upland variant, which is the tree form of *A. circummarginata*. It is a yellow barked tree to 5 m and its trunk can reach 30 cm diameter. It had mediocre nursery vigour probably due to high soil salinity. Most of the *Acacia spp.* are recommended for reforestation in semi-arid or arid areas that are denuded or unproductive.

823 WIELAND, R.G.; ORR, B.D.; HELIN, W. **Species elimination trials for reforestation in S.W. Somalia.** *Nitrogen Fixing Tree Research Reports* (1985) **3** 42-45

A report on the nursery and outplanting phase of the Inter-Church Response Forestry Program's research in determining which species should prove most successful for reforestation of cut-over areas around refugee camps at Luqq. Growth rates in the nursery of *Acacia senegal* was measured at 5.6 cm/30 days, about half of the fastest growing species (*Prosopis* sp.) during a drought year of 80 mm of rainfall.

824 WIELAND, R.G.; WERGER. M.J.A. **Land types and vegetation in the Luuq district of south-western Somalia.** *Journal of Tropical Ecology* (1985) **1** 65-87

A land use survey involving land typing and vegetation classification was conducted in within the Luuq District Refugee Area (2000,000 ha) in south western Somalia. Average rainfall and annual temperature of the area are 310 mm and 30.5°C. The area is composed of limestone and basalt uplands, gypsiferous and alluvial interplains and ancient and recent alluvial terraces of the Juba River. Land types are identified by aerial photo survey and ground observation and mapped on a 1:100,000 scale LandSat Satellite Image. Vegetation was sampled according to the Braun-Blanquet approach in 52 releves. Most community types identify distinct land types: basalt and limestone uplands, gypsum and alluvial interplains, and depressions and gentle rises of the Juba River Terrace. *Commiphora* and *Acacia* species dominate the open thorny bushland. *Acacia senegal* (L.) Willd var.

leiorhachis was found to be on the Upland areas with Basalt Parent Material with soilsub order typic haplargids (cover 90%) and typic torriorthents (cover 10%) with vegetation type- *Commiphora boranensis* community and 3 releves [2 releves per type by the Braun-Blanquet way]; and with Limestone Tableland - lithic torriorthents (100% cover) and Limestone Hills and rolling uplands -lithic torriorthents (100% cover), with vegetation type *Commiphora corrugata* community and 12 releves [1 releve per type, by the Braun Blanquet way]. *Acacia senegal* (L.) Willd. var. *senegal* was found to be on the Alluvial plain (Mesic), with vegetation type *Grewia villosa* and 4 releves [1 releve per type, Braun Blanquet way]; Limestone Hills and rolling uplands - lithic torriorthents (100% cover), with vegetation type *Commiphora corrugata* community and 12 releves [1 releve per type, by the Braun Blanquet way]; and on the gypsum interplain with associated sub soil lithic torriothents (80% cover), gypsum rock outcrop (10%) and typic camborthids (10%), with vegetation type *Acacia edgeworthii* community and 8 releves [5 releves per type].

825 WILLIAMS, G.R. **The processing of gum arabic to give improved functional properties**. In *Gums and Stabilizers for the Food Industry 5 (edited by Phillips, G.O.; Williams, P.A.; Wedlock, D.J.)* (1990) 37-40

Discusses how the processing of gum arabic has advanced over the past 30 years. Gums are cleaned by a mechanical process prior to processing to produce a pure product, free from impurity. Excessive temperature during processing can damage the product, and care must be taken to ensure that no deterioration of the gum properties occurs. The future suggests that gum arabic will become a specialized process product in powder form of varying particle size and bulk density, with specific enhanced solution attributes to meet end user requirements. This newer product can successfully challenge the competitive starch derived products.

826 WILLIAMS, P.A.; PHILLIPS, G.O.; RANDALL, R.C. **Structure-function relationships of gum arabic**. In *Gums and Stabilizers for the Food Industry 5 (edited by Phillips, G.O.; Williams, P.A.; Wedlock, D.J.)* (1990) 25-36

Recent developments on the structure of gum arabic are reviewed and are considered in relation to its rheological and emulsification properties. The effect of heat on the functional characteristics is also discussed. Gum arabic consists of three principal fractions, an arabinogalactan (AG), an arabinogalactan-protein complex (AGP) and a glycoprotein (Gl). The highly branched compact structure of the AG and AGP results in solutions of particularly low viscosity. The complex structure of the AGP, where hydrophilic carbohydrate blocks are linked to a main polypeptide chain, enables strong adsorption at the oil-water interface and promotes emulsion stability. The AGP and Gl components are denatured on heating resulting in a loss of emulsification efficiency and a reduction in solution viscosity.

827 WILSON, J.G. **Nutritional value of some common cattle browse and fodder plants of Karamoja, Northern Province, Uganda**. *East African Agricultural and Forestry Journal* (1963) **28** (4) 204-208

Tabulates the dry matter % of crude protein, fat, fibre, and the total ash etc. in the young shoots or pods of 25 herbs and 23 woody species, the latter including *Acacia albida*, *A. nilotica* ssp. *subalata* and *A. senegal*. For 10 of these woody species the calcium CaO, phosphorus P_2O_5, potassium K_2O, magnesium Mg, and manganese Mn contents are also listed.

828 WINLOCK, H.E. **Models of daily life in Ancient Egypt from the tomb of Meket-Re at Thebes**. Metropolitan Museum of Art, Egyptian Expedition, New York (1955) **18** 1-106

829 WOLF, J.N. **Influence of climate on the production of tropical crops**. *Proceedings of a regional meeting organized by the International Foundation for Science (IFS) and the Technical Centre for Agricultural and Rural Cooperation (CTA), Ouagadougou, Burkina Faso, 23-28 September 1991.* [Influence du climat sur la production des cultures tropicales. Compte rendu du seminaire regional organise par la Fondation Internationale pour la Science (IFS) et le Centre Technique de Cooperation Agricole et Rurale (CTA), Ouagadougou, Burkina Faso, 23-28 Septembre 1991.] Stockholm, Sweden; International Foundation for Science (IFS) (1992) 1-506

Papers presented at the meeting are arranged into seven chapters and in chapter 3 covering climate, microclimate and tropical crops. The correlation of climate and gum arabic in the silvopastoral zone of Senegal and its silvicultural implications is discussed.

830 WORKMAN, S.W. **Nodulation trials with selected arboreal legumes of Burkina Faso, West Africa**. *Nitrogen Fixing Tree Research Reports* (1986) **4** 7

A nursery study in Moundasso, Burkina Faso, to see if 26 legume species nodulated when inoculated with Rhizobium obtained from MIRCEN/NifTAL in Hawai. No species from the subfamily Caesalpinoideae nodulated after 60 days, and nearly all species from the Papilionoideae and Mimosoideae nodulated including 33% of the 15 seedlings of *A. senegal*.

831 WORLD HEALTH ORGANIZATION **Toxicological evaluation of certain food additives and**

contaminants. *WHO Food Additives Series, Geneva* (1990) **26** 77-79

832 WORLD HEALTH ORGANIZATION **Evaluation of Certain Food Additives and Contaminants**. *WHO Technical Report Series* (1995) No.859 39

833 WU, Q.; FUNG, C.; LAMPORT, D.T.A.; QI, W. **Gum arabic glycoprotein is a twisted hairy rope. A new model based on O galactosylhydroxyproline as the polysaccharide attachment site**. *Plant Physiology* (1991) **96** (3) 848-855

Separation of the wound exudate gum arabic from *Acacia senegal* on a preparative Superose 6 column gave 2 major fractions: a high MW gum arabic glycoprotein (GAGP) containing about 90% carbohydrate and a lower MW heterogeneous gum arabic polysaccharide fraction. Hydrogen fluoride deglycosylation of GAGP gave a large (_400 residue) hydroxyproline rich polypeptide backbone (dGAGP). Alkaline hydrolysis of GAGP showed that most of the carbohydrate was attached to the polypeptide backbone as small (_30 residue) hydroxyproline (Hyp) polysaccharide substituents. After partial acid hydrolysis of the Hyp polysaccharide fraction, O galactosylhydroxpyroline was identified as the glycopeptide linkage, identical with that of hydroxyproline rich arabinogalactan proteins (AGPs). However, unlike the acidic alanine rich AGPs, GAGP is basic and notably deficient in alanine. Thus, while the GAGP polypeptide backbone more closely resembles that of the Hyp rich cell wall protein extension, the GAGP polysaccharide side chains resemble AGPs. Possibly all 3 proteins comprise a phylogenetically related extensin superfamily of extended rod like macromolecules. The 'wattle blossom' model for AGP and gum arabic predicts a few large polysaccharide substituents along the polypeptide backbone of a spheroidal macromolecule. On the contrary, the data imply a rod like molecule with numerous small polysaccharide substituents (attached to 24% of the Hyp residues), regularly arranged along a highly periodic polypeptide backbone based, hypothetically, on a 10 to 12 residue repetitive peptide motif. Thus, a simple statistical model of the gum arabic glycoprotein predicts a repeating polysaccharide peptide subunit of about 7 kDa. The small polysaccharide substituents will maximize intramolecular hydrogen bonding if aligned along the long axis of the molecule, forming in effect a twisted hairy rope. Electron micrographs of rotary shadowed GAGP molecules support that prediction and may also explain how such apparently large molecules can leave the cell by endwise creeping through the small pores of the primary cell wall.

834 WUNDER, W.G. **The handling of seed in Sudan Forestry**. *Pamphlet, Forestry Research Education Project, Forest Department, Sudan* (1966) No.19 1-23

Gives seed bank details of various tree species, both exotic and native found in Sudan. For *A. senegal* var. *senegal* gives seed numbers as 8,300 per kilogramme, which germinated well after 14 days, if given the seed pre-treatment of 30 mins soaking in water at 60 degrees centigrade (97% germination).

835 WYATT, G.M.; BAYLISS, C.E.; HOLCROFT, J..D. **A change in human fecal flora in response to inclusion of gum arabic in the diet.** *British Journal of Nutrition* (1986) **55** 261-266

836 ZECH, W.; BOCHTER, R.; DERING, C. **The influence of site preparation on the water contents of sandy soils in Northern Senegal**. *Natural Resources and Development (Germany F.R.)* (1982) **16** 116-27

Through trials in Senegal, it was established that *Acacia senegal* plantations show considerable differences in growth, resulting primarily from differences in soil water supply. Soil under trees of vigorous growth always contained more water than that under trees of unsatisfactory growth. Water contents can be increased locally by digging micro catchments and by working the soil by disc harrow and hillère. In view of the results recommendations for practical application are made.

837 ZHANG, X.; HARPER, R.; KARSISTO, M.; LINDSTROM, K. **Diversity of *Rhizobium* bacteria isolated from the root nodules of leguminous trees**. *International Journal of Systematic Bacteriology* (1991) **41** (1) 104-113

Sixty rhizobial strains isolated from the root nodules of *Acacia senegal* and *Prosopis chilensis* in the Sudan were compared with 37 rhizobia isolated from woody legumes in other regions and with 25 representatives of recognized *Rhizobium* species by performing a numerical analysis of 115 phenotypic characteristics. Nineteen clusters were formed below the boundary levels of 0.725 average distance, which was the level that separated the reference *Rhizobium* and *BradyRhizobium* species. The results indicated that tree rhizobia are very diverse with respect to their cross nodulation patterns, as well as their physiological and biochemical properties, since 12 of the clusters formed consisted of tree rhizobia alone. Two distinctive features of tree rhizobia isolated in the Sudan were their high maximum growth temperature and their high salt tolerance.

838 ZOLLNER, D. **Sand dune stabilization in central Somalia**. *Forest Ecology and Management* (1986) **16** (1-4) 223-232

Describes a pilot project started in June 1983 in the Hiiraan region of central Somalia, where 30 ha. of

broken sands were crosshatched with cuttings of local *Commiphora* sp., and seedlings of 18 species of trees and shrubs (salt tolerant), planted at a 5 x 4 m. spacing between them. The *Commiphora* cuttings formed micro windbreaks which reduced wind velocity and blowing sand, and excluded livestock. *Prosopis juliflora* performed better in growth than the native *Acacias* after 15 months, though they all had high survival rates. After 15 months, *Acacia senegal* (local provenance) seedlings were on average 30 cm. high, and had an average crown diameter of 89 cm. After planting, ground cover increased from 5% to 29% in 18 months, with no supplementary watering.

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