Investigation of arthropods associated with agroforestry in Machakos, Kenya

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Mesoplatys ochroptera: MPT defoliator

Abstract

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A survey of arthropods associated with exotic multipurpose trees and food crops used in agroforestry and indigenous tree species (*Tamarindus indicus*) grown in the wild was conducted in 1990 and 1991. The exotic multipurpose tree species (MPTs) used were: *Gliricidia sepium*, *Leucaena leucocephala* and *Cassia siamea* growing in an alley cropping system and the food crops were *Vigna unguiculata*, *Zea mays*, and *Cajanus cajan.* The consequences of growing taxonomically related plant species in agroforestry systems were considered. Insecticidal knockdown technique was used to sample arthropods from the foliage. 92 species of arthropods belonging to 48 Families were found to be associated with tree species and the crops. Of these, 27 species were on MPTs, 3 species on crops, 12 species on the chosen wild tree, 13 species were shared amongst MPTs and crops while 14 species were shared between MPTs and the wild tree. A further 19 species were shared between all the groups of plant species (MPTs, crops and the wild tree) with 4 species being shared between the wild and the crop. The effect of tree pruning on arthropod communities on trees was also investigated and the results showed that pruned trees supported a richer arthropod fauna than unpruned trees.

Through simulated defoliation, the impact of insect defoliators on four MPTs was also investigated. There was a considerable reduction in overall growth rate, height and diameter increment depending on the level of defoliation. Several stress factors often predispose plants to insect attack. Pruning, as a stressing agent was investigated in relation to infestation of *Cassia siamea* by the stem borer *Xyleutes capensis*. Out of the 200 pruned trees surveyed, 90 % showed the signs of borer attack, compared with only 31.5 % of unpruned trees.

The role MPTs can play in aggravating infestation of stored pulses by a bruchid beetle, *Callosobruchus chinensis* was investigated by comparing its survival on seeds of three MPTs and *Cajanus cajan.* Whereas the bruchid was able to oviposit on both the MPT and crop seeds, no larval emergence was observed in any of the MPTs showing that the MPTs may not support reproduction and development of *C. chinensis* in the field.

To the memory of my Father
and to Joseph Hannington Oluoch

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Abbreviations used in the text

C	Celsius
CABI	Commonwealth Agricultural Bureau International
Cc	*Cajanus cajan*
Ccl	*Calliandra calothyrsus*
cm	centimetre
Cs	*Cassia siamea*
ETS	Evapotranspiration
FTC	Farmers Training Centre
Gs	*Gliricidia sepium*
Hs	Handsearch
ICRAF	International Centre for Research in Agroforestry
ICIPE	International Centre for Insect Physiology and Ecology
km	kilometre
Ks	Knockdown spraying
Ll	*Leucaena leucocephala*
m	meter
mm	millimetre
MPT(s)	Multipurpose tree (species)
NDRFS	National Dryland Farming Research Station
s	second
Sn	Sweepnet
Ti	*Tamarindus indicus*
UV	ultra violet
ULV	Ultra low volume
Vi	*Vigna unguiculata*
Ws	Wild shrub
Zm	*Zea mays*

Chapter 1

General Introduction

1.1 Population, food and climate

The imbalance between rapidly increasing populations in many tropical countries, and their dwindling food, fuel and fodder resources has reached alarming proportions resulting in even more pressure on the already threatened environment (Anderson & Grove, 1987, Myers, 1993). As an ecological zone, the humid tropics has an immense potential for high biological productivity (Bryson & Muray, 1977). Precipitation, ranging from 1,800 mm to 4,600 mm per year, exceeds evapotranspiration and nets sufficient moisture in the soil to nurture plants (Jackson, 1977). A substantial amount of solar radiation is received to boost photosynthesis since daylight hours are almost uniformly long and bright sunshine occurs most days of the year. In addition there are no extreme seasonal temperature variations (see, for example, Figure 1.3) to cause periodic plant dormancy and considerable nutrient inputs are provided through rain and litterfall (Altieri *et al*, 1987).

The vast species diversity and the luxuriant growth of tropical rain forest are indicative of this productive potential (Erwin, 1983). Paradoxically, however, most of the countries that are socio - economically depressed, and whose populations at times suffer from food shortages and malnutrition are located in these potentially productive humid tropics (Parry *et al*, 1992). Agricultural production has been declining through inappropriate land use (Murdoch, 1990) or devastating economic losses through the ravages of pests (Hulse, 1993). When for example, a natural forest ecosystem is transformed into an agroecosystem, the rate of nutrient drain increases considerably and usually exceeds the natural inputs by a substantial amount (Stoutjesdijk &

Barkman, 1987). The nutrient loss may occur through forest cutting and biomass exportation, as in logging prior to cropping (Gates, 1993); accelerated erosion and runoff caused by exposure to the erosive forces of wind and rain, and loosening of soil surface through cultivation (Altieri *et al*, 1987); and excessive nutrient exportation through frequent harvest of annual crops (Jackson, 1977). These environmental stresses placed on production systems have called for the incorporation of more structural complexity in agriculture to narrow the widening gap between the huge nutrient losses and minimal natural inputs (Hecht, 1982). This necessity has led to renewed interest in agroforestry research which can only be significant if it has value for the development of the better life for the poor farmers of the third world.

1.2. Agroforestry - the definition

According to the International Centre for Research in Agroforestry, ICRAF (1994), agroforestry can be defined as "a sustainable land management system which increases the overall yield of the land, combines the production of crops (including tree crops) and forest plants and / or animals simultaneously or sequentially, and applies to management practices that are compatible with the cultural pattern of the local population." Many other definitions have also been proposed. For example, Lundgren (1982) defined it as "a collective name for land use systems and technologies where woody perennials (such as trees, shrubs, palms) are deliberately used on the same land management unit as agricultural crops and /or animals, either in some form of spatial arrangement or temporal sequence". Though definitional differences do occur, some basic ideas about agroforestry do emerge (Nair, 1993): firstly that agroforestry is a land use system including the combination of agriculture, forestry, horticulture, and animal husbandry, secondly, that integration of trees with crops and / or animals has the main objective of reducing risks and increasing productivity; and finally that the integration of trees with agricultural systems may result in a more efficient utilisation of the natural resources such as sunlight, nutrients and moisture than is generally possible in alternative cropping systems.

In general, agroforestry aims to relate forestry resources production, human ecology, with various technical and cultural constraints to knowledge generation through technology. Agroforestry is a centuries - old practice. The communities have only been recently studied scientifically. That this practice is old tells us that the communities have not just recently developed.

1.3 Multipurpose Trees Species (MPTs)

Tree species used in agroforestry have frequently been described as 'multipurpose tree species' or MPTs and have been defined as "those which are deliberately grown or kept and managed for preferably more than one intended use, usually economically and / ecologically motivated major products and / or services in any multipurpose land use system, especially agroforestry systems" (von Carlowitz, *et al.*, 1991)). Though the term 'multipurpose tree' has been frequently used, it gives the impression that there is a particular group of species that qualify. However, no species in the plant kingdom can be said to have a single purpose. For example all plant species absorb carbon dioxide but to the farmer this is of no direct significance. However the effect of vegetation upon soil or water conservation (Nair, 1984, Altieri, 1987) is of more immediate concern to the farmer and the multipurposeness is measured entirely in terms of utility.

1.4 Role of trees in agroforestry

Considering that the trees are a dominating component in the agroforestry systems and offer many advantages at virtually no expense, it is useful first to give a general description of their role in agroforestry before discussing the specific MPT species in question. Growing of trees on farms has given the farmers some surety against the risk of total crop failure that is common in the tropics when rains fail. Mixed cropping systems supply most of the family's basic requirements, and the inclusion of trees in these systems has potential for even greater productivity and stability of the system. The role of trees in agroforestry land use systems is central. The long term persistence of trees provides a wide choice of management techniques such as training, lopping, browsing and pruning which are helpful in modifying their shape and growth pattern and flowering and fruiting behaviour (Duguma *et al.*, 1988, Li, *et al.*, 1994). The judicious use of leguminous trees can aid in nitrogen fixation, recycling of nutrients, and reducing soil water run off (Lal, 1989, Young, 1989). However, because of their long life cycles, woody perennials influence the investment pattern and restrict cropping flexibility. Inspite of such restrictions, trees are the most important components in the multiple productivity and sustainability of agroforestry systems.

1.5 Agroforestry Systems

Agroforestry systems involve combining agricultural and tree crops of varying longevity (ranging from annual through biannual and perennial plants) arranged either temporarily (crop rotation) or spatially (inter cropping) to maximise and sustain aggregate yields. Classifying the myriad of observable or hypothetical agroforestry systems has been problematic. Table 1.1 sets some of the examples of agroforestry systems and practices in developing countries based on the results of 'ICRAF' Agroforestry Inventory (Nair, 1993).

It is clear from the definitions of agroforestry that several practices may be involved in the constitution of agroforestry systems. Commonly these practices involve the arrangements of the components in space and time. There are several ways of classifying agroforestry systems based on the structure, function, production and arrangements of the various components (see for example Nair, 1989)

A recognisable system may be based on one criterion or the integration of various criteria. A good classification system should not only serve descriptive purpose but also provide a relevant and realistic framework for developing strategies and development of agroforestry land use. Most of the systems proposed so far have not included the development of research strategies. Much of the novelty of agroforestry as a field of systematic research and development lies in the introduction of the trees and shrubs into the agricultural and pastoral lands. Most attention so far has focused on various aspects of the woody component.

Table 1.1 Some examples of agroforestry systems and practices*

Agroforestry system	Subsystem	Description	Major groups of components
Agrisilviculture :	alley cropping	crops - including shrub / vine / tree crops - and trees agricultiral species in alleys in between hedges	woody, fast growing leguminous species, common agricultural crops
	MPTs on crop lands (block)	trees scattered according to some systemic patterns on plots	MPTs + fruit trees + common agricultural crop
	fuel production	interplanting firewood species on or around agricltural lands	woody - firewood species + agricultural crop of the locality
Silvopastoral :	Protein banks	trees with pasture and / animals production of protein - rich tree fodder on farm / rangelands for cut - and carry fodder production	leguminous fodder trees + herbaceuos trees + fodder for grazing
	Plantation crops with pasture and animals	trees, crops with pasture / animals	woody plantation crops + fodder for grazing + animals
Agrisilvopastoral :	Multipurpose woody hedgerows	woody hedges for browse, mulch, green manure, soil conservation, etc.	fast growing leguminous fodder trees and common agricultural crops

* Nair, 1993

Plate 1.1 Photograph showing alley cropping of MPT (*L. leucocephala*) with *V. unguiculata*. (Pruning on *L. leucocephala* prevents shading of the crop)

1.6 Entomology in Agroforestry

The arthropod colonisation of multipurpose tree species is of particular interest to agroforest entomologists and agroforesters in general since herbivory above- and below- ground may alter the rate of establishment and affect the success of the introduced plant species. This is of great relevance to agroforestry since majority of the MPTs have been introduced into most of the areas where agroforestry is being practised. Southwood *et al* (1982a) observed that the data collected for the British Isles demonstrated a tendency for the introduced species to have a lower incidence of phytophagous insects associated with them than the indigenous species. It would be interesting to know whether a similar pattern appears under tropical conditions.

Despite the recognition of the great need for agroforestry systems, little or no research has been carried out identifying insect pests that infest and damage trees used in agroforestry systems (some examples are shown on Table 1.2). Unknown also are the insect pests that feed on agricultural crops and trees when they are grown on the same piece of land, yet such information is extremely important. Without it, there is no real basis for standardised methodologies to control insect pests in agroforestry. There is therefore an urgent need for studies into the pest complexes of different types of agroforestry in each country where it is practised to provide information upon which control strategies could be based if needed.

From casual observation it is apparent that trees in agroforestry systems are subject to much infestation and damage by insect pests (personal observation). Many scientists (Epila, 1986, Huxley and Greenland, 1989) have highlighted the need for surveys to examine the invertebrates associated with MPTs. In general, ecologists have investigated invertebrates associated with trees in both tropical and temperate regions (Southwood *et al* 1982b, Stork, 1987). Such studies have considered not only the diversity and abundance of arthropods but also the impact on community structure and dynamics of a few of the physical and chemical cues which trees offer to invertebrates.

From the literature on tropical forest entomology (Gardner, 1957, Brown, 1961 Roberts, 1966, Browne, 1968, Odera, 1974, arap Sang, 1987, Hutacharern *et. al.*, 1988, Wagner *et al.*, 1991) it is evident that large numbers of insect pests, covering the main phytophagous taxa, between them attack all parts of the tree at all stages, from seedlings in the nursery to mature harvestable trees in the field and even after harvest. Certain species of the Coleoptera, Orthoptera and notably Lepidoptera are notorious tree defoliators. For example *Orgyia mixta* (Lepidoptera: Lymantridae), *Gonometa drucei* Bethume - Baker (Lepidoptera: Lasiocampidae) and *Manatha aethiops* (Lepidoptera: Lymantridae) all have been found to defoliate *Acacia mearnsii* De Wild. and other tree species in mixed forests in Kenya, whereas *Entypotrachellus meyeri* Klb.(Coleoptera: Curculionidae) attacks *Eucalyptus spp* and *Cassuarina montan* Lesh. ex - Meq. amongst other tree species (Gichora & Owuor, 1990). Outbreaks of these pests strip trees bare of leaves, disrupting their photosynthesis resulting in retardation of growth and development. Other insect species such as *Xyleutes capensis* Wlk. (Lepidoptera: Cossidae) make tunnels or bore into the stem of living trees, particularly *Cassia siamea* (personal observation), *C. didymobotrya* and *Abutilon zeylanicum*, thereby interfering with the nutrient and water transportation system of trees, as well as causing mechanical weakening (Khaemba, 1986). Examples of this type of pest include *Threnetica lacrymans* Thomson (Coleoptera: Cerambycidae) attacking *Delbergia cochinchinensis* Pierre (Papilionaceae)(Hutacharern, 1988) and *Coptotermes amanii* Sjostedt (Isoptera: Rhinotermitidae) on hoop pine, *Araucaria cunninghami* Don (Araucariaceae) (Gichora & Owuor, 1990). Notorious also are certain insects which attack and feed on the growing shoots of trees. Notable among them are certain species belonging also to the Coleoptera and Lepidoptera. They feed on growing points thereby frustrating normal growth as well as impairing the architectural development pattern of trees (Brown, 1968, Braza, 1991a, b)

Hemipterans (Table 1.2) as well as Thysanopterans (e.g. flower thrips, *Thrips florum* Schmuz, Thripidae, on sandalwood, *Santalum album* L. (Browne, 1968)) feed on plant sap, and by so doing they not only deprive trees of vital nutrients and auxins which abound in sap, but also inflict much mechanical injury to tissues by insertion of their stylets. Additionally, certain species of insect are vectors of diseases which they transmit to trees. In conclusion, it is clearly evident that insect pests cause much damage to trees.

Present agricultural systems owe their existence to traditional agroforestry practices which formed the backbone of farming in Europe, Asia, Africa and the Americas soon after the era of Hunting and Food Gathering (Epila, 1986). It can therefore be argued that the concepts and practice of combating the insects pests that ravaged man's food crops evolved and developed under agroforestry systems until the advent of monocultural agriculture in each of these continents. Unfortunately, however, the woody plant components of these traditional agroforests offered very little economic value to the peasant farmers and when it had developed as a discipline, the agricultural entomology of the time ignored them. Neither the impact of insects on them nor their influences on the crop pest ecology or biology, were directly assessed. However, with the passage of time, indirect interests in agroforest entomology began to appear in the literature. Entomologists had inadvertently discovered that, in order to study and fully understand the biology and ecology of a good many serious agricultural pests, it was necessary to move out into the adjoining woodlands or forests.

A number of discoveries suggested that growing food crops and trees together in an agroforestry set up could actually at times aggravate pest problems For example: (1)

some aphid populations can complete one to several generations on alternate wild woody hosts plants before migrating into various field crops (Dixon, 1987), (2) bruchids, the seed pests of grain legume crops, in general feed on the seeds of wild woody leguminous plants (Jenzen, 1969, Haines, 1991, Table 8.1), (3) a deliberate incorporation of wild flowering plants into the agricultural systems, or conserving such plants in the hedgerows as a source of nectar and pollen, enhances the effectiveness of the parasitoids and parasites in biological control practices (van Emden, 1965; Weseloh, 1976), (4) some non-food plants act as physical barriers and reduce dispersal and the effectiveness of parasites (Price, 1970), (5) some plants act as diluting agents of the volatile cues emanating from food plants and so confuse the parasites which rely on such volatile substances to locate their hosts (Vinson, 1976), and (6) some crop pests find refuge in the adjoining woodland, hedgerows, or forests, when environmental conditions in the field become unfavourable (Way, 1966, Callan, 1969). This gives credence to the supposition that growing food crops and trees together in an agroforestry set up could actually at times exacerbate pest problems.

Since the inception of agroforestry research over a decade ago, a great deal of time and effort has been devoted to the compilation of floral lists of those MPTs suitable for the particular ecological zones, and their overall utility, but very little to faunal lists of insects associated with them. References are scant to insects which attack the multipurpose tree species (MPTs) in tropical areas but some examples are shown in Table 1.2. This is particularly true for the situation of the small farmer. Over 200 tree and shrub species have been recorded as being promising for agroforestry use (Steppler & Nair, 1987) but for a good number there has been an increasing incidence of damage by insect pest (and diseases) (Huxley and Greenland, 1989). A classic example of insect pest in agroforestry is *Heteropsylla cubana* Crowford, (Hemiptera: Psyllidae) which had been reported to attack *Leucaena leucocephala* in Papua New Guinea (Maxon 1986). By 1989 it had become a serious problem in almost all countries of S.E.

Asia where *L. leucocephala* has been grown (Waage & Huxley, 1990) and in 1992 it was reported on the Kenyan coast (personal observation), and all over the country by 1994 (ICRAF, 1994). Further examples include insects on prosopis (*Prosopis juliflora)* (de Arruda *et al*, 1990), Acacia (A. *tortilis*) (Chandra, 1987, Singh & Singh, 1987) and Casuarina (*Casuarina equsitefolia*) (Chang & Weng, 1985).

The need for entomological research in agroforestry has been emphasised because of the likely consequences of growing taxonomically related crops as components in a given agroforestry system (Southwood *et al*, 1982a, Epila, 1986). Furthermore, polyphagous insects are known to be attracted by mixed orders and thrive in a habitat providing two or more essential hosts in close proximity (Rischs *et a*l, 1983).

Other potential pest problems which can arise in agroforestry include those involving not only insects, but also plant pathogens, weeds, mammalian and avian pests (Huxley and Greenland, 1989). Obviously any consideration of pest management must clearly focus on the tree species under consideration and the operational conditions occurring in any designated system. This would be particularly significant when we take into account the likely sources of insect pest problems in agroforestry: this is essential for the establishment of control strategies to deal with specific problems. The primary sources of these pest problems include, for example, those associated with importation of wild plants into intensely managed ecosystems and those related to the peculiar features of agroforestry itself (Epila, 1986).

Unfortunately most pest management programmes in agricultural situations have been unjustifiably slow in putting ecologically based theory into practice. The lack of "holistic thinking," and the sense of short-range urgency in applied practical research can inhibit the integration of theory and practice.

Mesoplatys ochroptera	Stal	Coleoptera (Chrysomilinae)	*Sesbania sesban*	defoliator	Kenya, Malawi	pers obs., Mchowa & Ngugi, 1994
Bruchophagus mellipes	Caillol	Coleoptera (Eurotomidae)	*S. sesban*	seed feeder	India	Bhalla et al. ,1988
Planococcus kenyae	Le Pelly	Homoptera (Pseudococcidae)	*S. sesban*	sap - feeder	Kenya	Browne, 1968
Celosterna scabrator	Fabricius	Coleoptera (Cerambycdae)	*Acacia nilotica*	borer	India	Singh et al., 1987
Cryptothelea crameri	Westwood	Lepidoptera (Psychidae)	*A. nilotica*	defoliator	India	Singh, 1986
Sahyadrassus malabaricus	Moore	Lepidoptera (Hepialidae)	*Gliricidia sepium*	borer	India	Devasahayam et al. 1987
Celosterna scabrator	Fabricius	Coleoptera (Cerembycidae)	*Proposis cineria*	borer	India	Sen - Serma , 1987
Onciderus pustulata	Thomson	Coleoptera (Cerembycidae)	*Prosopis chilensis*	severs branches	India	Browne, 1968 Felker et al., 1983
Lagria villosa	Fabricius	Coleoptera (Lagriidae)	*Cassia siamea*	defoliator	Kenya, Nigeria	Browne, 1968
Chrysolagria naivashana	Borchmann	Coleoptera (Lagriidae)	*C. siamea*	defoliator	Nigeria	Browne, 1968
Odontotermes nolaensis	Sjostedt	Isoptera (Termitidae)	*C. siamea*	root and shoot damage	Kenya	Rathore pers. comm.

1.6.1 Arthropod guilds in agroforestry

The concept of guilds illustrates the complexity of interactions which exists in the micro environment created by growing trees and crops together. A guild has been defined as "a group of species that exploits the same class of environmental resources in a similar way" (Root, 1973, Moran & Southwood, 1982). This definition groups together species that overlap significantly in their niche requirements without regard to taxonomic position. In addition, there are bound to be differences in pest / parasite relationships based not only on the relationship of crops and trees but also on factors as such as cultivar, season and soil type. These microeffects can be seriously affected by climatic factors which result in large scale immigration of major arthropod species. Moreover, different members of the guilds play their own roles which in some cases could be beneficial to the environment as a whole (parasites, detrivores, pollinators). Therefore, in our anxiety to control some of the pests of agroforestry, a whole range of innocent insects and other organisms may be detrimentally affected.

It is obvious from the integrated control programmes in cash crops, where pesticides are used in most effective way by ecologically guided application methods, there is an ever present danger of some degree of contamination and hazards to natural control agents and other non-target biota. For this reason it is very important to have a list of the fauna to be found in agroforestry systems, so that we have a knowledge of the range of organisms which may be affected whenever any pesticide is applied. There is also a need to get farmers better informed concerning pesticide usage in general. It was obvious from the discussions with the local farmers in the Kima Kimwe Settlement Scheme in Katumani, Machakos, Kenya that the majority of them (up to 80%) were unaware of the minimum requirements for safe pesticide application, and the disposal of residues as recommended by the manufacturers of the chemicals . As is the case in most developing countries the majority of pesticide users are unaware of the environmental problems of pesticides in general (personal observation).

The pesticides applied in the farmer's fields adjacent to the present study site could have been easily washed down into the nearby stream (see Figure 1.2) following a downpour, thus polluting the only water source, with serious health and economic consequences. If the pesticide used is systemic, (i.e. it can be taken up by the plants' roots from the soil and gets distributed into different parts of the plant). A classic example of the dangers posed to humans and organisms by pesticides was the usage of DDT many years ago. In an experiment to determine the distribution of DDT in a sprayed cowpea plot in Nigeria, 5% of the DDT applied was found to have been taken up by the plants, while 33% remained in the soil. The remaining 60% volatised into the air under the scorching tropical conditions. Thus, sprayed food crops may carry pesticides residue up to their time of harvest (Odum, 1987). The usage of DDT has been prohibited, but its replacements, though proclaimed safe by manufactures, still contain a high degree of risk when carelessly handled.

1.7 Aims and outline of the thesis

The aim of this research was to study a particular community in agroforestry. The principal community investigated was that of leaf dwelling arthropods both on the trees and crops. As a case study, one stem borer was also investigated. In this thesis, I have tried to collate entomological information that integrates the patterns of distribution of arthropods which are common on, and / or specialist of, woody plants and agricultural crops that can be grown in mixtures, on the one hand , while on the other, I have tried to elucidate the effects of tree management practices (pruning) on the distribution of arthropods. The arthropod community is described in terms of taxonomic composition, guild structure or trophic level organisation. It is hoped that this knowledge of community structure and functioning will result in further understanding of the processes at the community level in general and ecological impact which may result from our actions on agroforestry environments.

The results of comparative study of the various techniques available for sampling insect populations from tree canopies are presented Chapter Two. Chapter Three describes pilot studies for of the major sampling technique and the spray technology. In Chapter Four, the results of the faunal survey on the multipurpose tree species and crops in agroforestry and wild flora are described. The impact of defoliators on various tree species have been studied by many workers (e.g. Piene, 1980, Heichel *et al*, 1984, Bryant, 1991, Meyer, 1993). Therefore results of a simulated defoliation experiment on three MPTs are described in Chapter Five. The impact of pruning on arthropod abundance, richness and guild structure is discussed in Chapter Six. The effects of cassia stem borer, *Xyleutes capensis* on cassia trees are also described in Chapter Seven as a case study of an agroforestry pest. Chapter Eight analyses the host preferences for oviposition and development of *Callosobruchus chinensis* (Coleoptera: Bruchidae) which is a serious pest of stored pulses. Finally, a general discussion is given in Chapter Nine.

1.8 Study Area

This study was carried out at the International Centre for Research in Agroforestry (ICRAF) Field Station, in Machakos, Kenya (Figures 1.1 and 1.2).

The area is in the sub - humid to semi - arid zone at the latitude of 1^{o}-33"-S and longitude of 3^{o}-14"-E, at an altitude of 1660 m above sea level. It is located about 70 km Southeast of Nairobi and 10 km south of Machakos. It is bordered on two sides by the fields of the Farmers Training Centre (FTC) and the National Dryland Farming Research Station (NDRS), at Katumani, by a farm on the third side, and the Maruba river on the fourth (Figure 1.2).

Physiographically the area belongs to the uplands. It consists of a ridge with convex upper part (gradient 0 - 5%) and straight side slopes of (7-20%). Towards the river, the side slopes grade into narrow stretches of nearly flat river terraces of less than 2% gradient. Figure 1.3 shows the climate of ICRAF Field Station at Machakos. The average annual rainfall of 740 mm falls in two seasons, the long rains from about mid-March to about end of May with approximately 345 mm rain, and the short rains from mid October to mid - December with 315 mm rain. The water loss through potential evapotranspiration is estimated to be about 1800 mm per year. This gives rainfall / evapotranspiration ratio of 40 % which is typical of semi - arid to sub - humid areas (Jackson, 1977).

The wind blows with high consistency from easterly directions (80 - 100 degrees) with average monthly speeds ranging from 7.2 (June) to 12.0 (October) km / hr at 2m above the ground.

The dominant land use in the surrounding area is basically subsistence farming which includes both cattle grazing and the growing of crops.

This site was chosen because : (1) it had a well established agroforestry systems, being the centre for ICRAF's agroforestry research and demonstration projects for local farmers and international scientists, (2) the trees, planted in 1982 were of uniform age and had been pruned back to a height of 2 metres. The trees were of uniform vigour (i.e. with all branches bearing leaves and no evidence of disease): this makes it likely that the arthropods would have an equal chance of being on any tree, without bias.

Figure 1.1 Location of Machakos and major agro - ecological zones of Kenya

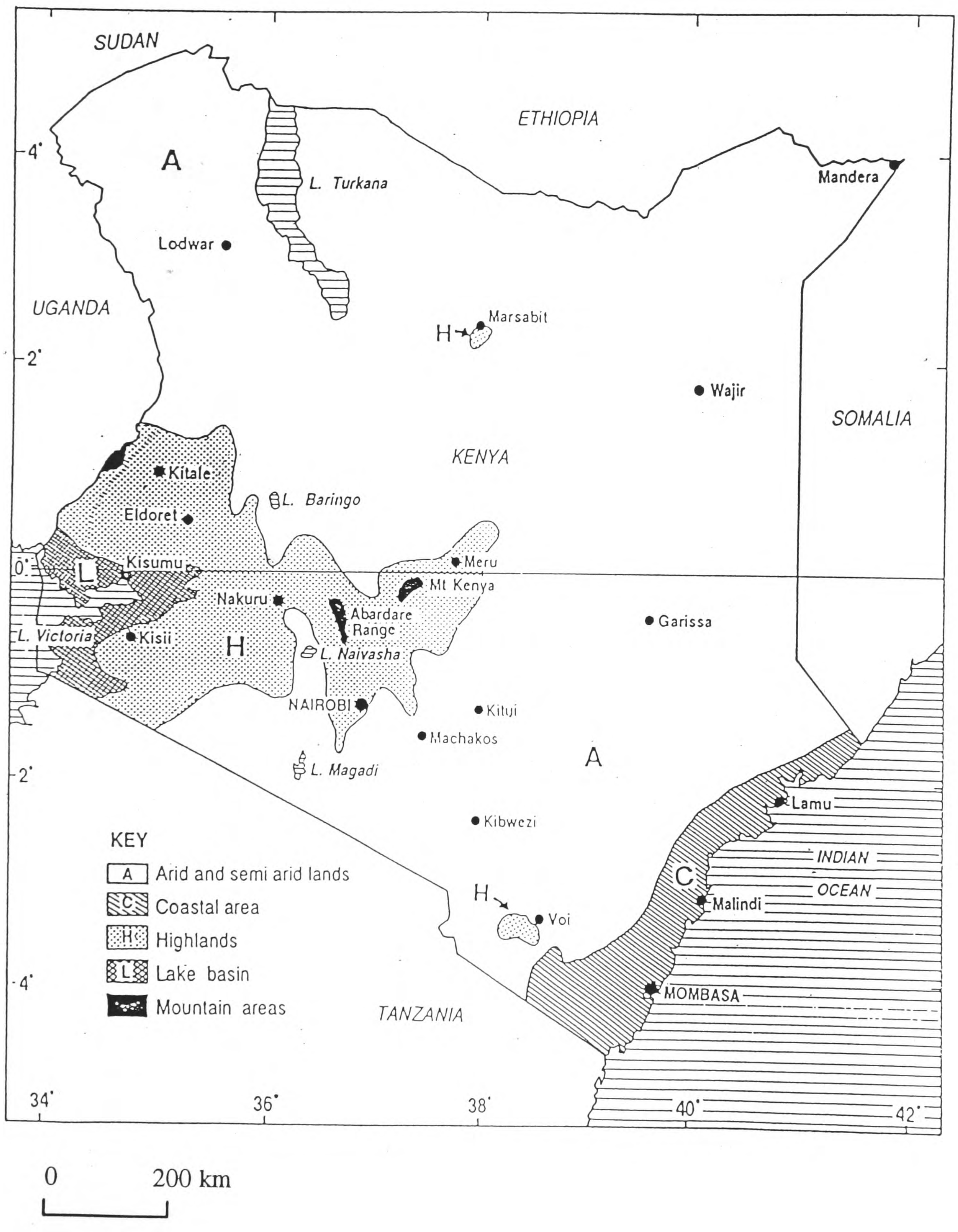


Figure 1.2 Site map - ICRAF Field Station Machakos

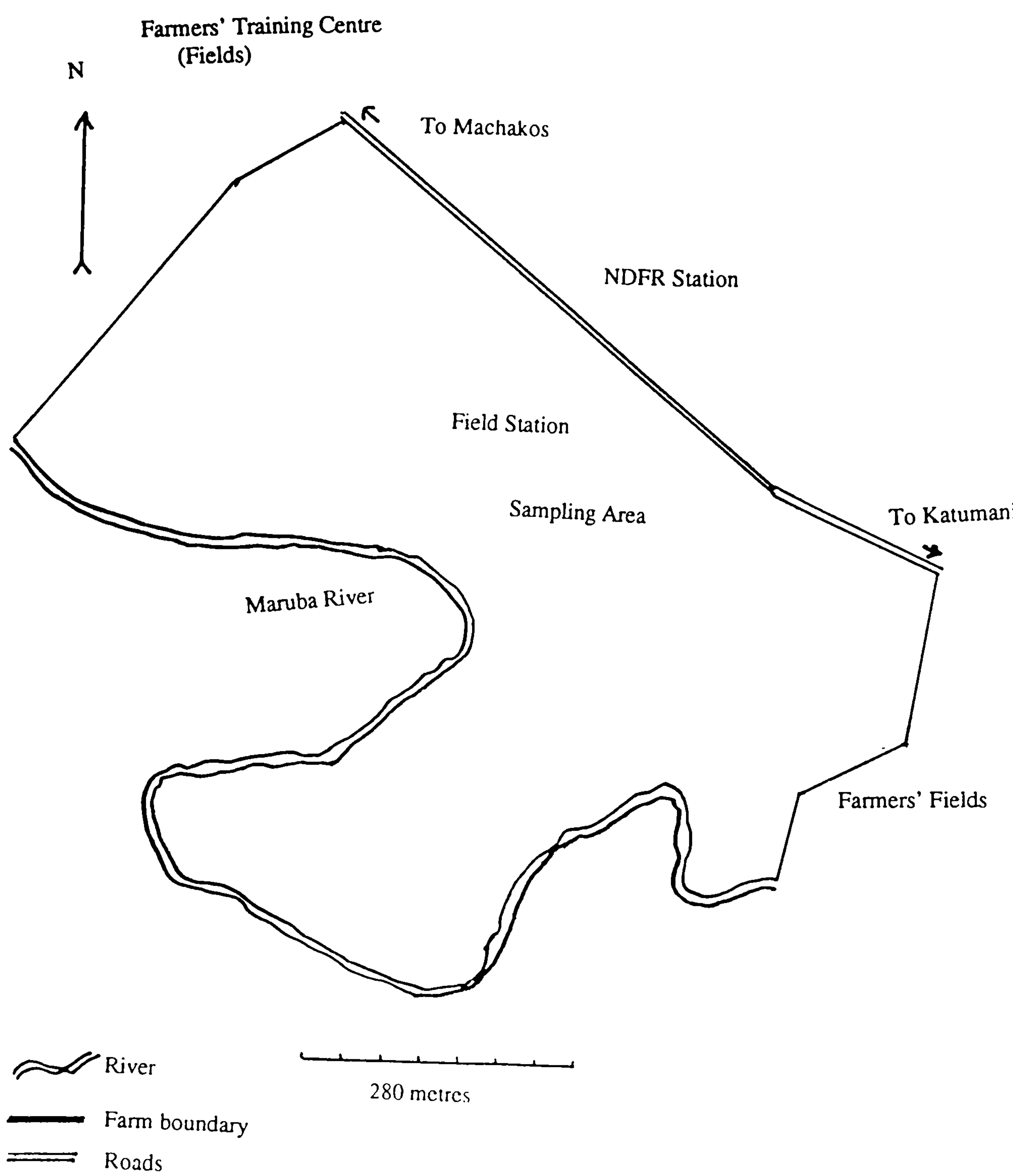
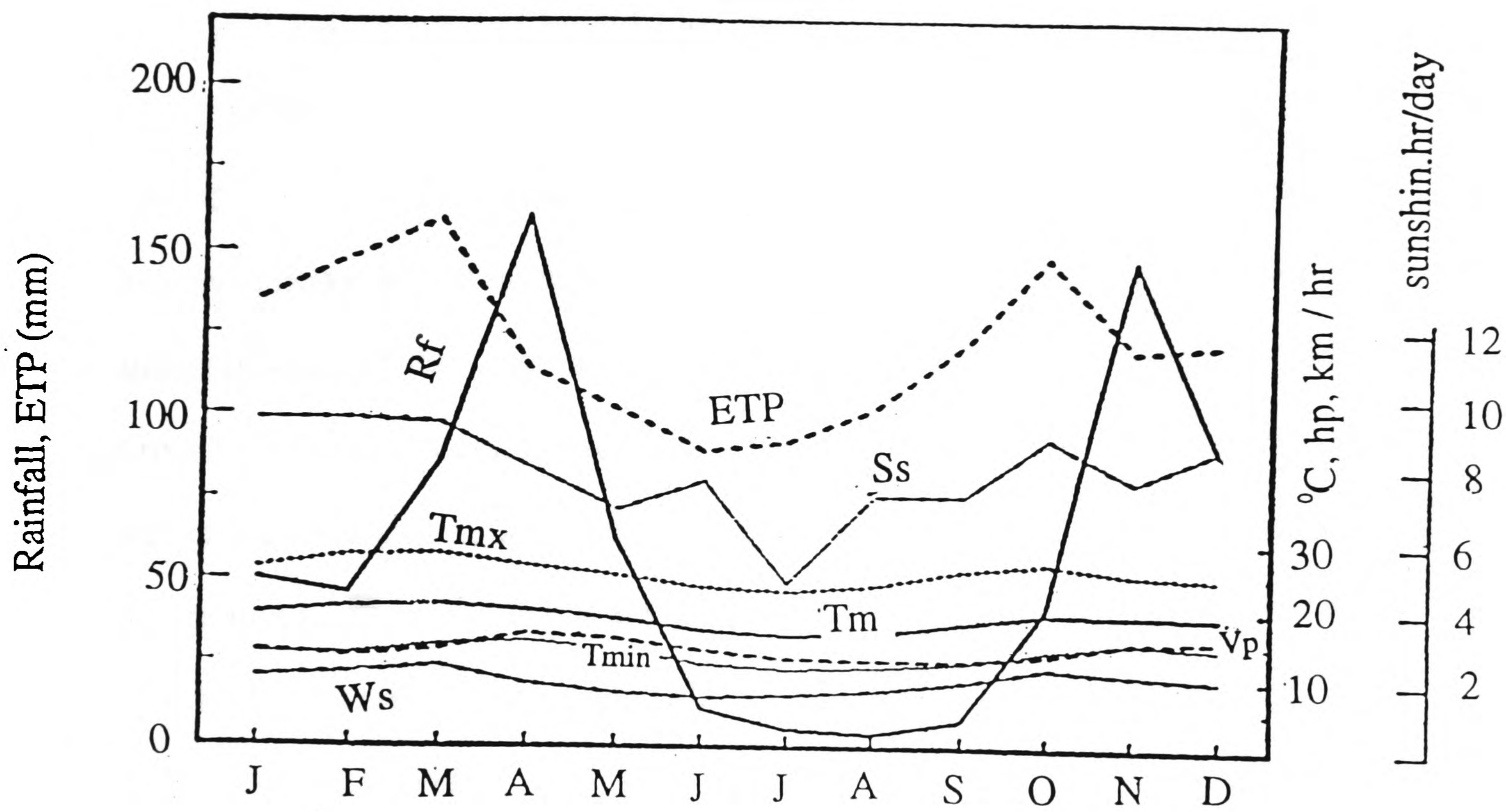


Figure 1.3 Climate diagram for ICRAF Field Station
Values for each month averaged over 1983 - 1987
except for rainfall and evapotranspiration (ETP), 1963 - 1987



Tmx (maximum temperature)
Tm (mean temperature)
Tmin (minimum temperature)
Vp (vapour pressure)
Ss (sunshine)
Ws (wind speed)
Rf (rainfall)
ETP (evapotranspiration rate)

Chapter 2

Efficiency of knockdown, sweepnet and hand search as sampling techniques for arthropod populations on *Gliricidia sepium* in agroforestry

2.1 Introduction

It is apparent from the review in Chapter One that pest management in agroforestry presents a very challenging task indeed. Firstly, not many insect pests or insects generally associated with the system have been studied in detail. Secondly, to carry out such studies and initiate any meaningful pest management strategy, accurate estimates of population densities of the associated insects must be known. Agroforestry prides itself as a relatively low cost enterprise with many benefits to the farmer. If this image is to be maintained then evaluation of the population dynamics of the total effective arthropod complex must be done in ways that are useful to growers. That means using sampling methods that are fast, accurate, reliable and sufficiently inexpensive to be implemented at the field level.

Several techniques have been developed for the sampling of invertebrates from foliage for both intensive and extensive studies (Kuno, 1991). These studies may involve the continual observation of the population of arthropods in the same area (intensive) with the view of collecting information on say the level of parasitism or the overall rate of population change (Morris, 1960, Barbosa & Wagner, 1989). Conversely, these studies may be carried out over a large area (extensive) and are normally concerned with, say, the relation of insect pest population to crop damage or with prediction of damage and the application of control measures (Richards, 1961, Boa, 1994). These techniques include sweepnets, beating trays or chemical sprays and may be used to collect samples to estimate abundance and diversity. They have their limitations and none of them is appropriate for all groups of invertebrates or in all habitats (Southwood, 1978). It is therefore necessary to define a set of procedures at the beginning of a particular ecological study. Most investigations involve the collection of samples from a habitat on one date, or over a period of time. Various external factors such as wind and rainfall will influence the composition of the samples obtained and these must be taken into consideration in the design of the procedure, if the sample units are to be comparable or truly representative of the population.

However, no direct comparisons have been made between the efficiency of chemical knock-down and that of other vegetation sampling techniques in agroforestry although comparisons between other methods have been made in other ecosystems. Ellington *et al.* (1984), for example, compared the efficiencies of sweepnet, absolute sampler and insectavac (IV) techniques in cotton ecosystems. The results show that in the chemical method several more arthropods were sampled on a per unit basis than with sweepnet method. Sweepnetting, though one of the most inexpensive and easy method to use, has been criticised for its inefficiency (in terms of canopy area coverage and destruction of foliage) in sampling crop ecosystems (Ellington *et al*, 1984). In another study, Race (1960) compared a mechanical blowing device to a 38-cm sweepnet and concluded that the sweepnet did not provide a dependable population index of lygus and stink bugs on cotton plants during the later half of the growing season. Gonzalez *et al* (1977), suggested that sweepnet sampling was less effective than D-Vac samples. Smith *et al* (1976), comparing sweepnet counts with counts using an area sampler, D-Vac, and whole-plant examinations on cotton, concluded that sweepnet samples can be used to determine population fluctuations and adjusted for quantitative use, although its efficiency can be affected by other factors such as density and height of host plants.

Comparing these techniques is made more difficult because of the problems of standardisation of the sampling unit. However, because the trees in the agroforestry system studied had been pruned back to a height of 2 metres, it was not difficult to estimate the area sampled.

The purpose of this study was to compare the efficiency of three sampling techniques (Table 2.1) for sampling arthropods in trees in agroforestry. The tree species chosen was *Gliricidia sepium* (pruned) planted in alley system.

Table 2.1 Some techniques for sampling arthropods on foliage*

Method	Description	Suitability
Knockdown spraying	insecticide with a rapid knockdown effect is used in a mist blower	covers a wide a canopy area and can be used on trees more than 10 m high Is expensive
Sweep net	a simple net, diameter of the mouth of net is 37 cm, and length of handle is 60 cm	less efficient , covers less canopy area, destructive to foliage, it is inexpensive and easy to use
Hand search	involves physically searching foliage and removing as many insects as can be seen within a prescribed area using a pooter	very inefficient, can cover only a small canopy area

* see Southwood, 1978

2.2 Method

Six healthy trees were selected for each technique. Sampling was carried out during August and September, 1991. The knockdown samples were collected as described in Chapter 3. Sweepnet sampling was with a net which had a diameter at the mouth of 37 cm, and a depth of 60 cm. The length of the handle was 60 cm. A similar sweepnet has been used to sample insects from the understory of tropical primary and secondary forest vegetation in Costa Rica and Caribbean Islands (Janzen, 1973a, 1973b). Sweeping was carried out vigorously on each of the trees until no more insects were obtained. No effort was made to avoid damaging the vegetation so that full force could be used to drive the net through the foliage. It was hoped that this would improve the chances for trapping the insects in the net. The foliage in the sample made sorting much more difficult but it was unavoidable. Hand search of the foliage of each of the six trees was carried out within the prescribed area and fixed time of 15 minutes.

The sampling unit in this case was the whole canopy for all the sampling techniques. For each sampling technique, samples from one tree formed the sampling unit. The insects were killed in a large plastic bag containing all the material from one tree. These were later identified as in Chapter 3. Sampling was carried out only when the foliage was dry to prevent the net getting wet and the specimens being damaged.

2.3 Results

The results show that the mean total arthropods collected was higher in knockdown spraying than in sweep net or hand search (Figure 2.1). Similarly the numbers from sweep net were in turn higher than hand search. These differences were found to be statistically significant ($P < 0.01$, Table 2.2). Descriptive statistics for the knockdown, sweepnet and hand search samples for all the insect species caught in all replicates are represented in Table 2.3. Knockdown means were always larger than sweepnets and hand search and sweepnet means were always larger than hand search except in the following cases: for *Aloecytus distinguendus* (Ks, $x = 1.0$, Sn, $x = 1.56$), *Nephus* sp. (Sn, $x = 0.89$, Hs, $x = 1.44$), *Cardiastethus* sp. (Sn, $x = 0.72$, Hs $= 0.72$) and *Cyclopelta tristis* (Sn, $x = 0.06$, Hs, $x = 0.22$). The hand search caught 12 %, the net caught 35 % and knockdown spraying 53 % of the total insects caught (Figure 2.2).

2.4 Discussion

It is clear from the above result that knockdown spraying is by far the most effective method for sampling insects from the foliage of *G. sepium* in agroforestry. Although the species caught were common in all the samples, the numbers varied considerably. The low numbers in hand search and sweepnet samples may therefore not reflect the actual population trends. A similar finding was reported by Byerly *et al.* (1978) working on cotton . Although sweep net and hand search may be inaccurate in assessing population trends, they may be useful tools in estimating relative numbers of insects especially when spraying of insecticides is undesirable. This is particularly so in agroforestry where tree foliage is used as fodder for livestock and therefore spraying of any insecticide would not be suitable.

A total of eleven different insect species representing seven families and five orders were collected from *G. sepium* in this experiment. These included *Piezotrachelus pullus* (Coleoptera: Apionidae), *Paraivonglus cyanipennis* (Coleoptera: Eumolpinae), *Nephus* sp. and *Exochomus* sp., (Coleoptera: Coccinellidae), *Cardiastethus* sp. (Heteroptera: Anthocoridae) *Cyclopelta tristis* (Heteroptera: Dinidoridae), *Aphis cracivora* (Homoptera: Aphididae), *Aloencyrtus distiguendus* and *Tremblaya oleae*, (Hymenoptera: Encyrtidae), *Myrmicaria* sp and *Componatus* sp., (Hymenoptera: Formicidae) (see Table 2.3). This list does not include the spiders and the immature stages of insects which were collected in such low numbers that they were not evaluated. These groups were distributed in the samples from all the methods though the numbers were highest with knockdown. In studies comparing the insectvac and sweepnet, it was also found that sweepnet samples, in general, were lower in numbers of species caught, (Ellington *et al.*, 1984).

Due to the fact that the groups of insects collected were similar in all the three methods, the cheaper methods may be resorted to when carrying out a limited survey on trees while the food crops are in the field and knockdown spraying cannot be used. Although the information gathered by sweepnet can be useful, it is restricted in practical application in an extensive survey for two reasons: it is slow in operation and is tiring to operate apart from obtaining small samples. Hand search can also be ruled out for extensive survey sampling in agroforestry for similar reasons. Knockdown spraying, expensive and environmentally unfriendly, offers the best sampling efficiency (in terms of statistical, economic, mechanical, and personal components) (Strictland, 1961) and was therefore employed in the main study.

Figure 2.1 Mean and ± S.E.total number of arthropods caught by knockdown spraying (Ks), sweep net (Sn) and hand search (Hs) from from the foliage of *G. sepium* Significant differences between pairs oftechniques (Duncan Test, n = 18, P < 0.01) are indicated by capital letters of thediffering technique inscribed above the error bar

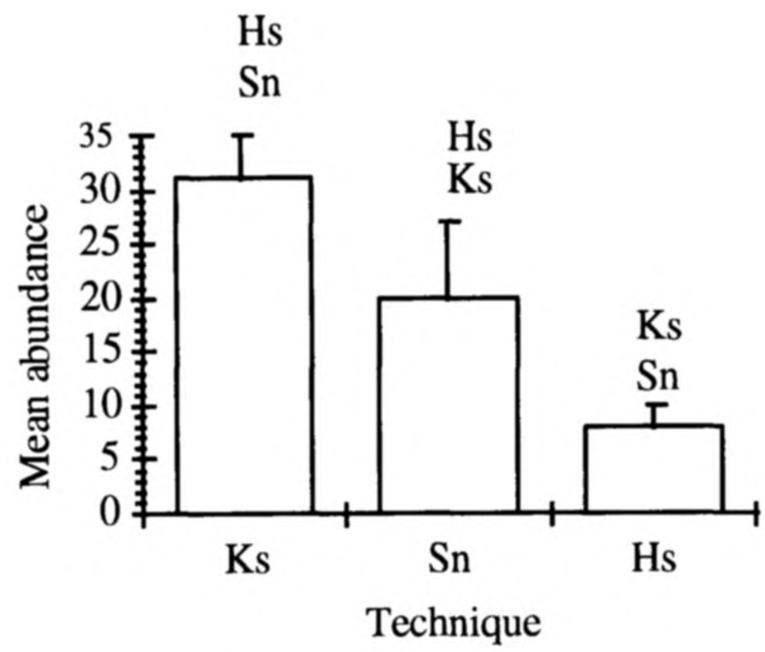


Table 2.2 ANOVA table for number of arthropods caught by knockdown spraying, sweep net and hand search from the foliage of *G. sepium*

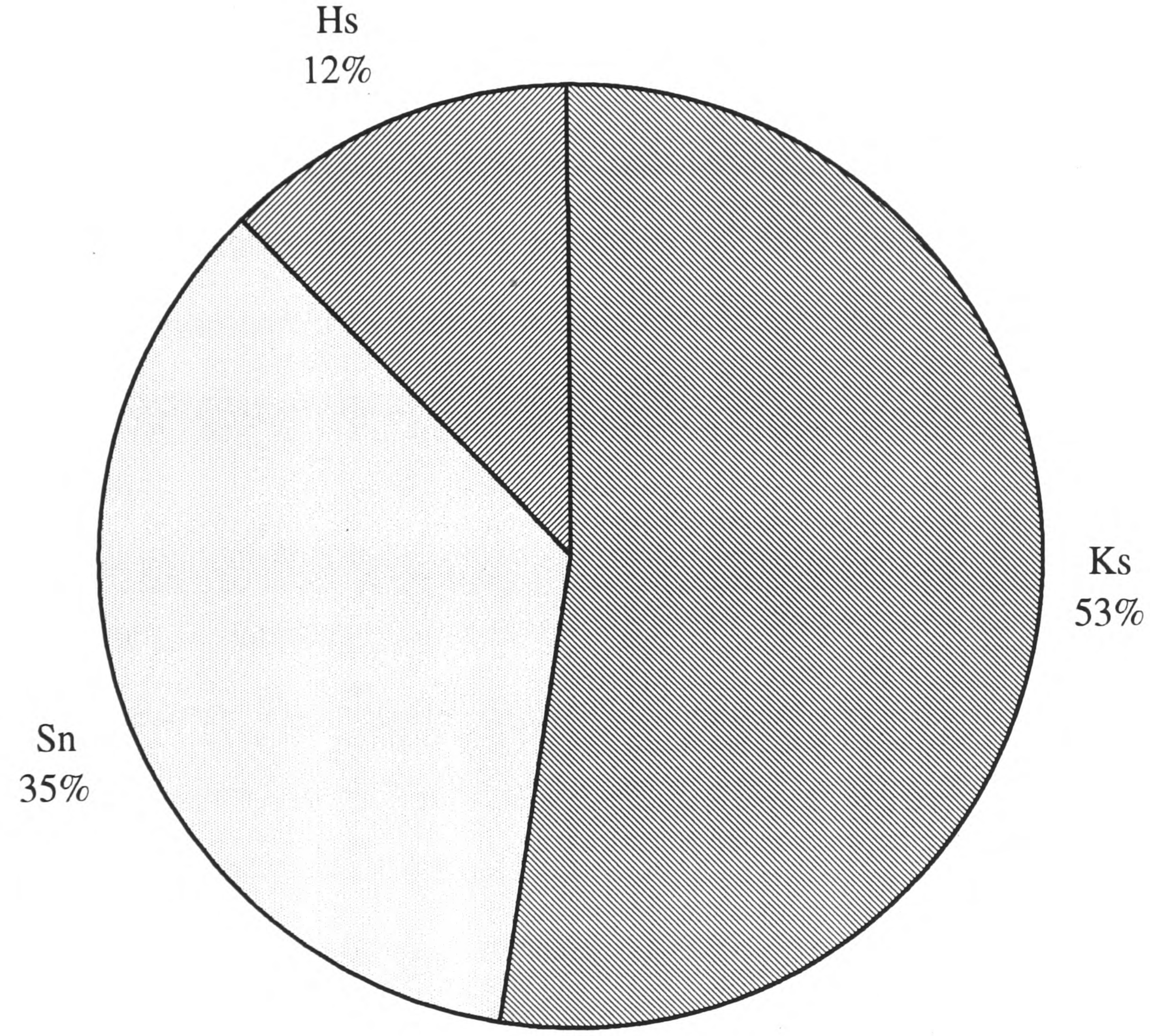
Source	DF	MS	F	P
Technique	2	35.95	10.4	P < 0.01
Error	51	52	3.47	

Table 2.3 Means and standard deviations knockdown spraying sweepnet and handsearch samples for insects collected from Gliricidia sepium

Species	Tech.	n	x	s
Piezotrachelus pullus	Ks	18	2.23	2.54
(Apionidae)	Sn	18	1.61	1.5
	Hs	18	0.56	0.78
Paraivongius cyanipennis	Ks	18	1	1.19
(Eumolpinae)	Sn	18	0.22	0.55
	Hs	18	0.33	0.59
Exochomus Sp.	Ks	18	2.56	2.94
(Coccinellidae)	Sn	18	0.78	1.52
	Hs	18	0.11	0.32
Nephus sp	Ks	18	2.17	1.47
(Coccinellidae)	Sn	18	0.89	1.71
	Hs	18	1.44	1.72
Cardiastethus sp.	Ks	18	1.11	1.49
(Anthocoridae)	Sn	18	0.72	2.16
	Hs	18	1.11	0.47
Cyclopelta trisis	Ks	18	1.06	1.11
(Dinidoridae)	Sn	18	0.06	0.24
	Hs	18	0.22	0.65
Aphis cracivora	Ks	18	3.28	8.09
(Aphididae)	Sn	18	3.11	4.17
	Hs	18	2.06	4.01
Aloencyrtus distiguendus	Ks	18	1	1.6
(Encyrtidae)	Sn	18	1.56	5.39
	Hs	18	0.22	0.73
Tremblaya oleae	Ks	18	1.44	2.4
(Encyrtidae)	Sn	18	0.72	1.23
	Hs	18	0.11	0.47
Myrmicaria sp.	Ks	18	11.61	15.63
(Formicidae)	Sn	18	9.72	19.78
	Hs	18	1.16	1.75
Camponatus sp.	Ks	18	1.94	2.46
(Formicidae)	Sn	18	1.44	2.9
	Hs	18	0.17	0.52

Ks = knockdown spraying, Sn = sweep net, Hs = handsearch, n = sample size, x = mean, s = standard deviation

Figure 2.2 Proportion of total number of arthropods caught attributable to knockdown (Ks), sweepnet (Sn), and hand search (Hs) methods



Chapter 3

Pilot study of knockdown Spraying

3.1 Introduction

Comparative studies of different sampling techniques (see results in Chapter 2) suggested that chemical knockdown would be the most suitable technique for the canopy habitat. In addition to being the most efficient, it affords the opportunity of collecting individuals from the entire canopy and so was likely to provide samples of the entire arthropod fauna with the exception of the bark and wood borers. In this Chapter, sampling procedures and spray technology used in this thesis in general are described.

In designing a sampling procedure the main factor that must be accounted for is the aim of the study. The extensive or intensive nature of the work will affect the selection of the techniques and the regime under which these are used (Ozanne, 1991). The nature of an appropriate sampling procedure is also affected by habitat type, scale and homogeneity. For example, to extract invertebrates from air, soil, water or vegetation, apparatus differing in design and operation would be needed. It has been recognised that vegetation is a particularly difficult habitat from which to collect samples because of relative structural complexity (Southwood, 1978). The problems involved in the design of a procedure that will generate representative samples are particularly acute for trees and shrubs because of the differences in canopy structure.

The scale of a habitat must be taken into account, not only by the selection of an appropriate technique, but in the sampling regime. For example, the use of chemical knockdown to estimate the abundance of arthropods in the canopy of a tree may produce samples that are more representative of the whole tree fauna than the use of a sweepnet that can only sample from beneath the crown if the tree is more than 1 m in height. Scale, in terms of area must be addressed from the viewpoint of the number and the location of the sampling units and need for statistical replication. The habitat may require subdivision if it is heterogeneous and again this will determine the type of sampling procedure developed.

The group of the invertebrates involved in the study is a key factor in the formulation of a sampling procedure. Some knowledge of the biology of the organisms to be sampled is necessary. At a very basic level the location occupied by the target organisms will determine exposure to particular techniques. For example, the larvae of *Xyleutes capensis* (Lepidoptera: Cossinae) are borers of *Cassia siamea*. Their populations can not be sampled accurately by using knockdown techniques, but can only be estimated by measuring secondary products such as exit holes (see Chapter 7), exuviae or frass. Also any attempt to sample foliage for jumping insects such grasshoppers with beating technique is bound to be unsuccessful especially under hot tropical conditions.

Climatic and weather conditions are the other factors that must be considered. Longer term surveys will inevitably be affected by climatic and seasonal changes. Under tropical conditions temperatures remain favourable most of the year for arthropods to have several generations in a year, but a major influencing factor could be rainfall and wind and cropping pattern (usually for staple foods like maize there are two crops in a year). Frequently the influence of weather conditions on invertebrate richness and diversity are the aims of the investigation and do not require 'factoring out'. Local weather conditions such as temperature, precipitation, humidity, wind speed, and cloud cover have all been shown to affect the composition of samples, (Harris *et al.*, 1972).

For example weak flying insects such as aphids, thrips, and white flies are easily and passively transported by wind (Epila, 1988) and this may affect their location within a habitat or their susceptibility to a sampling technique. Many techniques used to collect terrestrial arthropods do not sample effectively from a wet substrate and some are disrupted by strong wind currents. The timing of sample events must therefore be adjusted to avoid these conditions.

3.2 Methods

3.2.1 Sampling procedures

The chemical used as a knockdown agent was Pybuthrin 2/16 (Wellcome Foundation). It contains a solution of natural pyrethrin whose active ingredients are pyrethrin I and pyrethrin II plus cinerins and jasmolins. These are extracted from *Chrysanthemum cinerariaefolium.* In practice piperonyl butoxide is added to the pyrethrin. The piperonyl butoxide synergises with pyrethrin in a high grade petroleum distillate (kerosene) making a more effective knockdown agent.

Pybuthrin 2/16 has a rapid knockdown effect defined as the destruction of the capacity to co-ordinate wing movements with other movements (McFarlene, 1977), caused by repetitive axon firing. It was expected to immobilise most arthropods within a few minutes. The rate at which knockdown occurs is dependent on the speed of penetration of nerve membrane via the cuticle or spiracles (Burt and Goodchild, 1972). The synergist, piperonyl butoxide, was present to prevent recovery from the insecticide by attacking detoxification mechanisms, rather than to enhance the knock-down effects (Chen *et al.*, 1985) and (Silcox *et al.*, 1985).

Since the main component of the chemical was natural pyrethrin, half - life in the environment was very short. The active ingredients are destroyed by ultra violet light and it is estimated by the manufacturer that the chemical remains active for only 48 hours in the tree canopy. It has a low mammalian toxicity and is easily biodegraded. These were very useful attributes especially for use in the restrictive environment as found at the study site, restrictive in the sense that sampling was being carried out close to harvesting time and also some of the MPTs may be used directly for fodder for the livestock. It was also necessary to minimise the disruption to the arthropod communities within the systems and to avoid possible effects of residual pesticide on the harvested crops. As most of the plots used were experimental plots of other scientists, it was essential to cause minimal interference.

The spray machine used was the Hurricane Major back pack mist blower (Cooper Pegler) (Plate 3.1). Because the Pybuthrin 2/16 is oil based it was possible to use it in an Ultra Low Volume (ULV) spray system. The advantage of this system is that small droplets can be produced, ensuring that good coverage could be achieved using smaller quantities of the chemical. A pilot study was carried out in during the winter of 1989 to determine the suitability of this sprayer for this project. This was carried out at the University Parks, Oxford and involved spraying the canopies of the common yew, *Taxus baccata* L. using fluorescent dye and investigating the distribution of the dye in the canopy. The procedure and results can be found in Section 2.5.

The individual tree was used as the sampling unit in contrast to the canopy of four trees as been used in other studies (Ozanne, 1991). The reason for this was that in agroforestry the trees were smaller and there was no canopy overlap. Although in this study the trees were non - deciduous, the sampling procedure employed is comparable to the one used to assess the insect fauna of deciduous trees in South Africa and Great Britain in 1979 (Southwood *et al*, 1982a). This could enable comparison to be made between the results obtained in this study and those collected from deciduous trees.

One square meter white cotton sheets were spaced out on the ground spreading from the trunk of tree to edge of the canopy (Plate 3.2). The 1 m^2 cotton sheets were firmly pegged to the ground to prevent them being accidentally moved. Such sheets have been used in other studies (Southwood *et al.,* 1982 a & b). Each tree was sprayed with pybuthrin 2/16 for 60 seconds. Although the ingredients of Pybuthrin 2/16 are of low mammalian toxicity and marked as "no more than moderately hazardous" according to World Health Organisation designation, it was nevertheless necessary to wear full safety equipment during machine operation, spraying and sample collection. This included disposable protective suits, rubber boots and gloves, eye goggles, ear muffles and mist grade spray masks (all of which were imported from Oxford). The arthropods were collected from the sheets every quarter of an hour for up to 1 hour. At the end of the hour the trees were jarred / shaken before the cloths were removed (this released a few more insects). The arthropods were removed from the sheets using brushes and placed in labelled tubes containing 70% alcohol and were later transported to the laboratory for taxonomic analysis.

During the first sampling session in August 1990, foliage was removed from the tree after the samples have been removed and carefully examined to see whether any animals remained. It was found that the numbers remaining on the foliage were negligible. The technique therefore seemed to sample a highly representative section of the fauna. It was possible however, that some of the arthropods were driven away from the collection sheet by air currents generated by the spray and within the canopy. A vertical barrier sheet was erected to try and trap any such insects driven by the currents. Some weak flying insects such as aphids were trapped on the barrier but the numbers were again negligible. From fogging experiments, Stork (1988) noted that there is little evidence to suggest the losses from insecticide fogging were significant. Fogging and spraying are similar techniques because they both have a knockdown effect. However fogging employs the up draught of a thermal fog to carry the agent into the canopy and so can reach great height, whereas misting relies on a fan produced air current to lift the chemical into the tree. The latter technique is likely to disturb the arthropods from the foliage. Southwood *et al.* (1982a) were able to draw adequate comparison between knock-down spraying data and faunal list compiled for tree species, suggesting that no group was preferentially lost from samples as a result of the sampling technique. The other consideration was the positioning of the collecting sheets. In order to check whether one side was preferable over the, four 1 sq meter sheets were placed on the north, south, west and east sides under the canopy. The arthropods falling on sheets were compared. The numbers were found to be similar and therefore the placement of the sheet was not important.

This study was carried out on three MPTs and three food crops in alley cropping system. The trees were planted and managed by ICRAF in experimental plots to investigate different aspects of
agroforestry systems. The MPTs were planted in 1982 and had been pruned to a height of 2 metres. Sampling was also done on an indigenous tree species, *Tamarindus indica*, (see Table 2.1) growing in the wild.

3.2.2 Experimental design

During the period August to November 1990 and August to December 1991 samples were taken from each of the three MPTs in an alley agroforestry system. Sampling was restricted to the first fortnight of each sampling month thus leaving the other fortnight for sorting out the samples and preparing for the next sampling session. On each sampling occasion 12 trees of each species of MPT were sampled (i.e 6 trees from pruned and 6 from unpruned trees). Therefore, 48 individual trees were sampled each month. Thus during the period August to November 1990 samples were collected from 192 trees and from 240 trees during the period August to December 1991. One sample was taken from the food crops during August (except *C. cajan* which followed a similar sampling regime as the trees because it is a perennial crop but samples were taken only fron unpruned plants). A total of 6 plants were sampled from *Z. mays* and *V. unguiculata* in August each year. For *C. cajan*, 24 plants were sampled in 1990 and 30 plants in 1991. The sampling protocol followed in sampling the arthropods from wild tree canopy was similar to the one for MPTs except that in this case there were no pruned trees. The whole plant was the sampling unit in all the food crops as opposed to the $1m^2$ ground equivalent of canopy for the trees. For each unit sampled it was necessary to complete each total sample within a few days in order to minimise any variations, and sampling had to be done only on calm days. After spraying was completed each plant was tagged at the base so that it was not reused in the next sampling session. Each subsequent sample was therefore independent of all the previous collections.

In the laboratory residual plant material was removed from the samples and the arthropods were initially sorted out to the level of Order and counted. Some were subsequently identified to species level or were morphotyped. The taxonomic groups include Lepidoptera, Heteroptera, Homoptera, Orthoptera, Hymenoptera, Thysanoptera, Arachnida and Psocoptera. (See Appendix I for species list). Some of the morphotyping was carried out at the Kenya National Museum, Nairobi. The remaining specimens were transported back to Britain, the morphotyping being done at the British Museum of Natural History in London and the Hope Department of Zoology, Oxford University. The arachnids were identified (morphotyped) by Clive Hambler of the Department of Zoology, Oxford University.

Plate 3.1 Photograph of Hurricane Major mist - blower (Cooper - Peglar) being assembled at Machakos field station.

Plate 3.2 Photograph to show four 1 m^2 cloth spread on the ground in the test for sheet placement

3.3 Choice of agroforestry system and plant species:

Given the considerable extent of the present systems and of multipurpose tree species (MPTs) involved, I selected one system, three tree species and three food crops for this study. The system selected was an alley cropping system (basically a subsystem of agrosilvicultural system and is briefly described in section 3.3.1).

3.3.1 Alley cropping system:

This was the system studied in this project and its various components are outlined in Table 1.1.

Kang *et al.* (1985) defined an alley system of cropping as the growing of arable crops between hedge rows of shrubs and trees. The trees and crops are planted in alternating terraces and is sometimes referred to as hedgerow inter cropping (Fonzen and Oberholzer, 1984). Trees grown in alleys with arable crops are periodically pruned to reduce possible competition for light (Haggar, 1994, Plate 1.1).

In the study area for this research the alley cropping experiment was designed to maintain annual crop production and contain soil erosion.

3.3.2 Choice of plant species

Three MPTs (all exotic to Kenya), one indigenous tree species (wild species) and three food crops (Table 3.1) were selected for the main surveys of agroforest arthropod communities and for subsequent studies. They were selected because of their established status in the study area. The indigenous tree species was sampled in order to compare its fauna with those of exotic tree species.

Table 3.1 Taxonomy and uses of trees and crops used in this study

Botanical name	Authority	Common name	Family	Origin	Uses
Gliricidia sepium	(Jacq.) Steud.	gliricidia	Leguminosae (Papilionoideae)	Central America / Mexico	fodder, fuel wood, living fence, green manure
Leucaena leucocephala	(Lam.) de wit.	leucaena	Leguminosae (Mimosoideae)	Mexico	fodder, fuel wood, green manure, soil conservation
Cassia siamea	Lam.	cassia	Leguminosae (Caesalpinioideae)	South East Asia	fodder, fire wood, poles for building, timber windbreak
Cajanus cajan	L.	pigeon peas	Leguminosae	S.E. Asia	food for humans, fodder, green manure, fuel wood
Vigna unguiculata	L.	cowpea	Leguminosae	C. Africa / America	human consumption
Zea mays	L.	maize	Gramineae	Central America	human consumption
Tamarindus indica	de wit.	*kithumula**	Leguminosae	indigenous species	charcoal, shade

*Kamba language

3.4 Pilot studies (Tracer fluorescent particles)

There are obvious differences in terms of leaf size and density from one plant species to another. These differences can influence the effectiveness of an insecticide sprayed into the tree canopy by affecting its penetration and distribution in the tree canopy.
In order to investigate the ability of an insecticide such as pybuthrin to penetrate into the tree canopy, the first pilot study was carried out during May 1990 at the University Parks, Oxford, using tracer dye that was sprayed into the tree canopy using the Hurricane Major mist blower. The tracer used was the Tubair Ultra Violet Tracer. It contains Saturn Yellow pigment and is ready formulated for Ultra Low Volume (ULV) equipment. The tree species chosen for the pilot study was common yew *Taxus batata.* Yew was chosen because of the similarity in shape and size between its foliage and that of the agroforestry tree species.

The study was repeated in a second pilot study carried out at the ICRAF Field Station in Machokos, using three agroforestry tree species. The trees species used were *G. sepium*, *L. leucocephala* and *C. siamea.* However, in this case the distance between the operator and the base of the tree was also investigated (see section 3.4.3). Though tree height would not be an important factor in determining insecticide penetration in the MPTs under study, since all were pruned back and no more than 2 meters high, the distance of the operator from the base of the tree could possibly influence the knockdown. (The vertical range of the Hurricane Major is estimated by the manufacturer to be approximately 10 m).

3.4.1 Methods

In the first pilot study three yew trees of 10 m in height were chosen in the University Parks, Oxford. The three trees were sprayed with the UV tracer for one minute, then left for 15 minutes to enable the tracer to dry. Samples of foliage were then collected from the trees at 2 m, 4 m, 6 m, 8 m and 10 m using a long arm pruner. The samples were put in plastic bags and labelled and taken to the laboratory for analysis. In the second study in Kenya, three trees from each of the tree species were selected. The trees were 6 metres in height. The trees were sprayed from a distance of 1 m, 3 m and 5 m distance from the base of the tree. In the laboratory, five leaves of area 1 cm^2 were taken at random for each height and distance and the density of their fluorescent particles measured. This was counted manually under a stereo microscope illuminated by ultra violet light in a darkened room. The particles were counted from both the upper and lower surfaces. The particle density was expressed in terms of number of particles per square cm.

3.4.2 Data analysis

Data analysis was carried out using SPSS - PC (ANOVAR, Duncan Multiple Range Test) and Microsoft Excel spreadsheets. Significance was tested at 5% level.

3.4.3 Results

Figure 3.1 shows that Fluorescent Particles (FP) distribution on the foliage was lowest at 10 m height and highest 4 meters. Statistical analyses show these differences to be significant (Table 3.2, $P < 0.05$). The retention of FP on upper and lower surfaces was only marginally different though the upper surface was slightly higher (Figure 3.2) These differences were however, not statistically significant ($P < 0.05$). Figure 3.3 shows leaves of *L. leucocephala* have higher FP densities than either *G. sepium* or *C. siamea.* These latter two had a very similar FP distribution on their leaves.
Figure 3.4 shows that FP retention was higher at 2m from the trunk of the tree than at 3 or 4 metre distance for all the tree species. The differences between FP densities at 2

and 3 meters were however not statistically significant but the differences were statistically significant between 2 and 4 meters.

Figure 3.1 Mean and ± S.E. of fluorescent particles (FP) density at various heights in *T. batata* trees , University Parks, Oxford, (ANOVAR for effect of height on FP density, n = 10, P < 0.05)

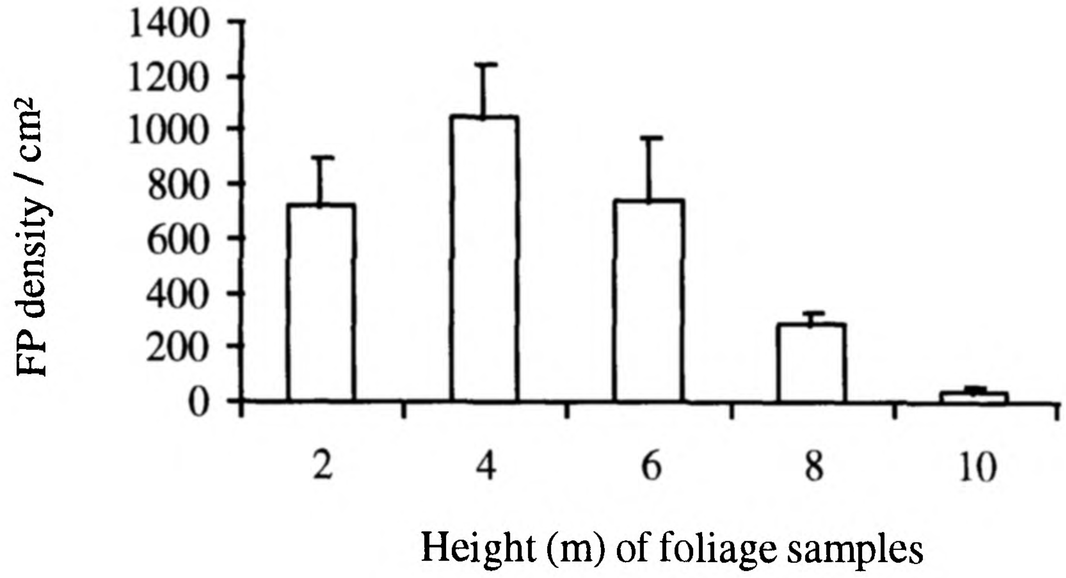


Table 3.2 ANOVAR table for fluorescent particle density from various height in *T. batata* leaves

Source	DF	MS	F	P
Height	4	327576	6.582	0.032
Error	5	49766.8		

Figure 3.2 Mean and ± S.E. for fluorescent particle (FP) density on upper and lower surface of *T. batata* leaves, University Parks, Oxford (ANOVAR, n = 10, P < 0.05)

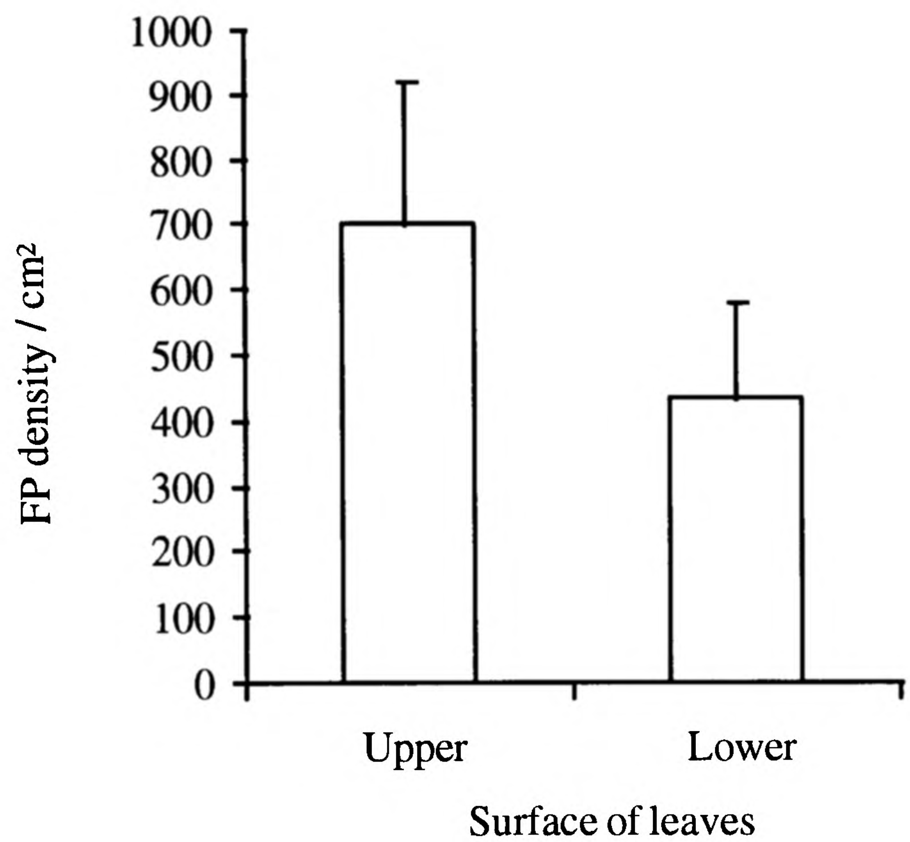


Table 3.3 ANOVAR table for fluorescent particles density on upper and lower surfaces of *T. batata* leaves

Source	DF	MS	F	P
Surface	1	176890	1.02	P > 0.05
Error	8	172781		

Figure 3.3 Mean and ± S.E. for fluorescent particles density at 6m height on leaves of *G. sepium* (Gs), *C. siamea* (Cs), *L. leucocephala* (Ll) at ICRAF, Field Station, Machakos (MPTs). Columns with the same superscript letter are not significantly different , Duncan Test, n = 5, P < 0.05)

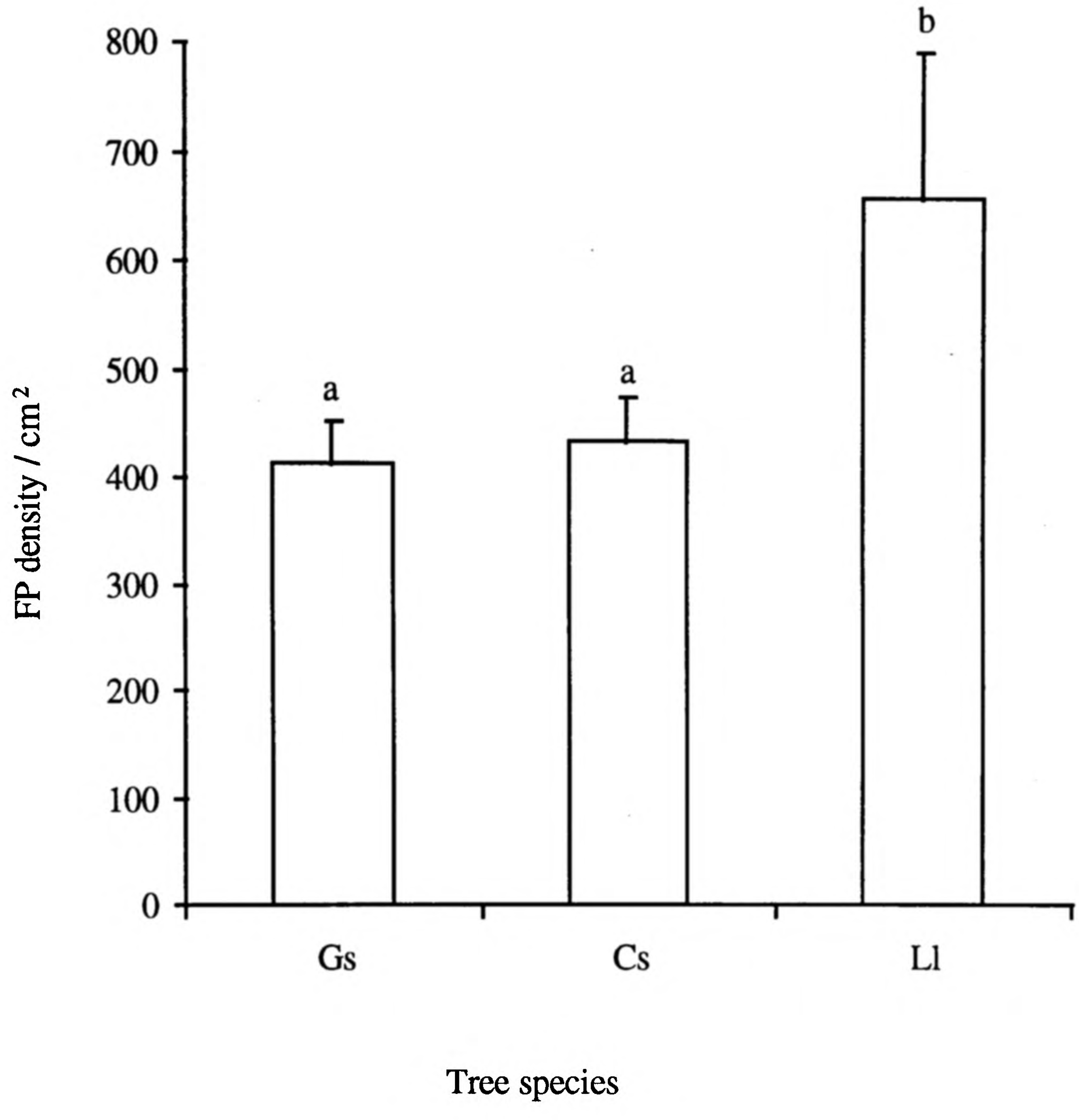
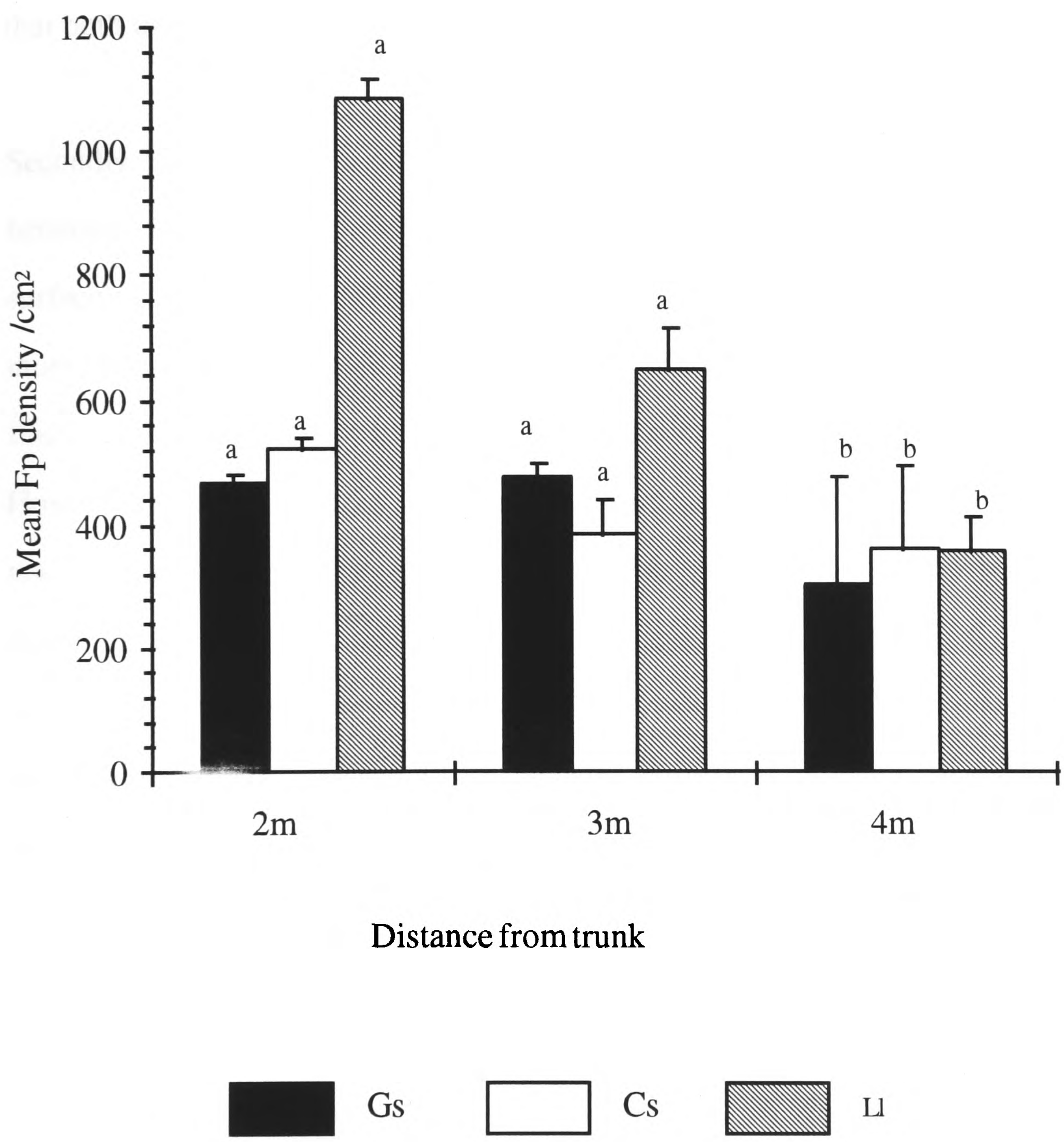


Figure 3.4 Mean and ± S.E. for fluorescent particle density on leaves of *G. sepium* (Gs), *C.siamea* (Cs), *L. leucocephala* (Ll) at various distances from the base of the tree trunk (columns with the same superscript letter are not significantly different , Duncan Test, $P < 0.05$) ($n = 15$ for each tree species or $n = 5$ for each height)



3.4. 4 Discussion

It is clear from the above results that several factors may influence the distribution of spray material into the canopy of the tree. Firstly, the results suggest that with the equipment used, the insecticide has a optimum coverage of foliage at 6 m from the ground at spraying at a distance of 2m. A greater distance may be considered unsafe especially in agroforestry situations where other crops that may be directly fed to livestock are normally within reach. It is therefore essential to choose a distance such that both interests are not compromised.

Secondly, the results have shown that there is a slight but non - significant difference between coverage of upper and lower surface leaves (upper slightly greater than lower surface). Chey (1994) working with forest trees found the distribution of FP to be more or less similar on both upper and lower surfaces of the leaves, but Ozanne (1991) found the lower surfaces had a higher concentration of FP than the top surface. However in both the studies the distances between the operator and the tree trunk were not mentioned and this may explain the differences. It may seem probable that being nearer the tree trunk will result in higher deposition FP on the lower leaf surface whereas being further away from the trunk will result in a more equal distribution on both the surfaces. In addition the distance between the operator of the sprayer and the base of the tree was also observed to be important. A distance of 2 meters gave the optimum FP density for trees of up to 6 m in height.

Finally, the leaf structure may play an important role in enabling the insecticide to penetrate the canopy. This is clearly shown by two of the MPTs used here: *Cassia siamea* and *Gliricidia sepiun* whose leaves are more or less similar in size and shape had no differences in the distribution of the fluorescent particles.

Chapter 4

Faunal survey of three multipurpose tree species (*Cassia siamea*, *Gliricidia sepium*, *Leucaena leucocephala*) and three crops (*Cajanus cajan*, *Zea mays* and *Vigna unguiculata*), in agroforestry, and a comparison with wild flora (*Tamarindus indica*)

4.1 Introduction

The technique detailed in Chapter 3 has been used to investigate the arthropod complex on MPTs described in this Chapter.

The arthropod colonisation of multipurpose tree species (MPTs) in agroforestry is of particular interest to agroforest entomologists and agroforesters in general since herbivory above- and below-ground may alter the rate of establishment and affect the success of the introduced plant species. This is of great significance since many of the tree species have been introduced into most of the areas where agroforestry is being practised in Kenya. *G. sepium, C. siamea, L. leucocephala* are widespread agroforestry tree species in Kenya. Despite their usefulness and their ability to become established quickly, there have been few studies examining the arthropod fauna associated with them. There is an impoverished fauna associated with these tree species in Africa (Webb *et al.*, 1984), and the CABI phytophgous insect data bank contains few records of species associated with these plants. However the insect pests of *Leucaena leucocephala* have been well documented (see for example Bray, 1994).

The determinants of insect diversity in relation to plants are complex and varied. Apart from the species - area relationship which tries to explain why widespread species of the plants are hosts for more insect species, importance of the vegetation's structural diversity, with both spatial and architectural components, is recognised (Southwood *et al.*, 1979, Speight and Wainhouse, 1989). The introduction of trees in agroforestry increases the heterogeneity in the physiognomy and species composition of agroecosystems, and this has an influence in insect populations (Pimentel, 1961, van Emden and Williams, 1974). Schaefer and Siva, (1990) observed that in plantations of *Chlorophora excelsa* (Welw.) in Eastern Usambaras, mixing 20 % of *Chlorophora excelsa* and 80 % of *Maesopsis eminii* (Engl.) lowered the population of gall bug, *Phytolyma lata* Walker (Hemiptera: Psyllidae) sampled in *Chlorophora* sp. This may be because of increased competition from other insect species and introduction of parasites as a result of increased diversity. The arrangement and management of trees in relation to crops within agroforestry technology has a bearing on micro climatic factors such as temperature, relative humidity, interception of solar radiation, distribution of precipitation, wind, carbon dioxide and water vapour (Altieri *et al.*, 1987). These factors may in turn affect the chemical composition of foliage or sap, and eventually defensive plant chemicals (Krammer & Kozlowski, 1979, Waterman & Mole, 1994). Subsequently, they influence arthropod communities in trees. Trees grown as windbreaks, hedgerows (in alley cropping systems) and live fences may reduce wind speed or affect rainfall distribution in small areas on the leeward side of the barriers. Such changes in wind and rain can influence distribution of aphids, scale insects and mites. It has been shown that even small differences in crop height may cause atmospheric turbulence, thereby facilitating mobility of weak flying insects (Bull and Reynolds, 1968, Epila, 1988). Another factor to be considered when sampling agroforestry fauna is the fact that the tree types are not grown in isolation from other vegetation types, so that there is some difficulty in determining which particular organisms are associated with them.

Introduced tree species have a tendency for a lower number of phytophagous arthropod species to be associated with them than the native species (Southwood *et al.,* 1982a). There has been much discussion concerning the validity of the hypothesis developed to explain this observation. There is evidence to suggest that the abundance of a tree species does contribute to the number of phytophagous insects and mites associated with it (Ward, 1977, Strong, 1979, Lawton & Strong, 1981, Fowler & Lawton, 1982, Nilson, *et al.*, 1988).

In order to consider further the factors which influence the structure and dynamics of arthropod communities in canopies of MPTs some baseline information concerning abundance and diversity during the seasons must be gathered. Here attention has been focused on the arthropod faunas associated with three MPTs and some food crops in agroforestry. Man - made agroforestry systems allow the control of some variations (such as tree height) which may influence arthropod populations, so that the investigation of faunas of the MPTs could provide greater rigour to the understanding of an ecological system, even though it is more artificial than a natural system.

The obvious differences (such as canopy architecture, leaf structure, defences, growth rate)(Table 4.1a) between the MPTs and food crops have potential impact for arthropod communities. The canopy architecture may, for example, affect weak flying insects (such as aphids, thrips, whiteflies) which are passively transported by wind in the later part of their journeys to their target resources (Epila, 1988). Therefore trees with their high canopies and complex canopy architecture may act as barriers which on the one hand may obstruct the landing of these insects on the food crops, while on the other hand act as brakes, create shelters of relative calmness and thus enhance the landing and accumulation of insects on the MPTs (Leyton, 1983). In addition, Russell - Smith and Stork (1995) observed that the complex canopy architecture of trees may be favourable particularly to web - building arthropods (arachnids). The chemical

composition of foliage may differ, particularly in relation to secondary or defensive plant chemicals such as phenols (Coley *et al.*, 1985, Waterman & Mole, 1994) and to seasonal availability of nutrients (Krammer & Kozlowski, 1979, Raghavendra, 1991). Leaf toughness (due to maturity), which differ markedly between cultivated crop and tree species may also affect arthropod phytophages.
The impact of other factors such as time of establishment of flora in the region (Kennedy and Southwood, 1984) and taxonomic relatedness (Connor & McCoy, 1979) have also been investigated. It seems possible that insects are more likely to switch to a closely related than unrelated hosts which are likely to share chemical and physical features (Epila, 1986, Cornell & Washburn, 1989). Indeed Claridge & Evans (1990) suggest that the presence of taxonomically related flora may be one of the most important factors in species accumulation. This phenomenon (of taxonomic relatedness) may be a reflection of the extent that co - evolution has overridden the influence of other variables (abundance and time). This may have some implications for the MPTs involved in this study since all of them represent a degree of taxonomic relatedness to the crops (i.e. they both belong to Leguminosae with the exception of *Z. mays* (Gramineae), (see Table, 3.1). The ability of leguminous plants to fix atmospheric nitrogen (Blair *et al.*, 1990) may make the nutritive status of their foliage attractive to insect herbivores in a similar way (White, 1993). Because of their recent introduction and exploitation in the African region (Burley & Wood, 1991), the effect of time of establishment of MPTs on insect species accumulation may still not be discernible.

The two groups of plant species (trees and food crops) have characteristic variations determined genetically. For example, factors such as growth rate, nutrient and general site requirements differ (Savill & Evans, 1986). These differentiating characteristics, often considered in the context of species choice for agroforestry systems, are particularly marked between plant species belonging to different genera. Plant species do show differences in susceptibility to insect pests, which may be related to defence mechanisms (by having chemicals which repel or poison insect herbivores) (see Schulz, 1988) or to insect habitat preferences.

Many of the factors intrinsic to the relationship between tree species and crops may be influenced by the environment in which the trees are located. This is perhaps more obviously the case for trees grown in agroforestry situations because of the inevitable competition with crops and other disturbances resulting from agricultural operations. Savill and Evans, (1986) reported that availability of nutrients may be affected by current management strategies. Nutrient supply in turn often affects the defensive mechanics of the plants (Hagrove *et al.*, 1984), but there are often marked variations within species and provenances which have adapted to localised climatic changes (Nicols, 1987).

Table 4.1a General differences between MPTs* and food crops**

Parameter	MPT	Crop
Growth season	perennial	annual*
Canopy structure	complex	simple
Defences	generally present	generally absent
Growth rate	slow	fast
Height	> 5 m	< 3 m
Yield	low	high

* Barthelemy, et al. (1991)
** Langer & Hill (1991)

4.2 Methods

The chemical knockdown method has been described in Chapter 3. Details of samples are shown on Table 4.1 appended opposite.

4.3 Results

4.3.1 Effect of month on abundance

It is clear from Figures 4.1 and 4.2 that the total number of arthropods collected was highest in August and this declined during the months of September through to November before rising again in December. Analysis of variance showed the effect of the month to be highly significant ($P < 0.001$) (Table 4.1b). Paired tests (Duncan Test, $P < 0.05$) reveals that the differences were significant in some cases but not in others, for example the mean number of arthropods caught in August and November were significantly different, but differences were not statistically significant between say, August and September (Figure 4.1). Analysis of variance also showed that plant species had a significant effect upon arthropod abundance (Table 4.2). The monthly fluctuations in the number of arthropod species followed a similar in all the perennial plant species during the five months (Figure 4.2). To test the relationship between the numbers of arthropods caught, tree species and month, analysis of covariance was performed with the number of arthropods as the dependent variable, tree species (factor) and month as the covariate (Table 4.3). There was a highly significant interaction between tree species and month ($P < 0.001$).

4.3.2. Effect of plant species on abundance

Figure 4.3, shows that *G. sepium* and the wild plant species (*T. indica*) supported similar number of arthropods with *Z. mays* supporting the least number, with other plant species lying in between. *G.sepium* had the highest throughout the months under study (Figure 4.3). Analysis of variance and covariance show that plant species has a significant effect on arthropod abundance ($P < 0.001$, Tables 4.3 and 4.4). Further analysis using Duncan's Multiple Range Test reveals that differences exist pair - wise between some plant species and not others (see Figure 4.3).

4.3.2.1. Comparison of arthropod abundance between trees and crops

The results for the two groups of plant species considered as two seperate groups (i.e trees as one entity and food crops as the other entity) are shown on Figure 4.4 and Table 4.4. It is clear that mean arthropod abundance was higher on the trees than crops, the differences being significantly different (ANOVAR, $P < 0.001$).

Figure 4.1 Mean and $\pm$ S.E.for number of arthropods caught (from all plant species) during five months (significant differences (ANOVAR, Duncan Test, $P < 0.01$) between pairs of months are shown by capital letter of the differing month inscribed above the error bar) ($n = 456$ for August, $n = 432$ for all the other months)

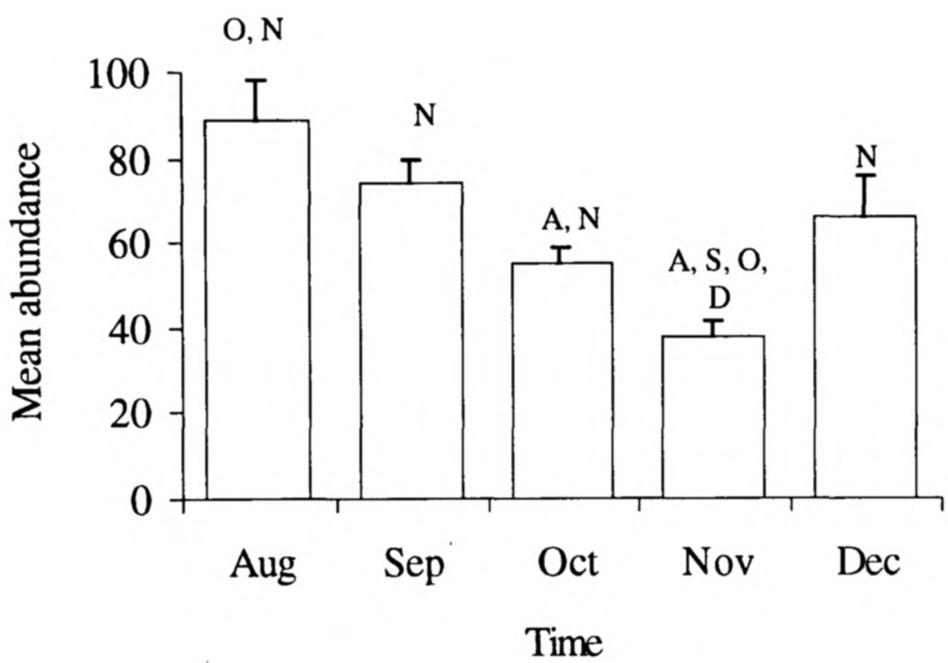


Table 4.1b ANOVAR table for the total number of arthropods caught during five months

Source	DF	MS	F	P
Months	4	26.78	7.21	< 0.001
Error	92	3.71		

Table 4.2 ANOVAR table for the total number of arthropods caught from various plant species

Source	DF	MS	F	P
Plant species	5	26.42	7.58	< 0.001
Error	83	3.49		

Figure 4.2 Mean monthly abundance of arthropod species on 3 MPTs and *C.cajan*

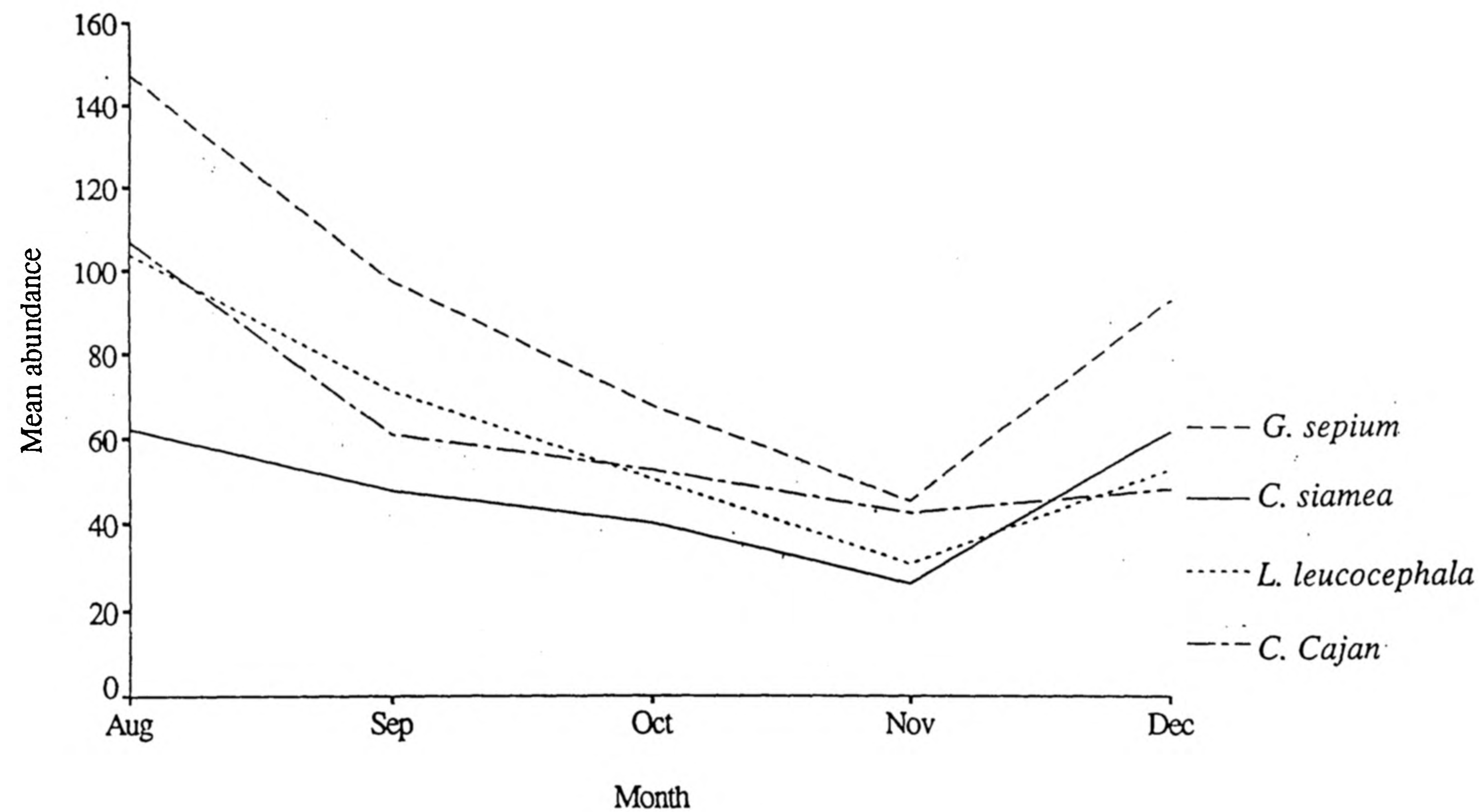
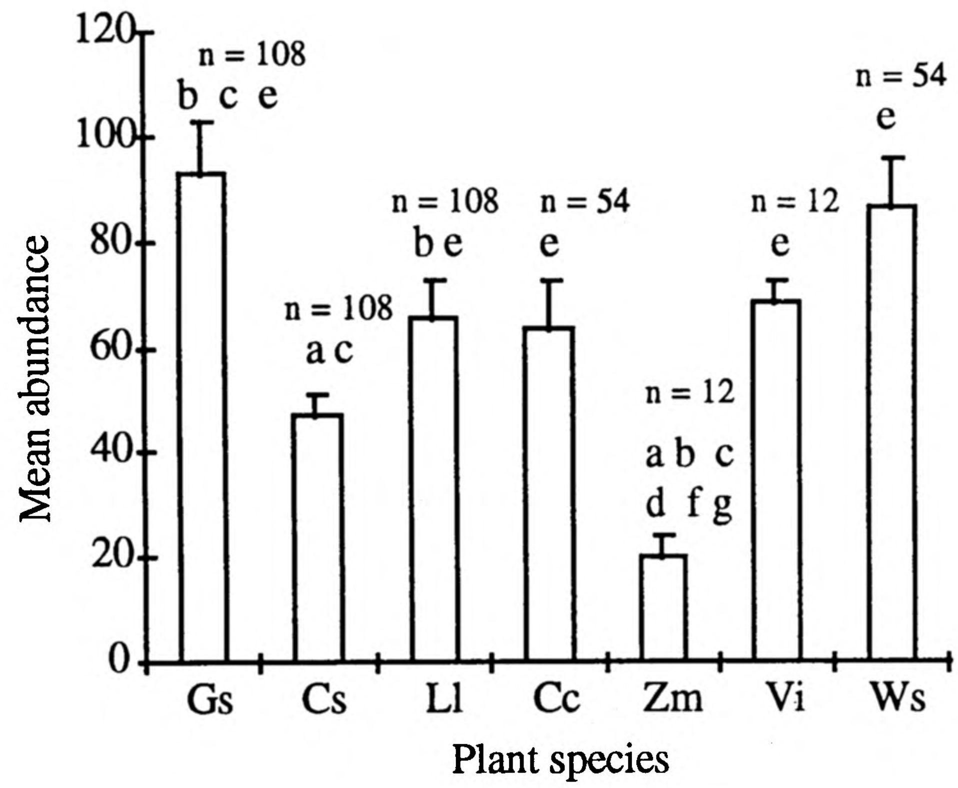


Figure 4.3 Mean and ± S.E. for number of arthropods on tree species and crops. Significant differences between pairs of plant species are shown by small alphabet representing the differing plant species (see key below, ANOVAR, Duncan Test, P < 0.05) inscribed above the error bar



Gs (a) = *Gliricidia sepium* (MPT) - Leguminosae
Cs (b) = *Cassia siamea* (MPT) - Leguminosea
Ll (c) = *Leucaena leucocephala* (MPT) - Leguminosae
Cc (d) = *Cajanus cajan* (Crop) - Leguminosae
Zm (e) = *Zea mays* (Crop) - Gramineae
Vi (f)- = *Vigna unguiculata* (Crop) - Leguminosae
Ws (g) = Wild species - Leguminosae
(*Tamarindus indica*)

Table 4.3 ANCOVA table for total number of arthropods (dependent variable) as function of month (covariate) with plant species (crops not included) as main effects (factors)

Source	DF	MS	F	P
Covariate				
Month	1	13.16	19.4	< 0.001
Factor				
MPTs	2	26.15	38.56	< 0.001
Factor x covariate interactions				
MPTs x Month	3	17.53	25.85	< 0.001
MPTs x Month	3	17.53	25.85	< 0.001
Error	13	0.68		

Figure 4.4 Mean and ± S.E for arthropod abundance on MPTs lumped separately and crops lumped separately (P < 0.001)

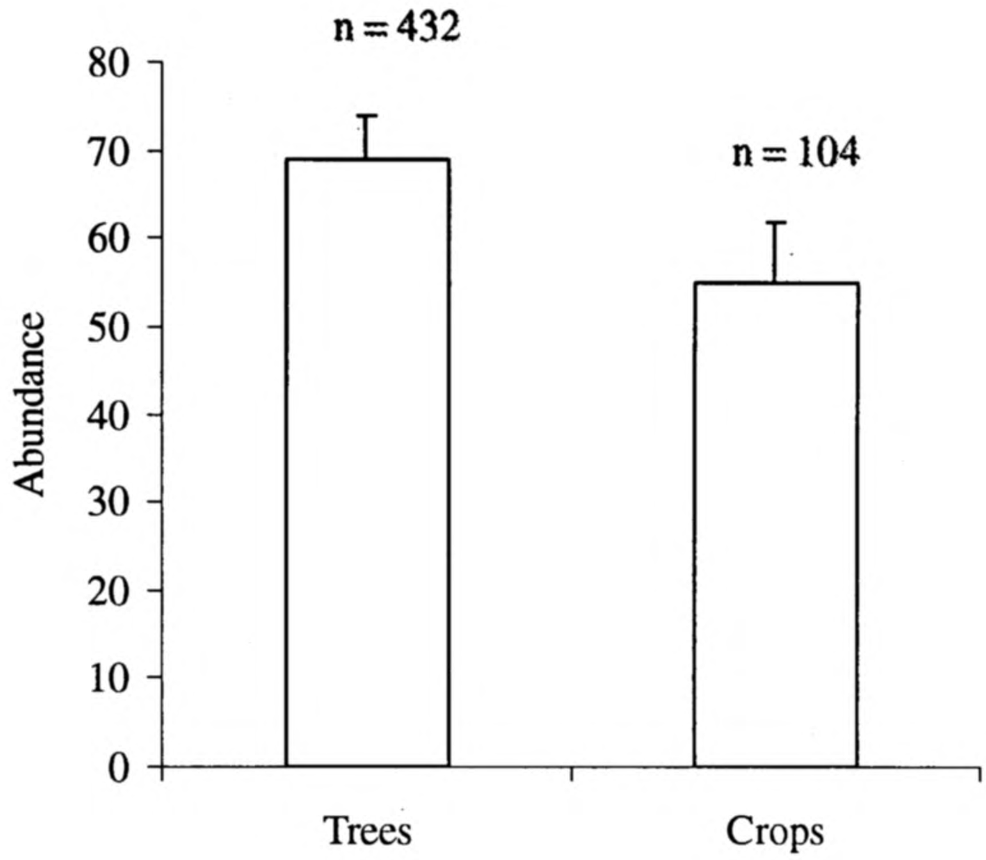


Table 4.5 ANOVAR table for number of arthropod species caught on plant species during five months

Source	DF	Ms	F	P
Month	4	463.62	4.12	0.004
Error	86	112.62		

4.3.3 Effect of month on abundance of major taxonomic groups

Figure 4.5 shows that the five major taxonomic groups were represented all through the months but their abundance varied. Coleoptera were most abundant in August but their numbers declined in September through to November before rising a little in December. Hymenoptera showed a steady decline from August to November before rising sharply in December to a maximum. The number of Homoptera was highest in August, declined in September then remained nearly the same through to December. The abundance of Hemiptera remained the same in August and September then declined in October and November before increasing in December. The Lepidoptera showed little variation in abundance except for a slight decline in November.
There was little change in the number of Arachnids throughout the five months.

4.3.4 Effect of plant species on the abundance of major taxonomic groups

Figure 4.6 shows that the comparisons of abundance of Orders between plant species and within each plant species. Comparisons in the former category show that Coleoptera were most abundant on *G. sepium, C. siamea, L. leucocephala, C. cajan* and on the wild tree species whereas the Homoptera were most abundant on *V. unguiculata*. Within plant species: Coleoptera showed highest abundance on all the plant species with the exception of *V. unguiculata* (Coleoptera and Homoptera are almost in equal proportions) and *Z. mays*. On *Z. mays* both the Arachnida and Coleoptera were most abundant although their abundance were far much below the other plant species. The number of Hemiptera was highest on *G. sepium* while the Lepidoptera were most abundant in the wild. All the taxonomic groups were represented in each plant species.

4.3.5 Effect of month on species richness

It is clear from Figure. 4.7 and Table 4.5 species richness was lowest in November but highest in September. ANOVA from the number of species caught during the months was significant ($P < 0.05$).

Figure 4.5 Mean monthly arthropod abundance (from six arthropod taxa) on plant species

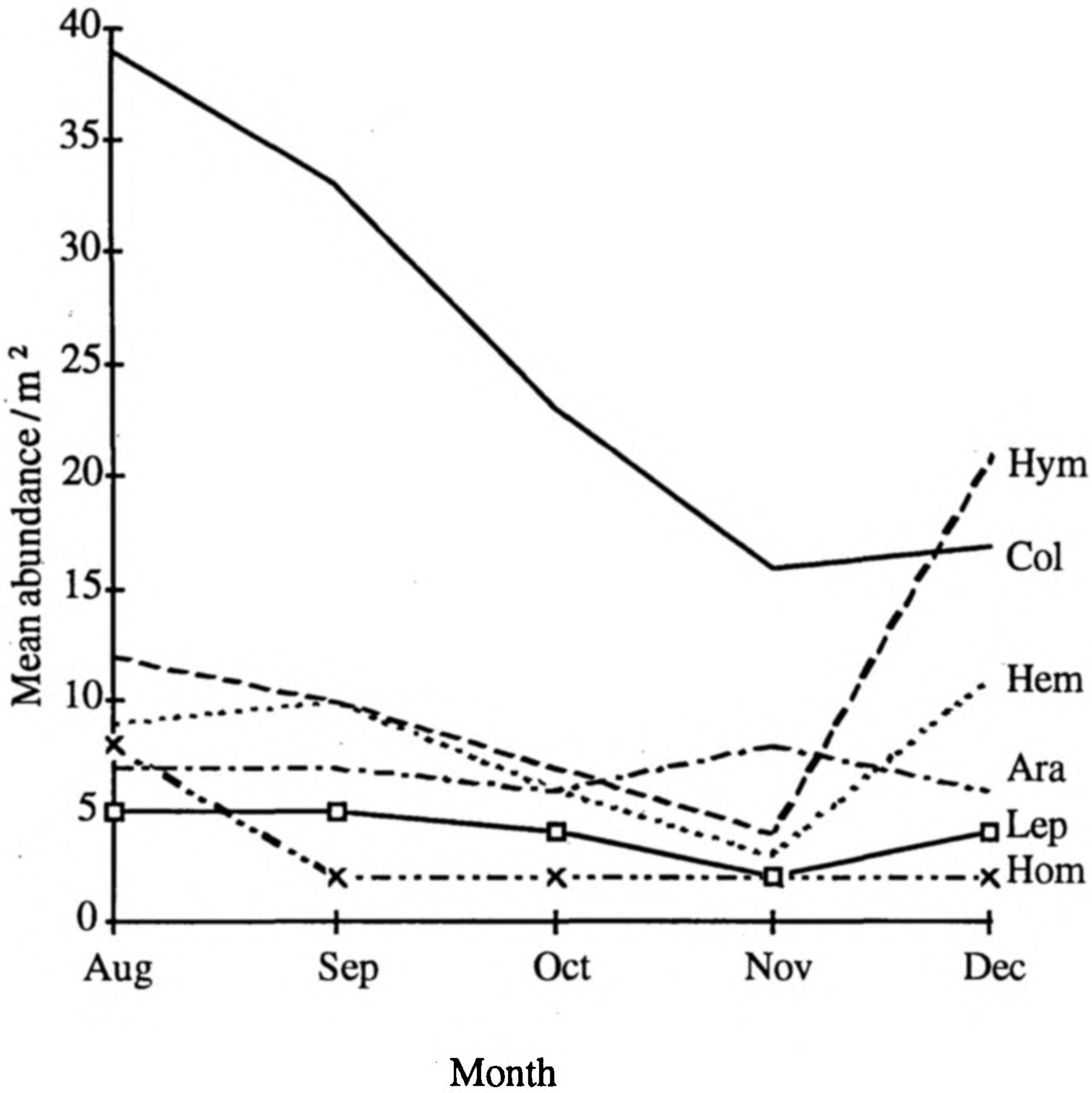


Table 4.5 ANOVA table for number of arthropod species caught on plant species during five months

Source	DF	Ms	F	P
Month	4	463.62	4.12	0.004
Error	86	112.62		

Figure 4.6 Mean and ± S.E. for number of arthropods from six taxa caught regardless of plant species, (ANOVAR, $P < 0.05$, $n = 108$ for Gs, Cs Ll, $n = 72$ for Cc, Ws, $n = 16$ for Zm, Vi)

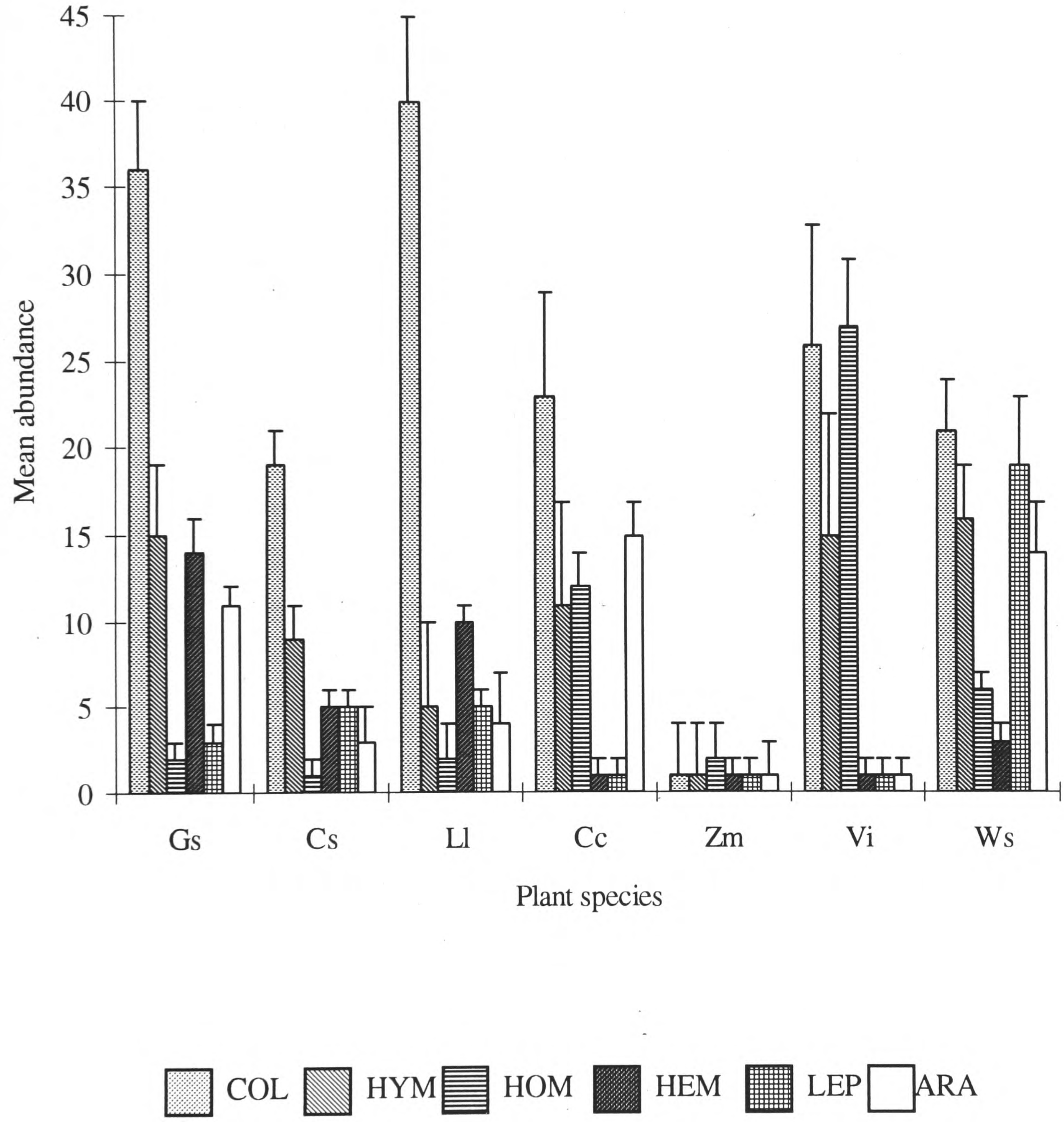
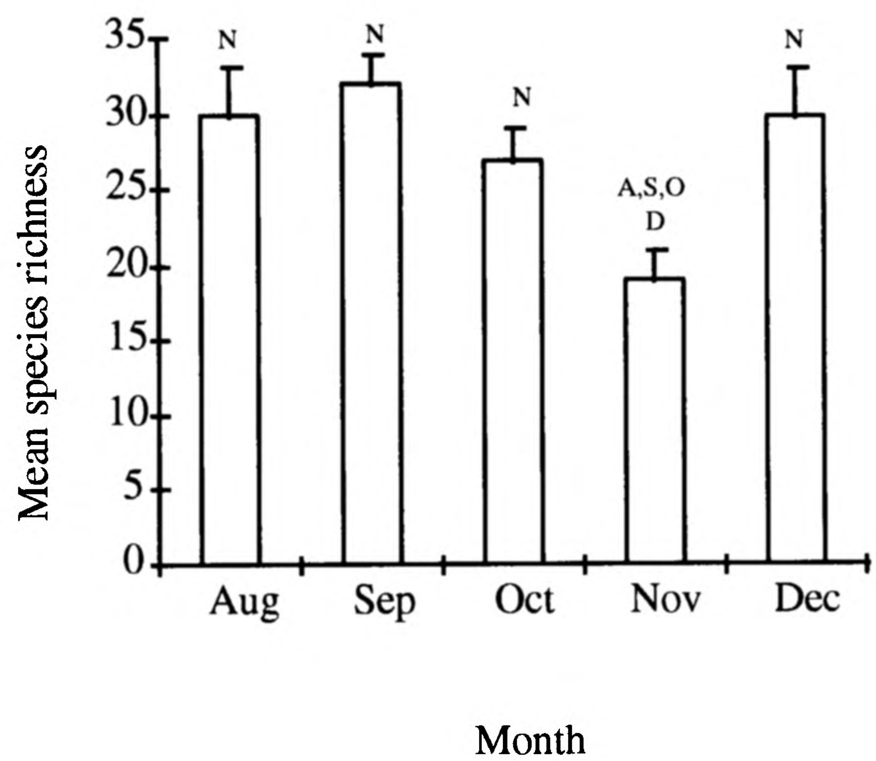


Figure 4.7 Mean and ± S.E. for species richness on various plant species during five months. Significant differences between pairs of months (ANOVAR, Duncan Test, $P < 0.05$) are indicated by the capital of the differing month inscribed above the error bar. For August, n = 456 and n = 432 for all the other months



4.3.6. Effect of plant species on species richness

Figures 4.8 show that *Gliricidia sepium* supported the highest number of arthropod species while *Zea mays* the least number species. The number of arthropod species associated with MPTs (*G. sepium, C.siamea* and *L. leucocephala* lumped) was higher than in crops (*Z. mays*, *C. cajan* and *V. unguiculata*). When the two groups were lumped separately (Figure 4.4) Analysis of variance for the number of arthropod species with respect to plant species was found to be highly significant ($P < 0.001$, Table 4.6)

The proportional distribution of arthropod species is represented Figure 4.9a. 30% of the species were from MPTs only, 13% from wild shrub, and 3% from crops only. 21% of the species were common to all the groups of plant species, 15 % common to MPTs and wild shrub ,14% common to MPTs and crops and 4% were common crop and the wild (Figure 4.9a, $\pm$ 95 % confidence limits).

4.3.7 Taxonomic and species composition of the arthropods

Figure 4.9b shows that Coleoptera formed the most dominant group in the foliage of these plant species under review. Its contribution was 44 % of the total arthropods collected. It was followed by Hymenoptera, 15.4 %, Hemiptera, 11.5 %, Arachnida, 10.8 %, Lepidoptera, (6.2%), Homoptera, 5.8%, and others, 6.5 %.

In terms of species, Coleoptera contributed 34.7% followed by Lepidoptera 20%, Hymenoptera (14.1%), Hemiptera (9.8%), Arachnida (7.6%), Homoptera (5.4%), Thysanoptera (3.2%) Orthoptera (2.2%), Psocoptera and Diptera each contributed only (1%).

4.3.8 Guild composition

Figure 4.9c clearly shows that in terms of numbers the herbivore guild (chewer and sap - feeder guilds) was most important followed by the predator , parasitic, tourist and fungivore guilds.

4.3.8.1 Effect of Month on guild composition

The trends of various guilds during the five months is presented in Figure 4.9d. Herbivore and predator guilds were highest in all the months compared with the other guilds. A general downward trend was observed in all the guilds from August to November. However, this trend was more pronounced in the larger guilds (herbivore and predator) than in the parasitoid, tourist fungivore or detrivore guilds. Predators, sap - suckers, parasitoids and tourists increased in abundance quite sharply in December.

4.3.8.2 Effect of plant species on guild composition

It is clear from Figure 4.9e that guild composition was generally similar on *G. sepium*, *L. leucocephala, C. siamea*, and wild flora with all the major guilds represented. On *C. cajan* four guilds, namely the chewers, sap - suckers predators and parasitoids are represented. On *Z. mays* only the predator, sap - sucker and fungivore guilds were present and on *V. unguiculata* all the major guilds were present.

Figure 4.8 Mean and ± S.E. for number of arthropod species caught from various tree species (significance differences between pairs (ANOVAR, Duncan's Test, $P < 0.05$) are indicated by the small letter of the differing plant species inscribed above the error bar). For abbreviations, see page x). (For: Gs, Cs, Ll, n = 108; Cc, Ws, n = 54; Zm, Vi, n = 12)

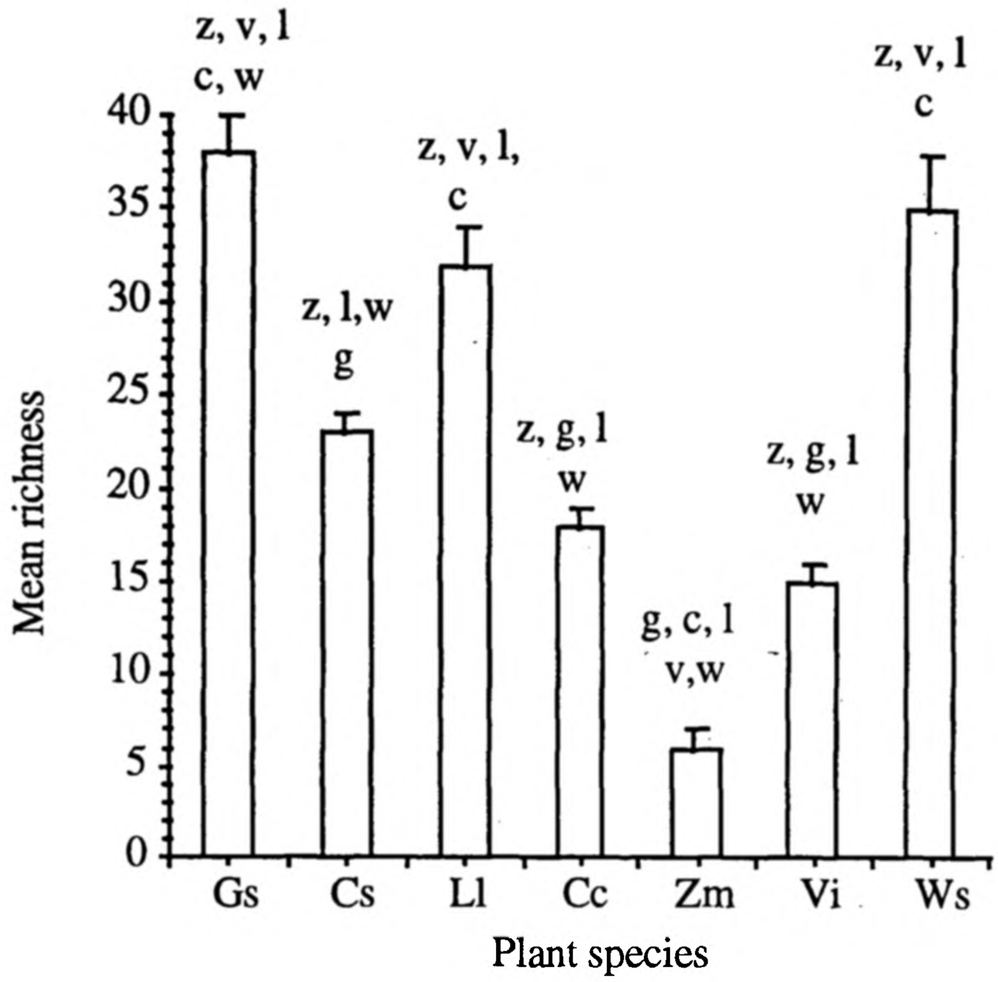


Table 4.6 ANOVAR table for number of arthropod species caught from various plant species

Source	DF	MS	F	P
Plant species	6	1129.67	19.928	< 0.001
Error	84	56.69		

Figure 4.9a Proportion of arthropod species found on MPTs, Crop, Wild and shared between the three groups of plant species (see Appendix I)

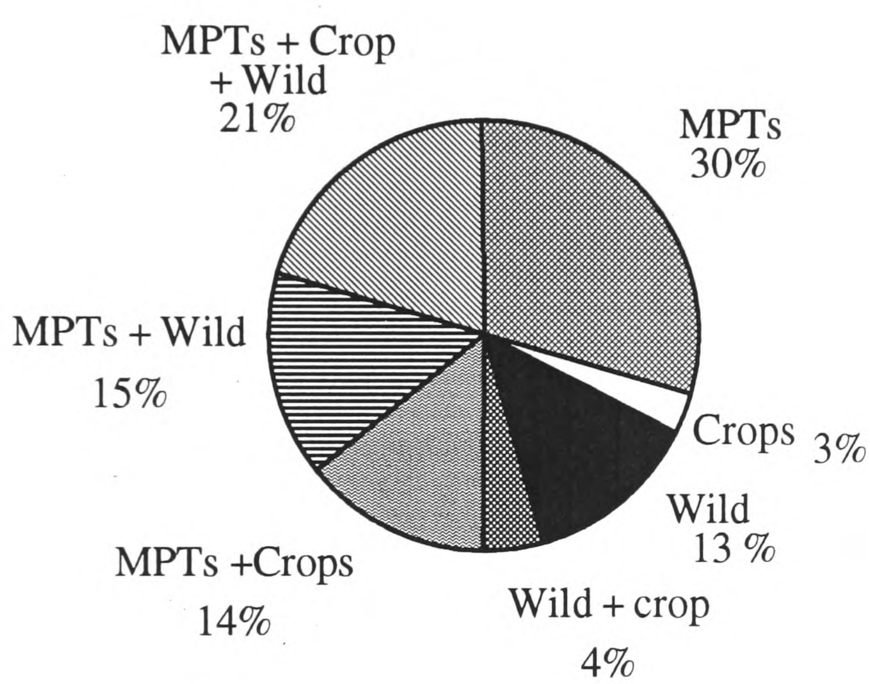


Figure 4.9b Percent contribution of various taxa to the arthropod community on MPTs

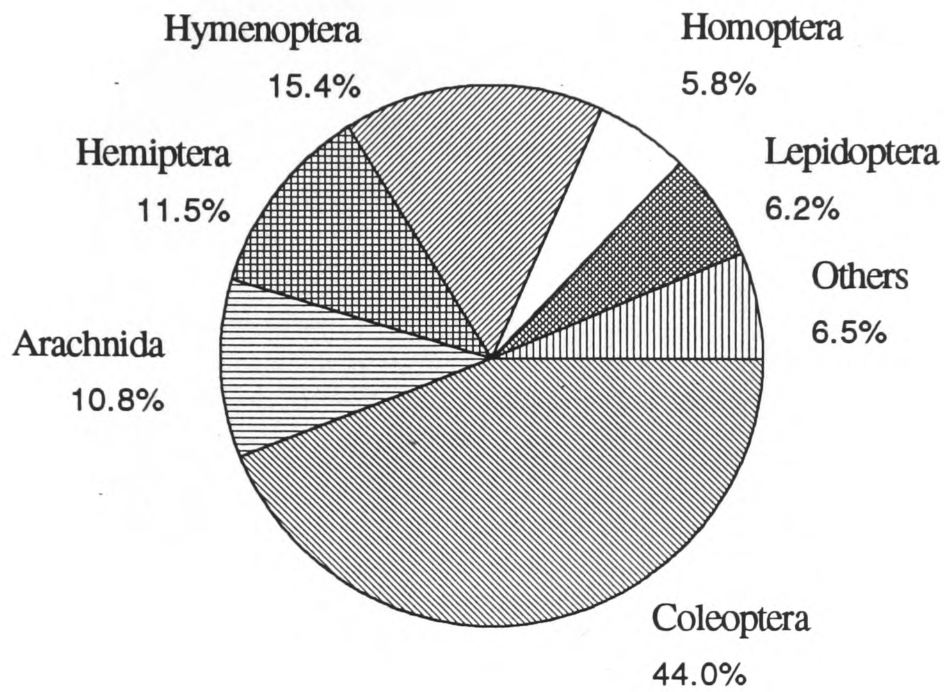
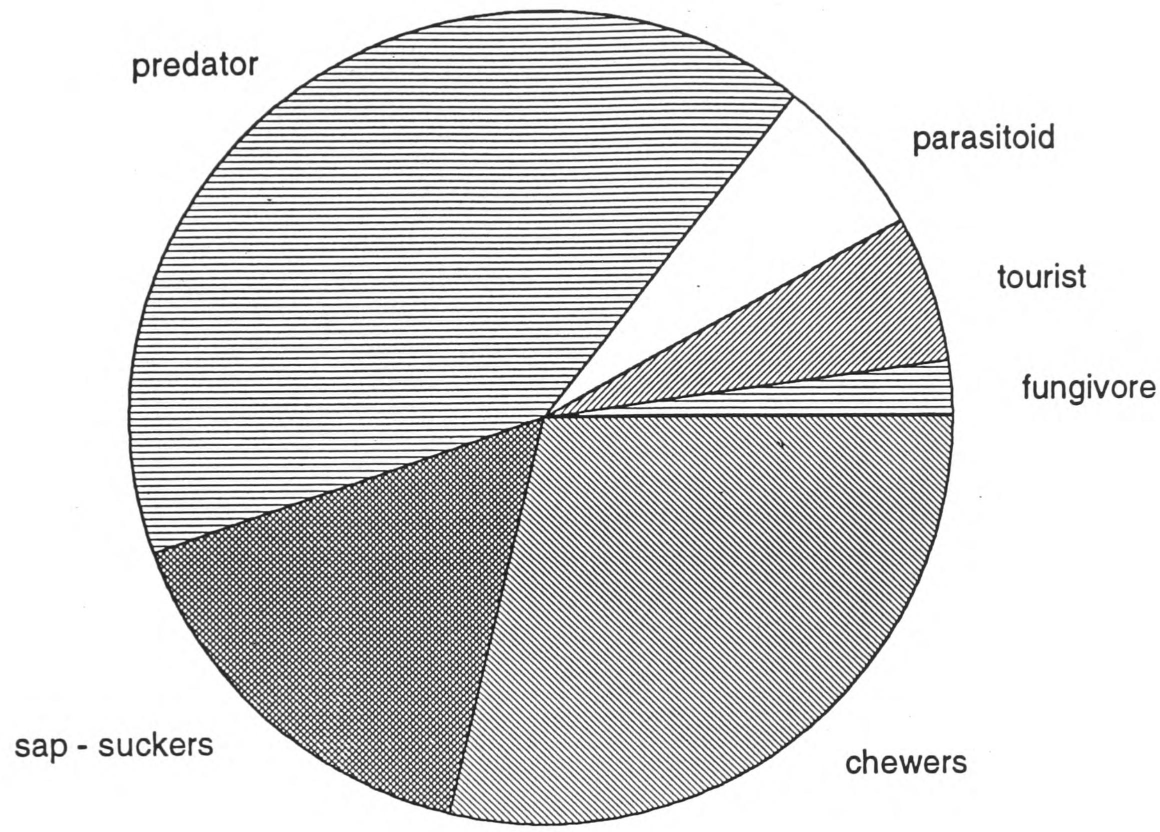


Figure 4.9c Guild structure of arthropod fauna from tree species and crops expressed as mean numbers of species



The above figure shows the number of species of arthropods arranged by guilds. The predator guild was overwhelmingly dominant followed by herbivore (chewers and sap - feeders). Fungivores were least dominant. The dominance of predators is mainly attributable to the large numbers of the families: Coccinellidae (Coleoptera) and Formicidae (Hymenoptera) (represented mainly by the ants). Coleoptera was the most prevalent taxon throughout the study period and tended to be well represented in the other guilds as well. The prevalence of predators was observed to be closely related to the fluctuations in the aphid (Aphididae) populations. It is known that Coccinellids are predators of aphids and their numbers follows closely with that of aphids. While the ants (Formicidae) like the Coccinellids may also predate on the aphids, on many occasions they get attracted to the honey dew produced by the aphids and may be observed to be quite protective towards the ants (they could sometimes be seen to be having ferocious fights with the coccinellids).

Figure 4.9d Arthropod guilds (expressed as mean species richness) during five months

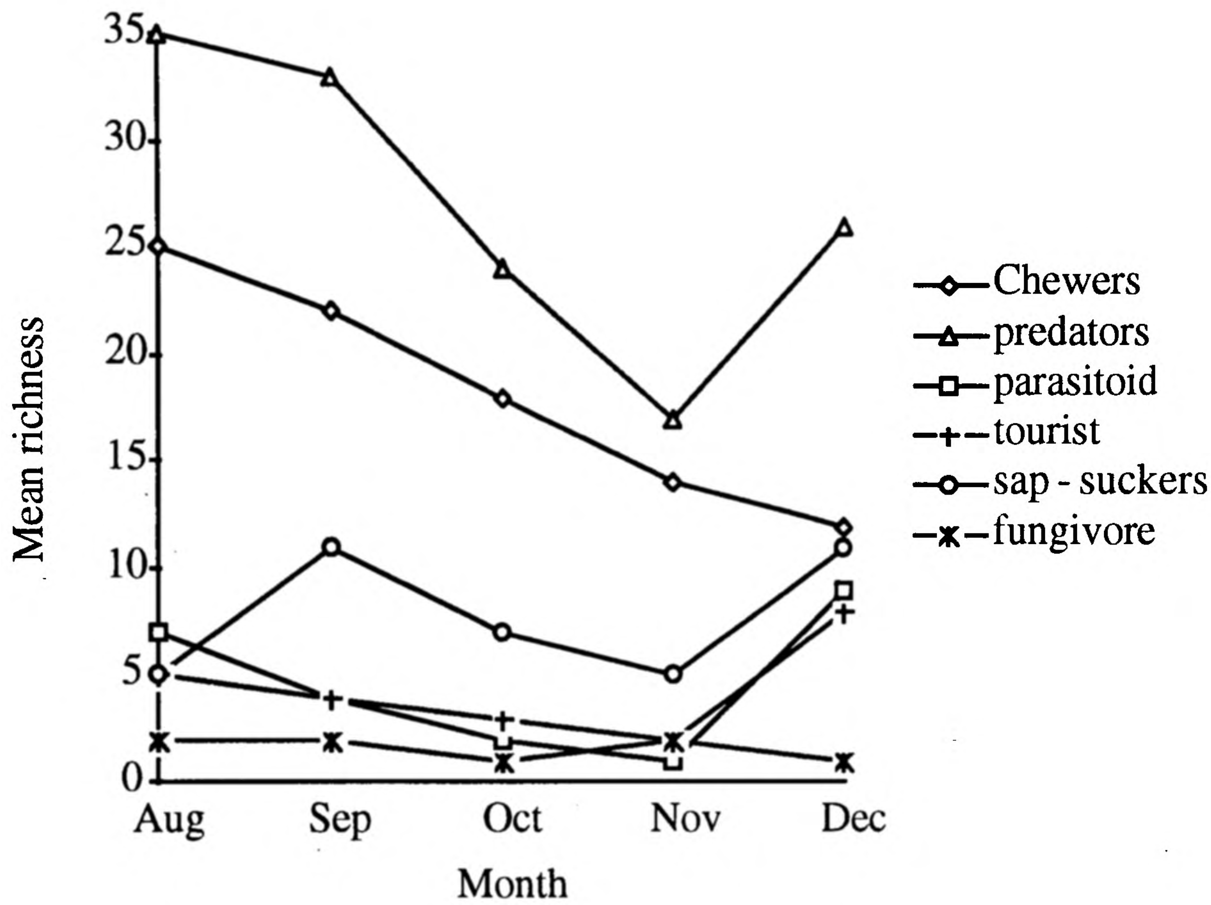
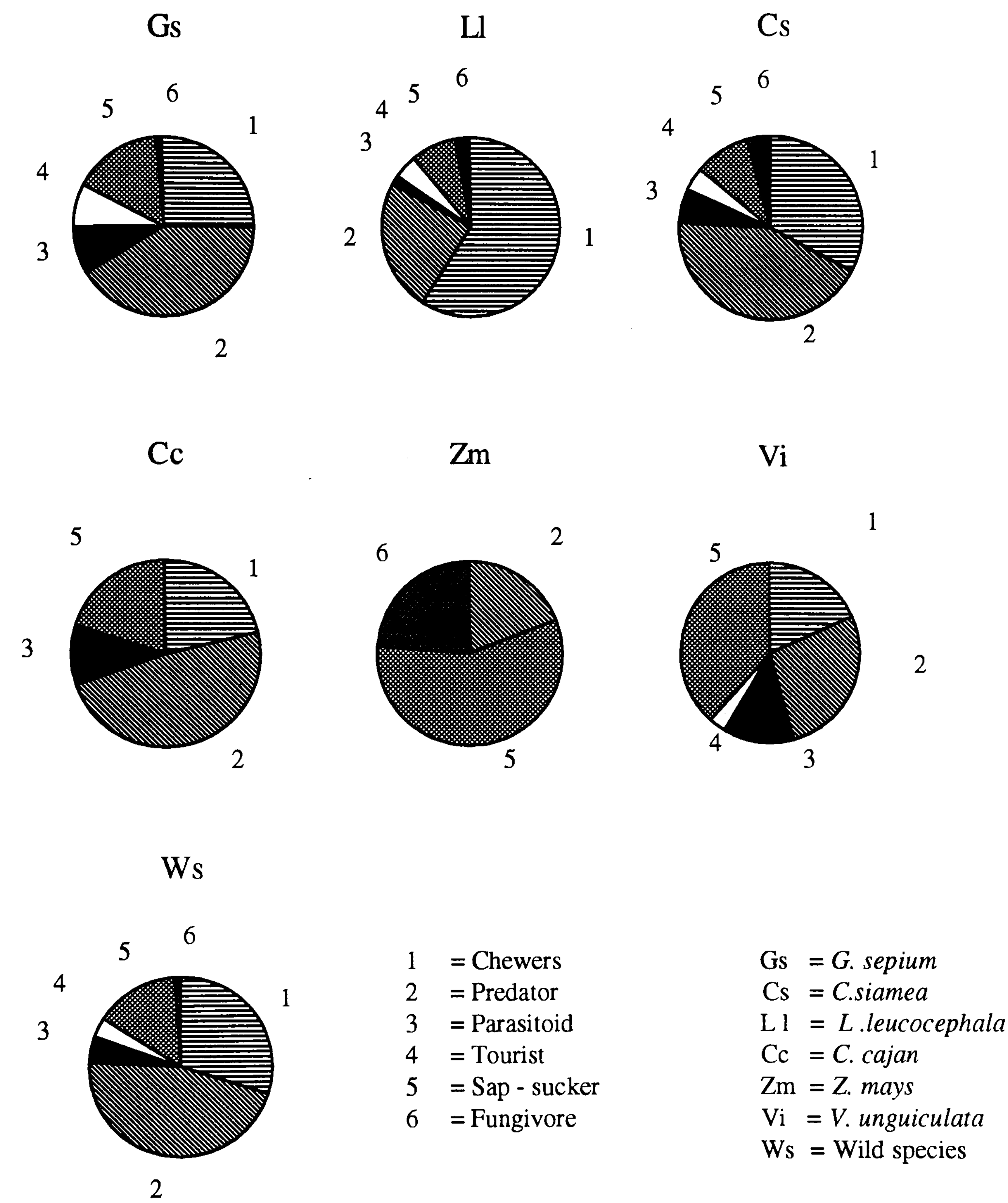


Figure 4.9e Guild structure of arthropod fauna on various plant species



4.4 Discussion

These results illustrate the complexity of factors influencing patterns of arthropod abundance and composition on plants in general and in particular in agroforestry systems. Arthropod abundance, the taxonomic composition and species richness of their populations change with the month and with management practice.

The monthly variations observed above (Figures 4.1 and 4.5) may be due to changes in the chemical composition of foliage and sap which other studies have shown to be important in relation to seasonal availability of nutrients (Krammer & Kozlowski, 1979). Water availability in Machakos is low during August, September and part of October (see Figure 1.3). Rainfall starts in late October and one would therefore expect the foliage quality to improve with rain. The appearance of fresh foliage leads to rise in arthropod numbers and species richness observed in December (Figures 4.1, 4.7). The lowest numbers in November is probably due to time lag between rainfall, the foliage flush and build up of arthropod species.

The various influences plant species have on arthropod communities in agroforestry can be attributed to the inherent plant differences between the plant species. Foliage toughness may differ between various groups of plant species and this may affect arthropod phytophages (Kennedy & Southwood, 1984, Coley, *et al.*, 1985). In comparing insect abundance in trees and crops, it would be expected that food crops should have a higher abundance and species richness than tree species since they are annual plants (except *C. cajan*) and hence the foliage is generally more tender and succulent. However this study shows the reverse to be the case. This may be due to several factors. Firstly, trees grow in the field for a much longer period, hence are able to accumulate more fauna than the crops which have a short life span. Secondly, the physical structure of tree canopies in terms of leaf and branch arrangement differs considerably from that of crops (Table 4.1a) (Strong *et al*, 1984). Accepting the canopy architecture hypothesis of Lawton (1978), which proposes that "larger and more complex plants with more niches support a greater variety if insects," the result obtained in this study that trees support more arthropods is understandable since trees with more diverse tissues than cultivated crops have more ways for arthropods to support themselves. Also, these tree characteristics are important in determining general canopy micro climate which is important for arthropods (Lawton & Shroeder, 1977, Moran, 1980) and could have influenced arthropod abundance and species richness observed in this study. Thirdly, as food crops mature and approach close to harvesting, their foliage begins to shrivel as they dry and their nutritive value as a source of food for insect herbivores becomes low. For example, leaves of maize plant (*Z. mays*) are normally dried up at harvest, and those of cow peas (*V. unguiculata*) become brown and shrunken (personal observation). This drying of foliage is probably attributable to plants trying to conserve their limited supply of nutrients by translocating them from senescing tissues (leaves) to storage (seeds). In contrast to crop plants, MPT leaves generally have a certain amount of green leaves throughout the year, thus providing a constant source of food for insect herbivores. It is recognised that the comparison of arthropod fauna between crops and trees is a rather strange one as these plants are very different not only in their life cycles and structural complexity but also their antiherbivore strategies. However, because the plants are grown together spatially and temporally in an agroforestry set up, this comparison is justified in order to establish how these arrangements affect insects and other arthropods.

Recognition of various arthropod communities on MPTs in agroforestry systems is important because the debilitating impact of insects on forage quality and quantity or seed production may be so great that the remedial activity is desirable (Sen - Sarma, 1987). The MPTs in this study are exotic legumes to Kenya and through time have accumulated a range of associated herbivorous insect species. Some of these insects may have invaded from elsewhere (see for example the species shared with the wild flora, Figure 4.9a), whereas other insects may have adapted to the introduced plant (represented by the species exclusively belonging to them, Figure 4.9a). But a lot of the insects seem to be shared by the wild shrub, and the cultivated crops, and probably use the trees as alternative hosts at times when their usual host (i.e. the crops) is unsuitable or unavailable. This is particularly relevant in agroforestry where food crops are grown in close proximity to the trees. It may be seen that insect species associated with crops alone accounted for only 3% of the total compared with 30% for trees. The number shared between trees and crops accounted for 14% (see Figure 4.9a), and if insect species in this fraction are herbivores, then the role trees can play in harbouring crop pests becomes apparent. This result is supported by a similar finding by Ritchie (1994) that *Afzelia cuanzensis*, a large leguminous tree indigenous to coastal Kenya and Tanzania acts as a wild host of maize cob borer, *Mussidia nigrivenella* Ragonot (Lepidoptera: Phycitinae). This is a serious pre - harvest pest of maize throughout tropical Africa and can also attack cocoa beans (*Theobroma cacoa*, Sterculiacea). The fact that it attacks plant species which are taxonomically unrelated makes the fraction (14 %) shared between crops and trees quite suspect comparatively. Most of the insects sampled here have only now, when the opportunity arose, been comprehensively studied to unravel their host plant relationships and other aspects of their ecology. For some even their host status is unclear. The most studied insect associated with MPTs, the leucaena psyllid (*Heterophylla cubana* Crawford) demonstrates the devastation that insect herbivores can inflict. Even in more natural situations than agroforestry, insects may consume more than other larger herbivores such as the ungulates. For example, over 60% of total leaf material consumed by herbivores in South African Savannah was eaten by insects, mostly lepidopteran larvae (Gander, 1982).

In dealing with insect communities, specific adaptations as well as more general ecological matters must be considered. Each species presents its own challenge which may vary with changing environmental conditions from area to area and from time to time (Walter, 1994). For example trees may vary in their physiological status which may in turn influence insect behaviour and abundance. This is particularly noticeable in the guild distribution (Figure 4.9e) where food crops tend to have fewer guilds. Some insect herbivores are known to perform better on stressed trees and therefore unpredictable stresses in the environmental (such as shortage of water in the soil, Lecowicz, (1987)) may increase herbivorous insects number (White, 1969). Why should insect herbivores prefer stressed plants? For their survival, reproduction and growth, insects, like other organisms require many different nutrients such as carbon, oxygen, hydrogen and nitrogen. Nitrogen, although abundant in nature is unavailable form to herbivores (Sprent, 1987) and must first be converted to an available form by plants (nitrogen - fixing plants). Hence nitrogen, in its available form stored in plant tissues, becomes the principal source for insect herbivores, although it is locked away in a form which both sucking and chewing herbivores cannot readily absorb without spending a considerable amount of time and energy to break them down. So when there is an internal physiological strain induced in the tissues of plants or parts of plants, in response, say, to drought, some nitrogen in a form which can be absorbed by insect herbivores is released from the senescing tissues (White, 1993).

Chapter 5

Impact of simulated defoliation on (*Cassia siamea*, *Gliricidia sepium*, l*eucaena leucocephala* and *Calliandra calothyrsus*)

5.1. Introduction

Analysis of arthropod guilds in Chapter 4 showed that insect herbivores (chewers and sap feeders) formed an important part of arthropod fauna on MPTs. Effects of defoliation on plants by insect herbivores are often overlooked when damage appears moderate or when losses do not surpass the economic injury threshold level. Inconspicuous effects are often disregarded but when duly considered they are frequently found to have negative effects on plants (Verkaar, 1988, Crawley, 1989, Meyer *et al.*, 1993). The manner by which the growth of a plant is affected when subjected to the characteristic damage done by these insect defoliators poses some questions of primary research interest. For instance, what effect have the various levels of defoliation on plant growth? What level is tolerable to the plant? Will moderate damage have a significant influence on growth? Answers to these questions have a bearing on the economics of planning and instituting any pest control program.

The impact of insect-feeding on trees have been shown to generate a huge range of plant responses, such as a reduction in relative growth rate (Nair *et al,* 1985, Carroll *et a*l., 1993) and, at times, positive effects such as increases in biomass or seed production (Inouye, 1982, Maschinski and Whitham, 1989). Graham (1931) concluded that the growth loss in Tamarack, *Larix laricina* Koch. is directly proportional to the degree of injury inflicted by the larch sawfly, *Pachynematus imperfectus* Zaddach (Hymenoptera: Tenthridinae). Partial defoliation, even at 75 percent, failed to kill the experimental trees. Piene (1980), in his studies on Balsam fir, *Abies balsamea*, Mill. has found that bud production generally increases with the severity of budworm defoliation, suggesting a stimulating effect which would be a helpful response of the plant from the point of view of the budworm (i.e. more buds to colonise). It is probable that the budworm produces a plant auxin which induces bud formation. In addition there is top killing and reduced diameter growth among surviving trees. The factors that generate this range of plant responses are poorly understood. However, it is clear that plant responses to damage are plastic, and depend on both the biotic and abiotic conditions that plants experiences (Maschinski and Whitham, 1989). In agroforestry, for example, different insects groups may cause damage of varying degrees to the MPTs but are often overlooked because the damage does not reach economic threshold.

The degree of damage is influenced by the feeding style of the insect. To demonstrate the impact on trees of leaf-feeding (chewing) insects (as opposed to sap - feeding), four multipurpose tree species (MPTs) were artificially defoliated to varying degrees and the effect measured. The simulation approach was resorted to owing to the variability of insect activity in the field and the complicated effects of uncontrolled environment (Myers 1993).

5.2. Materials and Methods

Four multipurpose tree species namely *Cassia siamea, Gliricidia sepium, Leucaena leucocephala and Calliandra calothyrsus* were grown in pots in a green-house at the Department of Zoology, University of Oxford. The seeds were planted in November 1989. The seedlings were closely monitored and when they were about two years old artificial damage was effected by use of a pair of scissors to clip off foliage to simulate damage by leaf chewing insects. Four defoliation regimes were imposed by removing leaves as follows: removing one out of every four leaves (25 % defoliation); every other leaf (50% defoliation); three of every four leaves (75 % defoliation); no leaves removed (0% defoliation). There were 10 plants per treatment and were 3 replicates of each treatment.

Response variables measured were diameter at pot level (DPL) and height. Defoliation was carried out, and measurements taken for 12 weeks at the following dates March (6, 14, 20 28/29), April (3, 19, /20), May (2 / 3, 15 / 16), June (12 / 13, 26 / 27), and July (11 / 12, 25 / 26), 1992.

Data analysis was by ANOVAR, SPSS - PC

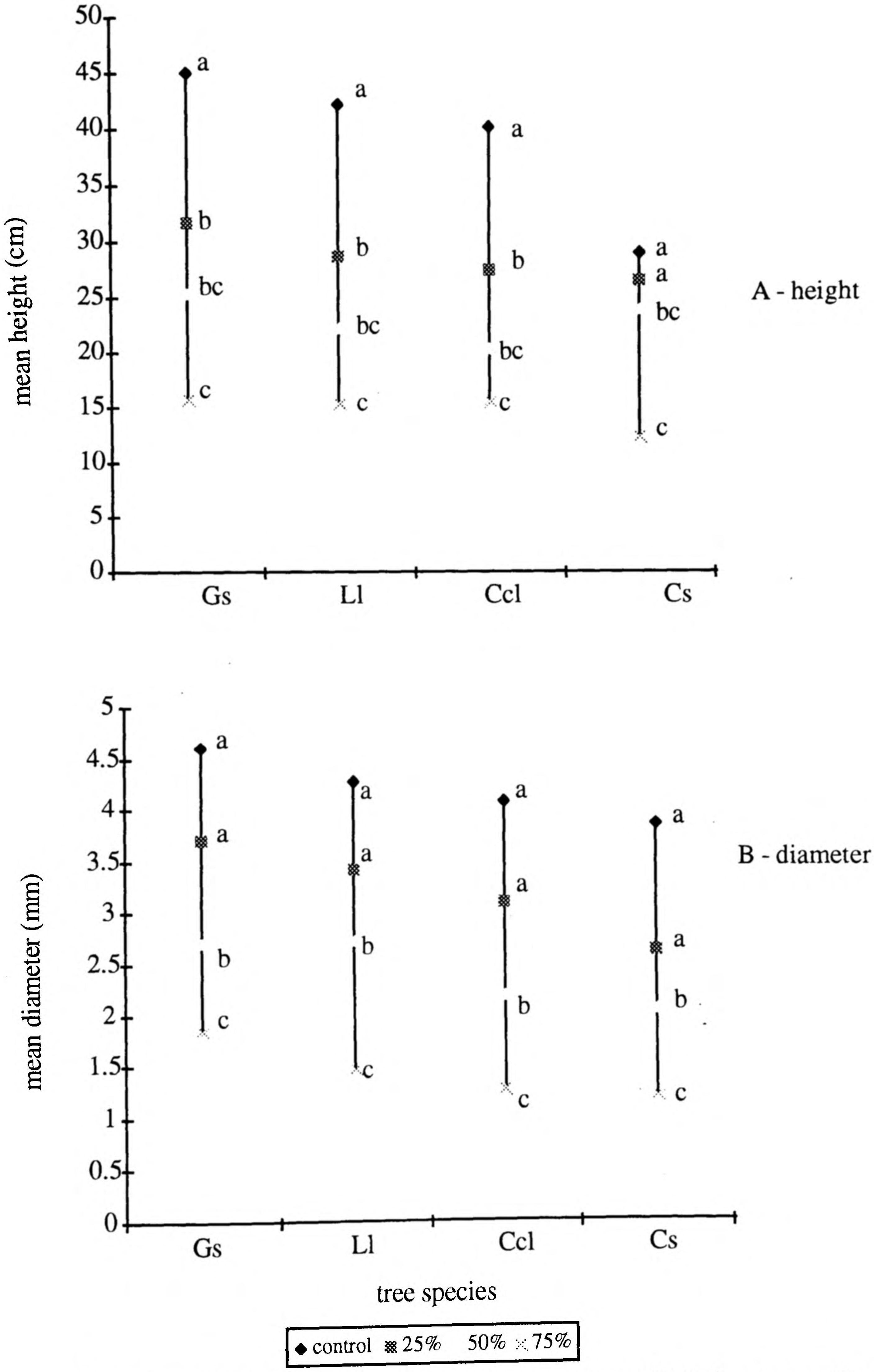
5.3. Results

Figures 5.1 A and B, 5.2, 5.3 Tables 5.1 and 5.2 shows the effect of different levels of defoliation on various MPTs. Height growth decreased as treatment level (defoliation) increased (Figures 5.1; 5.2). This was true for all the four tree species. Figure 5.1A shows that for *G. sepium* at 25 % defoliation, total height increment was reduced by as much as 30 percent with further reductions 43.7 %, and 64.9 % at 50, and 75 % levels of defoliation respectively. For *L. leucocephala*, the reductions were 30.9 %, 47.1 %, 63.5 %, at 25, 50, 75 percent levels of defoliation respectively (± 95% confidence limits). For *C. calothyrsus* and *C.siamea*, the corresponding reductions 25, 50 and 75 percent levels of defoliation were: 12.5 %, 38.8 % 60 % and 31.%, 49.4 %, 64 % respectively. These differences were found to be statistically significant (Table 5.1, $P < 0.001$).

Similarly, diameter growth decreased as treatment level increased (Figures 5.1; 5.3). This was observed in all the tree species. For example the total reductions in diameter increment were as follows: *G. sepium* (19.1 %, 41 %, 59.9 %), and *L leucocephala* (20.9 %, 36.7 %, 66 %) at 25, 50 and 75 percent levels of defoliation. Similar reductions were observed on *C. calothyrsus* and *C. siamea* (Figure 5.1 B, $\pm$ 95 % confidence limits). Statistically these differences were also found to be significant (Table 5.2, $P < 0.05$). However, a further analysis of Paired - Tests showed that although diameter increments for 0 % and the 25% defoliation were not significantly different for all the tree species, total height increment was significantly different between these same levels of defoliation with the exception of *C.siamea* (Figure 5.1A)

There was a significant effect of the treatments (degree of defoliation) on growth, whether height or diameter. There was also a significant effect of MPTs (the 4 species were not equally affected by defoliation), and a significant interaction between treatments (defoliation) and tree species (Tables 5.1, 5.2).

Figure 5.1 Average growth for four MPTs eight weeks after simulated defoliation. Means followed by same letter within plant species are not significantly different (Duncan Test, $P < 0.05$)



G. sepium (Gs), *L. leucocephala* (Ll), *C.. calothyrsus* (Ccl) *C.. siamea* (Cs)

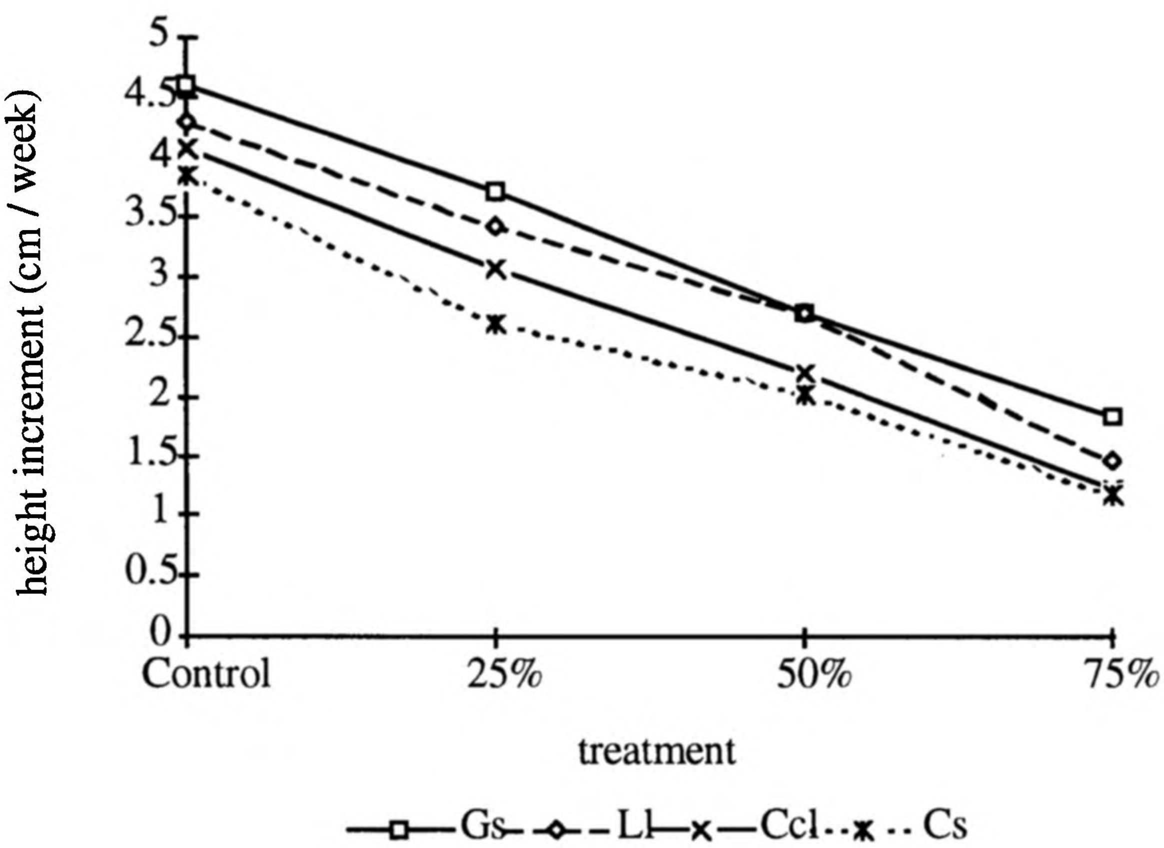
Table 5.1 ANOVAR table for height increment for all MPTs at four treatment levels

Source	DF	MS	F	P
Treatment	3	1380.87	240.4	<0.001
MPTS	3	87.65	15.3	<0.001
Treatment x MPTs	9	32.8	5.7	<0.001
Error	36	5.7		

Table 5.2 ANOVAR table for diameter increment for all MPTs at four treatment levels

Source	DF	MS	F	P
Treatment	3	17.64	1506.1	<0.001
MPTs	3	1.41	120.6	<0.001
Treatment x MPTs	9	0.04	3.6	<0.001
Error	36	0.01		

Figure 5.2 Average height increment for four tree species: *G. sepium* (Gs), *L. leucocephala* (Ll) *C. siamea* (Cs) and *C. calothryrsus* (Ccl).



5.4. Discussion

It is clear from the above results that the treatments affected the growth and growth rate (since different sizes were reached in the time). The diameter growth decreased as treatment level increased. The same pattern was followed by height growth. Sample plants within each treatment (level of defoliation), however, exhibited variations in growth. This may be partly attributed to inherent individual tree differences. Generally, insect impact on plants will depend both on what resources are lost to the plant, and how the loss of those resources affects plant function. Meyer (1993) found that some aphids had no detectable effect on plant growth, even though they consume sugars, nitrogen, and water. But in some cases (for example the cypress aphid *Cinara cupresii* (Aphididae)) can have very serious impacts on it host (Orondo & Day, 1994). It may therefore be that a critical factor determining an insect's impact on its host is how its feeding affects leaf area. The reduction in leaf area therefore provides a plausible explanation for the loss in growth observed in this study because the leaves are the principal site of photosynthesis for the production of carbohydrates, which are important food reserves and are part of the structural framework of the cell essential for growth (Salisbury and Ross, 1969). It has been shown that a plant's relative growth rate depends on its carbon gain per unit area and the ratio of leaf to total plant mass (Meyer, 1993).

Other studies have also shown that severe and repeated defoliation may contribute to reduction in overall plant growth and may also lead to loss of vigour and make trees more susceptible to other stresses (Heichel and Turner, 1984, Lowman, 1987). However it is very difficult to generalise about the selective pressures exerted by herbivorous insects on their host plants. Most plants are attacked by multiple species of insect herbivore. It may therefore be right to assume that plants would exhibit a broad range of responses to herbivore damage. The majority of studies show that herbivory has negative effects on plants (Krischik and Denno, 1983, Huffaker *et al.*, 1984, Schowalter *et al*, 1986, Verkaar, 1988, Crawley, 1989), but some herbivores do not cause any damage (e.g. Karban and Cortney, 1987) and even positive effects, such as increases in biomass or seed production have been reported (Inouye, 1982, McNaughton, 1986, Maschinski and Whitham, 1989). Overall by affecting the growth and survival of individual trees, insects directly reduce the productivity of agroforestry systems with serious economic and environmental implications for the resource poor farmers.

General conclusions for the natural situation (as opposed to the present experimental one) are very difficult to make about the effects herbivores on plants because of the numerous additional factors that influence impact in nature. These include timing of damage, site fertility, and the degree competition that the plant is experiencing (Maschinski and Whitham, 1989, Whitham *et al*, 1991). The tree species used in this study were able to regrow after defoliation, and this in the long run may in some aspects reduce the overall impact of herbivory (see van der Meijeden *et al.,* 1990, Whitham *et al.*, 1991). Many new shoots were developed by the defoliated trees, demonstrating that there is a possibility for these tree species to compensate for the tissue lost. Hjalten *et al* (1993), working with birches, showed that defoliated trees were capable of compensating or even overcompensating for tissue lost. On the one hand it is possible to say that there may be no long - term effects of herbivory on these plants, while on the hand it is acknowledged that most herbivores do adversely affect some components of plant growth and reproduction (Karban and Strauss, 1993). An important criterion for selecting agroforestry tree species is the ability for fast growth. Apart from the obvious advantage of having such fast growing species, there appears to be an added benefit of such species not being overly affected by insect herbivory. Slow - growing plants have lower ability to regenerate lost tissue compared with fast - growing ones (Whitham & Mopper, 1985, Garnier, 1991).

The importance of these results is that they can provide a basis for assessing the effect of damage under intensive culture (as in agroforestry). If necessary they can be used as a basis for determining when insect pest control measure should be applied, considering the costs involved in undertaking pest control programmes. More studies of this kind are required, involving a wide range of MPTs for agroforestry, considering other variables such as age classes, time of the year when damage is inflicted, the agroforestry system involved and the type of damage which are commonly found in the nursery and the field.

Chapter 6

Pruning effects on arthropod populations in agroforestry

6.1 Introduction

In Chapter Four, arthropods from various taxonomic groups and guilds have been shown to be associated with MPT and crops in one way or the other. In agroforestry systems, as in other agro - ecosystems, man persistently interferes with their functioning in diverse ways. In agroforestry for example, these interferences may occur through legitimate actions such as tillage operations or pruning of trees. Frequent tillage operations while making the soil more pliable for the cultivation of food crops in agroforestry may interfere with the plant root system eventually affecting insect herbivores. This Chapter investigates how pruning which has a more direct impact on these herbivores than tillage affects their population abundance and richness. Plate 1.1 (page 7) shows some of the pruned MPTs in an alley intercropping with *Vigna unguiculata.*

Why prune? The practice of pruning trees is of great significance particularly in orchard management as it enhances fruit production (Li *et al.*, 1994). In agroforestry, however, pruning as a management practice is aimed at reducing the undesirable effects of competition between trees and crops for light (Huxley *et al.*, 1984). In addition, it is through pruning that fodder for livestock is obtained from trees. The manner in which man defoliates plants through pruning may be equated with herbivore attack on plants, though differences exist with regard to pattern and extent of leaf loss. In pruning there is also loss of woody parts with a subsequent interruption of the functioning of the xylem and phloem. The chemical or biochemical consequences of both interfering with the conducting system and defoliation chemistry have received much attention and are reviewed by Edwards and Wratten (1985).

Carne(1965), Rockwood (1974) and, Webb and Moran (1978), have shown that insects may feed preferentially on regrowth foliage which may lead to increased levels of attack. In view of the relationship between susceptibility of various plant species to pathogens and insect pests following environmental disturbance, and the initial observations of workers that insect damage appeared to be higher in trees which have been pruned or otherwise defoliated or damaged, the role of pruning as stressing agent was pinpointed for investigation.

6.2 Methods

The knockdown method has been described in Chapter 3. The sampling of arthropods from the pruned and unpruned trees followed same protocol detailed in Section 3.2.1.

6.2 Results

6.2.1 Effect of pruning on arthropod abundance

There were significantly more arthropods on pruned than unpruned trees ($P < 0.05$, Table 6.1, Figures 6.1, 6.2). Table 6.2 further shows the effect of both tree species and pruning and their interaction to be significant. To test the relationship between arthropod abundance and tree species, pruning or not pruning and month an ANCOVA was performed with total number of arthropods as the dependent variable and month as the covariate (Table 6.3) on pruned and unpruned treas. A significant interaction between pruning , tree species and the covariate suggested that each tree species show the different time - related trend depending on whether it was pruned or not.

6.2.2 Effect of pruning on species richness

Figures 6.3, and Table 6.4 shows that pruned trees supported more arthropod species than unpruned and this difference is statistically significant ($P < 0.05$). Species richness in all the three species whether pruned or unpruned showed a downward trend from August to November before starting to rise again (see Chapter 4). In unpruned trees of all species, differences between them in arthropod numbers was essentially absent by November, whereas in pruned trees the differences were marked (Figures 6.4A and B).

6.2.3 Effect of pruning on guild composition

All the guilds were present in both the pruned and unpruned tree species in similar proportions (Figure 6.5)

Figure 6.1 Mean and ± S.E. for number of arthropod caught from pruned and unpruned trees. Highly significant means ($P < 0.001$, $n = 222$).

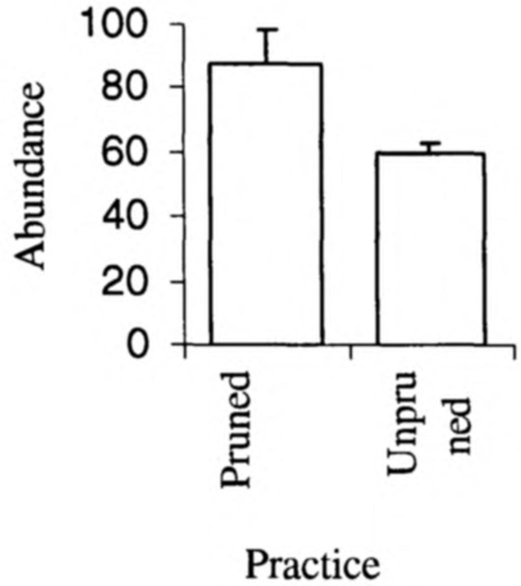


Table 6.1 ANOVAR table for number of arthropods on trees which have been pruned and those not pruned (irrespective of tree species)

Source	DF	MS	F	P
Pruning	1	46.58	10.74	< 0.001
Error	70	4.34		

Table 6.2 ANOVA table for number of arthropods on trees (MPTs) in two management practices: pruning or not pruning (abbreviated as PCT)

Source	DF	MS	F	P
PCT	1	46.58	14.32	< 0.001
MPTs	2	44.28	13.61	< 0.001
PCT x MPTs	2	3.08	0.95	0.394
Error	66	3.25		

Figure 6.2 Mean and ± S.E. for number of arthropods caught from pruned and unpruned *G. sepium* (Gs), *C. siamea* (Cs) and *L. leucocephala* (Ll). Differences between means statistically significant (ANOVAR, $P < 0.05$, $n = 74$)

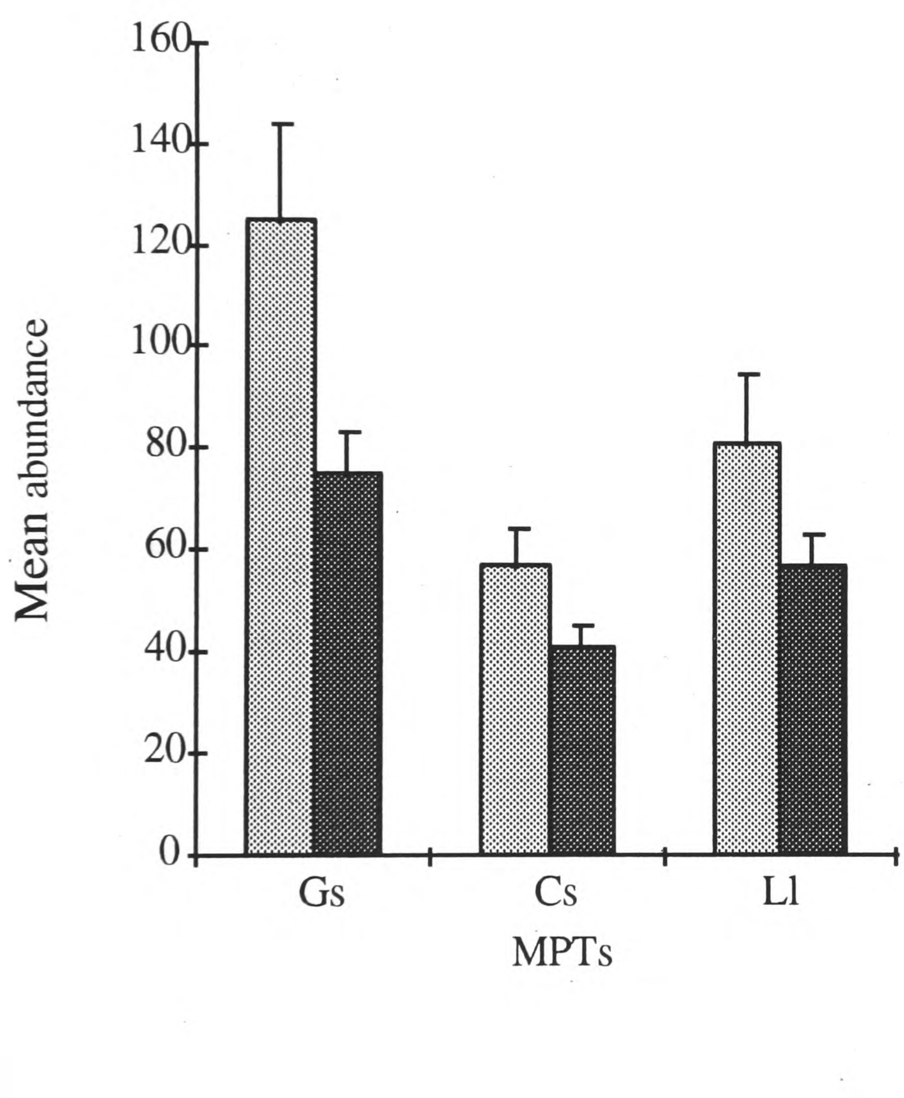


Figure 6.3 Mean and ± S.E. for number of arthropod species on pruned and unpruned tree species. Differences between means highly significant ($P < 0.001$, $n = 222$)

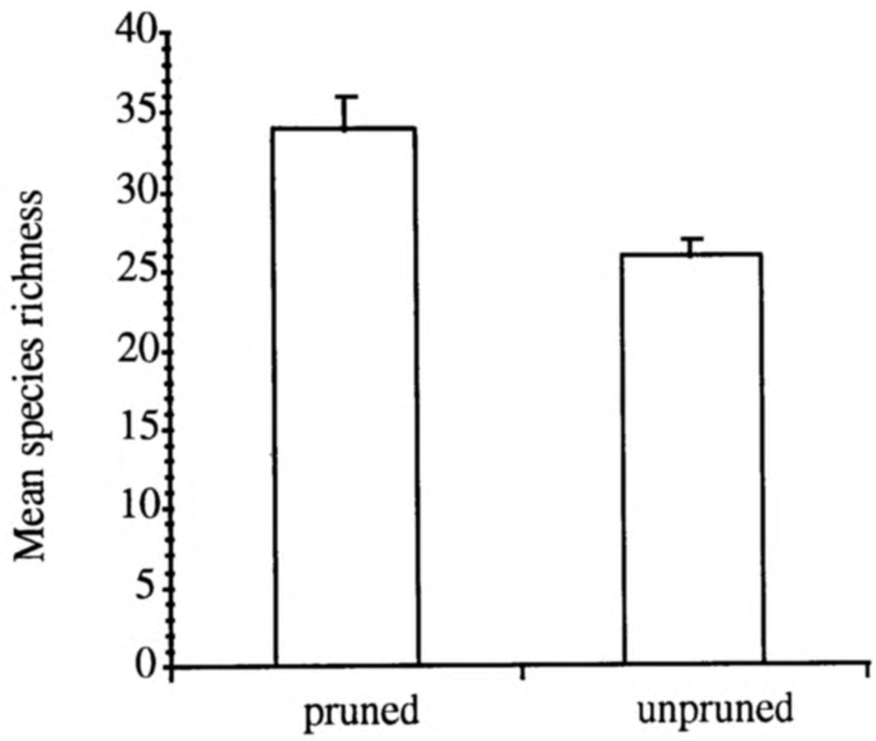


Table 6.3 ANCOVA table for the mean number of total arthropods (dependent variable) as a function of month (covariate) with pruning and tree species (factors). The insignificant MPTs x PCT interaction suggests that the covariate dependent relationship did not differ in pruned and unpruned trees

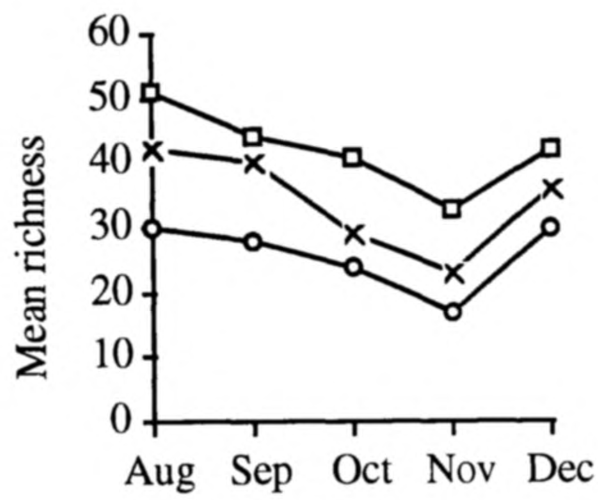
Source	DF	MS	F	P
Covariate				
Month	1	109.18	67.2	< 0.001
Factors				
MPTs	2	44.23	27.3	< 0.001
PCT	1	64.47	39.7	< 0.001
Interactions				
'MPTs x PC1	2	3.08	1.9	0.159
Error	65	1.62		

Table 6.4 ANOVAR table for number of arthropod species on pruned and unpruned trees

Source	DF	MS	F	P
Pruning	1	1198.78	10.31	0.002
Error	89	116.2		

Figure 6.4 Mean and ± S.E. species richness for five months on : (A) pruned and (B) unpruned *G. sepium* (Gs), *L. leucocephala* (Ll), *C. siamea* (Cs) trees

A



B

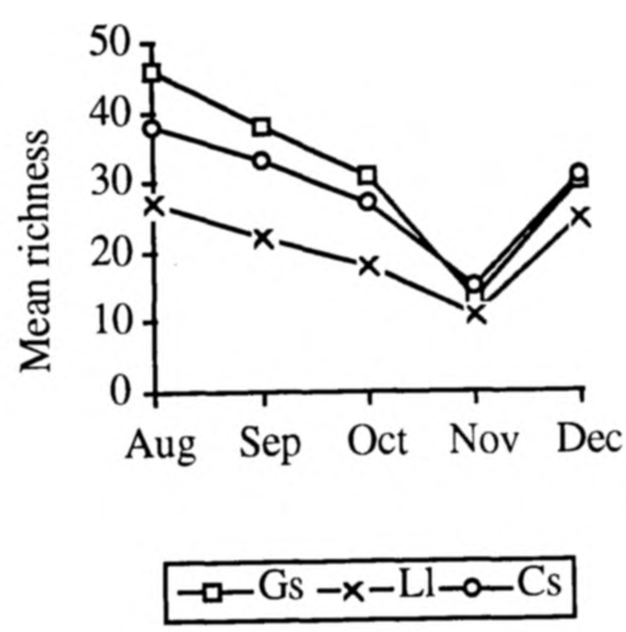
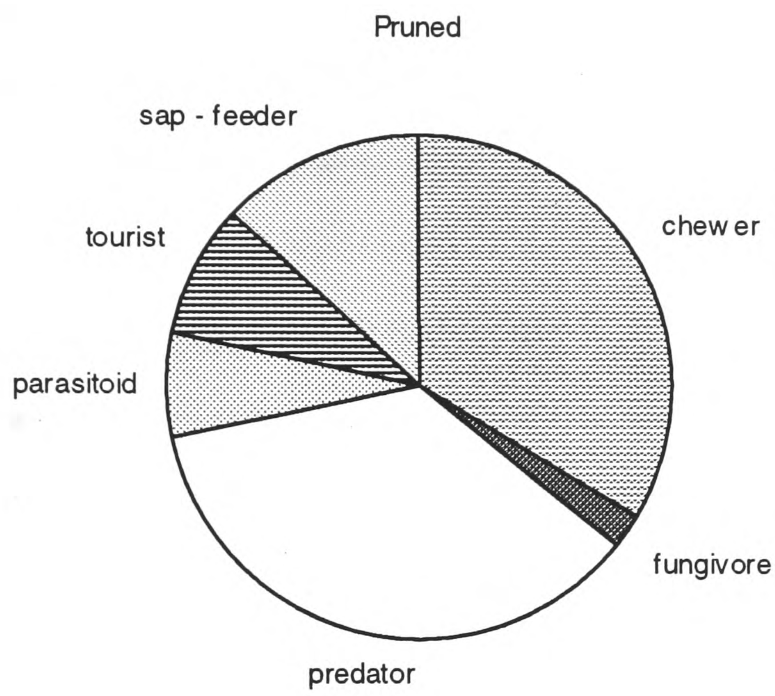
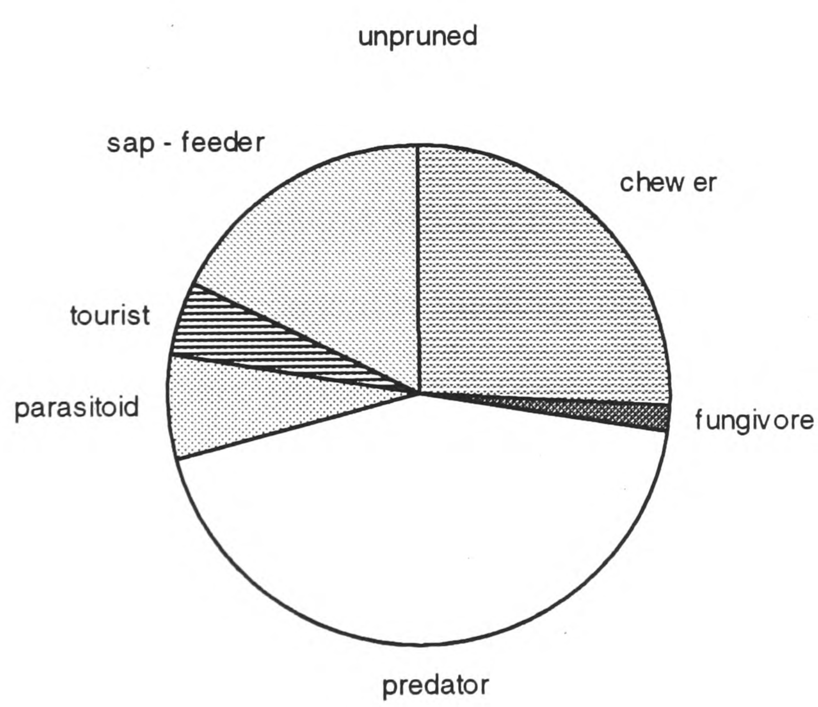


Figure 6.5 Arthropod guilds on pruned and unpruned tree species





6.3 Discussion

This study has demonstrated that pruning affects the nature of the community of arthropods found in tree canopies, not only in terms of abundance but also species richness (Figures 6.1 to 6.4). That the differences in the mean abundance and mean species richness in pruned and unpruned tree species were statistically significant suggests that the pruned trees were more suited for the arthropods as a source of food, shelter and mates. In case of herbivores increased food supply from pruned trees may occur in two ways. Firstly, pruning technically injures plants and this obviously is stressful them. Stressful conditions are known to weaken plant defences against arthropods and also to increase the levels of nutrients (especially nitrogen) available to herbivores (Speight and Wainhouse,1989, Waring & Cobb, 1992, White, 1993). Secondly, pruning may increase plant susceptibility to herbivores through production of young foliage (by enhancing coppicing or flushing): such young leaves tend to be of better food quality (Pullin, 1987). Many other insects have been found to feed preferentially on regrowth foliage. For example Carne (1965) noted that the young foliage of *Eucalyptus blakeyi* is more attractive to sawfly *Perga affinis affinis* as compared to older ones. Webb and Moran (1978) found that the psyllid *Acizzia russellae* may be primarily adapted to flushing growth of *Acacia karoo,* the production of which may enhance its reproduction. Rockwood (1974) reports that *Oedionychus* beetles preferentially feed on regrowth leaves of the tropical tree, *Crescentia elata*, and suggests that the availability of such leaves may be important to beetle survival and reproduction during the rainy season.

In terms of shelter many forest insects are generally known to be attracted to say, drought stressed trees for oviposition, such as wood wasps (Siricidae) (Maden,1971), bark beetles (Scolytidae) (Speight, 1986) and bud -mining Lepidoptera (Foggo, 1992). Though the causal bases of population patterns of the sort observed in the pruned and unpruned trees may be complex, it is reasonable to suppose that increasing the populations of herbivores may lead to a corresponding increase in the numbers if their natural enemies. Similarly, if more insects prefer stressed trees for oviposition, then more egg parasites would be expected on the same trees. Thus through such interactions most insect populations are kept at an equilibrium and below the threshold above which they become economically damaging. Such a phenomenon may explain the low incidence of insect pest outbreaks observed in agroforestry. The fact that regrowth leaves may be of better nutritional value to the insect herbivores raises an important question of whether this applies to the livestock as well, because one important utility of MPTs in agroforestry is as fodder source for the farm animals. It is also not yet known the extent to which increased insect herbivory affects the nutritive value of the MPTs grown for forage. This requires evaluation (Bryant *et al.* 1991).

It may be that on the one hand, pruning will be encouraged to promote fodder production, and on the other hand (from the point of view of insect pest management) pruning raises the possibility that trees are being moulded as reservoirs for many potential pests. It may therefore be necessary to strike some balance between the more beneficial aspects of pruning and the potentially dangerous one. This indeed is very pertinent, especially in semi arid areas such as Machakos, Kenya, where pasture land is very scarce and farmers have to resort to trees grown on their farms as a source of fodder for their livestock. A combination of pruning and the drought stress can make the trees even more vulnerable to pest attack as has been demonstrated by the case of borer (*Xyleutes capensis*) attack on *Cassia siamea* (Chapter 7). It is actually unfortunate that in many tree management decisions pruning has been recommended in complete disregard to its impact on foliage fauna. Many factors may contribute to this bias: (1) There is lack of information regarding the impact of these interactions; (2) the long established norm that pest control measures are taken only at their economic threshold to prevent pest population from reaching the economic - injury level (i.e. the lowest pest density that will cause economic damage, (Hill, 1983): when dealing with trees it is often difficult to quantify losses due to insect attack, and most pest outbreaks are often left to take their own course as the cost of applying any controls would be considered too great; (3) unavailability of certain seeds may force growers to risk the impact from insect attack; (4) apparent lack of animal feed to sustain livestock often leaves the farmer with no alternative other than to prune the trees; and (5) scarcity of agricultural land, on which food crops can be grown, coupled with the need to maintain soil fertility, forces the farmer to grow trees together with the food crops on the same parcel of land, necessitating the need for tree pruning to reduce the shading effect on the crop. Apart from using the trees as fodder, the pruned leaves may be ploughed back into the soil or left as mulch to improve fertility and maintain soil moisture. This is very important because most farmers in semi-arid areas are resource - poor and cannot afford the cost of fertilisers. This fact may illustrate the impact of the economic status of the local people on the ecology of agroforest insects.

It is also interesting to note that other practices in agroforestry may influence the arthropod communities on trees. Tillage operations during the planting and routine weeding of food crops may lead to a constant root disturbance on trees. Root disturbance has been shown to influence feeding of herbivores (Foggo *et al,* 1994) McCullough & Wagner (1987) found that trenching alongside ponderosa pine increased the feeding rate and duration of feeding period of sawflies, whilst decreasing larval survival and final pupal weight of the animals. The extent to which these factors influence the arthropods has yet to emerge as manipulative studies are still needed to further understand how these interactions actually work, and to establish the best ecological approach to this seemingly conflicting outcome of a well established management strategy.

Finally, if pruning indeed favours arthropods on trees, as this study shows, then it would seem beneficial from conservation point of view. Experience has shown that one of the effects of agroforestry has been to deflect people from obtaining fuelwood from natural forests, hence making quite a significant contribution towards conservation of biodiversity. Thus the role of tree pruning is just a subset of the wider role agroforestry plays in conservation. But from pest management point of view, more work is needed to asses the possible effects of increased arthropods numbers as potential pests.

Chapter 7

Pruning stress and the impact of stem borer, *Xyleutes capensis* (Lepidoptera: Cossidae / Cossinae) on *Cassia siamea* Lam. (Leguminosae : Caesalpiniodeae)

7.1 Introduction

The investigations in the previous Chapter has unravelled the consequences pruning has on arthropod communities on MPTs in general. This Chapter proposes to analyse how pruning, as a plant stressing agent, influences the colonisation of *Cassia siamea* by a stem borer.

Cassia siamea is a medium sized, evergreen ornamental tree with a dense crown of foliage and smooth, grey bark, attractive yellow flowers and long pods hanging in clusters. It coppices, produces root suckers vigorously; and is fairly termite - resistant (Webb *et al.,* 1984). It is a native of Southeast Asia but is now widely distributed in Africa and American tropics. It has a variety of uses ranging from producing good firewood to building poles, windbreaks (ICRAF, 1992) and a host for sandalwood (a parasitic tree) in India.

Despite its many uses, it has experienced an increased incidence of both insect and pathogenic attacks in the Machakos area in Kenya (personal observation). The main disease symptoms associated with it are those of powdery mildew which became quite severe during the colder months. A cossid larva (*Xyleutes capensis* Walker) was observed by the author to attack a large proportion of trees within the project area of the present study. The larva bores into the stem (at ground level) and this may lead to dieback - a condition characterised by the gradual dying back of tree branches beginning from the tip (Kolk, 1985, Ikawa, 1993, Foggo (in press))(see Plate 7.1). The attack is normally so serious that most infested trees die. Other insects have also been known to attack *Cassia siamea*. These include Lepidoptera (Pieridae) larvae of *Eurema blanda* Boisduval in Sri - Lanka (Bandara *et al*, 1986) and *Catopsila pomon* Fabricius in China (Gu, 1983); and *Macrotermes* sp. and *Microcerotermes* sp. in West Africa (Sands, 1956).

A casual observation by the author revealed that many previously pruned trees showed greater mortality than trees which were otherwise unpruned. A decision was made to survey the occurrence of *Xyleutes capensis* on pruned and unpruned *Cassia siamea*, and establish whether pruning aggravated the effect of the borer on the trees. Many workers have indeed observed that stress caused by drought, injury or nutrient deficiency makes plants more predisposed to pathogen and insect attack (Speight, 1991; Foggo *et al.*,1994). However the links between stress and increased susceptibility to insects are complex. A simple reduction in sap pressure as a result of canopy defoliation or soil aridity may remove physical defences against borers. Furthermore, physiological changes may evoke senescent characteristics providing a richer source of nutrients for boring herbivores (since there is a greater bulk of tissues and resistance is reduced with ageing) (White, 1984). For example, water stressed plants exhibit increased levels of proline , an amino acid vital for insects (Viera & Silva, 1976). In turn, the reaction of insects to stressed hosts also varies (Larsson, 1989), so that cambium feeders and other borer such as bark and longhorn beetles rely on stressed hosts for successful colonisation, and sap feeding insects perform best in these situations.

Plate 7.1 Photograph of pruned *Cassia siamea* showing die - back and powdery mildew conditions

7.2 Method

During September, 1991, a plot of *Cassia siamea* was surveyed to determine the extent to which the trees have been affected by the borer. The trees were planted in alleys. A total of 400 trees was examined in two plots of two hundred trees each. One of the plots comprised pruned trees while on the other they were unpruned. They were planted on ten rows each with 10 plants. All the ten rows were selected in each plot (pruned; unpruned). Trees were categorised as flush, wilted or dead. The various categories used to classify the state of the foliage are described in Table 7.1. Each tree was examined in detail for any evidence for the presence or absence of stem borer. The base of the tree was particularly critical for examination because the exit holes for the borer were mainly located here, as evidenced by the presence of the exuviea. Some of the dead trees were split at the base to reveal massive internal tunnelling by the borers. In many cases pupae and larvae were recovered.

The density of the borers was estimated by counting the exit holes per tree and correlating this with the condition of the foliage.

7.3 Results

7.3.1 State of foliage (tree status)as an indicator of effect of pruning on borer impact

The state of health of the trees (status) showed some correlation with borer presence and pruning (Figures 7.1 and 7.2). In general, the vigour of the tree is affected by pruning: there were more trees that were vigorous and unpruned than vigorous and pruned. So, there were many more unpruned trees with good foliage than pruned trees with good foliage (see Af, Figure 7.1), and many more pruned trees than unpruned trees were wilted or were dead (see Aw, Ad, Figure 7.1). Tree mortality was generally higher in trees which had been pruned and subsequently attacked by the stem borer

(Bd). In both the pruned and unpruned trees, some mortality was observed even though there was no evidence of borer attack. The levels were however very low (1% for unpruned and 2 % pruned, Figure 7.2).

The proportions of trees showing the presence *X. capensis* differed markedly between pruned and unpruned trees. Of the 200 pruned trees sampled, up to 90% were affected by the borer as compared to 31.5 % of the unpruned trees. Chi - square test showed the effect of tree pruning on borer invasion of the trees to be highly significant (Chi - squared = 158.42 with 3 d.f., $P < 0.001$, Table 7.2). In some of the trees with borer, the leaves were still flush and these accounted for 18 % and 17 % of healthy trees in pruned and unpruned trees respectively. But the trees which had been pruned showed an increased stress (as revealed by wilted and dead foliage) compared to the unpruned ones. Also the proportion of trees which showed signs of wilting was greatest among the pruned trees (see Bw 30 %) in contrast to the unpruned ones (see Bw 13%) (Figure 7.2).

7.3 2 Relationship between exit holes, tree status, pruning and borer impact

Figure 7.3 shows that the number of dead trees was highest amongst those with high number of exit holes. Trees which were flush had the least number of exit holes per tree, with wilted in between. These differences were found to be statistically significant ($P < 0.05$. Table 7.4). In all the categories of tree status, the number of exit holes was higher on pruned than on unpruned trees (Figure 7.4). Analysis of variance also showed a significant effect of pruning / not pruning on the number of exit holes (Table 7.4). There were more exit holes in pruned than unpruned trees However these differences were not statistically significant ($P < 0.05$, Table 7.3). A further analysis showed the interaction between pruning and number of exit holes (borer) density was significant (Table 7.5).

Table 7.1 Classification of foliage of *Cassia siamea* in stands of pruned and unpruned trees

Category	Description
Af	borer absent / foliage flush
Aw	borer absent / foliage wilted
Ad	borer absent / foliage dead
Bf	borer present / foliage flush
Bw	borer present / foliage wilted
Bd	borer present / foliage dead

NB. Some of the plants without borers apparently died from other causes

Figure 7.1 Number of trees of *C. siamea* showing various impacts of *X. capensis* on depending on whether a tree was pruned or not

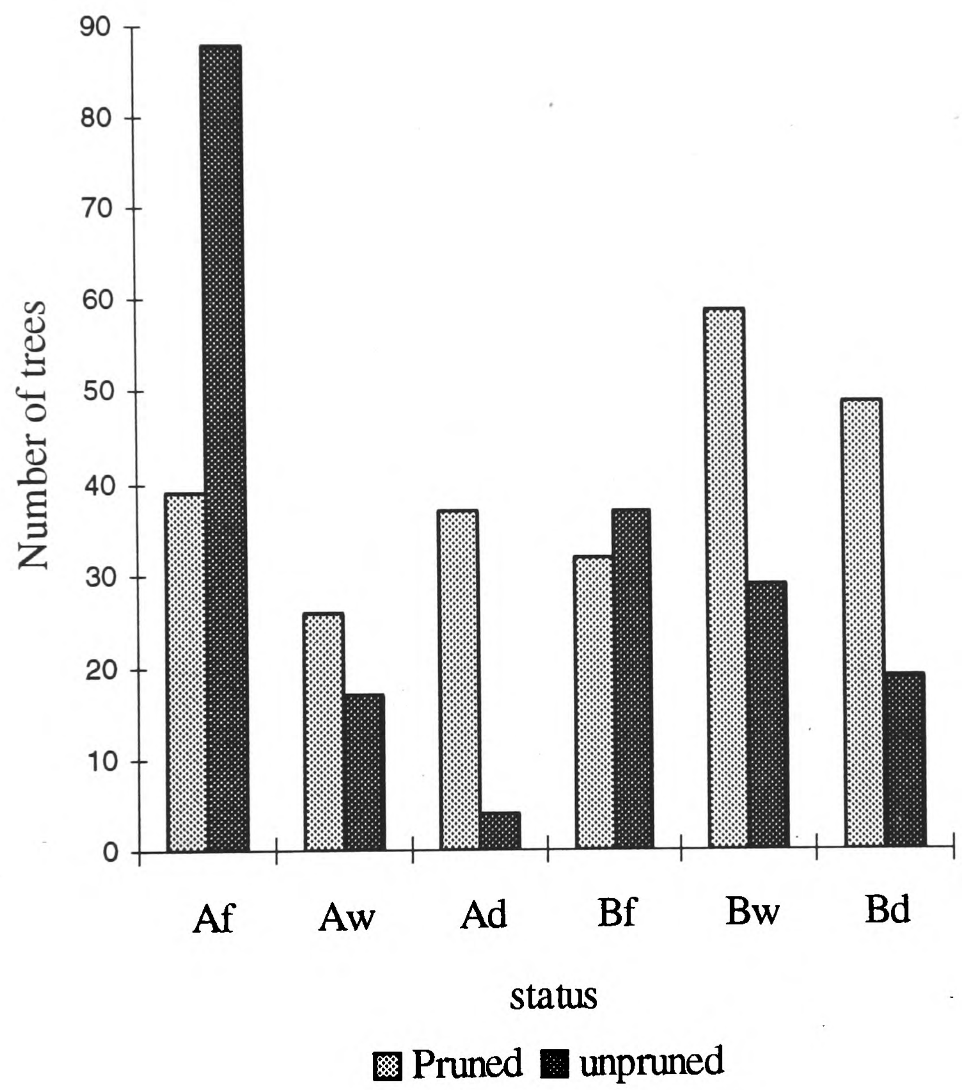
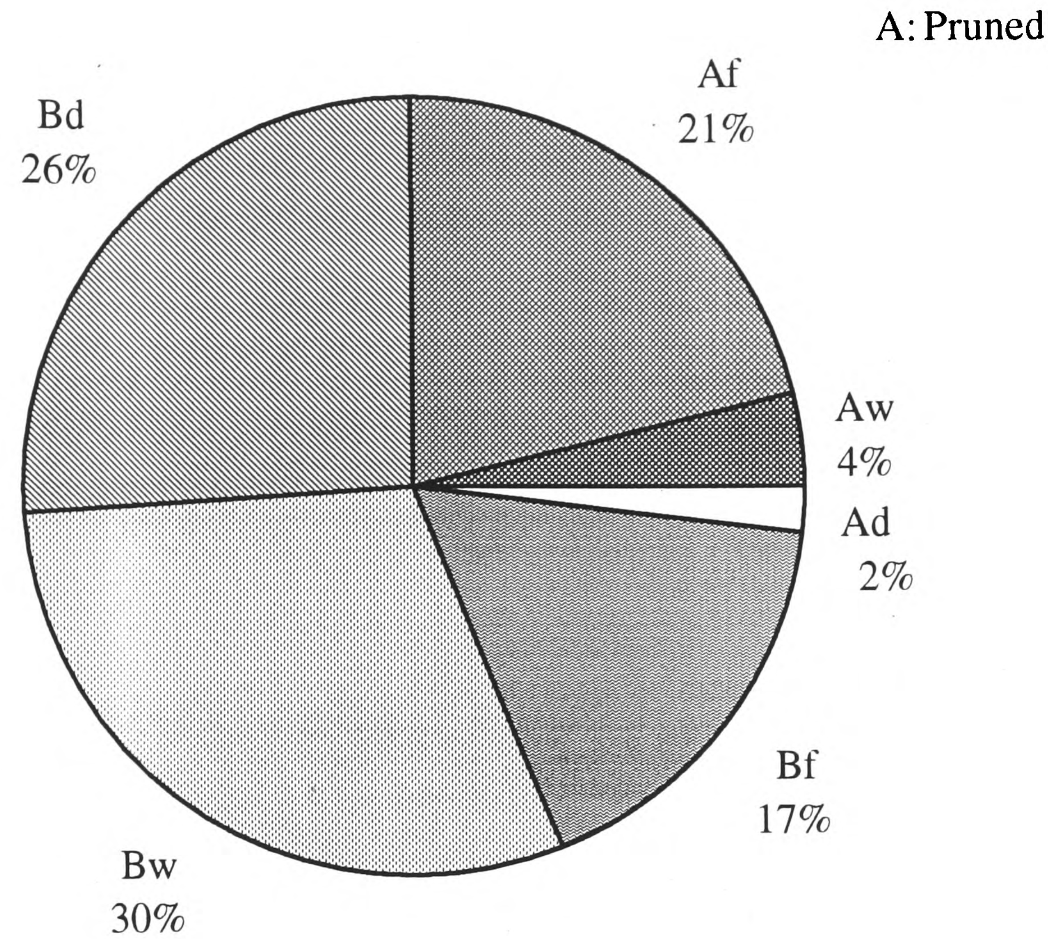


Figure 7.2 Proportions of *C. siamea* trees showing various degrees of foliage conditions in reletion to presence or absence of borer in A:pruned trees and B: unpruned trees. (A / Bd, A /Bf, A /Bw denotes absence /presence of borer with leaves being dead, flush or wilted respectively, see also Table 7.1)



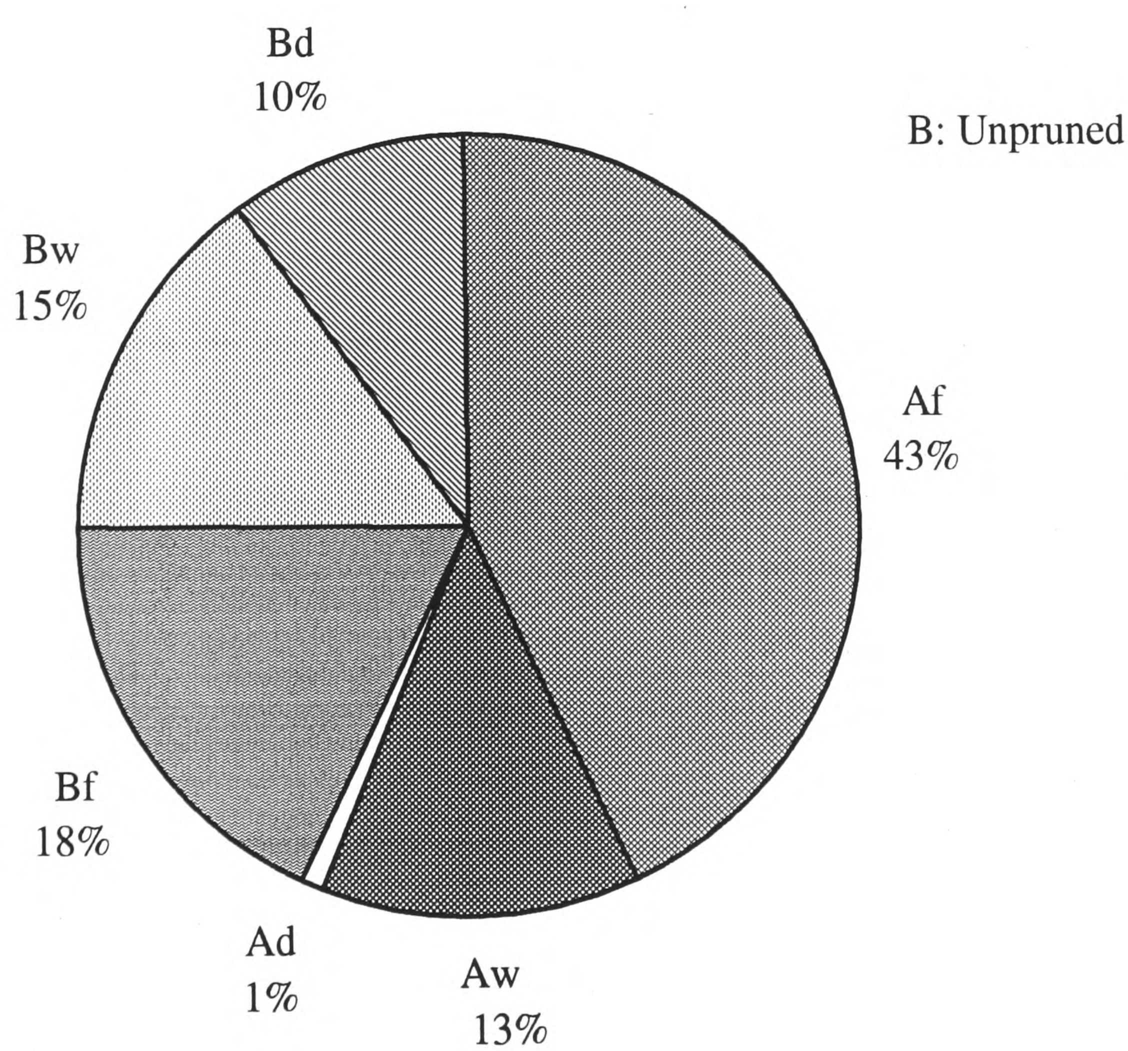


Table 7.2 Chi - square test to investigate the effect of pruning on the invasion of *X. capensis* on standing trees of *C. siamea*

Category	Presence of borer	Absence of borer	Total
Pruned	180	20	200
Unpruned	61	139	200
Total	241	159	400

Chi - squared = 158.42 with 3 d. f. , $P < 0.001$

Figure 7.3 Mean and ± S.E. for number of exit holes of *X. capensis* on *C. siamea* trees depending on the status of the foliage. Difference between means statistically significant (ANOVAR, $P < 0.05$, $n = 6$)

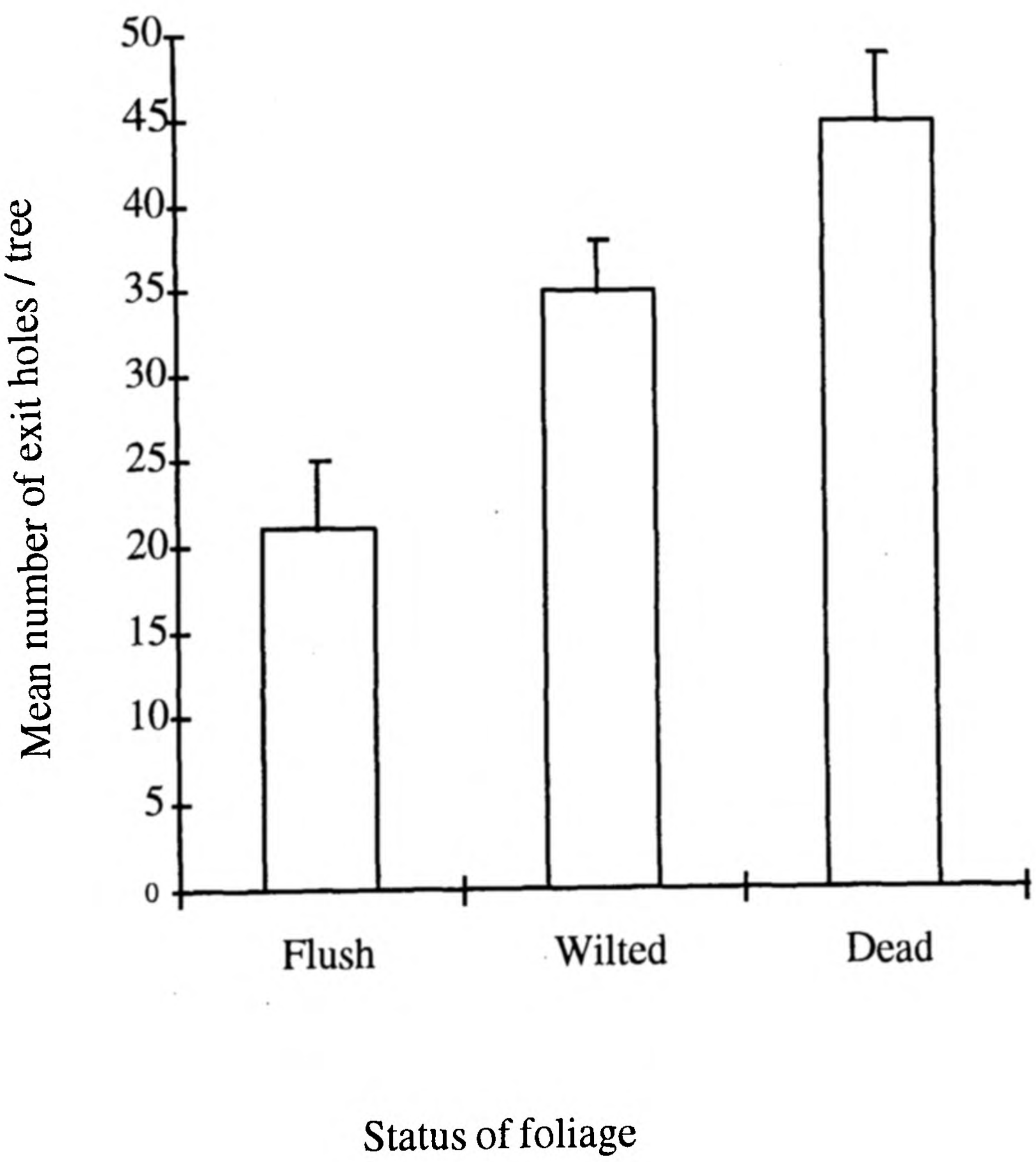
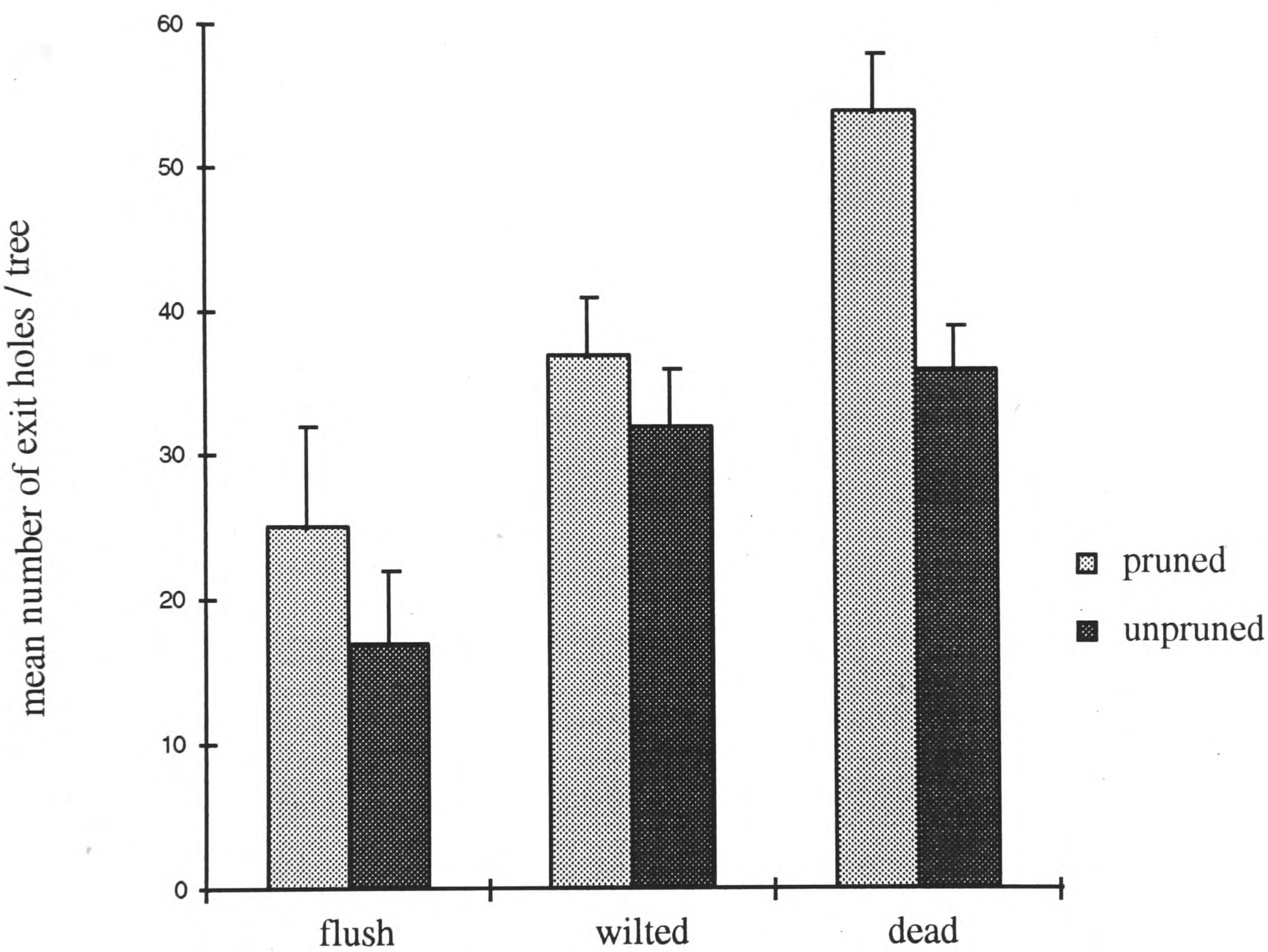


Table 7.3 ANOVA table for mean number of exit holes of *X. capensis* on flushed, dead,or wilted trees (status) (*C. siamea*)

Source	DF	MS	F	P
Status	2	856.06	9.906	< 0.05
Error	15	86.42		

Figure 7.4 Mean and ± S.E. number of exit holes on pruned and unpruned *C. siamea* trees depending on foliage status (ANOVAR, $n = 6$, $P < 0.05$)



7.3 Discussion

The above findings show that pruning not only influences the number of borers on the trees but also the response of trees to borer presence (Figures 7.1 to 7.4). As the results indicate, the higher number of borers (as evidenced by the exit holes) were likely to be associated with the pruned trees than with the unpruned trees. While it is true that unpruned trees without the borers also died, mortality was evidently higher in pruned trees.

How can these observations be explained? Firstly, there is the question of physiological changes occurring in the host plant due to stress, and secondly whether such changes can alter the feeding conditions for the borers (Larsson, 1989). Most studies have dealt largely with the effect of environmental factors such as weather in causing stress on plants, but little attention has been paid to physical injury as a source of stress. In order to explain pruning effects, we may suppose that pruning is stressful. However, since plants may not respond in similar ways to different types of stress, we must be cautious when generalising plant responses to different types of stress. Because of the observation that: (1) there is wilting and death of plants associated with borer; (2) pruning would seem stressful; (3) others have shown that stress increases susceptibility to diseases and pests (White, 1993); (4) there more borers in pruned than unpruned tree; (5) there is a relationship between pruning and status; it may be concluded that pruning as a stress increase the likelihood of borer attack The critical stage for the borers is the colonisation of the host tree. As the level of stress increases, more borers are able to colonise the tree (colonisation is regarded as a sign) (see Figure 7.4). Mullock and Christiansen (1986) observed that colonisation success for naturally occurring bark beetles increased when the trees were under stress. Borers, like bark beetles, are unique among herbivores in that they depend upon a food source that is normally resistant (Raffa, 1988), and environmental stress therefore renders trees less resistant (Sommers, 1986, Ferrell, 1978)

Due to a relatively high water stress in Machakos, some of the trees showed signs of wilting and death although they did not have borers. In these cases borer attack was not the proximate cause of death. From this result emphasis is to be laid upon two predisposing factors, namely drought and pruning, which make the plants more vulnerable to borer and fungal attacks leading eventually to death of the tree. It is, however, not possible to say with certainty whether the observed correlation between stress of the plant and borer attack is due to changes in plant physiology or general condition(Meyers, 1988).

The devastation caused to *C.siamea* by the larvae of *X. capensis* in the Machakos area was massive. Its impact has been to reduce the amount of *C. siamea* planted in this area. This case has demonstrated the kind of problem which can arise if the main criterion used in tree species selection is based solely on a few beneficial aspects. In agroforestry a lot of attention has been directed at the multiplicity of uses and fast growth rate of particular tree species, without much consideration to site suitability or impact of pests and diseases. *Cassia siamea* evidently may not have been suited for planting in the Machakos area because it is less drought tolerant (see Webb *et al*, 1984). Trees of low vigour show poor growth and low energy reserves, and hence are unlikely to defend themselves against exploitation by insects.

Chapter 8

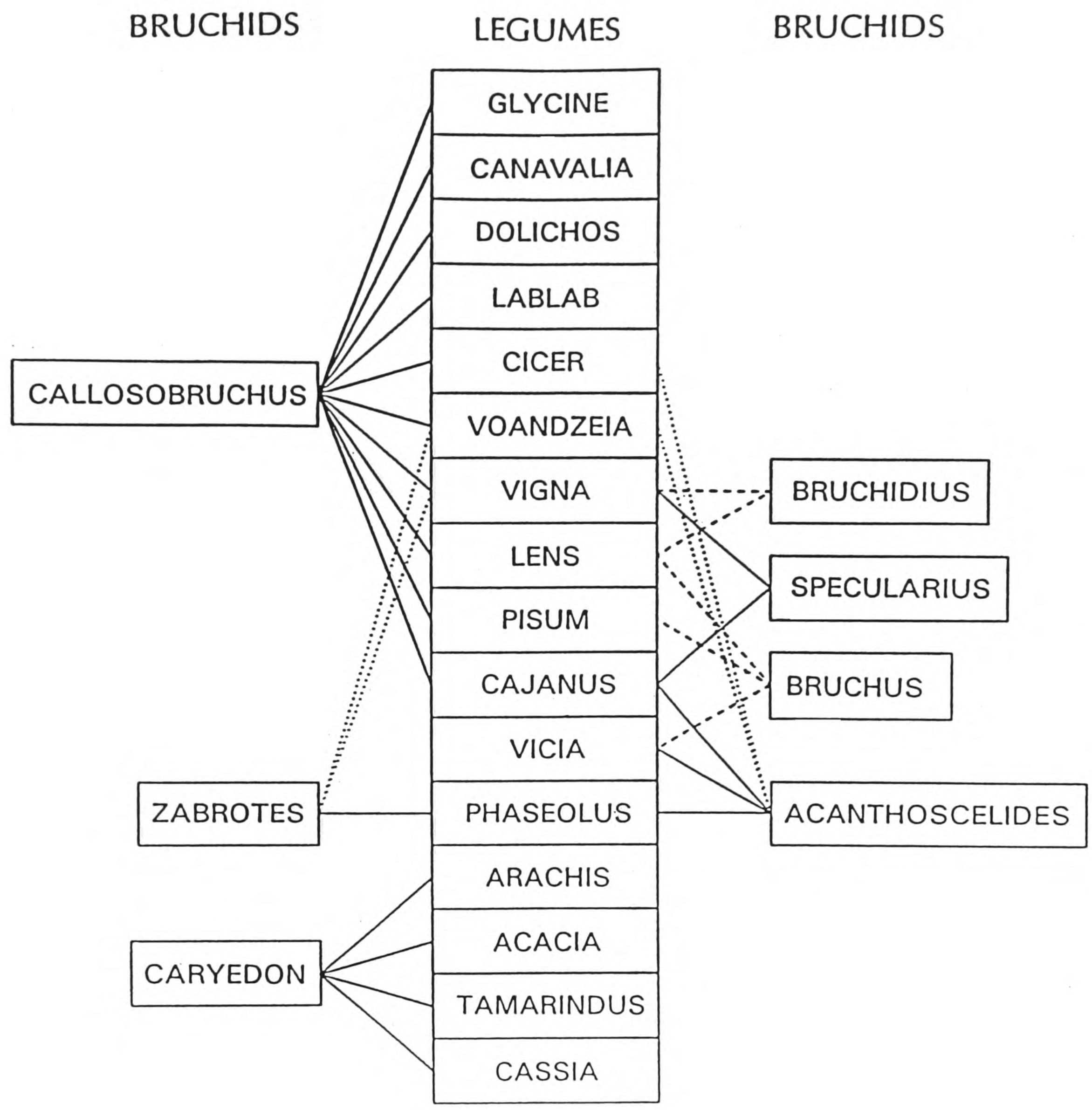
Survival of *Callosobruchus chinensis* Linnaeus (Coleoptera: Bruchidae) on seeds of three MPTs. (*L. leucocephala*, *Gliricidia sepium*, *Cassia siamea*) and *Cajanus cajan*.

8.1. Introduction

Multipurpose tree species and food crops studied in this project shared 14 % of the arthropod species associated with them (Chapter 4). This Chapter investigates a storage - seed feeding beetle, *C. chinensis* (Bruchidae) associated with *Cajanus cajan* and some of the MPTs in the field (see Appendix 2). The Bruchidae is a cosmopolitan family of chrysomeloid beetles comprising more than 1300 species (Southgate, 1979). The larvae of these beetles develop in the seeds of plants, mainly legumes (Table 8.1), and a number are widespread pests having been transported in the seed of grain legumes to many countries. Many species have obvious economic importance. For example, the species *Callosobruchus chinensis* commonly known as adzuki beanseed beetle is a major economic pest. It originated in Asia but is now cosmopolitan in the tropics and subtropics. It usually infests seeds of pigeon peas (*Cajanus cajan*) (Plate 8.1), chickpeas (*Cicer arietinum*), lentils (*Lens culinaris*) and cowpeas (*Vigna unguiculata*), but appears to be incapable of developing in common beans (*Phaseolus vulgaris)* (M.L. Cox personal communication). Other species, however, destroy seeds of an immense number of leguminous trees and shrubs, which though they have no obvious economic value, stem the advance of the deserts into the marginal cultivated areas of the world. When this ecosystem in mismanaged by practices such as overgrazing, then any organism that restricts the normal regeneration of seedlings will, in the long run, affect agriculture adversely (Lamprey *et al.*, 1974).The present interest in the management of arid areas and the introduction of alternative tree species to provide timber, fodder, or shade has stimulated a detailed study of the ecology of some leguminous trees and shrubs that has revealed some deleterious effects of bruchid beetles on the seeds of these plants (Coe & Coe, 1987, Dinerstein & Wemmer, 1988).

During routine sampling in the field several bruchids individuals of *Callosobruchus chinensis* appeared in the samples. It was therefore decided to rear these in the seeds of other MPTs grown at the field station to determine the possibility of these tree species acting as an alternative host to this bruchid in the absence of its known host.

Table 8.1 Relationships between major bruchid genera and legume genera*



*Haines, 1991 (Source)

8.2 Life history of *C. chinensis*

The adult beetles do not feed on stored produce and are short - lived. The females may lay up to 70 eggs under optimum conditions. The optimum temperature for oviposition is about 23°C. As the eggs are laid, they are firmly glued to the surface of the host seeds (Plate 8.1) and the eggs hatch within 5 - 6 days of oviposition . At hatching, the larva bites through the base of the egg, through the testa of the seed and into the cotyledons. The developing larva feeds entirely within a single seed, excavating a chamber within the cotyledons as it grows. The optimum conditions for developing are around 32°C and 90 % R.H. and the minimum development period is very short (22 - 23 days) (Haines, 1991).

Infestation commonly begins in the field where eggs are laid on seeds of maturing pods. As pods dry the pest's ability to infest them decreases. Thus, dry seeds still in their pods are quite resistant to attack, whereas the threshed seeds are susceptible to attack throughout storage.

8.3 Methods

In October 1991, a colony of beetles (*C. chinensis*) were reared on stored seeds of pigeon pea, *Cajanus Cajun* (their preferred host) at ICRAF field station, Machakos, Kenya. After boosting the colony, the infested seeds were securely sealed and transported to Oxford where this experiment was carried out. Some of the beetles were sent to the British Museum of Natural History in London where their identity was confirmed

During December 1991, the experiment was set up by exposing the beetles to the seeds of *L. leucocephala, G. sepium, C. cassia* and *C. cajan* under controlled the laboratory conditions. Beetles were placed in emergence boxes measuring 21 cm by 10 cm by 7 cm containing 50 seeds of each of the MPTs and pigeon pea. The boxes were then placed in the incubator at 21 ± 1°C and R.H. 50 - 60 %. Seeds of *C. cajan* were used as control. There were three replicates for each of the MPTs. The boxes were checked daily and the number of emerging beetles (if any) was tallied.

8.4. Results

Figure 8.1 and Table 8.2 shows that the beetles were able to oviposit on seeds of the three tree species as well as those of *C. cajan* but the mean number of eggs was much lower on the tree seeds. Table 8.3 shows that emergence holes were present only on the seeds of *C. cajan*. No emergence holes were present on the seeds of *L. leucocephala*, *G. sepium* or *C. siamea* (Plate 8.2). The differences between seeds of *C. cajan* and the seeds of the other three plant species in the mean number of eggs laid per seed was highly significant statistically.

Plate 8.1 Photograph showing infestation of *Cajanus cajan* by *Callosobruchus chinensis*

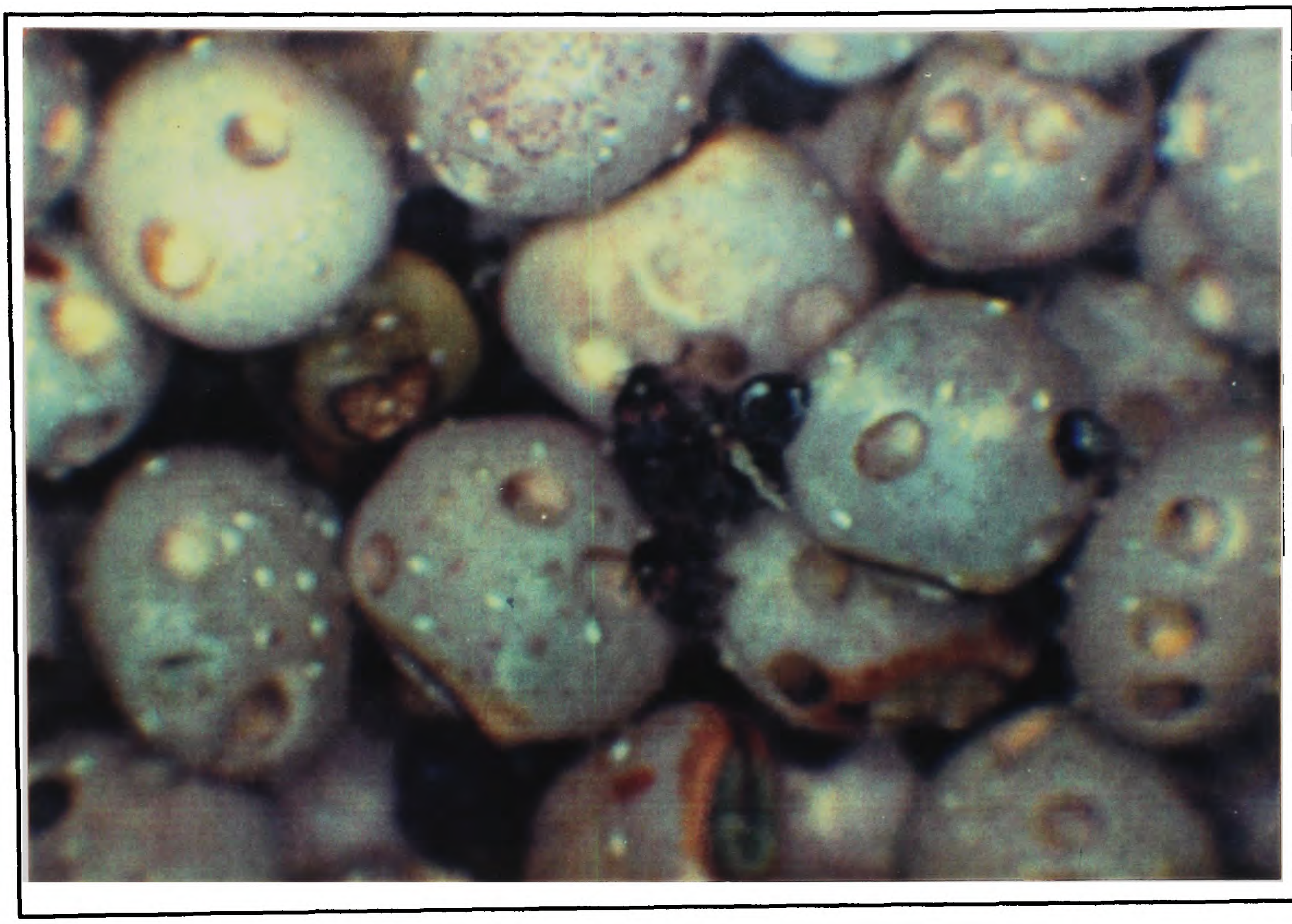


Plate 8.2 Photograph comparing eggs and exit holes of *C. chinensis* on seeds of MPTs and C. cajan. Numbers in red shows: (1) *L. leucocephala*, (2) *G. sepium* and (3) *C. siamea* with sparsely distributed eggs and no holes eggs, and (4) *C. cajan* densely placed eggs and exit holes

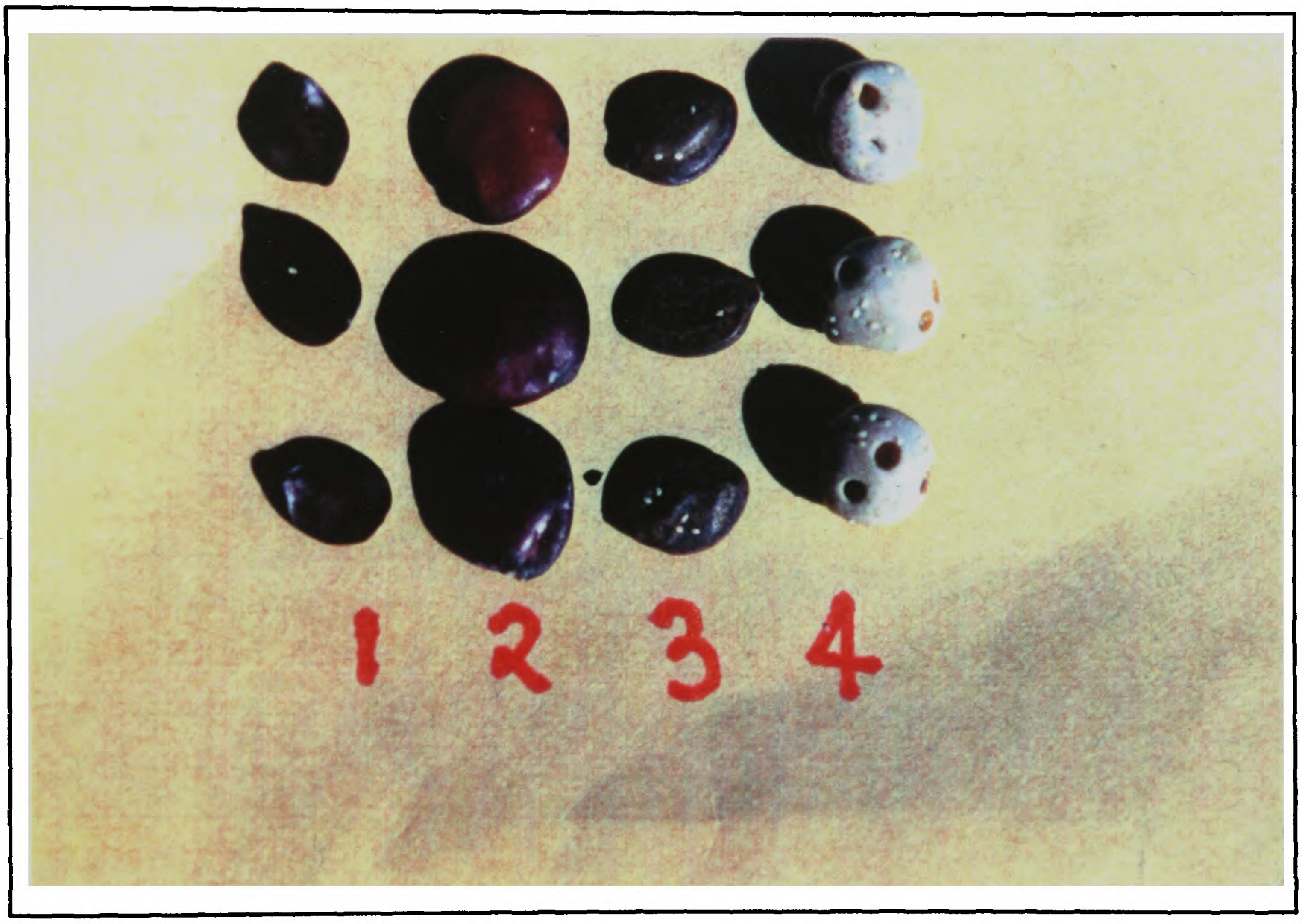


Table 8.2 Table of mean, S.E., S.D. and range for the number of eggs laid on seeds of various MPTs and pigeon peas (*Cajanus cajan*)

Plant species	N	mean	S.E	S.D	Range
C. cajan	50	16.6	0.77	5.36	23
C. siamea	50	1.7	0.18	1.27	5
G. sepium	50	0.1	0.04	0.28	1
L. leucocephala	50	0.2	0.07	0.46	2

Table 8.3 Table of mean, S.E., S.D., and range for the number of emergence holes om MPTs and *C. cajanus*

Plant species	N	mean	S.E	S.D	Range
C. cajan	50	5.8	0.27	1.89	8
C. siamea	50	0	0	0	0
G. sepium	50	0	0	0	0
L. leucocephala	50	0	0	0	0

8.5. Discussion

It is apparent from the results that although the bruchids were able to oviposit on both the seeds of *C. cajan* and MPTs, the seeds of the MPTs were unable to sustain the larval development as evidenced by the fact there was no emergence from them. This result is hardly surprising as published data on oviposition tactics of bruchids (Johnson, 1981a) show that some of the species (for example *Stator vachelliae*) will rarely oviposit upon non - host seeds and develop in even fewer (Johnson, 1981, b1984). *Callosobruchus chinensis* has five main hosts which are food crops (Table 8.1) although Haines(1991), reported the inability of *C. chinensis* to develop other food crops such as in the seeds of *Phaseolus vulgaris* (common bean). This deferential feeding habit exhibited by many bruchids may be due to several factors. Firstly, there are ecological factors (Smiley & Wisdom, 1985), and secondly physiological restrictions imposed by plant chemistry (Gilbert, 1979) which influences ovipositional behaviour. Ecological factors which may be encountered include competition and the presence of natural enemies.(Siemen *et al.*, 1991). Due to the fact that there were no potential competitors, the ecological explanation can be ruled out. Therefore physiological explanation remains the only feasible one for the results obtained here. It may be that females select seeds which are suitable (in terms of size and nutritive value) for the larval development. Indeed the seeds of MPTs are lighter and smaller than those of *V. unguiculata* and therefore may not be suitable for larval development. For this reason, the number of eggs laid on them was fewer (Table 8.2). Mitchell (1975) found that females of *C. maculatus* would preferentially lay eggs on larger seeds which presumably would support larval development. This finding may give an explanation for higher number of eggs on *C. caj*an compared to the MPTs in general. This result agrees with the findings of other workers (Avidov *et al.,* 1965a, b, Booker, 1967, Jakhmola & Singh, 1971) that the bruchid beetles are general known to be selective in the species and size of bean on which they place eggs.

The findings are probably good news for agroforestry in that problem of seed eaters (bruchids) on the pulses may not be aggravated by the growing of leguminous trees within the system. However, the fact that the bruchids are able to lay eggs on the tree seeds at all still carries a risk factor if, under field conditions, even only a few are able to complete their development. Most of the bruchid species have been able to generate exceedingly high levels of infestation even when only one, or the most, two generations were passed on the host. Seed destruction is of obvious importance for the survival of a plant species, especially where seedlings are subjected to severe climatic stresses (in the study site there is water stress) and trampling by animals. Although seed destruction and seedling survival are two different problems, economically they become related: seedling mortality added to seed destruction (in circumstances where seedling mortality is likely to be high) would clearly affect adversely the plant population. I suggest that this study should be followed by a field study to measure the effect of bruchids on germination or subsequent survival of seedlings for agroforestry species, as so far there are no data on this. Some investigations have been done particularly on *Acacia radian*a, *Acacia gerrardii* subsp. *negevensis*, and *Acacia tort*ilis by Halevy (1974), and these showed that a very small proportion of infected seeds germinate in spite of damage to the cotyledons. For example, *A. gerrardii* had a 64% infestation and 6% germinated, and in *A. raddiana* 72% were infested and 1% germinated. Seeds such as some *Acacia* spp. that have a hard, water-resistant testa and need to pass through the gut of herbivore, or subjected to fire or scarification, may benefit from the boring of the first stage larva. The entry hole of the larva would allow the ingress of water and a little damage to the cotyledon would not hamper germination seriously, provided the seed was not exposed to micro-organism for too long a period (Miller, 1994).

Chapter 9

General Discussion

During the past decade or so environmental degradation and biodiversity conservation issues have become a major concern to conservationists, ecologists, administrators and even to politicians (McNeely *et al.*, 1990, Groombridge, 1992, Wilson, 1992). In many tropical countries, one way through which this environmental degradation has taken place is the encroachment of local people into forested areas for firewood and farmlands (Bennett, 1992, ICRAF, 1994).This problem of destruction of forested areas has been tackled from two angles in some countries. Firstly, in Kenya for example, certain forest lands have been designated as "protected areas" (seeAppendix III). Secondly, the large scale encouragement to farmers to adopt agroforestry (Nair, 1984), witnessed in these countries over the past decade, was partly aimed at reducing over - dependence on forests for fuel wood by rural farmers, thus reducing pressure on forests. However, the introduction of the woody plants into the intensely cultivated lands was bound to have some impacts, particularly on arthropod communities within these systems due to altered micro - climate (Altieri, *et al.*, 1987). The woody plant components, being in general perennial, tend to build up their arthropod populations more than annual crops as years go by. The observation in this study (see Chapter 4) that there is a greater abundance of arthropod on tree species compared to three crops studied here strengthens this view.

For a very long time it was clear to both field workers and researchers that pest problems in agroforestry are a reality that everyone in the field has to contend with sooner rather than later. As in most cases of insect pest outbreaks, spraying insecticides is often the immediate recourse to save the plants. For example this was the case when *Mesoplatys ochroptera* and *Macropulvinaria inopheron* attacked *Sesbania sesban* and *Calliandra calothyrsus* respectively in western Kenya during the late 1980s (personal observation, Kaudia, 1990). It is envisaged that for agroforestry to positively contribute towards conservation into the next century, it may be appropriate for alternative methods of control to be adopted. In order to work out these alternative methods of control in dealing with insect pests, it was first necessary to have some knowledge of the types of arthropod communities on the canopies of plant species used in agroforestry. In addition, their behaviour, reproduction, feeding habits, host range and the impact on their hosts must be known. These considerations gave birth to the objectives of this thesis.

The first step was to establish a sampling technique for the arthropods from the tree canopies. Most sampling techniques available were designed for use either in forestry or agriculture. Although agroforestry is more or less similar to other agroecosystems in the early stages in that both are immature production systems, it could not be assumed that the same sampling techniques for arthropods could be used in both. This is because the plant canopy strata in agroforestry are different from those of agriculture and forestry systems. It was therefore necessary to evaluate various sampling techniques for arthropods from tree foliage so that the most appropriate one could be selected. Insecticidal knockdown spraying was adjudged the best as it sampled more arthropods on a per unit basis as compared to either the handsearch, and sweep net (see Chapter 2). However, its limitations in terms of environmental "friendliness" remains a major concern.

Finding an appropriate sampling technique was the key to working out what types of arthropods in general, are found on some agroforestry tree species. Using the chemical knockdown technique it has been possible to show that agroforestry, like adjacent forestry and agriculture, harbours all the major taxonomic groups of arthropods. Some of these are likely to be pests while others may be beneficial. In all 10 arthropod Orders, representing 48 Families and 92 species, were collected. They could be placed into various guilds: herbivores (sap - feeders and chewers), parasitoids, predators, fungivores, detrivores, and tourists (Appendix 1). Analysis showed that 27 arthropod species were unique to the tree species (MPTs), 3 species to the crops, and 19 species were shared between all the plant species (Appendix II). On the basis of this evidence, it is reasonable to assert that the shared insects, if they were pests, could present very serious problems to farmers, considering that most of the plants used in this study were legumes (with the exception *Zea mays*). It is also reasonable to suppose that some of the insect species, though at present not shared between the crops and the tree species, might under field conditions, switch over from one food source to another. The switch - over trait in herbivory is not a new one. Tindale (1928) demonstrated a switch - over to occur in the genus *Chlenias* (Geometridae) from *Acacia* to cultivated *Pinus* in South Australia.

Although this study has shown the complexity of arthropod interactions in agroforestry, there is no evidence as yet to suggest that the pest picture in agroforests is more or less alarming than in other agro - ecosystems. Evidence from di - and poly - cultural systems of agriculture does indicate lessening severity (Trenbath, 1975; Baliddawa, 1983). This can help us to deduce that there is an increased niche availability, due to diversity and complexity of plant species in agroforestry which may enhance, in various ways, the activity of biological control agents. However, biological control is often slow in regulating pest outbreaks, and at present there is a tendency towards the integration of all suitable control techniques including chemical control methods, to suppress insect pest populations to economically tolerable levels (van den Bosch *et al.*, 1971, Smith *et al.,* 1976). Farmers often resort to the use of pesticide as matter of expediency as most of the methods are often too slow to protect the crops sufficiently. However, there are intrinsic problems associated with the use of insecticides. On the one hand, there are problems due to toxicity, and on the other hand there are those associated with the adoption of the technology of chemical control techniques developed and perfected under generally immature monocultural systems of agriculture, for use in agroforestry systems whose configurations are temporally more diverse, including problems related to production cycles (Epila, 1986). The cost of chemical control would also inevitably reduce the economic benefits to the farmer whatever the use of the tree species.

The other problem associated with pest control in agroforestry (especially with woody components) is the determination of the economic threshold. Unlike the food crops, economic impacts of pests on the yields of woody components have not been studied in any detail. In the present study, it has been shown that experimental defoliation can have a serious impact on the growth of *G. sepium*, *C. siamea*, *L .leucocephala* and *C. calothyrsus* (Chapter 5). There is still a need to elucidate how these biological losses translate economically (Nair *et al.*, 1984). The data gathered in this study on *Cassia siamea* interacting with a stem borer, *Xyleutes capensis* also has demonstrated that the impact of stem borers can be very serious as many affected trees die, leading to total economic loss to the farmer. A further likely impact of the borer is the discontinuation of planting such vulnerable tree species in areas where there is a higher risk of attack by borers.

The impact of seed borers (Bruchidae) on woody perennials has been studied extensively particularly those associated with two genera *Prosopis* and *Acacia* (Singh & Bhandari, 1986). Of all known bruchid hosts, 84 % are in the leguminosea, and their impact on these pod bearing tropical species is greater than any other insect group (Southgate *et al*, 1989). Economic losses due to these bruchids has been estimated at 95 % for *Ateleia herbert - smithii* in Costa Rica (Johnson, 1984) and 90 % for

Prosopis chilensis (de Arruda, *et al.*,1990). In the present study, however, the pulse seed borer, *Callosobruchus chinensis* (Bruchidae), has been shown to be unable to develop in the seeds of MPTs, further underlying its host specificity.

From this study, one overiding recommendation can be made: There is still an overwhelming need for further research on insect diversity, their patterns of abundance and the threshold (or economic injury level) at which their ravages are economically damaging. Such investigations should cover both pestiferous and beneficial insects for a whole range of MPTs. This research should be integrated with the farmers traditional knowledge of pests in their systems (Rocheleau and Malaret, 1987) to decide on suitable combinations of plant species.

The choice of species and cropping patterns will, however, largely depend on the objective of, and overall benefit to, the agroforestry system. Nevertheless, the choice of tree and crop species for any agroforestry system must ensure entomological compatibility between woody and crop plants before introduction (Verma and Palmer, 1988). Some trade - offs between agronomic advantages and entomological disadvantages are inevitable (Norton, 1975). If the purpose of the intercropped tree species is to provide feed for livestock or manure for other plants, the benefit of improved soil fertility and resultant crop yields (Dreyfus *et al*, 1985), gains in livestock weights (van Eys *et al.*, 1986), or increased milk production (Shrestha and Pakrin, 1989) might outweigh the cost of pest control. This will apply provided that the insecticides are selected which have a low toxicity for mammals and other non - target biota, and low persistence in the foliage. On the other hand, if the tree species are to be used mainly for shade or windbreaks, then selection of plant species which do not exacerbate the pest situation would obviously be ideal.

Additional Recommendations

Interactions whereby many pests are shared between various host plants have been demonstrated to be uncommon in the crops and trees used in this study because of the dissimilarity of the species involved. However some exceptions have been observed with polyphagous pests such as *Lagria villosa* (Coleoptera: Tenebrinidae), *Aphis cracivora* (Homoptera: Aphididae) which were found to be common both on the MPT, wild plant species and food crops. These types of pests pose the most serious threat to the growing of trees and crops together in an agroforestry set up.

This study investigated arthropods on three MPTs. The results indicated that *G. sepium* had a higher number of herbivores (chewers and sap - feeders) than either *L. leucocephala* or *C. siamea.* On this basis, the growing of *G. sepium* in Machakos may not be advisable. *C. siamea*, which although has a relatively low numbers of herbivores, has been devastated by the stem borer (*X. capensis)* and therefore is an unsuitable species for this locality. This leaves *L. leucocephala* to be the most recommendable tree species for Machakos in terms of a lower susceptibility to insect herbivores. However, the recent world wide spread of its most serious pest, the leucaena psyllid (*Heteropsylla cubana*) may render its suitability short lived.

Some of these susceptible tree species may still be planted if the pestiferous insects can be controlled by the moderate use of insecticides. However this course can only be resorted to if the overall utility of the tree species in question can supersede the dangers posed by the pesticide application. In agroforestry trees, the use of pesticides is not recommendable as these trees are often fed to cattle directly. Furthermore, the use of pesticide in this area may not be advocated for the simple reason that there is the likelyhood of the chemicals being washed into the nearby river which serves as the main water source for domestic consumption for the inhabitants in this locality. Due to a relatively high number of predotors observed in this study, their use as biological control agents should be explored as an alternative to chemical control.

In this study, I investigated in detail how pruning affects insect herbivores and other arthropods. A recommendation arising from this is that pruning should be limited as it is likely to exacerbate pest problems by increasing plant stress especially in semi - arid lands such as Machakos. Alternatively, increased spacing between trees and food crops should be adapted if that could help in reducing the need for exessive tree pruning to minimise the effects shading on the crop.

In conclusion, it can be noted that economic injury level or threshold is a relatively difficult measure to workout for tree crops because of the relatively low value attached to the products. A farmer, growing trees for fodder or fuelwood, for example, may not be overly concerned with a few leaves being consumed up by insects as this still leaves quite a substantial amount for his animals. To an orchard farmer on the other hand, just a single hole by fruit borer on the guava or mango fruit renders the commodities valueless. Therefore the economic thresholds in the two situations are very different - quite low for the orchard farmer could very high for the silvopastoralist.

Appendix I

Arthropod species distribution on various plant species

1 = species present
0 = species absent

Species	Authority	Gs	Cs	Ll	Cc	Zm	Vi	Ws	Freq
Coleoptera:									
(Apionidae):									
Piezotrachelus pullus	Boheman	1	1	1	0	0	0	1	4
Piezotrachelus sp	unidentified	1	0	1	0	0	0	1	3
(Bruchidae):									
Bruchidius sp.	unidentified	0	0	1	1	0	1	1	4
Callosobruchus chinensis	Linnaeus	0	0	1	1	0	1	0	3
(Buprestidae):									
Agrilus sp.	unidentified	0	0	1	0	0	0	1	2
(Carabidae):									
Pheropsophus kersteni	Gerst.	1	0	0	0	0	0	0	1
Chrysomelidae (Alticidae):									
Chaetocnema sp.	unidentified	0	0	1	0	0	0	0	1
Chrysomelidae (Chrysomelinae):									
Mesoplatys ochroptera	Stal	1	1	1	0	0	0	0	3
Mesoplatys sp.	unidentified	1	1	1	0	0	0	0	3
Chrysomelidae(Clytrinae):									
Smaragdina sp.	unidentified	1	1	1	0	0	0	0	3
Chrysomelidae (Eumolpinae):									
Paraivongius cyanipennis	Gerstaecker	1	1	1	0	0	0	0	3
Chrysomelidae (Hispinae):									
Diclodispa striticollis	Gestro	1	1	0	0	0	0	0	2
Coccinellidae:									
Cheilomenes lunata	Fabricius	1	1	1	1	0	1	0	5
Cheilomenes sulphurea	Olivier	1	1	1	1	0	1	0	5
Diomus sp.	unidentified	1	0	1	1	0	0	0	3
Exochomus sp.	unidentified	1	1	0	0	0	0	0	2
Nephus sp. 1	unidentified	1	1	1	0	0	0	0	3
Nephus sp. 2	unidentified	0	0	1	0	0	0	0	1
Nephus sp. 3	Unidentified	0	0	1	0	0	0	0	1
Scymnus alluaudi	Sicard	0	0	1	1	0	0	0	2
Scymnus sp.1	unidentified	1	1	1	1	0	1	0	5
Scymnus sp.2	unidentified	1	1	1	0	0	1	1	5
Scymnus sp.3	unidentified	1	1	0	1	0	0	1	4
Stethorus sp.	unidentified	1	1	1	0	0	0	1	4
Corylophidae:									
Arthrolips sp.	unidentified	0	0	1	0	0	1	1	3
Cucujidae:									
Planolestes brunneus	Grouvalle	1	0	1	0	0	0	1	3
Curculionidae :									
Nematocerous casteneipennis	Hustache	0	0	0	0	1	0	1	2
Lathradiidae :									
Melanothalma sp.	unidentified	0	0	0	1	0	0	0	1
Meloidae :									
Mylabris sp.	unidentified	1	0	1	0	0	0	0	2
Mycetophagidae :									
Berginus sp.	unidentified	1	0	1	0	0	0	0	2
Nitidulidae :									
Cybocephalus sp.	unidentified	1	1	0	0	1	0	0	3
Tenebrinidae (Lagriinae) :									
Lagria villosa	Fabricius	1	1	1	0	1	0	1	5
Diptera									
Chloropidae :									
Trachysiphonela sp.	unidentified	0	0	0	0	0	0	1	1
Heteroptera:									
Anthocoridae:									
Cardiastethus sp.	unidentified	1	1	1	0	0	0	0	3

Dinidoridae:									
Cyclopelta tristis	Stal	1	1	1	0	0	0	0	3
Miridae :									
X2 sp.	unidentified	1	0	1	0	0	0	0	2
Pentatomitidae:									
Macrohapis acuta	Dallas	1	1	1	0	0	0	1	4
Piezodorus pallescens	Germar	0	0	0	1	0	0	0	1
Piezodorus sp.	unidentified	1	0	1	0	0	0	0	2
Platispidae:									
Libyasis sp.	unidentified	1	1	1	0	0	0	0	3
Pyrrhocorridae:									
Dysdercus nigrofaciatus	Stal	1	1	1	0	0	0	1	4
Tingidae:									
Dictyla sp.	unidentified	1	1	1	1	0	0	1	5
Homoptera:									
Ahididae:									
Aphis cracivora	Koch	1	1	1	0	1	1	1	6
Aphis sp.1	unidentified	0	0	0	0	0	1	1	2
Aphis sp. 2	unidentified	0	0	0	0	0	1	1	2
Sitobium nignectaria	Theobald	0	0	0	0	0	1	0	1
Auchenorrhyncha :									
X3 sp.	unidentified	1	0	1	0	0	0	0	2
Hymenoptera:									
Bethylidae:									
Epiranae sp.	unidentified	1	1	0	0	0	0	0	2
Encyrtidae:									
Aloencyrtus distnguendus	Waterston	1	0	0	0	0	0	0	1
Tremblaya oleae	Silvesri	1	0	0	1	0	0	0	2
Psyllaephagus (cullainus)	Prinsloo	0	1	0	0	1	0	1	3
Eulophidae:									
Aprostocetus (Ootetrastichus) sp.	unidentified	1	0	1	0	0	1	1	4
Euderus sp.	unidentified	1	1	0	0	0	0	1	3
Pediobus sp.	unidentified	1	0	0	0	1	1	1	4
Eurotomitidae:									
Eurytoma sp.	unidentified	0	0	1	1	0	1	0	3
Formicidae:									
Componatus sp.	unidentified	1	1	1	0	0	0	0	3
Myrmicaria sp.	unidentified	1	0	0	0	0	0	0	1
Pheidole sp. (megacephalus)	Smith	0	0	0	0	1	0	1	2
X4 sp.	unidentified	1	0	0	0	0	1	1	3
X5 sp.	unidentified	0	0	0	0	0	0	1	1
Lepidoptera:									
Geometridae: Ennominae									
Rhodophthitus commmaculata	Warren	0	0	0	0	0	0	1	1
Lymantridae:									
Euproctis sp.	unidentified	0	0	0	0	0	0	1	1
Noctuidae:									
Helicoverpa sp.1	unidentified	0	0	1	0	0	0	0	1
Helicoverpa sp.2	unidentified	1	0	0	0	0	1	0	2
Arctiidae (Arctiniinae):									
Spilosoma jacksoni	Roths.	0	0	1	1	0	0	1	3
Paralacydes minorata	Berio	1	0	0	0	0	0	0	1
Eupteroptidae:									
Haplojaria abysssinica	Roths.	0	0	0	1	0	0	0	1
Lichenopteryx despecta	Felder	0	1	0	0	0	0	0	1
Cossidae:									
Xyleutes capensis	Wlk.	1	1	0	0	0	0	0	2
Saturnidae:									
Alppenus strigulosa		0	0	0	0	0	0	0	1
Estigmene quadriramosa	Koll.	0	0	0	0	0	0	1	1
Estigmene trivita	Walk.	0	0	0	0	0	0	1	1
Usta terpischore	Mssn. &Weyn	0	0	0	0	0	0	1	1
Leucoteryx ansorggei	Roths.	0	1	0	0	0	0	1	2
Ciriana forda	Westwood	0	0	0	0	0	0	1	1
Bunaea aslauga	Kirby	0	0	0	0	0	0	1	1
Gonimbrasa feldori	Roths.	0	0	0	0	0	0	1	1
Bunaeopsis rothschildi	Le cerf.	0	0	0	0	0	0	1	1
Bunaeeopsis oubie	Guerin - Mener	1	0	0	0	0	0	1	2

	Orthoptera:									
	Acrididae : Cyrtacanthacridinae:									
	Cytacanthacricris tatarica		1	1	0	0	0	0	1	3
	Pygomorphidae:									
	Phymateeaus aegrotus	Gertaecker	1	1	0	0	0	0	1	3
	Arachnida:									
	Sporassidae	unidentified	1	1	1	1	0	0	1	5
	Salticidae	unidentified	1	1	1	1	0	0	1	5
	Araniedae	unidentified	1	0	1	1	0	0	1	4
	Oxyopidae	unidentified	1	1	0	1	0	0	0	3
	Clubionidae	unidentified	1	0	0	0	0	0	0	1
	Linphiidae	unidentified	1	0	0	0	0	0	1	2
	Theriidae	unidentiied	1	0	0	0	0	0	1	2
	Psocoptera									
	X6 sp.	unidentified	1	0	0	0	1	0	1	3
	Thysonnoptera:									
	Phlaeothripidae:									
	Elopothrips sp	unidentified	1	0	0	0	1	0	1	3
	Gastrothrips sp	unidentified	1	1	1	0	1	0	1	5
	Haplothrips gowdeyi	Franklin	1	0	1	0	1	0	0	3
	Total		58	36	45	19	11	16	47	
	Analysis :									
	No. sp. on MPTs = 27									
	No. sp. on Crop = 3									
	No. sp. on Ws = 12									
	No. sp. on MPTs+Crop = 13									
	No. sp. on MPTs + Ws = 14									
	No. sp. on MPTs+Crop+Ws = 19									
	No. sp. on Ws + Crop = 4									
	No. sp. common in 7 plant sp. = 0									
	No. sp. common in 6 plant sp. = 1									
	No. sp. common in 5 plant sp. = 9									
	No. sp. common in 4 plant sp. = 9									
	No. sp. common in 3 plant sp. = 24									
	No. sp. common in 2 plant sp. = 23									
	No. sp. common in 1 plant sp. = 26									

Appendix II

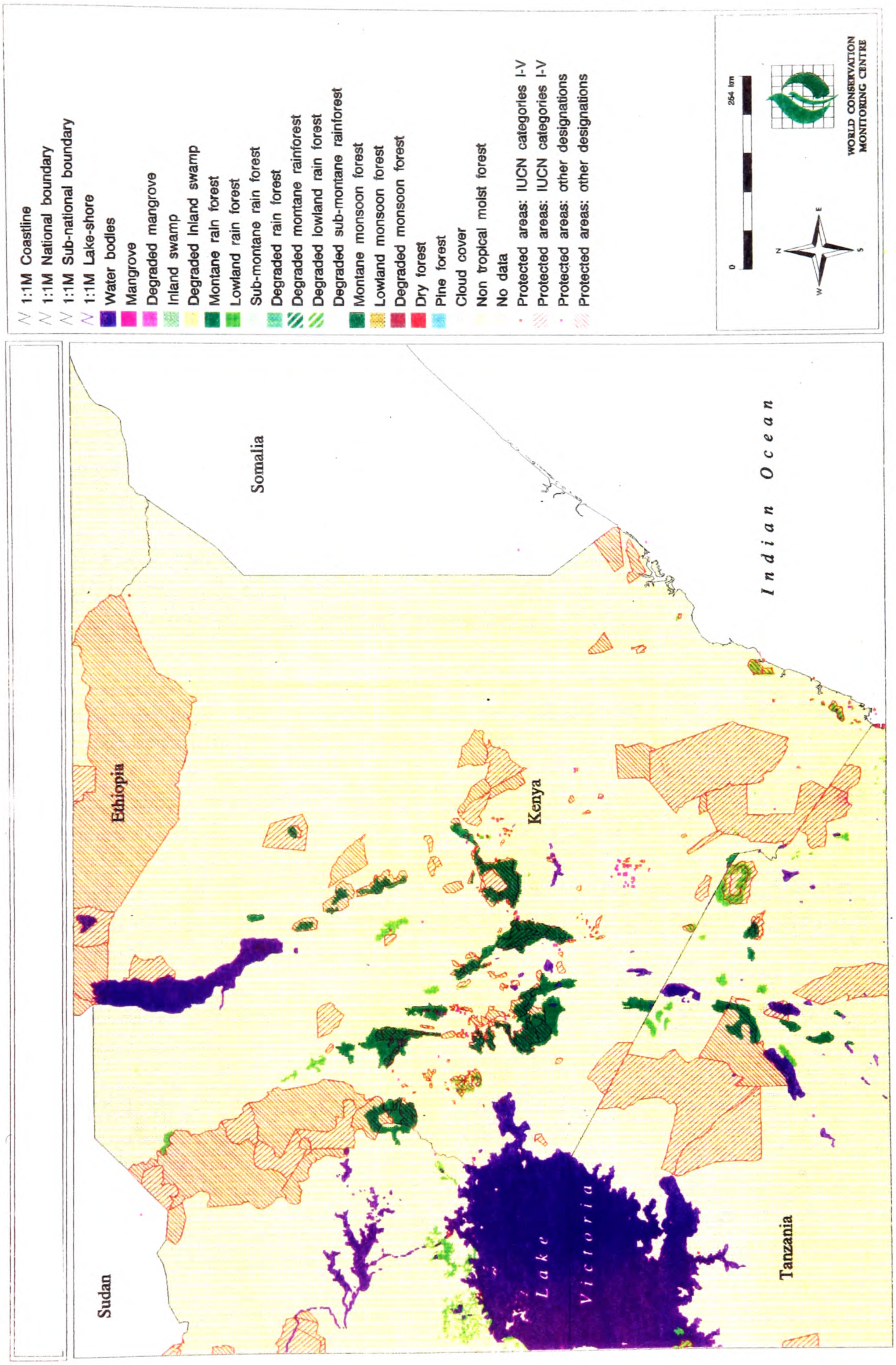
Arthropods associated with various plant species and their guilds
(*see page x for abbreviations)

Species	Host Range*	Guild	*Ref.
Coleoptera :			
Apionidae			
Piezotrachelus pullus	Gs, Cs, Ll, Ws	herbivores (seed feeders, defoliators)	1
Piezotrachelus sp	Gs, Ll, Ws,	herbivores	1
Bruchidae			
Bruchidius sp.	Ll, Cc, Vi, Ws.	herbivores (feed on stored grains)	1
Callosobruchus chinensis	Ll, Vi	seed pest : pigeon peas, chickpeas, lentils, cowpeas	1
Buprestidae:			
Agrilus sp.	Ll, Vi	herbivore (wood borer)	2
Carabidae			
Pheropsophus kersteni	Gs	general predator	3
Chrysomelidae (Alticinae)			
Chaetocnema sp.	Ll	herbivore (potential leaf - feeder)	1
Chrysomelidae (Chrysomelinae):			
Mesoplatys ochroptera	Gs, Cs, Ll	herbivore: on legumes 9Sesbania, Aeschynomene, Erythrina)	1
Mesoplatys sp.	Gs, Cs, Ll	herbivore?	1
Chrysomelidae(Clytrinae):			
Smaragdina sp.	Gs, Cs, Ll,	herbivore	1
Chrysomelidae (Eumolpinae):			
Paraivongius cyanipennis	Gs,Cs,Ll	herbivore	1
Chrysomelidae (Hispinae)			
Diclodispa striticollis	Gs,Cs	herbivore	1
Coccinellidae:			
Cheilomenes lunata	Gs,Cs,Cc,Vi	predator on aphids	2
Cheilomenes sulphurea	Gs,Cs,Cc,Vi	predator	2
Diomus sp.	Gs,Ll,Cc	predator	2
Exochomus sp.	Gs,Cc	predator	2
Nephus sp. 1	Gs,Cs,Ll	predator	2
Nephus sp. 2	Ll	predator	2
Nephus sp. 3	Ll	predator	2
Scymnus alluaudi	Ll,Cc	predator	2
Scymnus sp.1	Gs,Cs,Ll,Cc,Vi	predator	2
Scymnus sp.2	Gs,Cs,Ll,Vi,Ws	predator	2
Scymnus sp.3	Gs,Cs,Cc,Ws	predator	2
Stethorus sp.	Gs,Cs,Ll,Ws	predator	2
Corylophidae:			
Arthrolips sp.	Ll,Vi,Ws	dettrivore- mould feders, damp leaf, pollinators	2
Cucujidae:			
Planolestes brunneus	Gs,Ll,Ws	tourist	2
Curculionidae :			
Nematocerous casteneipennis	Zm,Ws	herbivore (feeds on maize, sweet potato)	1
Lathradiidae :			
Melanothalma sp.	Cs	(fungivore) feed on fungal spore	2
Meloidae :			
Mylabris sp.	Gs,Ll	predator	2
Mycetophagidae :			
Berginus sp.	Gs,Ll	predator	2
Nitidulidae :			
Cybocephalus sp.	Gs,Cs,Zm	predator of scale insects	2
Tenebrinidae (Lagriinae) :			
Lagria villosa	Gs,Cs,LL,Zm,Ws	herbivore, adult polyphagous, pest of fruit and vegetables	2
Diptera			
Chloropidae :			
Trachysiphonela sp.	Ws	predator of ant - prey of spider	4
Heteroptera:			
Anthocoridae:			
Cardiastethus sp.	Gs,Cs,Ll,	predator	5
Dinidoridae:			
Cyclopelta tristis	Gs,Cc,Ll,	predator	5

Miridae :			
X2 sp.	Gs,Ll	tourist	5
Pentatomitidae:			
Macrohapis acuta	Gs,Cs,Ll Ws	herbivore(sap - feeders)	5
Piezodorus pallescens	Cc	sap - feeders	5
Piezodorus sp.	Gs.Ll	sap - feeders	5
Plataspidae:			
Libyasis sp.	Gs,Cs,Ll	sap - feeders	5
Pyrrhocorridae:			
Dysdercus nigrofaciatus	Gs,Cs,Ll,Ws	sap -feeders	5
Tingidae :			
Dictyla sp.	Gs,Cs,Ll,Cc,Ws	sap - feeders	5
Homoptera:			
Ahididae:			
Aphis cracivora	Gs,Cs,Li,Zm,Vi,Ws	herbivore, polyphagous - prefers leguminoseae,	6
Aphis sp.1	Vi, Ws	do	6
Aphis sp. 2	Vi,Ws	do	
Sitobium nignectaria	Vi	feeds on Cajanus indicus, other legumes	6
Auchenorrhyncha :			
X3 sp.	Gs,Ll	tourist	7
Hymenoptera:			
Bethylidae:			
Epiranae sp.	Gs,Cs	tourist	7
Encyrtidae:			
Aloencyrtus distinguendus	Gs	parasitoid of soft scales	8
Tremblaya oleae	Gs,Cc	parasitoid	8
Psyllaephagus (cullainus)	Cs,Zm,Ws	parasitoid of psyllids	8
Eulophidae:			
Aprostocetus (Ootetrastichus) sp.	GS,Ll,Vi,Ws	egg parasite	9
Euderus sp.	Gs,Cs,Ws		9
Pediobus sp.	Gs,Zm,Vi,Ws	egg parasite (Lepidoptera, Coleoptera)	9
Eurotomitidae:			
Eurytoma sp.	Ll,Cc,Vi	tourist	9
Formicidae:			
Componatus sp.	Gs,Cs,Ll	predator - aphid attendance , extra flora nectaries	7
Myrmicaria sp.	Gs	do	7
Pheidole sp. (megacephalus)	Zm,Ws	do	7
X4 sp.	Gs,Vi,Ws	do	
X5 sp.	Ws	do	
Lepidoptera:			
Geometridae: Ennominae			
Rhodophthitus commmaculata	Ws	herbivore	10
Lymantridae:			
Euproctis sp.	Ws	herbivore	10
Noctuidae:			10
Helicoverpa sp .1	Ws,Ll	herbivore	10
Helicoverpa sp 2	Gs,Vi	herbivore	10
Arctiidae (Arctiniinae):			
Spilosoma jacksoni	Ll,Cc,Wc	herbivore	10
Paralacydes minorata	Gs	herbivore	10
Eupteroptidae:			10
Haplojaria abysssinica	Cc	herbivore	10
Lichenopteryx despecta	Cs	herbivore	10
Cossidae:			10
Xyleutes capensis	Cs,	herbivore (stem borer of Cs)	10
Saturnidae:			
Alppenus strigulosa	Ws	herbivore	10
Estigmene quadriramosa	Ws	herbivore	10
Estigmene trivita	Ws	herbivore	10
Usta terpischore	Ws	herbivore	10
Leucoteryx ansorggei	Cs,Ws	herbivore	10
Ciriana forda	Ws	herbivore	10
Bunaea aslauga	Ws	herbivore	10
Gonimbrasa feldori	Ws	herbivore	10
Bunaeopsis rothschildi	Ws	herbivore	10
Bunaeeopsis oubie	Gs,Ws	herbivore	10
Orthoptera:			10
Acrididae : Cyrtacanthacridinae:			

	Cytacanthacricris tatarica	Gs,Cs,Ws	Herbivore	
	Pygomorphidae:			
	Phymateeaus aegrotus	Gs,Cs,Ws	Herbivore	
	Arachnida:			
	Sporassidae	Gs,Cs,Ll,Cc Ws	Predator	11
	Salticidae	Gs,Cs,Ll,Cc Ws	Predator	11
	Araniedae	Gs,Ll,Cc,Ws	Predator	11
	Oxyopidae	Gs,Cs,cc	Predator	11
	Clubionidae	Gs,	Predator	11
	Linphiidae	Gs,Ws	Predator	11
	Theriidae	Gs,Ws	Predator	11
	Psocoptera			
	X6 sp.	Gs,Zm,Ws	Grazing herbivores on algae and fungi	12
	Thysonnoptera:			
	Phlaeothripidae:			
	Elopothrips sp	Gs,Zm,Ws	Herbivore (sap - suker)	13
	Gastrothrips sp	Gs,CsZmWs	do	13
	Haplothrips gowdeyi	Gs,Ll,Zm.	do	13
	Total			
			*References :	
			1 = M.L.Cox (identification report - CAB International	
			Institute of Entomology (IIE*)	
			2 = R.G.Booth - IIE*	
			3 = G.G.Kibby- IIE*	
			4 = J.S.. Dearning / I.M.White - IIE*	
			5 = J.M.Stonedahl - IIE*	
			6 = P.A.Brown - IIE*	
			7 = A.Polaszek - IIE*	
			8 = J.S.Noyes - IIE*	
			9 = J.Lasalle - IIE*	
			10 = J.Holloway	
			11= C. Hambler	
			12 = D.Hollis - IIE*	
			13 = G.J. duHeaume - IIE*	
			* IIE Collection No. 22295 / 6792a / b, Europe (1992, 1993)	

Appendix III. Moist Forests and Protected Areas in Kenya



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