TROPICAL FORESTRY PAPERS 23

Procedures for Monitoring Tree Growth and Site Change

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DEPARTMENT OF PLANT SCIENCES
UNIVERSITY OF OXFORD
1990

TFP23 Procedures for Monitoring Tree Growth and Site Change P.G. Adlard OFI

Cover illustration (Photo: S.J. Dury)

Karnataka State, India.
Soil pit excavation to assess root development.

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Procedures for Monitoring Tree Growth and Site Change

A Field Manual

P.G. Adlard

This field manual was originally prepared under project UNDP/FAO/HON/82/008 Coordenación y Producción Forestal y Desarrollo de la Industria Primaria, set up by the Forestry Department of the Food and Agriculture Organization of the United Nations (FAO). It is published by permission of that organization.

Oxford Forestry Institute
Department of Plant Sciences
University of Oxford
1990

ISBN 0 85074 118 1
ISSN 0141–9668

Printed in Great Britain by Burgess & Son (Abingdon) Ltd., Thames View, Abingdon, Oxfordshire.

author's preface

Forest management attempts to control the structure and dynamics of forest communities to achieve specific objectives. These range from the aim of maximizing production of timber of a certain size and quality on a unit area of ground, through such objectives as the protection of the soil on a hillside, to the preservation of a landscape or local climate.

Agriculture and urbanization have developed within a forest matrix. Up to recent times in Europe, and even now in less developed regions of the world, the first stage of development has been the removal of the natural forest for agriculture and human settlement. The forest has always been in the background, supplying its benefits of goods and services, without fear of its disappearance.

Suddenly, it seems, man has become conscious of the receding forest and the danger that this poses. On many maps the forests are nothing more than relict islands within intensively cultivated and populated landscapes.

This new consciousness is a spur to action to ensure the maintenance of the forest, where it still exists, and to replace tree cover on suitable land through tree plantations, where it has disappeared.

Knowledge of the growth rates of trees, either in the natural forest or in artificial plantations, is the basis of forest management. Trees interact with each other and with their surroundings as they grow. The silviculturist can control this development through selection of species and of improved seed sources, through better planting techniques and tending, through spacing, thinning and pruning and the time and pattern of felling.

Unless the effects of these treatments are 'monitored' there can be no scientific management of the forest or plantation. Neither will there be any mechanism by which timely remedial action can be taken when the management has been inappropriate.This is the justification for the publication of this 'field manual'.

It has been found, in practice, that continuous forest inventory (the conventional way of monitoring the growth of trees and tands) requires clearly defined procedures that will be followed through, and beyond, the rotation of the stand. The manual attempts to supply such procedures to the selection and setting up of sample plots, their consistant measurement and re-measurement and to the preliminary stages of data processing.

The routines included here do not, however, have to be applied rigidly. Every inventory is different, having different problems to solve and objectives to meet. The manual will probably be most useful to those planning and designing a specific inventory for the first time. Many of the routines may be adapted. In some cases the details given may be excessive for a particular application and should be modified. The 'model' field forms, for example, should be treated as check lists to ensure that all aspects of the inventory are taken into account at the planning stage. Many applications would use data loggers in the field. The field forms would, in these cases, be used as the basis for programming the input formats for the loggers.

Short-rotation, monospecific, forest plantations are increasing in extent (there may be over 35 million ha of them in the tropics) as a consequence of the rapidly declining areas of natural forests. There is growing concern over their ecological effects. Good management must, therefore, concern itself not only with the efficient production of forest produce but also demonstrate that the traditional beneficial influences of the forest are not being jeopardized through intensive 'economic' management of plantations. 'Monitoring' includes, therefore, the study over time of changes in the total biomass productivity and the physical and chemical nature of the soils under the plantations. Some indications of ways of doing this are included here. Some recent developments, however, such as the use of isotopes for the assay of nutrient uptake by roots, are not.

Monitoring the water use of different species under varying management patterns is of great importance in many tropical areas, but is beyond the scope of this manual. Recent field experience, on which parts of the recommendations are based, have been carried out within industrial and social forestry plantations of eucalypts and other exotic species in Southern India in association with the Institute of Hydrology, Wallingford, UK, who can advise on methods of monitoring the water use of forest stands.

The PPR package (for Permanent Plot Records) is a tool box of programs, mostly in both compiled and interpreted BASIC, that has been developed over a long period at the Oxford Forestry Institute for processing permanent sample plot data. It is now available for use on IBM-compatible personal computers and may be obtained at a small charge (to cover administrative expenses) by completing the order form at the back of the manual. While care has been taken to check all the programs for errors, no responsibility can be accepted for any errors that remain, or for problems that may arise when used with data sets for which the programs have not been designed.

The output from most of the PPR programs can be sent to serial files for further processing on spreadsheets, statistical packages or database programs. Only brief references are made to the use of such software in the manual. A 'PPR Operators Manual' giving worked examples of most of the programs is in preparation.

acknowledgements

This guide is based on the experience of many people, both at the Oxford Forestry Institute, and in several countries where permanent plots have been established. It would be impossible to mention individually everyone who has contributed over the years. However, the work and help of research staff in the Forest Departments of Kenya, Uganda, Tanzania, Malawi, Honduras, Mexico and Karnataka, India who have played an important part in the development of the field practices recommended here is gratefully acknowledged.

The first draft was prepared as part of a FAO project in Honduras in 1982. A monitoring system was adapted with its own package of microcomputer programs specifically for that project by D. Hughell, and provided an example of how general instructions should be adapted and developed for local conditions. Without the encouragement and support of Mr Jan Troensegaard of the Forestry Department of FAO the manual would not have been completed. The permission of FAO to publish this material is gratefully acknowledged.

At Oxford, H.L. Wright has been responsible for the initiation of most of the work on sampling for growth data and for the development of the first programs for data processing which date back to the 1960s. The overall guidance of H.C. Dawkins has been invaluable. Assistance with conversion of the computer programs from main frame machines to micros has been given by J.P. Smith, K. Wilkinson, and F.R. Miller. J.A. Johnson played a large part in the preparation of the first drafts of the guide during the research project R 3738 supported by the Overseas Development Administration (ODA), London.

Recent developments have been made as part of the current research project with the Karnataka State Forestry Department and the Mysore Paper Mills Ltd., also supported by the ODA.; R.B. Matthews and S. Dury have made important contributions. Alan Ek, J. Vanclay, E.F. Brunig, D. Hughell, C. Groothausen and O. Lindgren, have all made valuable suggestions for amendments to the manuscript and software. R. Wise has drawn the figures in Chapters 1 and 2 and Figures 3.1 and 3.3. The remaining figures are by Apex Display Company, Prestbury. C.E.M.Lines assissted with the final draft and preparation of the manuscript for publication. The help of A. Greaves in the final editing process is gratefully acknowledged.

A.P. Fraser has applied the procedures at the TANWAT Estates, Njombe, Tanzania, under ODA's Professional Training Assistance Scheme in collaboration with the Commonwealth Development Corporation.

Summary

Procedures for monitoring the growth of forest plantations, principally in the tropics, are presented.

These include methods of setting up a system of both, temporary and permanent sample plots located objectively within managed plantations and replicated field experiments. The experiments test the effects of silvicultural management on tree- and stand-growth patterns. Together the information collected provides the basis for the management of the plantation (in the form of volume and yield tables and functions) and for detecting site change, for example when applied to related studies on tree water use and nutrient cycling.

Methods for collection of data in the field and its processing using small personal computers is suggested.

Recommendations for the assessment of above- and below-ground phytomass production are given in addition to procedures for measuring and recording the conventional tree and stand variables.

While it is assumed that the reader has some familiarity with forest mensuration and sampling techniques, attention is drawn to particular sources of error that are likely to arise in practice.

Chapter one details the scope of the manual and the objectives of a growth monitoring system in forest plantations. Chapter two is an elementary summary of the steps to be taken in planning a continuous forest inventory. Chapter three gives details on how to lay out the different types of sample plots in the field with step by step instructions on how to record the measurements and observations. This is followed by details of summarizing the data file, with information on spreadsheets, databases and other packages. The final chapter argues that a number of complimentary controlled experiments are required to test the effects of stand density, fertilization and other treatments in order to understand the results of the continuous forest inventory correctly. Some model 'experimental' plans are provided.

Model field forms are included as an aid memoire to planners of continuous inventory and monitoring programmes.

contents

page

3. Implementation

Tables

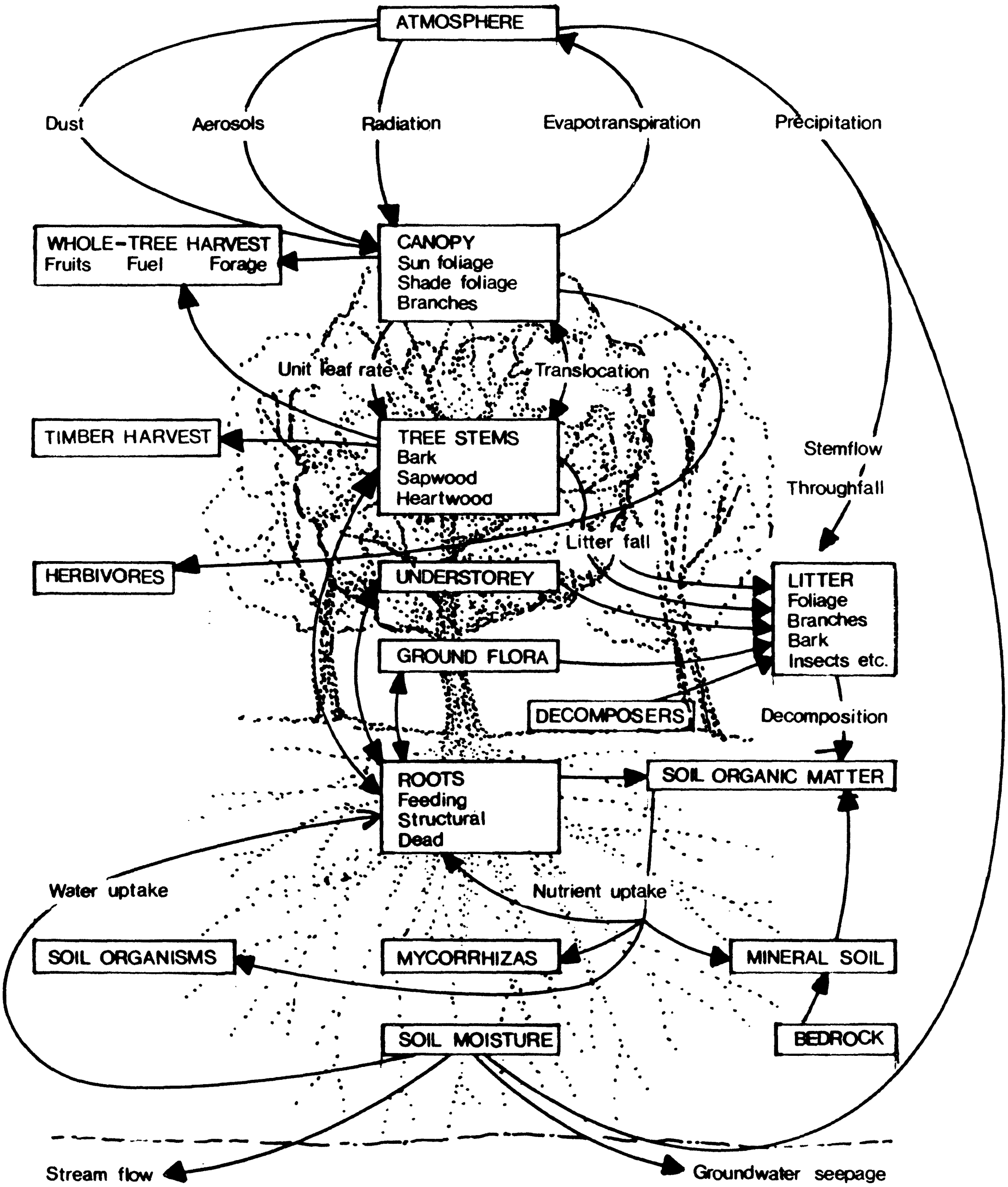

Figure 1.0
Compartment model of a plantation system

1

general introduction

1.1 Aims of this manual

This document is designed as a guide to the planning and implementation of a continuous forest inventory with permanent sample plots in natural and planted forest stands managed for industrial and social purposes, in tropical and subtropical regions. It assumes that the reader has a basic understanding of forest mensuration, and has some experience in inventory techniques. A list of texts for background is provided for those wishing to refresh their knowledge.

Continuous forest inventory is a component of an environmental monitoring system and may include assessment of dynamic changes, not only of the above ground woody growth, but also of the chemical and physical states of the site and rates of energy flows within the ecosystem (see Figure 1.0). It is a task normally given to the research authority within a forestry organization, though it could arguably be considered an integral part of good forest management. If the latter is accepted, there is need for a detailed guide to the procedures involved in setting up and maintaining a consistent monitoring system based on past research. If the task is left to the research department it is helpful to have a set of procedures outlined in detail as a baseline for further research and applications under, perhaps, a new set of objectives and conditions.

In either of the above cases, whether the establishment of plots for monitoring is considered part of standard management practice, or whether it is considered as part of a research project, the work must be coordinated, planned and executed by trained specialist staff. This manual is directed to those with such a responsibility. However, it is hoped that it will also be of interest to managers and planners who may thereby appreciate the place and importance of monitoring forest growth and site change under forest plantations in both industrial and rural development programmes.

1.2 Forest types to which the procedures may apply

The procedures outlined are applicable to forest stands of simple structure, whether natural or artificial, but do not cover the inventory or growth monitoring of tropical high forest types. 'Plantations', for the purposes of this manual, do not include line-planting within a matrix of high forest or scattered or irregular planting patterns within pre-existing forest types. The only natural forest types specifically included are stands predominantly of conifers with some broadleaved species, such as the pine and oak forests of Central America and Mexico. Plantations are normally assumed to be dense plantations, usually even-aged, established on cleared or open ground and comprising one or a few dominant species. Monitoring of the growth of the tropical high forest types (including enrichment planting within them) on the one hand, and of complex mixtures of species and age classes associated with annual crops on the other, require different techniques from those outlined here. For the former the reader is referred to Synnott (1979), and for the latter to the recent publications of ICRAF (1984). Nevertheless, most of the recommended procedures could be adapted to these forest types by anyone with experience in continous forest inventory, through suitable adaptation of plot sizes and the variables assessed.

The field experience behind the recommended procedures has been obtained in the coniferous plantations of tropical pines in the highlands of east and central Africa, in fast-growing short rotation plantations of wattle and eucalypts in Africa and India, and in the natural pine forests of Mexico and Honduras.

1.3 Outline of the manual

Four aspects of a monitoring programme are dealt with in the following chapters:

Planning
Implementation
Data capture and analysis
Experimental plots for supplementary information.

These chapters include a review of the general principles on which a continuous monitoring programme should be based with model procedures that may be adapted to any specific situation.

The manual contains some information that was previously included in a special supplement applying the general recommendations to a field project in Karnataka, Southern India. The project was designed to monitor the effect of short-rotation forest plantations (especially of eucalypts) on the water and nutrient relations of a range of sites. A number of experimental designs applied in that project have been included in the Appendices as they may have applications, with appropriate modifications, in other monitoring projects. It is recommended that supplements be issued to cover applications of the recommended methods for specific monitoring projects.

Chapter 2 reviews the main steps involved in planning a continuous forest inventory (CFI)* : defining the objectives, selecting the sampling design, choosing the type of plot and deciding which variables have to be assessed to satisfy the objectives.

In Chapter 3 an attempt has been made to outline the operations involved at the various stages of establishing and evaluating sample plots in the field so that the plots and trees can be relocated when necessary for recurrent measurements of growth and the assessment of site change.

Chapter 4 provides an outline of the steps most generally followed in producing summaries of the data collected and their analysis in the form of simple yield models. This chapter is in the form of a guide to a package of programs for microcomputers that, though under continuous development, does already provide a tool for a forest management organizations setting out to implement a CFI monitoring system. This package is an essential complement to the manual and may be purchased from the author using the order form enclosed.

The last chapter includes some suggestions for designs of field experiments for evaluating the reaction of forest stand and tree growth to silvicultural treatments, in particular to spacing, thinning and fertilizing.

The emphasis throughout is on the use of recurrent sampling of the forest or plantation by means of plots objectively located and subject to the normal management operations applied to the forest or plantation as a whole. In order to develop a general model of stand growth, as distinct from merely describing the observed behaviour, some supplementary information is needed. In particular data of two main types are required. These types may be called 'tree data' and 'site-treatment response data':

(i) **tree data**: includes the many inter-relationships within an individual tree often known, inaccurately, as "allometric" relationships. These may include stem volume, crown radius, branch volume, weight, calorific value, root mass, etc., in relation to height or diameter (dbh) or other easily measurable variable. These relationships are important for the construction of various management tables and development of models which describe the partitioning of photosynthetic products between the different parts of a tree. Data for management tables are normally obtained from destructive sampling of individual trees within plots associated with the permanent sample plots described in Chapter 3, and some suggested procedures are included in that section.

(ii) **site-treatment response data**: the growth responses of a given genotype (species, provenance, or progeny) to silvicultural management on a given site. These growth responses include changes in stand

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* for abbreviations see Appendix 1.

density (controlled through spacing and thinning), modification of soil nutrients (by fertilizing), and modification of moisture relations (through drainage or irrigation). Assessment of response to stand treatment can only be obtained by means of carefully designed, usually long-term, field experiments. Recommendations of suitable experimental designs are therefore given in Chapter 5 as an introduction to this subject. This manual does not however aim to cover the design and analysis of silvicultural experiments in general.

If the proposed growth model is intended to cover mixed-species stands or even to attempt to describe the growth of trees growing in association with other crop types, as in many agro-forestry systems, a third type of supplementary data will be needed. These we may call 'species-interaction data'.

(iii) **species-interaction data:** the competition or cooperation between two species growing on the same site in mixtures of various patterns. This needs careful testing in field experiments. Examples are included in the 'Karnataka Supplement' but not in the main text as generally they will not be required in a CFI.

1.4 Objectives of a continuous forest inventory:

- to provide information on stand growth for the efficient management of the forest or plantation
- to estimate the potential production of the site
- to provide data on the effect of management of the forest stand on the physical, chemical and biological properties of the site. This is particularly relevant for the study of the effects of intensive cultivation of fast-growing monocultures.
- to quantify the effects of silvicultural treatment on growth and yield
- to monitor changes in site productivity over successive rotations of tree crops under management.

1.5 Some definitions

In describing tree and stand growth there is the possibility of confusion through ill-defined use of the terms growth, yield, production and productivity. The following definitions are used in this manual for these and related terms:

Biomass : all matter, living or not, organized in a permanent manner as a constituent of a living organism.

Fertility : the current productive potential of a site to produce crops on a sustained basis.

Increment : growth of diameter, basal area, height, volume, quality or value of a tree or stand. It is normally used in the restricted sense of 'rate of growth' or increase within a given period, usually of one year, or as a periodic annual increment which is the average rate of growth observed over a number of years.

Leaf area index (LAI): the ratio of total leaf surface to total ground surface.

Phytomass : the living vegetative component of biomass. Biomass is often used, incorrectly, to refer to phytomass.

Primary productivity : the rate by which energy is captured by the activity of producer organisms - photosynthetic or chemosynthetic - in the form of organic substances which can be utilized as food material.

Plant productivity : is the measure of energy accumulation by the plant component of the ecosystem over a specific time period and given area expressed variously as:

cals per m^2 of vegetation per year
joules per m^2 per year
tonnes (yield) per ha per year

It is assessed usually as **Production.**

Production : the amount of accumulated organic matter on a given area at one time. The ecologist defines **production** as the quantity of organic matter in a given area at one time. This is directly related to the **total biomass** and is usually expressed as g/m^2. To the farmer or forester it can mean the usable quantity of crop produced by the end of the growing season expressed as tonnes per ha.

GPP - gross primary production: is the assimilation of organic matter by a plant community over a specific time interval, including that used by plant respiration.

NPP - net primary production: is the increase in plant material observerd as plant growth measured by dry weight. NPP is the rate of accumulation of vegetable tissue less the material respired, that is, the growth of phytomass in unit time.

Secondary production: is the rate of accumulation of plant and animal material measured by dry weight at the trophic level of consumers and decomposers.

Potential forestry production: is an arbitrarily defined portion of the phytomass production, or yield. It usually refers to the production of stem-wood (that is excluding leaves, branches, stumps and roots).

Utilizable forest production: is always less than the potential forestry production. As it depends on the vagaries of the market it cannot be defined in this context.

Site : an area considered in terms of its environment. It may be classified qualitatively into **site types** or quantitatively into **site classes. Site quality** is used in a general sense to refer to the potential of the site, that may or may not carry a forest crop, to support an expected rate of growth of a given species under optimum management. **Site productivity** is often used synonymously with site quality. In this manual the former term will be used in the general sense to refer to the potential of a site while the latter will imply that quantitative assessments of at least some of the site factors influencing growth have been attempted. Cf. **fertility**.

Site index: the dominant height of an even-aged plantation at a given 'index' age. It is obtained from **site index curves** which are representations of the relationship between dominant stand height and age for different sites and stand densities. Site Index Curves are widely and traditionally used for growth prediction of even-aged forest stands

Yield : forest produce, actual or estimated, that may be harvested from a specified area over a stated period. Yield is the simplest index for assessing productivity and production.

Yield class : the maximum mean annual volume increment, irrespective of age, which a stand of trees can attain, usually expressed as m^3/ha.

1.6 Types of permanent sample plots

Quantitative data may be obtained both through observation and experiment.

There is a clear distinction to be made between the observation of field sample plots growing under normal management conditions (as described in Chapter 3) and silvicultural experimental plots (Chapter 5). The former are referred to as sample plots, both temporary and permanent, and the latter as experiments. Further subdivisions are of course possible and those to which reference is made below are included in the classification of plot types given in Tables 1.1 and 1.2.

Individual treatment plots within a silvicultural experiment are 'permanent sample plots' in a sense but with the objective of estimating treatment response on a given site. PSP, on the other hand, provide dynamic information of growth under the actual conditions pertaining in practice. Both sources of data are required for calibrating stand growth and management models.

Figure 1.1
A 'permanent' sample plot

Table 1.1

CLASSIFICATION OF FIELD STUDY PLOTS (1)

Key	Description
	Observation plots
T	Temporary sample plots on which basal area and dominant height are estimated. Object: Growing stock data; mapping stand variation as basis for stratification.
P1	Conventional permanent sample plots on which tree diameters and selected heights are measured on more than one occasion. Object: Tree and stand increment data for construction of site-index curves and yield models.
P2	Productivity plots. These are a subsample of P1 plots in which available soil moisture, foliar, litter and soil nutrients are measured in order to monitor water relations and nutrient cycling. A few additional measurements on individual trees are required such as tree positions, crown height, etc. Object: to relate growth to the site conditions and to detect site change over time.
	Destructive sampling
D	Destructive sample plots on which trees are felled for volume estimation and branches and foliage are removed for detailed measurement, root excavation etc. Object: to obtain data for estimating volume and 'allometric functions' used in predicting many tree and stand parameters from simple field measurements in plot types T, P1 and P2.
	Water-use study plots
E1	Intensive water-use study plots. These will be selected subjectively in fully-stocked stands or in annual crops. Neutron probe measurement may be made at frequent intervals, usually daily. An automatic weather station may be installed at at these sites. Object: to develop a general water use model applicable to a wide range of species and sites.

Table 1.2

CLASSIFICATION OF FIELD STUDY PLOTS (2)

Key	Description
	Experimental plots
E2	Spacing and thinning trials. Replicated designs are recommended for evaluating the growth response of planted tree crops to initial spacing and subsequent thinning. The treatments should cover the extreme conditions of unrestricted growth of individual trees and maximum stand density with density-dependent mortality. Object: to observe growth of the individual tree in relation to stand growth under controlled stand densities for deriving stand density functions for use in growth models.
E3	Experimental plots designed to investigate the effect of different species on run-off and the physical properties of the soil, the effect of crop density on the productivity of different crop components and other crop/site interactions that are not included in the intensive study plots nor in the observation plots. Ad hoc experimentation without direct links to the general growth and water use models are not be included. Plots falling in this category include existing silvicultural and agro-forestry experimental plots within which additional measurements, in particular of water use, are desirable in order to test the applicability of general models to a wide range of conditions. Object: to quantify the effect of plant and site interactions under specific crop combinations and spacing, and to provide data on the effect of species and treatment on soil properties.
E4	Intensive production plots. Close spacing and intensive cultivation may be used to assess an accelerated effect of a tree stand on the soil, and to provide a field laboratory for the study of nutrient cycling and the sustainability of high productivity. Object: to detect site change associated with intensive cultivation of monocultures within the shortest possible time.

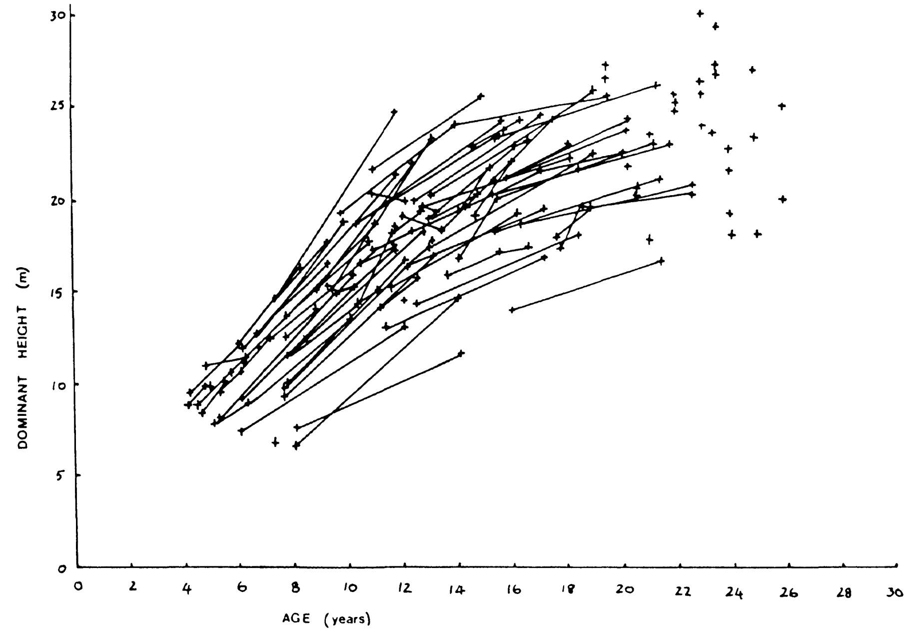

Figure 1.2
Height growth data from P1 plots

1.7 Data collection and analysis

The manual is a guide to the collection of field data required for satisfying one or more of the objectives defined in Section 1.3 above. The choice of variables to be recorded should depend on the objectives of the monitoring system being applied. The hierarchy of plot types given in Tables 1.1 and 1.2 indicate various intensity levels for the study of stand growth and site change. The intensity at which a forest or plantation should be monitored will depend on the degree of urgency for the information as recognized by management set against the availablity of resources that are available for carrying out the programme.

Suggestions are given in Table 2.1 for the choice of variables that might be assessed within each of the proposed observational plot types.

Procedures are given in Chapter 3 and model field forms are included in a separate section. These should provide material for the implementation of a monitoring programme. In some cases, for example if a new programme is being drawn up, it may be appropriate to follow the proposed methods closely. In other cases, where existing plot procedures have been well tried, the proposals presented here may suggest possible additions or improvements to the existing system.

The manual differs from earlier publications on the subject of plot procedures in providing an introduction to microcomputer software for the processing of the data from most of the field forms presented. As this is an area of rapid change there may be a large number of editions of the programs that are mentioned for different machines. Enquiries from readers will be welcomed by the author as to the availability of the current software. A description of one of the first set of programs developed for the data capture and processing of tree and stand data from permanent sample plots is given in Chapter 4.

1.8 Results expected

From temporary plots or from the first measurement of permanent plots:

- growth summaries of individual plots at each assessment (e.g. Appendix 14, following page 157)
- tree and stand stem volume tables to various diameter limits
- phytomass tables for estimating branchwood, foliage weight and area, bark percentage and, possibly, root weight, from tree diameter and height
- plot maps for ease of relocation of individual trees and estimation of 'competition' indices.

From subsequent assessments of permanent plots:

- site index curves and functions for grouped plots (in strata, Figures 1.2 and 1.3)
- yield summaries by strata
- data base of the site variables that have been assessed linked to a data base of the crop growth for the testing of correlations between growth, site and treatment.

This will lead, after a period of observation, to the modelling of the growth observed in terms of site and treatment.

Where complementary experiments have been installed (E type plots) the treatment effects will be modelled more precisely.

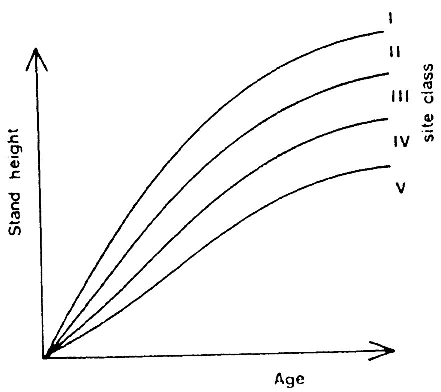

Figure 1.3
Site class curves

1.9 Management implications

The continuous forest inventory proposed for monitoring site change should be considered part of management rather than merely another research project. The data are designed to provide a feed-back of information to test management predictions and, if appropriate, lead to modifications of management practice (Figure 1.4).

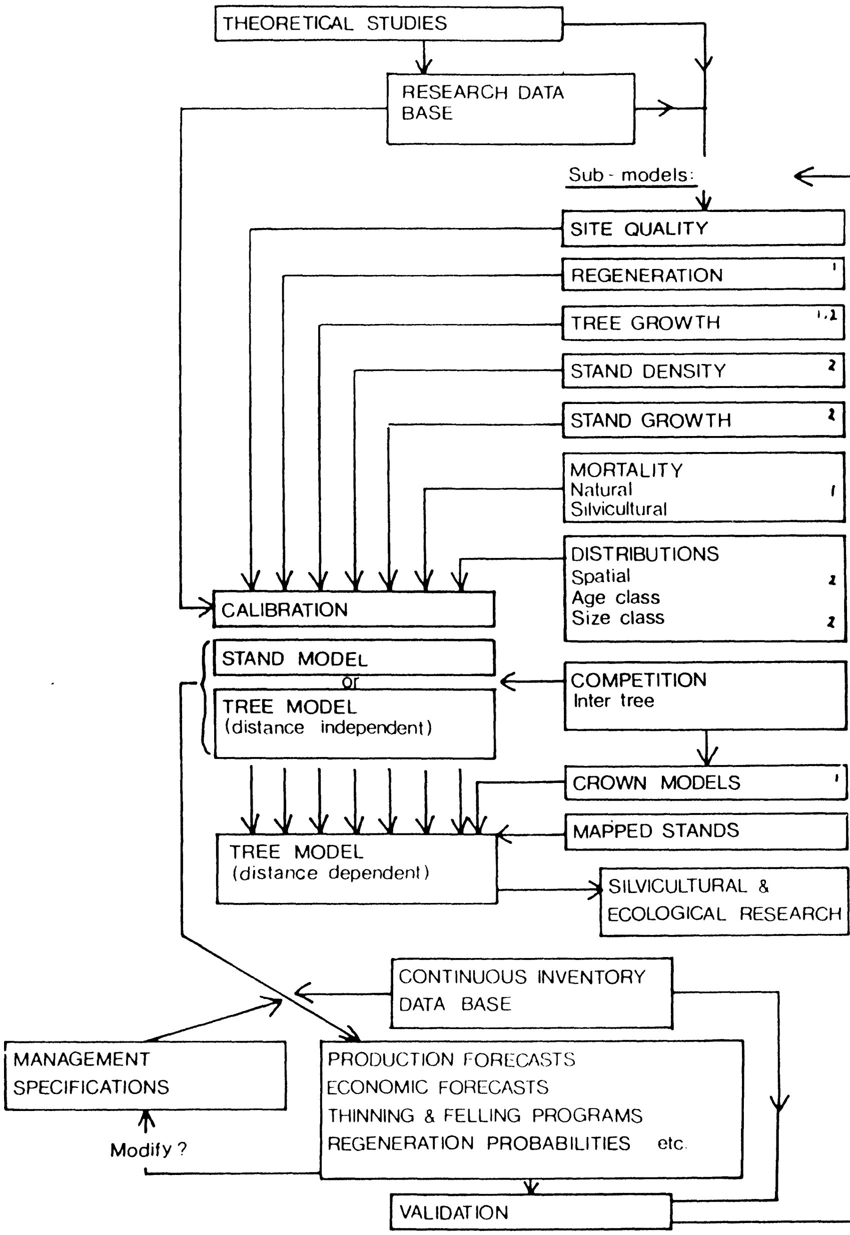

Figure 1.4
Feed-back to management

2

planning

2 Introduction

This chapter sets the scene for the field studies. Go to Chapter 3 for practical field instructions.

2.1 Defining the population

'Population' in the statistical sense has a precise meaning that must be clearly defined for a particular inventory or monitoring programme. This should be distinguished from the concept of a forest stand as a 'population' of trees of varying species and size. This refers to the natural, or ecological units that are being sampled. The natural population will be defined as a forest type of a given species composition and structure, for example: 'even-aged plantation of Pinus patula occurring above an altitude of 1500 m in Malawi'. This is descriptive but not very precise as a number of provenances may be included that perhaps should be identified. Furthermore this description does not define what characteristics of the plantation are to be measured. It is often assumed that total bole volume will be of greatest interest. For management purposes stand density may be of more importance in the younger age classes while the Utilization Officer needs information on the variation of wood density in the different parts of the stand.

A population is therefore defined as 'any set of individuals (objects or sampling units) having some common observable characteristic'. The population is the 'aggregate' from which the sample is chosen. 'Population' may be used, in different contexts, to refer to the measurements of the unit or to the unit itself.

Examples of 'populations' include, number of trees per unit area, number of trees per sample unit, branchwood volume per tree, total bole volume per sample unit, and diameters of all trees.

Any of these could be the 'reference population' that is to be sampled. The limits of the reference population have to be defined for any particular survey or monitoring programme. The last example is meaningless unless qualified.

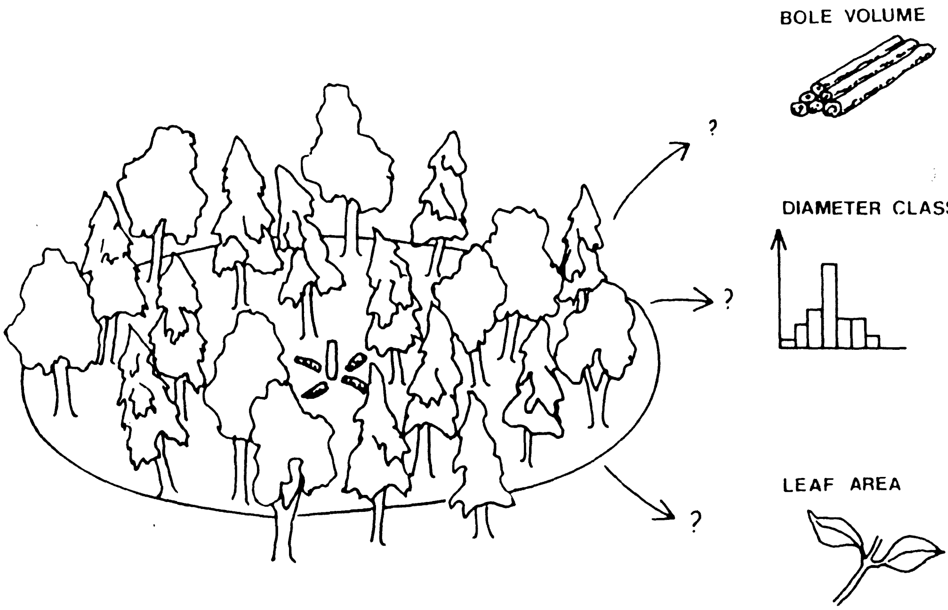

Figure 2.1
Defining the 'population'

2.2 Parameters, variables and sample units

A population is characterized by certain constants which are known (to statisticians) as **parameters**. The mean and variance of the diameters measured within a sample plot are examples. If the diameter distribution can be assumed to be 'normal' these parameters provide a sufficient quantitative description of this aspect of the stand of trees being sampled. The tree diameters vary one from another in a random manner and so 'diameter', in this example, is called a **variable**. For a given population the mean and variance, however, are constant. Thus a sample survey will be summarized in the form of a number of parameters that describe the population of interest quantitatively (the mean) with a known precision (derived from the variance).

The object of sampling is to estimate these parameters. The choice of sample unit to estimate the parameters of a particular population is one of the most important decisions to be made in planning the programme.

The basic sampling unit proposed is a plot of known area as in most continuous forest inventories. **Two-phase sampling**, or the use of subsamples for the measurement of subsidiary variables (usually costly or difficult to assess) are frequently used in sampling for growth studies. For example, individual trees within a fixed-area plot might be selected, using some objective method, to provide a subsample for volume and foliage weight assessments. Branches might be selected within a tree for obtaining data of branch weight. This would represent a third phase of subsampling within the plot.

2.3 Sampling design

A search for the optimum design at least cost is essential to the planning stage of a conventional forest inventory. The criterion of precision (sampling error) is not necessarily appropriate for determining the sampling design and sample size for monitoring forest growth. In most situations the cost of establishing and maintaining the necessary number of permanent sample plots required to give an acceptable precision for the estimate of the mean of, say, total volume increment per unit area, will be unacceptably high. However, a satisfactory design can be achieved if the permanent sample plot is considered as a subsample within a primary sample of temporary inventory plots, whether the primary sample has been established in reality or not.

Within the range of alternatives between simple and stratified, single-stage and multi-stage, systematic and random sampling that may be considered appropriate for a particular forest type, no single design can be recommended. The choice depends on the variability of the population, accessibility and the relative costs of locating and measuring an individual sample unit. A discussion is outside the scope of this manual but reference should be made to the standard references cited. Notes on the various types of sampling are given briefly in the following sections.

2.3.1 Subjective and objective sampling

To ensure that an acceptably precise estimate of stand parameters is calculated from any sample plot data base, it is important that the sampling frame be located objectively rather than subjectively. A subjective design, where sample units are chosen deliberately by the designer, would ensure an initial bias where there is no need for one. Loetsch and Haller (1973) state that "under no circumstances" should sample plots be subjectively selected.

2.3.2 Systematic sampling

Objective sampling designs for growth and yield studies tend to be either random or systematic. A systematic approach consists of selecting a sample of N units from which a unit is selected at random from the first K units and every subsequent K-th unit (Cochran, 1963).

Although the first sample unit is randomly chosen all other samples are selected according to a strict pattern. In practical terms the positioning of the first sample unit determines the location, usually laid out in grid fashion, of all other selected units (Figure 2.2). Systematic designs are normally used for forest inventories, particularly those carried out in areas being surveyed for the first time (FAO, 1981). They are attractive in that all parts of the population appear to be covered, and the unit cost per plot sampled is relatively low. Disadvantages associated with this type of sampling are that it is not possible to calculate the precision of any estimates and, more significantly when considering growth studies, the sampling intensity and related costs are excessive to requirements (Alder, 1980). Systematic sampling can also lead to biased estimates if the interval between sample units coincides with some naturally occurring periodicity within the population.

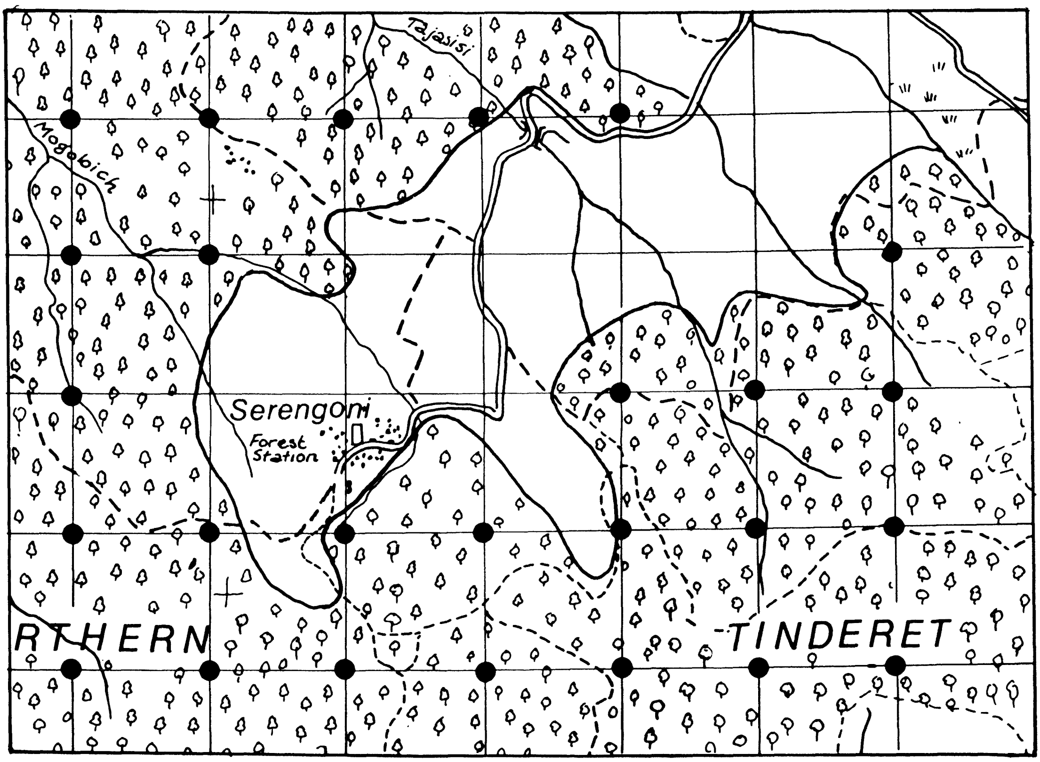

Figure 2.2
Systematic sampling

2.3.3 Simple random sampling

A simple random design can be defined as the equal probability of selecting a sample of any combination of N units from the given population. This is illustrated below. Sample units can be selected with replacement (they have an equal probability of being selected again), or without replacement (once selected they cannot be sampled again). The latter condition assumes an infinite size of population yet is the one adopted for most forest sampling designs. Clearly any population is not of an infinite size. Therefore when calculating precision of estimates a correction is made, the 'finite population correction'. This however can usually be ignored when the sampling fraction does not exceed 5% (Cochran, 1963). One criticism of simple random designs is that, sometimes, significant areas of the population remain unsampled as shown in Figure 2.3.

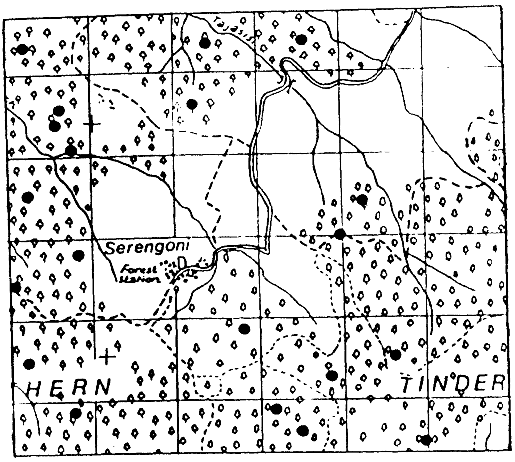

Figure 2.3
Random sampling

2.3.4 Stratified random sampling

Prior knowledge about a population can be used to increase the precision and efficiency of a sampling design. If units of the population can be grouped together into sub-populations or strata on the basis of similarity in some characteristic then, once delineated, each strata can be sampled independently. Group estimates are then combined to give a population estimate. If the within-stratum variation among units is less than the between-strata variation among units the total population estimate will be more precise than if sampling had been random throughout the entire population (Freese, 1962, see Figure 2.6). Stratification, as shown in Figure 2.4, helps to avoid any very irregular distribution of selected units throughout the population. It is often used with simple random designs and also provides estimates of means for each stratum. One constraint is that within each stratum two samples must be selected. A stratum does not have to be a single consolidated unit within the population but can be fragmented.

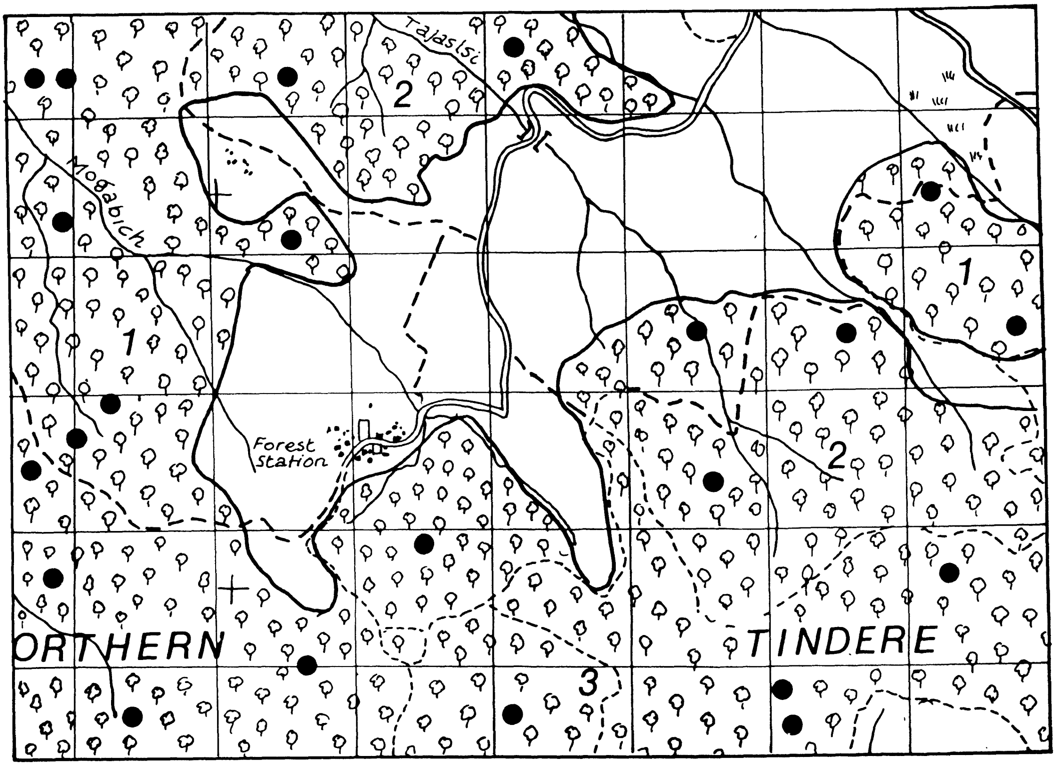

Figure 2.4
Stratified random sampling

2.3.5 Multistage designs

A recognized cost effective method of sampling is termed multistage. This is characterized by sub-dividing the population into a frame of primary units. A number of selected primary units are sub-divided still further into secondary units. Sample units are selected from within these, or the process is carried a step further and selected secondary units are subdivided into tertiary units from which the final sample units are chosen. The final selected units may be arranged as illustrated in Figure 2.5. In comparison with a simple random design, a multistage of the same sampling intensity reduces the cost of locating and physically getting to the sample units. More selected primaries with fewer secondaries lead to a higher cost but greater precision. Fewer primaries with more secondaries cost less but also give less precise estimates. One disadvantage of multistage designs is that only some of the sub-divisions are sampled; in stratified designs all are sampled.

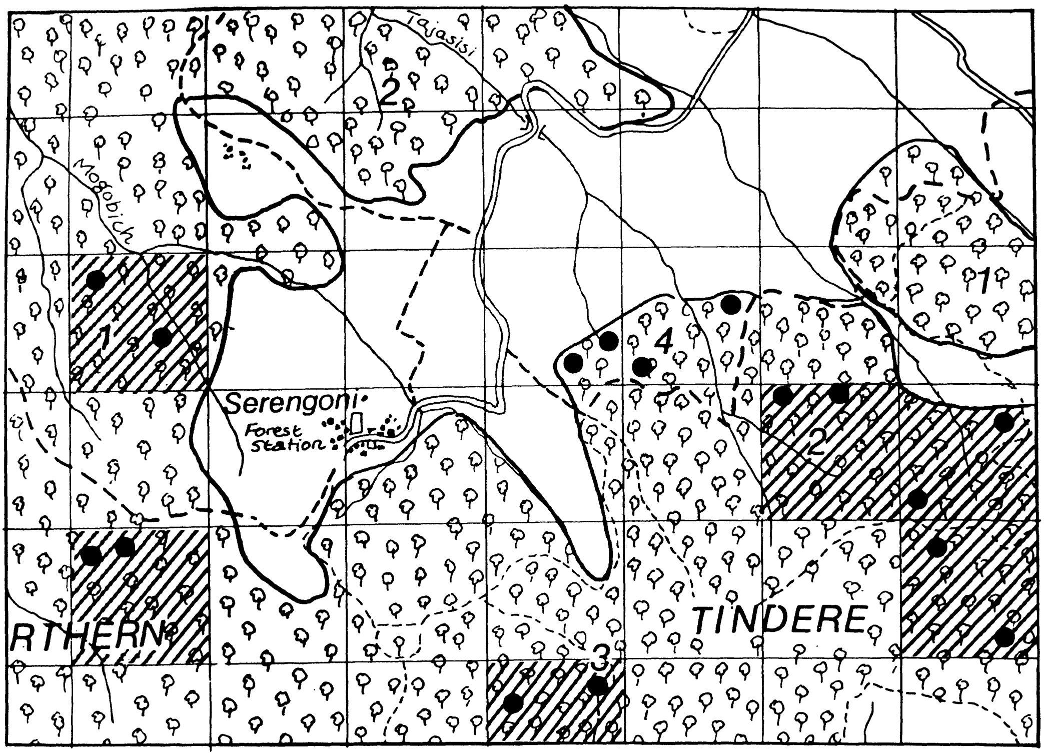

Figure 2.5
Multistage designs

2.3.6 Sampling with partial replacement

At the second and subsequent assessments a review of the information provided by all plots should be undertaken to ascertain whether some plots may be discarded or replaced by new plots either in newly planted areas or on sites under-represented by existing plots. This is known as sampling with partial replacement (SPR). It will increase the efficiency of the sampling design by reducing the number of P1 plots that must be retained permanently, with little loss of precision of growth estimates.

2.3.7 Use all available data when designing the inventory

The sample design need not be the same in all districts and units. It should take account of existing inventories and related studies (for example in Honduras - such as those in the ESNACIFOR school forest, or the USAID Site Productivity Project). Use should be made, whenever feasible, of existing data or of data being collected in other projects. Where sample growth plots exist, even if intended for other purposes, it will be unlikely that new CFI plots will be needed if these can provide the essential minimum data on stand growth. The subsampling for P2 (productivity) plots can be made on any existing sampling pattern.

2.4 Methods of stratification

Stratified random sampling is suggested in the section above as being the most appropriate design for the allocation of P1 plots. The basis of stratification should be some characteristic of the population that is derived independently from the observed growth variables. Examples are species, planting year, soil type, topography or climatic zone. A characteristic that can be extracted from aerial photographs, topographic or soil maps is often convenient (Figure 2.8). Where no such basis for stratification exists it may be possible to group the units of the population on the basis of some site factor assessed during the inventory but independently of the growth data using a post-stratification procedure. Estimates of growth rates for the stratified sample are likely to be more precise than for an unrestricted random sample.

Part of a map of a plantation forest in East Africa is shown in Figure 2.7. This would provide one of the sources of information for planning the inventory, first with temporary sample (T) plots, if required, and then for the location of continuous forest inventory (P1) and productivity (P2) plots.

Figure 2.8 shows the same map divided into two strata, one on each side of the central ridge. Stratum A could represent a zone of higher rainfall than B. The area could also have been stratified on the basis of altitude, soil type, species, age of plantation, or many other criteria.

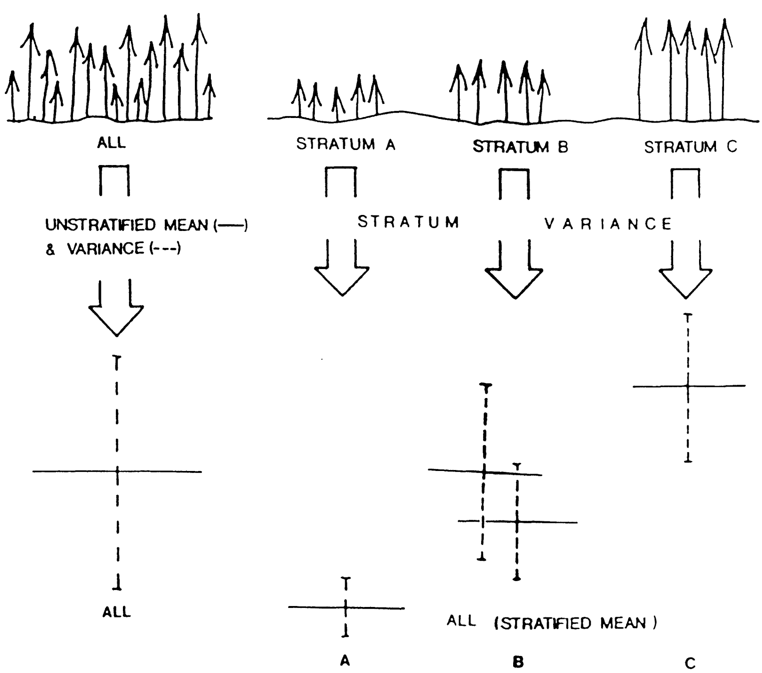

Figure 2.6
Stratification and variance

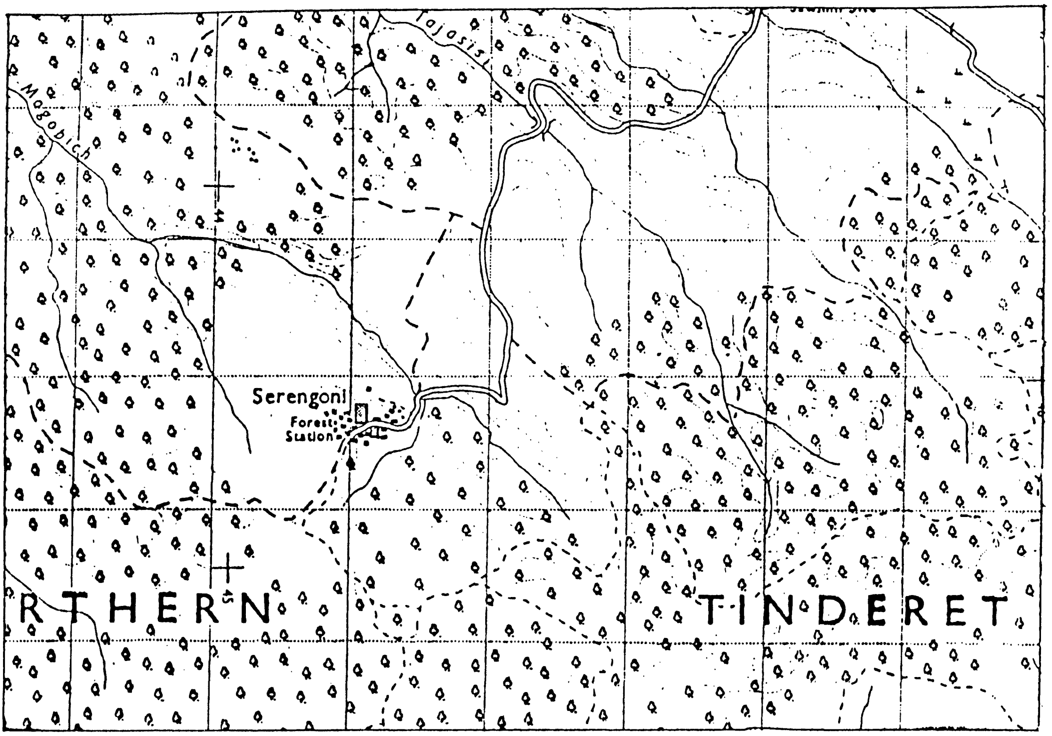

Figure 2.7
Map for planning the inventory

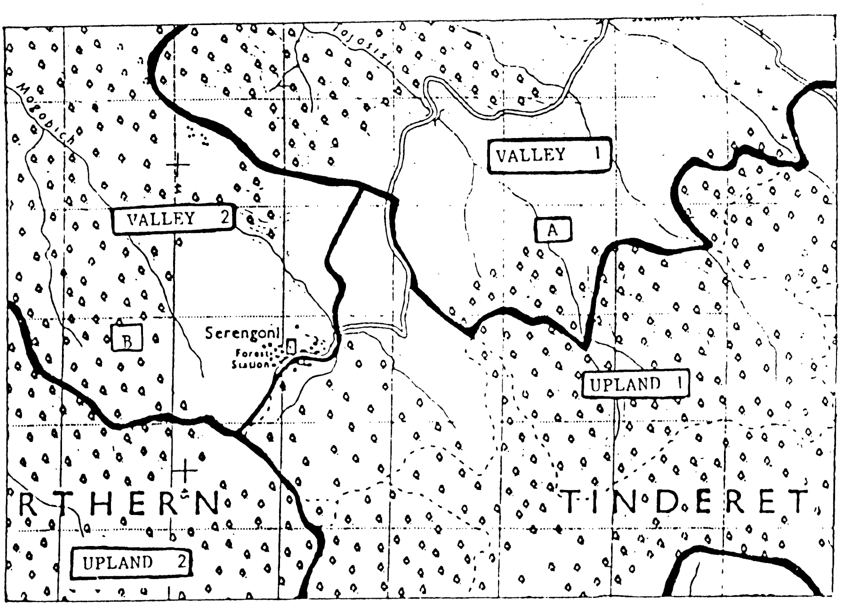

Figure 2.8
Stratifying the inventory area on topographical features

2.5 Selection of variables

A decision made at the planning stage about what is and what is not to be measured is crucial. It is easy to decide to collect as much information as possible from a sample plot or a felled tree in the expectation that it will be useful at some later stage. This can lead to unnecessary cost, and usually does, unless specific plans for the processing of the data and its application to a research or management problem are also laid down at this stage. On the other hand, failure to assess a variable may result in limiting the useful options available to the monitoring programme. For example, should crown length be measured in P1 plots sited in an even-aged plantation? This is not necessary for estimating the normal stand growth parameters but, for the application of many growth models crown length has been found to be a significant predictive variable. Of greater importance, because of the high cost involved, is the decision to measure site variables, such as some physical properties of the soil, or not. The decision obviously depends on the objectives of the monitoring programme (see section 1.3), but there will remain an element of 'star gazing' in deciding whether the inclusion of an additional variable can be economically justifiable.

Table 2.1 gives a check list of variables that may be considered necessary for inclusion in a monitoring programme. These are listed with reference to the various plot types given in Table 1.1.

2.6 Sample size

The sample size refers to the number of sample units at each stage, or each phase, of sampling. The total number of tree diameters, or of any other variable, measured in an inventory will depend also on the size of the sample unit chosen at each stage or phase. A brief note on size of plot, being the primary sample unit recommended for a CFI, is given in Section 2.8 below. The number of sample units (plots) of each of the three observational plot types described in Table 1.1 (T, P1 and P2) and the destructive sample plots (type D) depends on policy, resources available and the variability of the forest being monitored. The following suggestions may be used as a general guide.

2.6.1 Number of T plots required

The number of temporary (T) plots per stratum may be determined by the estimated variability of the population (usually total stand volume, dominant height or basal area) and the sampling error percentage that is acceptable to management ninety-five times out of a hundred. The optimum number of plots in the sample will also depend on the relative cost of locating the plots to the cost of measuring variables within the plots. In most practical situations the desired optimum number is constrained by the funds available for the inventory (see the example in Appendix 10).

Table 2.1

Check List of Variables
to be recorded on observation and destructive sample plots

		+Plot type: P1	P2	D	CA
Living organic matter					
Stand	Age	*	*	*	*
	Mean diameter	*	*	*	*
	Distribution of diameter	*	*	*	*
	Dominant height	*	*	*	*
	Mean height	*	*	*	*
	Height/diameter relation	C	C	C	C
	Total bole volume	C	C	*	C
	Utilizable volume	C	-	*	-
	Branch volume	-	C	*	C
	Above-ground phytomass	-	C	*	C
Tree	Total height	*	*	*	*
	Diameter over bark (ob) at 1.3 m	*	*	*	*
	Diameter under bark (ub) at 1.3 m	-	-	*	-
	Diameters (ob/ub) at other hts	-	C	*	C
	Diameter of sapwood at 1.3. m	-	*	*	*
	Diameter of sapwood below crown	-	*	*	-
	Bole volume	C	C	*	C
	Bole weight	-	C	*	C
	Neighbour-tree weighted distance	-	-	*	*
Crown and foliage	Crown length	-	*	*	*
	Crown diameter	-	C	*	C
	Branch diameters	-	-	*	-
	Heights of branch bases	-	-	*	-
	Leaf area index	-	C	*	C
	Total crown weight	-	C	C	C
	Foliar samples for analysis	-	*	*	*
Understorey vegtn	Total weight	-	C	*	C
	Species abundance	-	*	*	*

(+) see Tables 1 and 2 on pages 5-7. CA = catchment area study.
C = values estimated from regression; R = value obtained from records
* = values measured on this plot type.

Table 2.1 (continued)

Check List of Variables
to be recorded on observation and destructive sample plots

		Plot type: P1	P2	D	CA
Root systems	Density of roots at var.depths	-	*	*	*
	Dimensions of coarse roots	-	*	*	*
	Fine root weight	-	*	*	*
	Root samples for analysis	-	*	*	*
Dead organic matter					
Leaf litter	Weight on successive occasions	-	*	-	*
	Nutrient content	-	*	*	*
Dead branches,	Weight on successive occasions	-	*	-	*
fallen wood, bark.	"	-	*	-	*
Soil					
Physical properties	Drainage (water level in pits)	-	*	-	*
	Organic matter content	-	*	-	*
	Depth of humus	-	*	-	*
	Depth of A0,A1 horizons	-	*	-	*
	Depth to limiting horizon	-	*	-	*
	Texture	-	*	-	*
	Structure	-	*	-	*
	Consistency	-	*	-	*
	Permeability	-	*	-	*
	Bulk density	-	*	-	*
	Available moisture capacity	-	*	-	*
	Actual moisture content	-	*	-	*
	Effective rooting depth	-	*	-	*
Chemical properties	Total nitrogen	-	*	-	*
	Potassium	-	*	-	*
	Calcium	-	*	-	*
	Available phosphorus	-	*	-	*
	Cation exchange capacity	-	*	-	*
	Base saturation	-	*	-	*
	Carbon/nitrogen ratio	-	*	-	*
Climate					
Precipitation	Annual	R	R	-	*
	Growing season	C	C	-	*
	Monthly means	R	R	-	*
	Stem flow	-	-	-	*
	Through fall	-	-	-	*
	Chemical analysis	-	-	-	*

Table 2.1 (continued)
Check List of Variables
to be recorded on observation and destructive sample plots

		Plot type: P1	P2	D	CA
Temperature	Annual	R	R	R	*
	Degree days	C	C	R	*
	Monthly means	R	R	R	*
	Monthly maxima	R	R	R	*
	Monthly minima	R	R	R	*
	Frost days	R	R	R	*
Humidity	Saturation deficit	-	R	-	*
	Potential evapotranspiration	-	R	R	*
	Relative humidity at 0900 hrs	R	R	R	*
Radiation	Latitude	R	R	R	R
	Aspect	*	*	*	*
	Measurements	-	-	-	*
Windspeed	Mean monthly at 2 m above ground	R	R	-	*
Topography					
Altitude		R	R	R	*
Local topographic position		*	*	*	*
Slope, angle and type		*	*	*	*
Exposure		*	*	*	*
Hydrology					
Ground water	Soil water depletion rates	-	-	-	*
	Nutrient content	-	-	-	*
Run-off	Rate	-	-	-	*
	Nutrient content	-	-	-	*
Silvicultural notes					
Phenological observations		*	*	*	*
Pests and diseases observed		*	*	*	*
Chlorosis		*	*	*	*
Dates of thinnings		*	*	*	*
Intensity and type of thinnings		*	*	*	*
Dates and height of pruning		*	*	*	*
Fertilizer inputs and dates		*	*	*	*
Unplanned removals		*	*	*	*
Termite activity		*	*	*	*
Common fungal species		*	*	*	*
Principal mycorrhiza species		*	*	*	*

If CV% is the coefficient of variation in relation to the mean of the population, and E% is the size of the sampling error in relation to the mean (both expressed as percentages) that will be tolerated, and 't' is Student's 't' value at the 5% probability level, then for an unstratified population the number of plots required, (n) is equal to:

$$\frac{t^2 \times CV\%^2}{E\%^2}$$

It is usual to allocate the number of plots in a stratified random sample in proportion either to the area or the variability and cost of each stratum, (see Freese, 1962, p.32, for an example).

2.6.2 Number of P1 plots required

The number of conventional permanent sample plots (P1) will be determined by the need for information on growth and yield for management. If growth models (yield tables) exist for the species and provenances planted on similar sites the CFI plots serve as a dynamic checking system on the applicability of the models. More commonly, CFI plots are required for calibrating new growth models. In this case there should be a minimum of four plots within each age class within each site (topographic) stratum for each major species. As the plantation area is extended to new sites partial replacement of plots can ensure an even distribution throughout the plantation.

2.6.3 Number of P2 plots required

The sample size of productivity (P2) plots will be limited by resources in personnel and money that can be dedicated in the medium term to productivity studies. These will depend on the urgency given by management to the possibility of site decline in successive rotations. It is suggested that two plots be established within each major stratum (species x site) as a minimum programme.

2.6.4 Number of D plots required

The number of destructive sample (D) plots will be related to the number of P2 plots and to the requirements for basic information on volume and phytomass relationships. Depending on the existing knowledge available for a given species, one or more plots will be felled and measured in each major stratum.

2.7 Plot shape

2.7.1 Fixed area and variable-radius plots

Fixed area plots are recommended as being more reliable to maintain in the field. Variable-radius plots can be used for CFI, and where these are already in use they should be continued if they are providing compatible data for yield and productivity studies. Theoretically, variable-radius plots are more efficient.

2.7.2 Square or circular plots

Square or circular plots will normally be used for most forest types. They have the advantage of a small perimeter/area ratio (circular have the smallest). Large circular plots are difficult to lay out on steeply sloping ground. Square plots in regularly aligned plantations can lead to high between-plot variation when a row the length of the side of the square may be included or excluded on the basis of a single distance measurement.

2.7.3 Irregular shapes

Irregularly-shaped plots are not recommended except in exceptional circumstances (to assess a narrow shelterbelt for example). Plot area is a critical parameter and must be assessed with the maximum accuracy. This can be done more reliably in a circular or square plot.

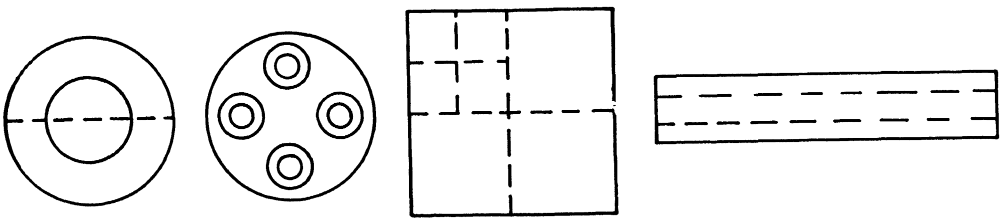

Figure 2.9
Plot shapes

2.7.4 Recommendations

Circular plots should be used in plantations with regularly spaced trees for plot areas up to 0.08 ha (radius of 15.96 m). Square plots should be used in natural stands and open, irregularly stocked plantations, for plot sizes greater than 0.08 ha (see Figure 2.9).

2.8 Plot size

2.8.1 Plot size in relation to the pattern of natural variation

The correct choice of plot size is of great importance. If there is a pattern of variation in the population being estimated, the relation of the size of the components of the pattern (for example, clusters of regeneration, and mosaic of poorly drained hollows in the soil surface) to the size of the sample plot will have a significant effect on the estimated means and variances. The plot should be large enough to include within it variation due to factors that are not of interest to the manager (for example, microclimatic variation, or species groupings) and small enough to give a low within-plot variance in relation to the between-plot variance, for the variables that need to be estimated with the greatest precision.
The plot size will often be determined largely by the number of trees

it will contain at maturity. Less than ten trees will be unsatisfactory. In order to take account of accidental losses a rule of thumb guide is to estimate the plot size containing 20 trees after the last prescribed thinning.

The plot should not, on the other hand, be larger than necessary because the larger the plot the greater the likelihood of including variation that is of interest to the manager. Soil catenary changes for example, may occur within the plot, so that its effect cannot be quantified. There is a greater cost of assessment incurred with larger plots with no greater precision in estimates of stand means.

2.8.2 Recommendations

The following plot sizes are recommended as a rough guide as appropriate:

Energy plantations on very short rotations (>10 years):	0.02 ha
Pulpwood plantations on short rotations (10-20 years):	0.04 ha
Conifer plantations with thinnings on medium rotations:	0.08 ha
Natural pine stands (e.g. P.oocarpa, Honduras):	0.16 ha
Multispecific broadleaved natural forest:	1.00 ha

The decision on appropriate plot size will apply equally to plot types T, P1 and P2. D plot size should be dependent on the number of trees selected for felling to ensure that sufficient observations are obtained for regression analyses. Owing to the time and cost of the field work D type plots will tend to be small.

2.9 Choice between conspicuous and hidden plot marks

The description and permanent demarcation of sample plots is vitally important. In heavily-used forests the plot must be "difficult to recognize for those who do not know where it is, but easy to find for those who do and are looking for it" (Dawkins, 1971).

2.9.1 Advantages of conspicuous plot marks

(i) Conspicuous plot demarcation enables the plot to be easily sighted and relocated.
(ii) It is usually a cheap and easy way to mark a plot, requiring only manual labour and spades or picks to make the ground mark.
(iii) Ground marks which involve, for example, digging holes create no incentive for pilfering.

2.9.2 Advantages of hidden plot marks

(i) Reduced likelihood of interference by inquisitive people.
(ii) The plot will be treated during silvicultural operations in exactly the same manner as the remainder of the stand which it is designed to represent.

2.9.3 Disadvantages of conspicuous plot marks

(i) Conspicuous plot marks, such as line cutting and ground marks, may necessitate disturbance on an unacceptable scale.
(ii) The plots may be made so conspicuous that they attract special attention during harvesting or treatment (or from local people who have access to the forest), thus making them less representative of the whole stand.

2.9.4 Disadvantages of using hidden plot marks

(i) The cost of using metal markers and detectors, combined with their doubtful permanence may be unacceptable.
(ii) The detector must be reliable and robust and easily portable in forest conditions and fast in locating markers.
(iii) The life of both marker and detector may be shortened under tropical conditions and any replacement of parts or servicing will be a problem.

On balance, permanent visible monumentation, in the form of cross-cut trenches in the plot centre, is recommended as the most appropriate choice for marking plots. Other methods are illustrated in Figure 2.10.

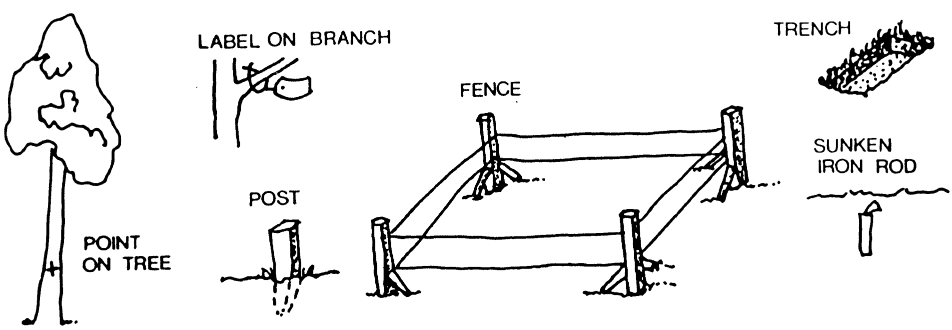

Figure 2.10
Plot markers

3

implementation

3 Introduction: how to use this part of the manual

The text of this chapter gives detailed instructions on the layout and measurement of the different types of plot used in a monitoring programme, on destructive sampling and on methods of measuring the most commonly recorded variables. Suggestions are also made on procedures for collecting sample material. When establishing a full monitoring system the text should be followed from beginning to end systematically.

However, the text will be probably be used more frequently as a reference manual and as a reminder of specific procedures. The first section gives, therefore, a summary of the main variables that should be recorded in the different plot types. Reference should be made to this part, where the appropriate section or field form to be used is indicated, until the layout of this chapter becomes familiar.

The paragraph numbering in this chapter is more detailed than in other chapters to assist in referencing and updating with supplementary material in the future.

3.1 Summary of variables to be measured in all plot types

3.1.1 Tree growth on P1 (conventional inventory) plots

3.1.1.1 On successive occasions a number of measurments should be made.

(i) For all trees greater than 9.5 cm dbh (greater than 4.5 cm for fast-growing tree crops) record:
- number
- species
- diameter at 1.3 m
- indices of disease, pest and mechanical damage.

****
SECTION 3.12/1
FIELD FORM 2
****

(ii) Take a systematic sample of ten or more trees and record the total height (for estimation of the regression of height on diameter from which stand mean and dominant height will be derived).

****
SECTION 3.12/3
FIELD FORM 3
****

(iii) For trees less than 9.6 (or 4.6) cm dbh and greater than 2 m height count by species in two size classes:
- less than 4.6 cm
- greater than 4.5 and less than 9.6 cm.

****
SECTION 3.12/2
FIELD FORM 2
****

(iv) To assess regeneration of the main crop record:
- presence/absence count in four 1 m^2 quadrats
- plot description.

****
SECTION 3.12/8
FIELD FORM 2
****

(v) To assess thinnings and other controlled treatments record:
- observable changes of drainage, soil compaction, erosion
- changes in understorey and ground flora
- occurrence of disease, pests and biotic influences
- damage to plot marks - record on the plot history sheets.

****
SECTION 3.10
FIELD FORM 1
****

3.1.1.2 Some measurements should be made once each rotation.

(i) Describe the location and specifications of the plot and general site information.

****
SECTION 3.11
FIELD FORM 1
****

(ii) Record the tree position in plot (for plot map).

****
SECTION 3.8
FIELD FORM 4
****

(iii) Record the other plot vegetation:
- ground cover, the type and main species
- understorey, the type and main species.

****
SECTION 3.11/5
FIELD FORM 1
****

3.1.2 Tree growth on P2 (Productivity) plots

All standing trees should be measured as in Section 3.1.1 and other additional measurements should be made.

(i) For all trees greater than 9.5 cm dbh (greater than 4.5 cm for fast-growing tree crops) record:
- height to base of crown
- crown radius - only in low density stands
- crown class code
- diameter over bark at base of crown
- increment boring at base of crown - optional
- increment boring at 1.3 m - optional

(ii) For all trees less than 9.6 cm dbh and greater than 2 m height count by species and calculate mean height.

(iii) Measure rate of leaf fall.

****
SECTION 3.14/2
****

(iv) Collect sample of litter from 4 sample points over area of 20 x 20 cm (Figure 3.4).

****
SECTION 3.14/3
****

(v) Collect soil samples from 4 sample points and at 3 depths.

****
SECTION 3.14/3
****

3.1.3 Bole and crown measurements on D (Destructive sample) plots

(i) Measure the standing trees as for P1 plots (Section 3.11) then follow procedures for selecting and measuring felled sample trees for estimation of bole volume, bark volume, leaf weight distribution and leaf area index.

(ii) Select ten sample trees (four from smallest 20%, four from largest 20% diameter size-class and two median trees) while still standing. If the tree is large climb into crown with ladder and remove branches one by one from as high as practicable, lower them to ground with rope and pulley, measure and record in field:
- branch height
- branch diameter 5 cm from branch base
- green weight of large live branches
- green weight of small (less than 2 cm diameter) branches
- green weight of foliage
- green weight of new and old cones separately.

****
SECTION 3.15/2
FIELD FORM 5
****

(iii) After felling measure and record:
- green weight of top, or the whole crown in the case of small trees, in same categories as above
- volume measurement in 3m sections over and under
- bark.

****
SECTION 3.15/2
FIELD FORM 6
****

- bag sample of foliage and twigs
- bag sample of cones (ca.150 g for dry weight/green weight estimation)
- cut sample disk (8 - 10 cm in length, 3 - 4 cm thick) to represent:
  - large branchwood
  - small branchwood
  - bole at 1.3m mark
  - 50% crown-free bole
  - bole at base of live crown
  - bole at mid-point of crown
  - foliage from top third of living crown (ca.100g for chemical analysis).

****
SECTION 3.16
****

(iv) For two median trees cut disks 3cm wide every 3m (every 1m above 10 cm bole diameter) for stem analysis in the laboratory. This is optional.

(v) Select a sample of leaves for leaf area estimation. LAI is estimated from the regression of leaf area on leaf weight.

3.1.4 <u>Tree volume measurements</u>

(i) If D plots have not been measured, or if insufficient trees have been measured for the construction of volume functions, it may be necessary to select further sample trees for volume measurement.

****
SECTION 3.15/2
FIELD FORM 6
****

(ii) Volume of felled trees: select 'plot' and sample trees as for D plots, but omit all measurements except that of volume measurement in 3m sections, both over and under-bark.

(iii) To measure the volume of standing trees select a sample of P1 plots allocated proportionally to stratum areas. Within each plot either:

(a) select ten trees as described for D plots above, or,
(b) select five trees, one within each 20% diameter class of the plot diameters.

The second alternative may be preferred for small plots (less than 0.08 ha). Upper-stem diameters are estimated with an optical dendrometer or telerelascope. Tree volumes are then calculated from these observations with the help of a calculator or computer. A program is available for direct calculation of bole volume from observations of upper stem diameters made in 'telerelascope units' when a telerelascope is used (PPR program TELREL).

****
APPENDIX 14
FIELD FORM 7
****

The number of volume sample trees required will be determined by their variability and will be shown by the regression analysis included in the micro-computer package PPR (program VOLREG). Eighty to one hundred trees are usually sufficient for the construction of a reliable volume function for a single species and ecological region.

****
SECTION 3.14
SECTION 3.16
FIELD FORM 7
****

3.1.5 Measurements on tree roots

Roots washed and separated from soil cores collected from both P2 and D plots may be weighed and samples measured for length/weight relationships to be estimated. Details of the method using excavated trenches are also given. Further research is needed before firm recommendations can be given on the best methods of determining (a) root biomass and (b) fine root turnover.

3.2 Selection and location of T and P1 plots

In developed countries, or wherever intensive forest management is being practised and geological, soil and growing stock maps have been prepared, the information for stratifying the forest for the purpose of sampling is already available. In most tropical regions more information of the distribution and variability of site types within the area of the forest enterprise is required. As indicated in Section 2.3, the most satisfactory design for a continuous forest inventory under such conditions is one which is considered as a subsample of a growing stock inventory of temporary sample plots. This will ensure that P1 plots are located objectively. P2 plots may then be selected at random from the list of P1 plots subject to the constraints mentioned below (3.2.3). D plots will be located in the vicinity of selected P2 plots. The determination of the location of plots must be random (use a random selection method) in order that they are a representative sample of the population.

3.2.1 Setting up the sampling frame in the office

The sampling frame may be based on a site-type map, aerial photographs, a growing stock map or exploratory inventory depending on the conditions and information available. The first step is to stratify the area into relatively homogeneous units within which sampling will be carried out in one, two or more stages. In the description below a two-stage sample is given as an example.

The forest resources of a country are normally already stratified at a number of levels. The first level is commonly divided into administrative regions. These are frequently subdivided for ease of management into individual areas of contiguous forest of similar type - for example a plantation which may then be subdivided still further into compartments. It is assumed that a number of compartments will be physically similar in terms of the species, age of the trees and environment. These compartments may be aggregated as a basis for stratification. Within each stratum two or more first-stage units (compartments) may be randomly selected. In such an example the second stage is represented by two or more sample plots located randomly within each previously selected compartment.

However, where the information exists a more satisfactory basis for stratification may be based on site variation using topography, soil type or vegetation type, to define the strata boundaries.

3.2.2 <u>Selecting the sample units for a two stage random sample</u>

3.2.2.1 First stage sample units

(i) Mark the primary sampling units on a topographical or other convenient map at a scale of about 1:50,000. This scale or smaller (1:100,000) is convenient for the overall planning stage. The primary units may be forest compartment boundaries, or some natural unit recognizable on aerial photos.

(ii) Mark the stratum boundaries on the map using aerial photographs and other supplementary information (contours, soil, maps, results of previous surveys and so on).

(iii) Place a grid marked on a transparent sheet as an overlay on top of the map.

(iv) Within the range of the forest area use randomly selected x and y coordinates and select **two** compartments within each stratum.

3.2.2.2 Second stage sample units

For the second stage select two pairs of random coordinates to locate the position of two sample units (or plots) within each first-stage compartment. A compartment map at a scale of 1:10,000 is suitable for this.

3.2.3 <u>Location of T and P1 plots on the ground</u>

3.2.3.1 Locate the access points to each plot location marked on the large scale (1:10,000 or larger) map. Determine the orientation angle in degrees and distance in metres of the plot from a convenient access point.

3.2.3.2 When in the field it is vital to follow the instructions drawn up in the office very closely unless these are found to be impracticable. This could occur if the predetermined plot position was found to land on an inaccessible swamp or steep rock that was not marked on the maps used. It is advisable to select additional plot locations in the office to replace those which cannot be found in the field.

3.2.3.3 Ensure that an accurate record is kept of the plot location and identification, preferably on a map overlay or on the map itself.

3.2.3.4 Draw a sketch map of the compartment or block showing the plot position and unique identification number for the plot file together with details of the access point and directions for locating the plot in the field.

3.2.3.5 It is useful for both field and office work if plot locations can be marked on the relevant aerial photographs. Once an individual plot location has been determined and the point of access decided it is possible, providing the photographic scale and the adjustment for magnetic north are known, to calculate the compass bearing and distance to the plot centre, using a ruler and set square. Using stereoscopic pairs of aerial photographs, points of easy access can be identified and those plots falling on completely atypical, unrepresentitive locations, such as a river bank or a gap, can be eliminated and an alternative selected.

3.2.3.6 A similar routine would be followed if a systematic sample is being laid down. Both the position of the first plot location and the orientation (azimuth) should be selected by a random number procedure. An example of how this may be done is given as Figure 3.2. In this case a grid of sample points is being laid down as a second-stage sample unit within randomly selected first-stage units (compartments).

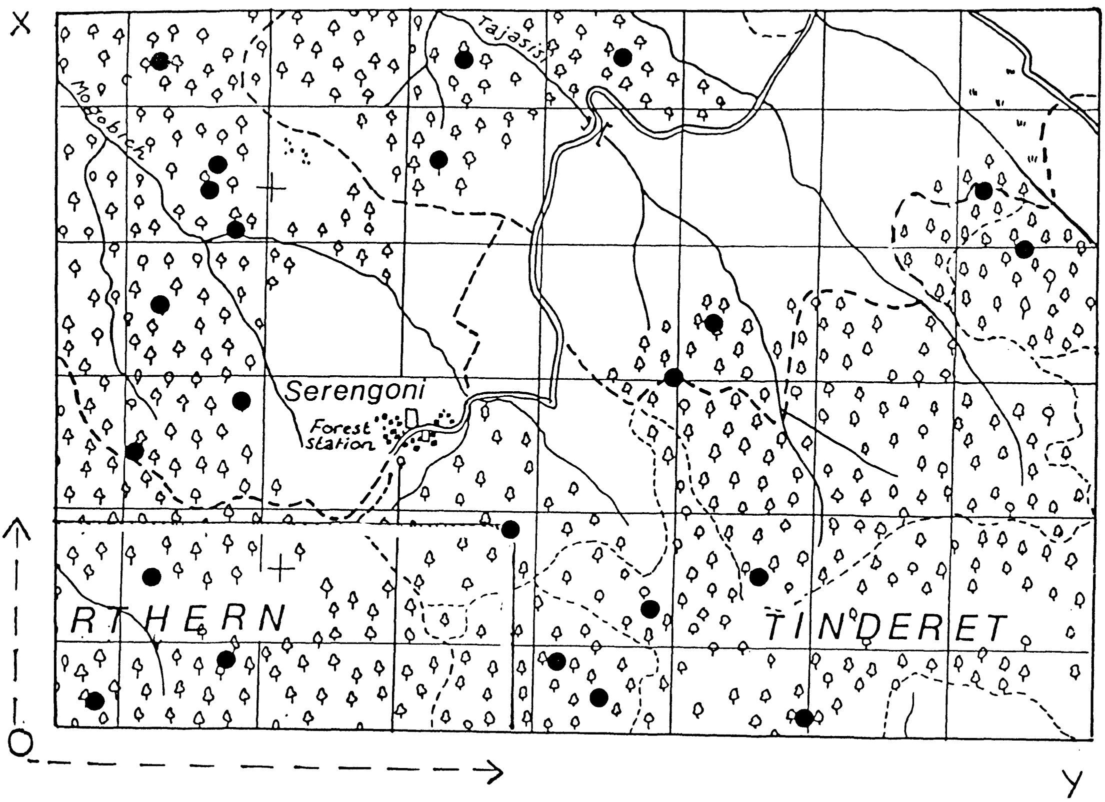

Figure 3.1
Map of plot locations

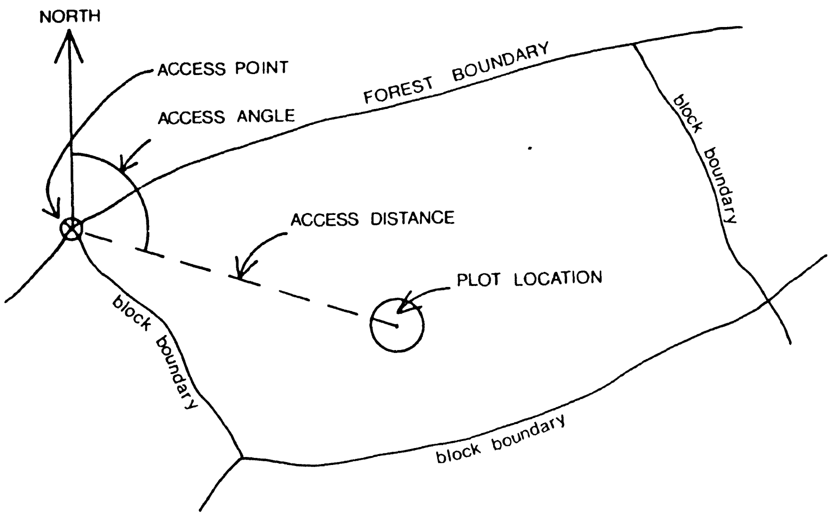

Figure 3.2
Marking the access point

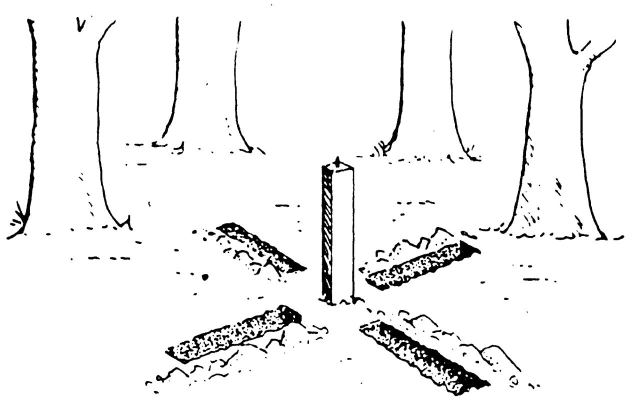

Figure 3.3
Marking the plot centre

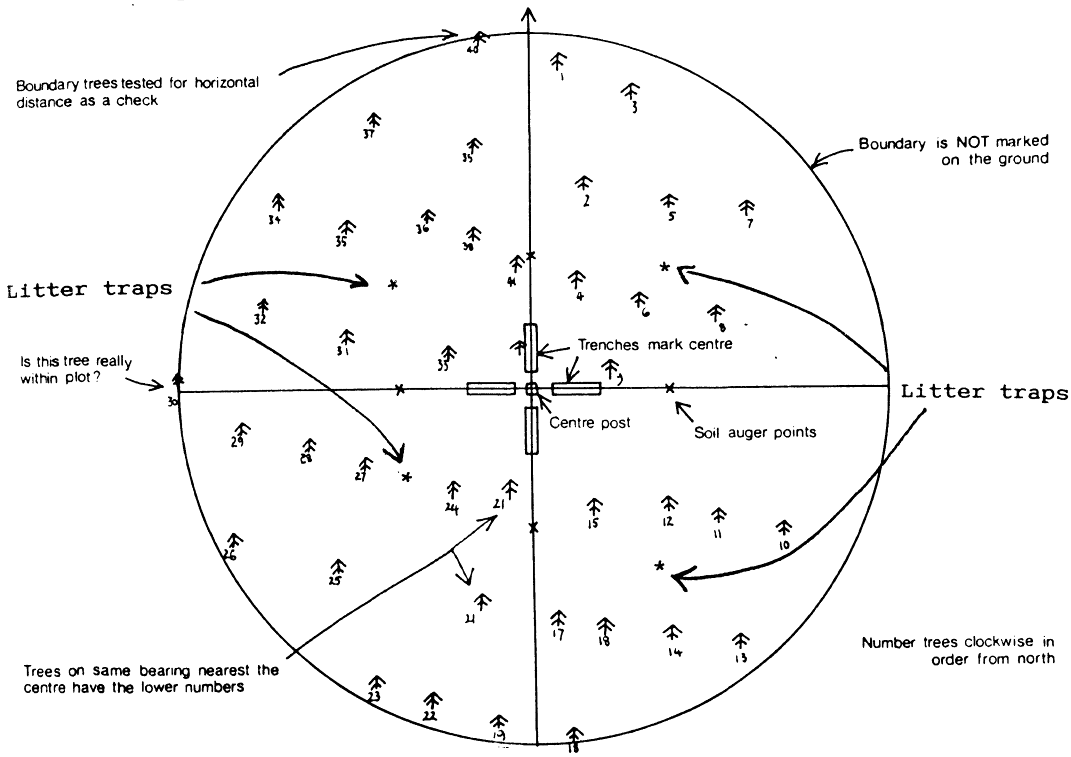

Figure 3.4
Marking a circular plot on the ground

3.3 Selection and location of P2 plots

P2 ('productivity') plots are selected under some subjective constraints in order to avoid inaccessible areas, atypical, very open or damaged stands.

3.3.1 Selecting plot locations in the office

3.3.1.1 Make a list of all P1 plots and mark, with defined reasons, all plots which are unsuitable as subsample plots for productivity studies.

3.3.1.2 Select the required number of plots from the remainder using a random number selector. Where two P1 plots have been sited within each block or compartment, at the first random selection stage, it is necessary to select a sub-sample of blocks in which both P1 plots will be treated as P2 plots.

3.3.1.3 The number of P2 plots selected does not depend on any statistical calculation but on the availability of personnel and resources to carry out the detailed observations required. Where there is concern over the possibility of site degradation due to the management system applied it is advisable to establish at least one P2 plot in each stratum of the forest or plantation.

3.3.2 Location of P2 plots on the ground

Follow the procedure for P1 plots in the Section 3.1.3.

3.4 Selection and location of D plots

3.4.1 Locating D plots

D plots (destructive sample plots for phytomass estimates) are located systematically in association with the selected P2 plots. Site the D plot on the same contour level at a distance of 100 m from its associated P2 plot.

3.4.2 Number of D plots

The number of D plots will be less than the number of P2 plots. In some circumstances no D plots may be needed. This could be the case for an organization where many experimental studies have already been carried out, providing much of the data on stem, branch and foliage volumes, weights and calorific values that are needed for the proper evaluation of the field measurements in the growth (P1) and productivity (P2) plots.

3.5 Marking circular plots on the ground

3.5.1 Plot access points

Mark the access point with a notice board giving the plot identification, distance and bearing from magnetic north. Indicate also whether P2 and D plots exist at the same location.

3.5.2 Plot centres

3.5.2.1 Insert a 10 x 10cm wooden post, treated with preservative, in the ground at the plot centre, leaving 50 - 100cm above ground level. A length of rigid plastic tubing would also be suitable. Hammer an 8cm nail, centrally, into the top of the post, for holding the linear tape.

3.5.2.2 Dig trenches 30cm wide and 25cm deep along the north-south and east-west axes of the plot as shown in Figure 3.3 leaving at least 1 square metre at the centre as a firm observation point. Trenches should not be dug where the disturbance caused is undesirable.

3.5.3 Plot boundaries and trees on the perimeter

3.5.3.1 The area of the plot will have been determined according to the recommendations given in Section 2.8. Radii of circular plots of different areas for a range of slope angles are obtained from the program given in Appendix 7. The BASIC program, SLOPE, will be found on the PPR disk. It may be modified to give radii and diagonals for other plot sizes and shapes.

3.5.3.2 The plot boundary need not be marked in any way on the ground (see Figure 3.4). Any tree with a centre point 1.3m above ground level which is **outside** the plot boundary should **not** be included for assessment (as shown in Figure 3.7). It is of great importance that only trees within the precisely defined plot area are measured. Since the plots are relatively small samples of the total stand, any errors would be magnified when calculating stocking, basal area and standing volume on a hectare or gross area basis. Linear tapes must be calibrated frequently and used carefully, neither stretching them unduly nor allowing slack or kinks. With practice in laying out small circular plots, the approximate plot perimeter can be optically estimated. It is then essential to recognize the trees near the boundary and to determine their horizontal distance from the plot centre accurately. Never 'step' the tape in an attempt to estimate horizontal distance. Always hold the tape parallel to the ground and measure the slope with a clinometer.

3.6 Marking square or rectangular plots on the ground

3.6.1 Procedure

3.6.1.1 The procedure for determining the access point and locating the plot centre is similar to that for circular plots (see Fig. 3.5).

3.6.1.2 Lay out the diagonals of the square (or rectangle) in NE-SW and SE-NW directions, using a tape and clinometer to obtain the correct horizontal distance. On irregular ground it may be necessary to divide the diagonal into sections of roughly constant slope, each being measured separately.

3.6.1.3 Insert a 'preserved' post of approximately 10cm diameter into the ground at each corner after checking lengths of each side.

3.6.1.4 Trenches may be dug just outside each corner of square or rectangular plots.

3.6.1.5 Locate further marks according to Figure 3.5 as appropriate.

3.7 Marking individual trees

3.7.1 Marking trees

3.7.1.1 Attach numbered cards to all trees falling within the prescribed plot area when laying out the plot for the first time, to ensure that all trees included within the plot have been allocated a unique number. The numbers should be made permanent at a later stage (see 3.7.1.3 below).

3.7.1.2 It is only necessary to check a few marginal trees carefully with a linear tape and hypsometer to ascertain the horizontal distance and to determine whether a tree is within the plot. Slope corrections for the commoner plot radii used are given in Appendix 7.

3.7.1.3. Paint a horizontal mark at 1.3m above ground level (measured on the uphill side of the tree) facing the plot centre with permanent enamel paint. In D plots all trees scheduled for felling will be numbered and a ring painted on the tree at breast height to provide the datum point for bole measurements on the felled tree.

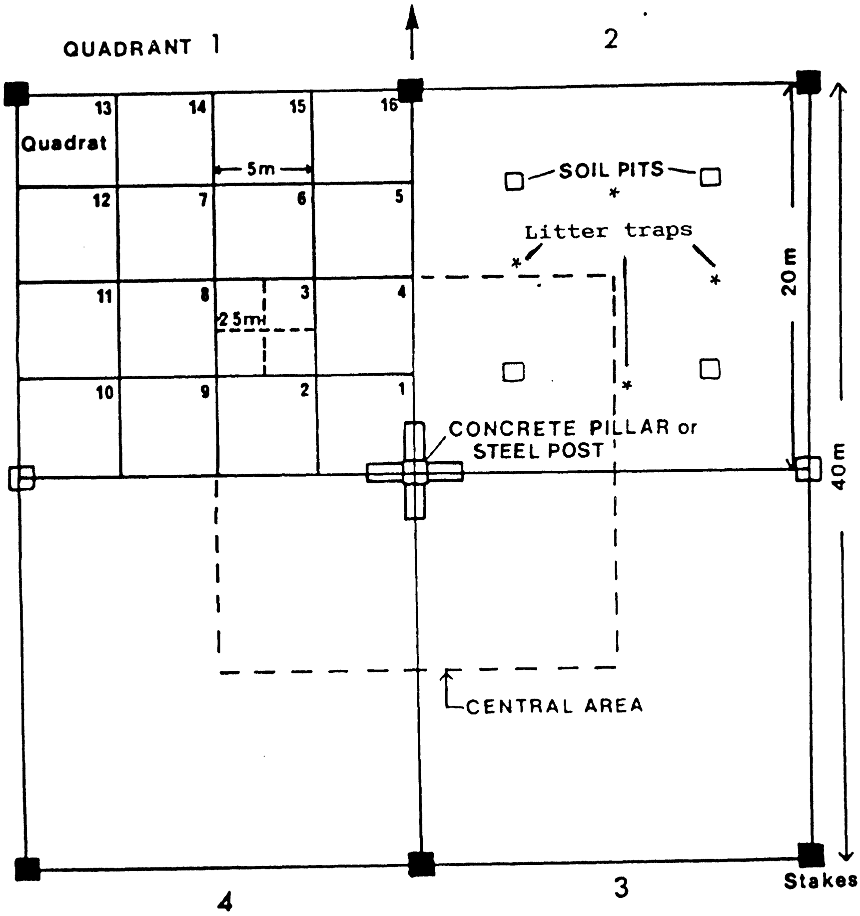

Figure 3.5
Marking a square plot on the ground

3.7.1.4 Number and mark all trees greater than 9.5cm dbh in P1 and P2 plots with a painted number or plastic label. Number trees consecutively from north in a clockwise direction as observed from the plot centre. If two trees lie on the same radius the tree nearest the plot centre has the lower number.

3.7.1.5 Numbering in P1 plots will normally first be carried out when the majority of trees have reached the 10cm diameter class, that is all trees greater than 9.5cm. However, in fast-growing, short rotation crops and 'energy' plantations it may be necessary to number trees to a lower diameter limit, say 5cm.

3.7.1.6 Ingrowth trees will receive the next highest available number irrespective of their position.

3.7.1.7 Paint the tree number (unless inconspicuous marking is essential) at a height of 2m facing the plot centre. Less conspicuous markings can be made using a 'Dymo' label attached to a copper (or other soft metal) nail inserted at a height of 2m on the bole or by using plastic tags loosely wired to the bole or large branch. Steel nails, or other material that could damage equipment when the tree is harvested, should never be used.

3.8 Mapping and registering plots

Tree positions should be recorded in P1 and P2 plots using polar coordinates (that is the bearing and horizontal distance of each tree from the plot centre), unless the plot is large and rectangular when cartesian coordinates may be more convenient. Field Form 4 in the Appendix may be used for recording polar coordinates. These data are all that are needed for the production of a scale plan of the plot using a microcomputer program (see Chapter 4). The plot plan will show the location of all trees (above a specified lower diameter say, 9.6cm) with their identification numbers and diameters (Figure 3.4).

3.9 Additional work for P2 plots

It is beyond the scope of this manual to give full details of the measurements and observations that should be carried out in the 'productivity' (P2) plots. These will vary with the objectives in each particular project and will depend on the importance of the growth factors at each site. For example it may be of particular importance to measure soil water depletion rates, in which case three or four access tubes for neutron probe insertion and recording should be installed in each P2 plot. In other cases data for evaluating the nutrient balance and dynamics of the stand may be a main objective (Figure 3.6). This would require special equipment to be installed in some or all of the plots.

The quantification of changes in the nutrient budget of the stand during the life of the crop, and from rotation to rotation, is a key objective of most monitoring programmes. Until process models of nutrient cycling have been developed for the particular forest type being monitored, the most robust method of observing changes in the nutrient status of the site is to determine the static nutrient budget of the stand (phytomass and soil) on successive occasions. As soils are frequently highly variable over short distances, successive samples must be taken from the same position in the plot on each occasion.

The number of soil samples needed will vary according to the forest, soil type and intensity of management. As a general guide it is recommended that soil samples are collected at four points within a P2 plot and at three depths at each point (see Figure 3.4 and below under Section 3.13). The samples from the same depth will be aggregated from each of the four sample cores for bagging, transport and analysis. The object is to give a measure of the average soil condition of the plot. A soil auger should be used for collecting samples when possible but a small soil pit may, alternatively, be dug. A pit may cause an undesirable disturbance in a P2 plot.

For assessing the nutrient budget, foliage and litter must be sampled and analysed at regular intervals. The method recommended for the collection of foliar samples is detailed under Section 3.14. No special installation is required in the plot. Litter traps, however, must be constructed and installed within the P2 plot. The mean litter weights collected at intervals from four traps within a plot will give better estimates than one large trap.

The plot layout should be completed by the marking of small quadrats, also indicated in Figure 3.5, for the recurrent recording of regeneration and the ground flora. These should be marked in such a way as to avoid trampling during inspections and assessments.

In areas subject to heavy grazing some or all sample plots should be fenced as a protection from domestic livestock. In some cases where a large plot is being installed only part of the plot may be fenced to demonstrate the effect of protection. An alternative to fencing the observation plots is the establishment of designed trials (an experiment type E5 could be added to Table 1.2, perhaps) to evaluate grazing effects in specific localities.

To summarize, the following additional installations will be required for establishing the plot on the ground when monitoring site change under the influence of a tree crop and other effects:

- location of soil sample points or soil pits
- installation of litter traps
- demarcation of regeneration and ground flora quadrats
- fencing.

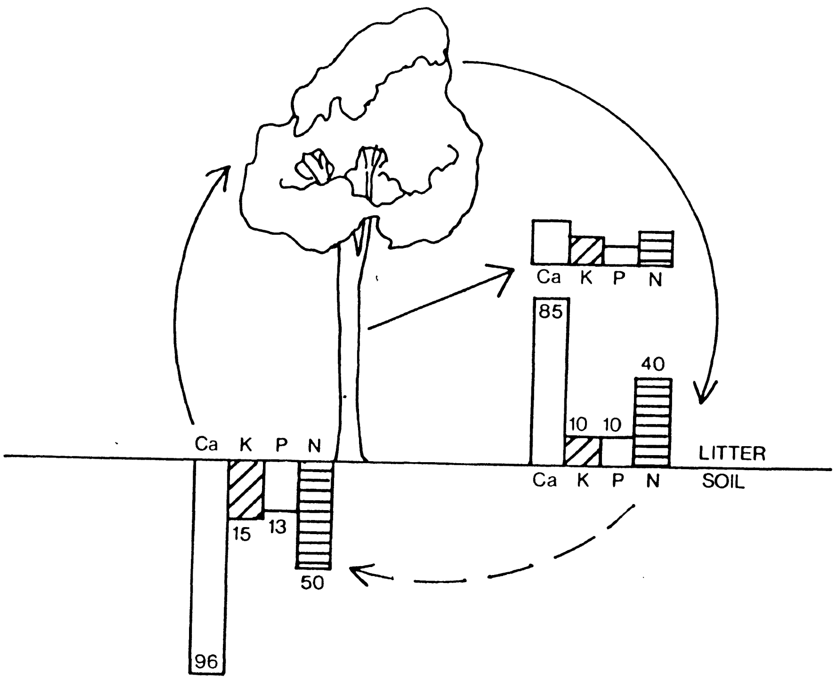

Figure 3.6
Nutrient budget diagrams

3.10 Use of field forms

Examples of a number of 'model' field forms are given as appendices to this manual. These constitute the core of the manual. Much time will be saved if these forms are used, not necessarily as they are, but as check lists of the variables that should be recorded at the different stages and in the different plot types of a monitoring programme. Some of the forms present the field data in a convenient form for their transference to a microcomputer using one or other of the programs described in Chapter 4. This is no longer of great importance however, since 'front end' programs can be prepared quite easily to permit the efficient data capture of information presented in any form. The following sections describe how to collect the field data necessary to complete the field forms.

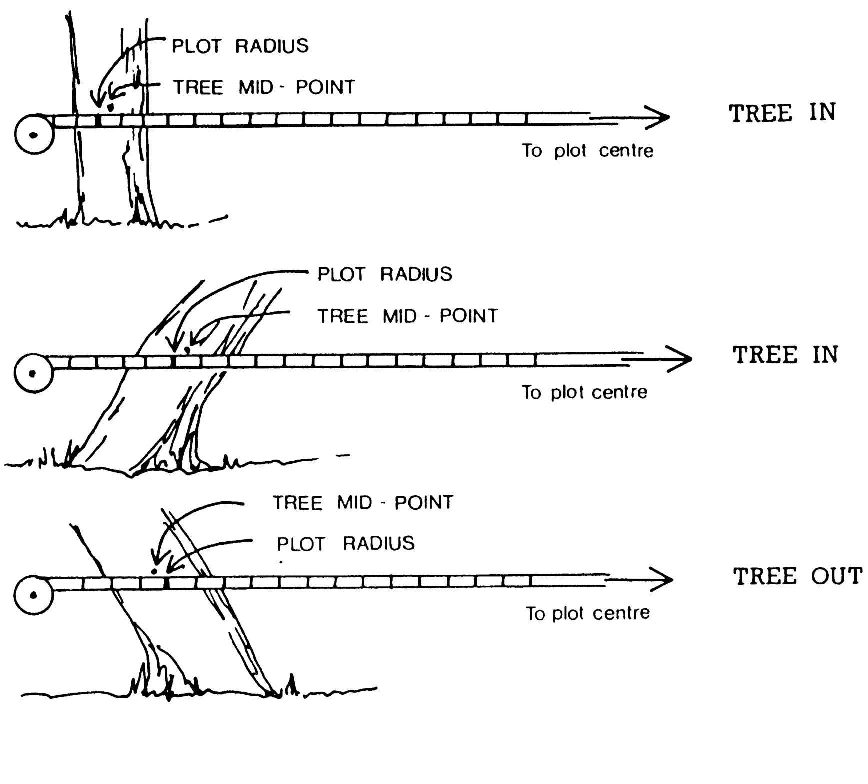

Figure 3.7
Boundary trees

3.11 Site variables

These are recorded on 'Field Form 1 - General plot description' as an example. In order to avoid long verbal descriptions and possible ambiguity many of the site variables have been coded. There are various ways in which such data may be recorded. For experienced field teams it may be possible to enter the codes directly on to Form 1. An alternative is to write brief notes in the field which can be coded later in the office. A third choice is provided by the form with boxes in which the range of codes is specifically listed.

Such forms should be completed for both P1 and P2 plots. In the former the entries may be less detailed than for the latter. For example, under the 'soils' a general indication of soil texture should be given and later supplemented by the detailed information from the analysis of the soil samples collected from P2 plots.

Site and stand data that should be recorded on this form fall under six headings:

- locality
- climate
- topography
- soils
- forest crop
- disturbance.

Some experience is needed before the site description can be completed satisfactorily. In order to record the maximum amount of information in a compact form suitable for a database file, the majority of the site details, should be entered as class codes. The list of the class codes are given in Appendix 2. Form 1 and Appendix 2 should be studied together before attempting to complete Form 1.

Some of the entries on Form 1 depend on information available from maps and official records. Others depend on direct observation. The 'soil' section requires some knowledge of soil science and some competence in plant identification. It will rarely be possible for one person to complete the site details on a single visit.

In practice it may be preferable to record a verbal description on the field form for coding later in the office. Whatever the case it is necessary to have a clear idea of the significance of the variables listed before unambiguous descriptive terms can be used.

Most of the terms should be familiar to a trained silviculturalist and the application of the appropriate codes should require no elaboration. The short notes that follow aim to clarify a few particular aspects of site description.

3.11.1 Locality

All plots within a country should have a unique number. This should itself be sufficient to identify a plot. For purposes of sorting and stratification of plots the full plot identification code will be used for the database. In Kenya this is an eight-digit code composed from left to right as follows:

- plot	3	digits
- country	1	digit
- district/forest	2	digits
- stratum	1	digit
- compartment	1	digit

The digits used here for plot, country, district and compartment constitute a unique reference. The digit coding of a stratum will depend on the basis of stratification which, as indicated in section 2.4, may be planting year, species, topography, climatic zone or soil type. This identification code is an extension of that applied in the past to sample plots. In practice local systems of plot numbering are likely to be adopted, following the same principles of unique plot identifiers.

The map reference should include a map series number and scale followed by a sheet number and coordinates. The form used will vary between countries and regions and, therefore, a free format entry is allowed as in Field Form 3 (see also number in column 1 of Field Form 1). Access points may be expressed in the same form as the map reference, or a text description where no map coordinates are be given.

3.11.2 Climate

The minimum data that can be sensibly used for quantifying climate as a factor in forest growth studies are monthly rainfall and temperature, and minimum and maximum monthly temperatures. Although rainfall and temperature are the two major factors, and are the most readily available on forest stations, there are other factors such as wind, radiation, humidity and sunshine which ideally should be included in a climatic classification.

Numerous systems of classification exist which attempt to integrate the components of climate. Systems designed to differentiate between bioclimatic zones are of little use in growth studies where microclimatic differences within a forest cause important growth differences within small areas. Köppen's system of climatic classification is one of the most widely used of the general systems and should be included here as a means of comparison between plots of different countries and regions.

Of greater potential value for growth comparisons in time and space is the soil water balance. This is the balance between the income of water from precipitation and the outflow of water by evapotranspiration and runoff. It is mainly a climatic balance because precipitation and evapotranspiration are active factors of climate, but it is also dependent on soil factors which determine the maximum water holding capacity.

Calculation of the water balance depends on an estimate of the soil water holding capacity and the potential evapotranspiration. Both

Penman's and Thornthwaite's methods have been used to estimate the latter. The only data required for the calculation of Thornthwaite's PE (potential evapotranspiration) are mean monthly temperatures and latitude. See Burley and Wood (1976, pp.185-190), and Figure 3.8.

With Penman's method, surface water evaporation (EO), usually estimated from mown grass growing with ample supply of water, is first calculated. Maximum and minimum periodic temperatures, wet and dry bulb temperatures and hours of sunshine have to be recorded to carry out the necessary calculations. Computer programs are available to facilitate these. Penman's estimates of EO must be multiplied by a factor to find actual evapotranspiration (Et). The ratio Et/EO changes as a soil dries and is not constant.

In localities where Thornthwaite's PE has been calculated this should be recorded on Form 1. Penman's EO could alternatively be entered here, with a suitable amendment in column 2. Otherwise the data on latitude and temperature would be used later to calculate PE. The object is to ensure that the minimum necessary data are recorded for calculation of the water balance.

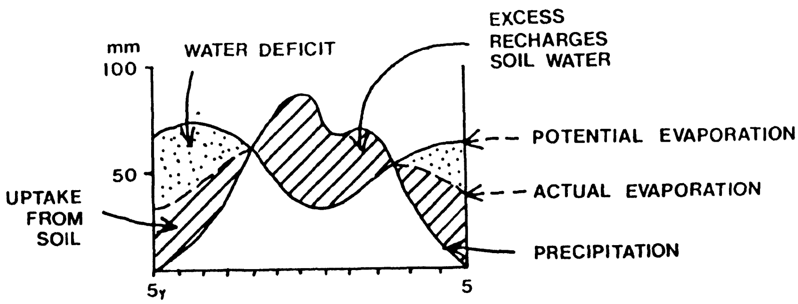

Figure 3.8
Water balance diagram

3.11.3 Topography and catenary position

Position on slope, or catenary position (Figure 3.9), is often a significant variable in growth prediction equations. Soil depth, drainage and other factors may be correlated with catenary position. The class codes, together with the figures, should need no further explanation.

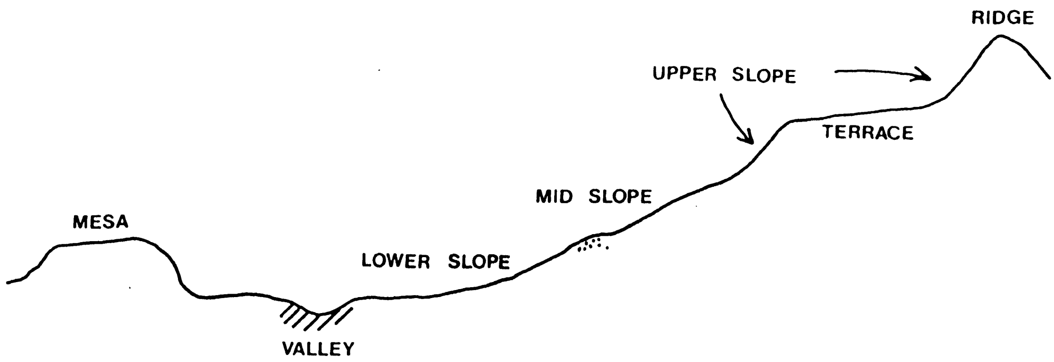

Figure 3.9
Topographic position

3.11.4 Soils

The variables listed are all easily assessed in the field. Some of the terms used have been defined as class codes in Appendix 2. When the soil observations are made in a P1 plot only a general indication of the surface soil (down to about 20 cm) need be made. It may be convenient to extract soil at the four soil sample points shown in Figure 3.4 to make the necessary manual and visual tests. The average coded values only will be recorded in the database. If a P1 plot is later selected as a P2 plot for more detailed studies, soil samples should be taken from the surface litter and at three depths for laboratory analysis. The results from the laboratory analysis should be recorded on a separate form, which is not given here as this will vary from laboratory to laboratory.

3.11.5 Forest crop

Information about the forest crop that remains relatively unchanged throughout a rotation is recorded on Form 1. This includes identification of the dominant canopy species, together with provenance and seedlot numbers if planted. In multispecific natural stands with more than one dominant species in the sample plot it is necessary to record the code for each (to a maximum of five).

The record of tree positions should also logically be included on Form 1. To avoid unnecessary duplication of forms tree positions may be recorded on Form 4 for both P1 and P2 plots. In the former case columns 1, 2 and 7 - 9 only would be completed. The last column would be used to indicate the species code in a multispecific stand. A plot diagram will be produced by microcomputer from this data that can be useful for relocating trees at subsequent assessments.

The species codes used are those of Webb et al.(1984) and cover the large majority of tropical planted species.

Both understorey and groundflora should be described by coding and, if required by species lists, under the forest crop section of Form 1. Understorey refers to trees and woody species growing under an overstorey. There is no upper height limit. An understory is frequently absent in plantations. The understorey should be distinguished from the ground cover which refers to herbaceous plants, including grasses and ferns as well as low shrubs that are not forming an understorey. The broad coding that may be useful for stratifying plots on different soil and topographic types should be supplemented by noting the principal species in the understorey and ground flora on page 2 of Form 1. When changes of a significant nature occur during the life of the stand these will be noted on supplementary pages attached to this form.

3.11.6 Disturbance

As much detailed information as possible of biotic and climatic damage in the sample plot at the time of its establishment should be recorded here. Changes during the course of observation should also be recorded on the continuation sheets to Form 1.

3.12 Recording stand variables in P1 plots

3.12.1 Diameter of standing trees in the 9.5cm class and above

The diameter of all trees of dbh greater than 9.5cm will be measured and numbered individually. (Figure 3.10). It is assumed that the 9.5cm diameter class (trees with a diameter at 1.3m above the ground level greater than 9.5cm and less than 10.6cm) is the lowest for which the trees attain a utilizable volume. This is a generalization and should not prevent smaller size classes being numbered and measured individually when the need arises.

These are recorded in the main section of Form 2, at least at the first assessment. For subsequent assessments a computer-printed form will probably be supplied with details of earlier measurements. Individual tree diameters should be recorded to the nearest millimeter.

3.12.2 Standing trees of less than 9.6cm dbh

Small trees need not generally be individually numbered on the plot nor on the field form, but may be recorded at the base of Form 2 as a tally in two size classes, less than 4.5cm and 4.6 to 9.5cm. This may include young coppice shoots. In coppice it will be more convenient to use Form 2b where the growth of shoots can be related to permanently numbered stools.

3.12.3 Height of trees with diameter over 9.5 cm

3.12.3.1 A systematic sample of trees (usually selected from the tree number list) within the plot should be measured for total height. Sufficient trees should be measured to give a reliable regression of tree height on tree diameter from which stand dominant height and stand mean height will be estimated.

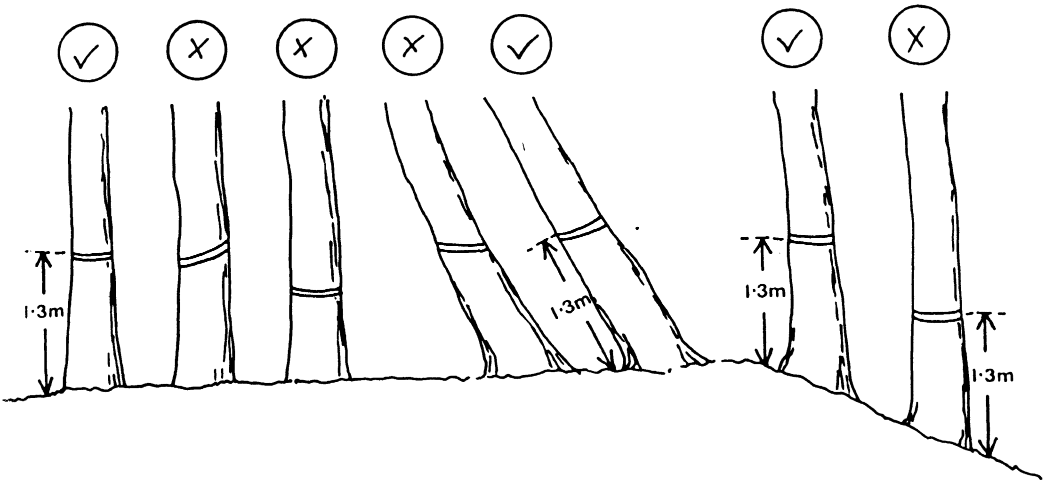

Figure 3.10
Measuring diameter

3.12.3.2 Stand dominant height (equivalent to the mean height of the hundred largest diameter trees per ha) is an indicator of site. As such it is a basic variable in growth studies and therefore tree heights must be assessed with care (Figure 3.11). Mean height will also be estimated from the same regression.

3.12.3.3 Height will be measured to the nearest whole metre.

3.12.3.4 If the P1 plots have been selected from a larger number of temporary plots (T) the data for the regression can be obtained by selecting the tree nearest the plot centre on each T plot for height measurement. The data may be stratified later in order to compare regressions when there is a possibility of a site effect on the height/diameter relationship.

3.12.4 Measurement of tree volume

3.12.4.1 If the full CFI programme is being carried out the data necessary for the construction of volume functions and tables will be obtained from D plots, otherwise either existing volume tables may be applied or data of felled tree volumes must be specially collected. The procedure is the same whether the trees are being felled in D plots or being selected from the stand in the neighbourhood of P1 or P2 plots (which can be assumed to be on the same site type). Volume functions are, of course, required for the summary of normal CFI plots. In some cases volume tables may already exist. It is essential to check the validity of such tables to the stands under observation

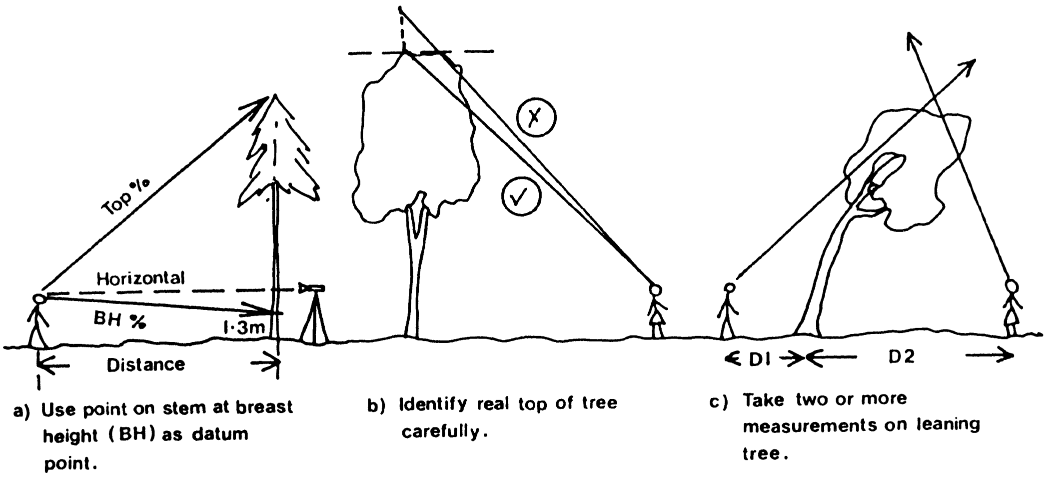

Figure 3.11
Measuring height

by measuring the volume of a small sample of trees in each stratum and comparing the observed values with those predicted using the volume function or table.

3.12.4.2 If there is no suitable validated volume table available it will be necessary to measure volume on felled or standing trees. The trees should be selected for volume measurement from the same strata and sites as the sample plots to which the consequent volume functions will be applied.

3.12.4.3 If volumes of standing trees are being measured the procedure for sample tree selection in P1 plots will be the same as that recommended for D plots in Section 3.14.1.

3.12.4.4. See Section 3.14.2 for the procedure for selecting and measuring the volume of felled trees.

3.12.5 <u>Selection of sample trees for volume measurement</u>

3.12.5.1 When D plots are being established volumes of a systematic sample of all trees in the plot will be measured.

3.12.5.2 Where a programme with only P1 plots is being applied trees should be selected for felling outside the sample plots, 100 m away on the same contour. (Follow the instructions for D plots, Section 3.14).

3.12.6 Volume measurement on standing trees

3.12.6.1 A telerelascope or other optical instrument mounted on a firm tripod should be used for measuring the upper stem diameters needed for volume estimation of standing trees (Figure 3.12). A hand held relascope is not suitable. See Appendix 5 for a description of the recommended procedure.

3.12.7 Injury and disease

3.12.7.1 The presence and degree of physical damage to a tree caused by, for example, high winds or disease should be coded and recorded.

3.12.7.2 Obviously any such loss of increment could have severe repercussions for present and future rotations. Use the codes suggested for the stand and site variables recorded at plot establishment on Form 1. A local system of coding should be devised and the codes entered against the tree number (if over 0.5cm) on Form 2 in the column indicated.

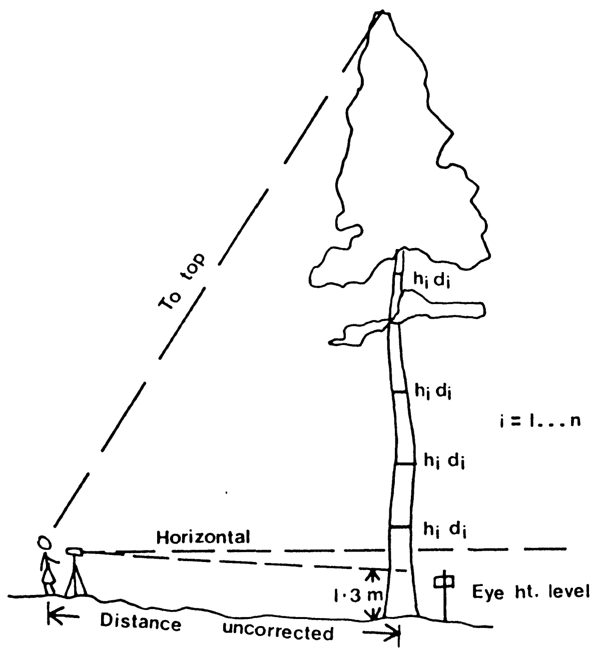

Figure 3.12
Measuring volume of a standing tree

3.12.8 Regeneration

Regeneration includes seedlings and saplings that may or may not be the same species as the main crop. In a plantation only seedlings of the dominant canopy species should be recorded as regeneration.

3.12.8.1 Define regeneration as regrowth less than 2 m high.

3.12.8.2 Assess regeneration either by counts within each of four small quadrats (1 - 4 m^2) or as presence and absence in small quadrats. The size of the quadrat in the latter case will depend on the criterion established in every 2.5 m^2 quadrat in a sample survey. This would indicate a potential stand density of 1600 stems per ha.

3.12.9 Age determination

3.12.9.1 In an even-aged plantation age should be defined as decimal years since sowing. Therefore, when analysing the data the nursery period should be added to the 'age since planting' which is often, incorrectly, used for the age of the plantation. In most tropical plantations the nursery period is so short as to make this adjustment necessary for particular research studies only.

3.12.9.2 In most natural stands, age cannot be determined with any confidence. The trees may be of several age classes, either as small groups or as an intimate mixture of age classes. The range of ages in a natural coniferous stand may not be evident from superficial inspection.

3.12.9.3 There are two ways of determining age in such stands, counting growth rings and observing growth in the sample plot from the time of regeneration. Neither are satisfactory, the first because of the poor correlation between growth rings and annual growth under tropical conditions, the second because reliable growth data will not be available until observations have been made throughout a rotation.

3.12.9.4 Growth rings may be counted on increment cores extracted from near the base of a standing tree or on stem disks. It is easier to distinguish an annual growth ring from a false ring when using disks taken from felled trees. This, of course can only be done on material from D plots. Analysis of increment cores taken from P1 plots observed over a period of 10 years or more should be carried out with the aim of understanding when 'false' or 'missing' rings occur and developing better methods of growth assessment for the future. It is necessary to:

- determine age from records (record on Form 1) and check the range of age classes in the plot

- extract cores from bark to pith for all species and size classes in a plot for which the tree ages are known

- assess the probability of growth rings being annual rings by calibration of ring counts on trees subject to wounds, or with incisions made at a specific date in the past.

3.13 Recording variables from productivity plots (P2).

All the assessments recommended for P1 plots will be made in P2 plots together with the following additional measurements.

3.13.1 Crown variables

3.13.1.1 The size, shape, physical condition and relative position of the crown of a tree (Figure 3.13) determine the quantity and quality of incident light that falls on the leaves, rate and degree of photosynthesis and the consequent rate of growth. Dominance classes remain of great value in analysing the role of individual trees in the stand at a qualitative level (Assmann, 1970). A simplified coding of crown class, form and vigour is given in Appendix 2. This may be used in completing Form 3 (standing tree heights) for both P1 and P2 plots. Two simple quantitative measures of the crown, the crown length and crown diameter, have frequently been used as predictor variables in growth functions and should be recorded.

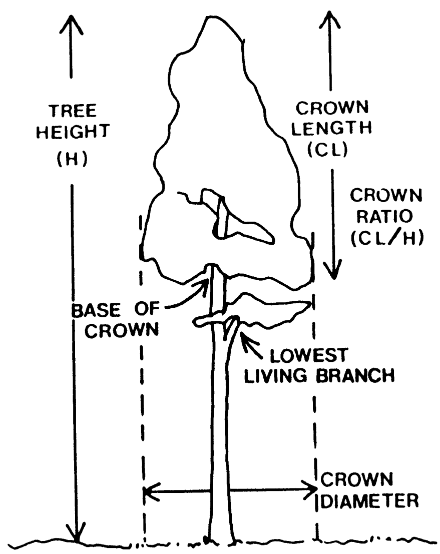

Figure 3.13
Crown measurements

3.13.1.2 Crown diameter or radius can be measured using a circular protractor scale on the tripod of a telerelascope together with formulae that adjust for slope and angle of sight. More cheaply, a Suunto hypsometer can be used to view the edge of the crown with the scale at 90 degrees to locate a point on the ground directly below it. A tape then gives the distance to the tree bole which is equal to the crown radius. At least four measurements of crown radius should be made to give a mean crown diameter. It is neccessary to:

- measure height to crown base to the nearest metre for large trees but to the nearest 0.1 m when possible for smaller trees

- classify crown according to codes for dominance class, form and vigour

- whenever possible measure crown radii.

3.13.2 Sapwood area at the base of the crown

A close relationship has been found in many tree species between the sapwood area at the base of the crown (point on the bole just below the lowest living whorl) and the quantity of living foliage measured as weight or area, thus providing a possible index of current tree vigour (Figure 3.14). This is however difficult to measure. The diameter of the bole at the base of the crown can be estimated when measuring other crown variables with an optical instrument, such as the telerelascope (see Field Form 7). Investigations by destructive sampling in D plots will be required to estimate the parameters relating sapwood area below crown to other more easily measured variables such as sapwood area at breast height, for example. In the absence of such destructive samples the sapwood area can be measured from increment cores taken at the base of the crown of small and medium-sized trees using ladders. In young trees in which heartwood has not formed in the stem at the level of the base of the crown the sapwood area at breast height (1.3 m) may be measured instead.

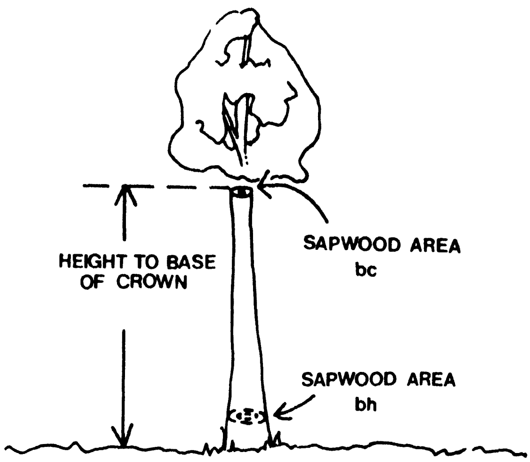

Figure 3.14
Sapwood area at base of crown

3.13.3 Leaf area index

Leaf area per tree, often expressed as the leaf area index (LAI, see Section 1.5), can be determined by destructive sampling at the same time as bole and branchwood volume and weight are determined as described in Section 3.15 below. This may not always be convenient and is not suitable when LAI determinations are required frequently. For many physiological measurements involving light interception, photosynthesis and stomatal conductance, estimates of LAI at the time of measurement are needed. Similarly, because LAI changes throughout the year due to new leaf growth and the fall of old leaves, annual estimates may be misleading. One method used for assessing LAI on young eucalypt trees by Matthews (1988) is described here.

3.13.3.1 On small trees the total number of leaves on each branch of each sample tree is recorded. Ten branches are selected systematically through the crown length. Each branch represents a crown stratum. A sample of ten leaves is taken from each branch. The outlines of the sampled leaves are traced on paper, and later, cut out for length, width and area determination with a leaf area meter. The sample of leaves is bulked, dried at 105° F for 48h and weighed for specific leaf area (area of leaf per unit weight) determination. Total leaf area is calculated from the sum of the product of mean leaf area for each crown stratum and the total number of leaves in the stratum. LAI is then calculated as the ratio of total leaf area to ground area occupied by the tree. This is obtained from crown measurements (Section 3.13.1) or from growing space estimated from plot maps graphically by calculation of available growing space (APA) for which computer programs are available.

3.13.3.2 Rapid estimation of LAI may be possible through direct measurement of light interception by the crown using solarimeters after suitable calibration. Calibration requires the physical measurement of leaf area related to tree size, crown structure, tree social position and site. To obtain this inter-related information the procedures for destructive sampling given below (Section 3.15) should be followed.

3.14 Collection of sample material from P2 plots

3.14.1 Foliage samples

3.14.1.1 Samples of foliage should be collected from the top third of the crown and from the outer third of that part of a branch carrying vigorous foliage. Collections should be made at the end of the growing season, if only one annual collection can be afforded, or at intervals throughout the year.

With the recommended equipment (light aluminium ladder and park pruner with 6m aluminium sectional handle, (Figure 3.15) it should be possible to cut foliage samples from the upper part of the crown on standing trees up to 12 m tall. In order to take foliage samples from taller trees it will be necessary either to climb into the crown or to fell the tree. The latter is recommended whenever possible. It is quicker and safer than climbing. In stands managed for growth of saw timber the foliage sampling should be coordinated with routine thinning operations. Otherwise the sample trees are felled and left in the stand.

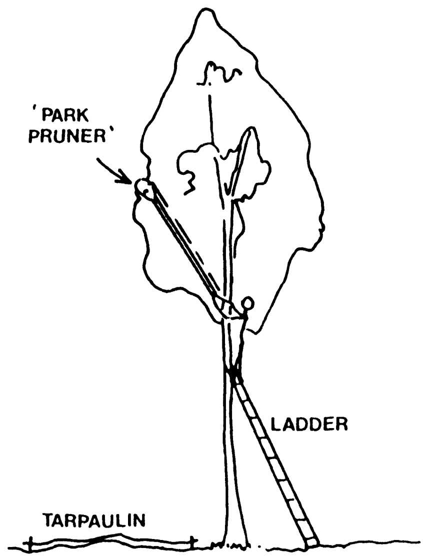

Figure 3.15
Collecting foliage samples

Reminder: the foliage is taken from the end of a lateral branch cut within the top 33% of the living crown.

3.14.1.2 The sequence of operations, when the trees are felled, is:

- select five trees from the stand surrounding the permanent P2 plot representative of the range of diameters within the plot

- mark the 1.3 m point on the bole before felling

- after felling record stump height, height to base of crown (below first living whorl of branches) and total height

- measure the equivalent of 10% of the crown length from the top and cut a branch, or branches bearing foliage nearest to this level

- strip the needles or leaves from the branch and place in a paper bag with a label

- weigh the foliage and bag in the field. If a field balance is not available use a plastic bag (to avoid moisture loss) and remove to a laboratory for weighing with the minimum delay

- place the paper bag in a plastic bag with a second label and tie loosely

- transport to a laboratory quickly and oven dry then weigh the foliage (still contained within the inner paper bag) as soon as possible

- do not leave the sample in plastic bags while moist as the samples will ferment

- transport dried samples to the laboratory for chemical analysis.

3.14.1.3 If the trees are less than 12 m tall, or when it is easy to climb into the crown the sample trees will be measured standing and not felled. In this case the sample trees will be selected from within the plot and the same tree numbers will be sampled on successive occasions.

3.14.1.4 When trees are felled the opportunity should be taken to measure the bole in sections for volume (see Section 3.15.4.3).

3.14.2. <u>Rate of leaf fall</u>

Leaf fall is recorded using litter traps. A possible way of doing this would be to locate four litter traps within a P2 plot as indicated in Figures 3.4 and 3.5.

See Appendix 4 for instructions for constructing a simple litter trap.

3.14.3 <u>Collection of soil and litter</u>

Soil and litter sampling are done simultaneously and at the same sample points suggested in P2 plots. Soil may be collected using an auger or by digging small pits. A suggested procedure follows.

3.14.3.1 Place groundsheet near the sample points (if disturbance is to be avoided this should be just outside the plot).

3.14.3.2 Near the the four points indicated in Figures 3.4 and 3.5 but at equidistance between four or six trees:

- record the litter depth, if any

- cut a 30 x 30 cm x depth of litter block with sharp knife and place on the groundsheet.

3.14.3.3 To collect the litter sample:

- separate branchwood and twigs, cones and foliage

- aggregate the separate portions from the four sample points and place in 20 x 30 cm paper bag

- label, place in outer plastic bag and tie.

3.14.3.4 To describe the soil profile:

- remove vegetation from a slightly larger area at the same four points and dig a small pit with a hoe or panga (machete) down to 50 cm or rooting depth, whichever is less.

- record depth of humus layer and other visible horizons.

- record effective rooting depth (put greater than 50 cm if not limiting in pit)

- note texture, consistence, stoniness etc as on Field Form 1.

3.14.3.5 To collect soil samples:

- collect samples of 150 - 200 g at three levels,

  0 - 5 cm: cut wedge from the side of the pit with knife
  10 - 15 cm: cut wedge from the side of the pit with knife
  30 - 50 cm: scrape soil from a 5 cm layer as deep as possible in this zone or at the base of pit, avoiding soil falling from higher layers, or use an auger to these depths

- mix the samples from the four sampling points for a given depth and put in double plastic bag with label between the two bags

- note sample serial number on Field Form 1.

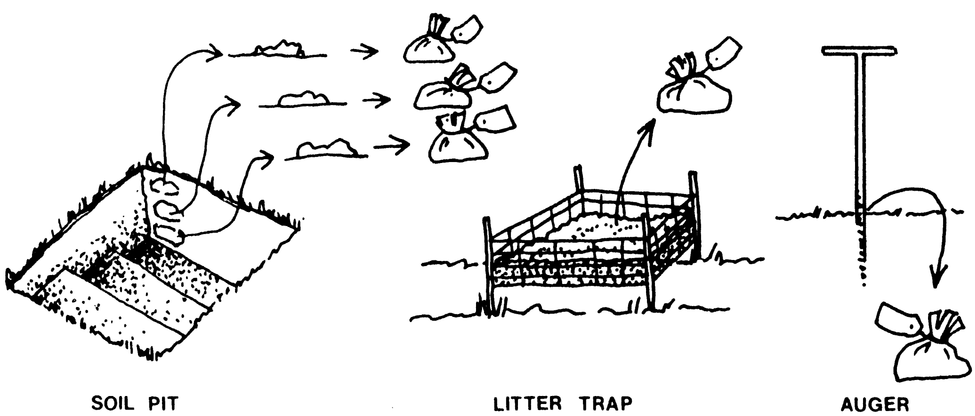

Figure 3.16
Collecting soil and litter samples

3.14.4 Collecting root samples

Root mass and dimensions may be estimated from soil samples extracted with a Jarrett borer or soil corer, by cutting out blocks of soil from the soil profile pit or by using the trenching technique. All these methods involve a great deal of disturbance in the plot and should be carried out in the destructive sample (D) plots rather than in P2 plots (see Section 3.16.4). However, methods are under investigation for monitoring of root growth using small non-destructive samples.

3.14.4.1 Bagging and labelling litter

The sample should weigh approximately 100 g and fit conveniently into a paper bag of 20 x 30 cm which is then placed in an outer plastic bag of similar size. Complete two labels, following the example shown in Figure 3.17, place one with the sample in the inner bag and the other in the outer bag. Close bags with wire ties for transport to a laboratory for drying and weighing.

```
              --------------------
     /           301/K/TIM/3/6  |   Plot identification as on Form 1
   /                        10  |   Sample point
 0                      1/1/83  |   Date
   .                        25  |   Serial number
     .                          |         (repeat on reverse side)
              --------------------
```

Figure 3.17
Example of label for a litter sample

3.14.4.2 Bagging and labelling soil

The sample should weigh approximately 200 g. Bag and label as for litter but the inner bag will be of strong plastic, not paper. An example of a label for the soil sample is shown in Figure 3.18. Record the serial number on form 1 with the sample point number and depth.

```
              --------------------
     /           301/K/TIM/3/6  |   Plot identification as on Form 1
   /                      15/3  |   Depth of soil/Subsample point
 0                      1/1/83  |   Date
   .                       152  |   Serial number
     .                          |         (repeat on reverse side)
              --------------------
```

Figure 3.18
Example of label for a soil sample

3.15 Assessing and recording variables in the phytomass (D) plots

3.15.1. Objectives of destructive sampling

Three main classes of data will be collected from the destructive sample plots:

- bole and bark volume measurements for developing volume and taper functions and tables
- data for determining both dynamic and static relationships between easily measured parameters, such as dbh and age, with other tree parameters that are difficult to determine, such as branch, foliage and root weight, LAI, and wood density
- data describing and quantifying tree structure, including crown size and shape, leaf area distribution within the crown in relation to neighbour tree, and root distribution and structure.

In the process of collecting data for the first two objectives essential information is obtained for the scientific management of social forestry programmes as well as for the industrial plantations and natural forest areas.

3.15.2 Preparatory measurements

All measurements recommended for P1 plots should be completed prior to selecting trees for destructive sampling.

3.15.3 Selection of sample trees

Selection of trees for felling will be made from those larger than a certain minimum diameter - 10 cm for pine, say, or 5 cm for an energy plantation. To select the trees:

- from those trees greater than the minimum diameter identify the smallest and largest diameter tree numbers
- to estimate the diameter range from which to choose the sample trees for volume measurement trees, add 5 cm to the smallest tree dbh and select 4 trees from within the diameter range. If there are less than four trees select the tree nearest in size to the upper diameter limit
- in the same way subtract 5 cm from the largest diameter and then follow the routine given above to select four more large diameter trees
- select another two trees from the middle of the complete range of diameters measured. Each of the ten selected trees is measured and sampled individually.

3.15.4 Assessments made on single trees

In addition to assessment of total phytomass, distribution of woody material and foliage within the crown may need to be quantified. To prevent destruction of the crown and loss of measurable material in larger trees it is recommended that the lower branches are cut one by one on the standing tree before felling. After felling measure the volume of the bole both under and over bark as described below (Section 3.15.4.3). In some cases, where stem analyses are to be carried out, cut disks for measurement of growth ring diameters. Branches that can not be cut from the standing tree due to their inaccessibility should be measured after the tree has been felled together with the leading shoot. Branches should not normally be cut separately from trees with dbh of less than 20 cm. In this case all measurements should be done on the ground after felling.

3.15.4.1 Before felling:

- mark 1.3 m (breast height) on the bole of the selected trees
- climb into the crown with a ladder and remove branches one by one from as high as practicable, lowering them to the ground with a rope and pulley, for measurement and recording
- leave the top 10% of crown on the tree undisturbed
- measure the height of the live and dead branches above the 1.3 m mark.

3.15.4.2 To measure cut branches:

- measure branch diameter 5 cm from branch base
- measure the green weight of all branches greater than or equal to 2 cm diameter
- measure the green weight of all branches less than 2 cm diameter
- measure the green weight of all foliage
- measure the weight of new and old fruit or cones separately.

3.15.4.3 To measure the bole of the felled tree (Figure 3.19):

- enter dbh and total tree height to nearest 0.5 m on Field Form 6
- place linear tape along bole with the 1.3 m mark at the previously marked breast height
- measure overbark bole diameters at the base, at 1.5 m and 3 m from ground level and at every 3 m thereafter up the bole to a limiting diameter of say 7 cm

- using a bark gauge, measure the bark thickness at two points at the same points of measurement. If preferred, for greater accuracy, remove the bark and remeasure the diameters under bark. In the latter case a slight modification to Field Form 6 and the input to the VOLCOMP program will be required.

- complete assessments of remaining branches as above

- ensure the remaining 10% of the crown material, although weighed is kept separate from the rest

- measure total tree height to nearest 0.5 m

- measure green weight of top to nearest 0.2 kg

- cut stem disks for stem analyses if required.

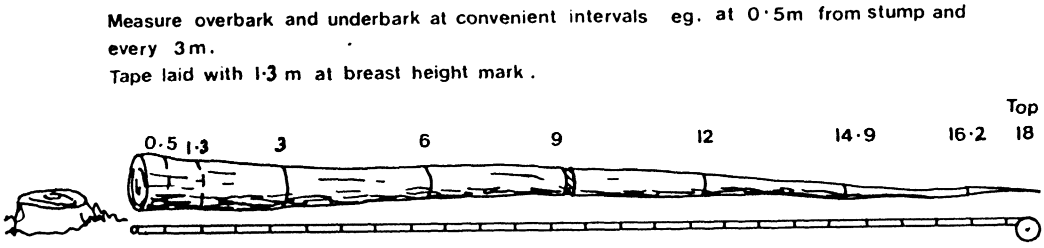

Figure 3.19
Measuring felled tree for volume

3.16 Collection of sample material from D (destructive sample) plots

Samples of bole, branch and foliage material are selected for drying, chemical analysis and stem analysis. All material should be weighed in the field with a spring balance and results are entered on Field Form 5. Only samples that are to be taken to the laboratory for drying will be labelled (and bagged, as appropriate) following the example in Figure 3.20.

It is important that samples are clearly and precisely labelled.

301/K/TIM/3/6	Plot identification as on Form 1A
14	Tree number
4/12/6	Whorl number/Whorl height/Serial number
1/1/83	Date
6	(Repeat serial number on reverse)

Figure 3.20
Example of label for branchwood or foliage sample

3.16.1 Samples for leaf area estimation

Collect foliage of three branches, one from each third of the living crown for evaluation of leaf area in the laboratory. Select the branches from the measurements recorded on Form 5 at the appropriate heights.

3.16.2 Samples for foliar analysis

From each branch collect approximately 0.1 kg of foliage (leaves or needles only) for chemical analysis. For each sample:

- place label and sample in a paper bag, weigh and tie securely

- place the bag inside a plastic bag with another label and tie

- if sampled material, especially foliage, is left in plastic bags for some time it will deteriorate quickly.

3.16.3 Samples for tree biomass estimation

Samples from all parts of the tree should be selected for biomass estimation. These include:

- a mixture of foliage and twigs from which 0.2 kg should be selected then bagged, weighed and labelled

- a sample of approximately 0.2 kg of cones/fruit should be objectively selected then bagged weighed and labelled

- large branchwood (greater than 2 cm diameter) should be cut into sample lengths, of approximately 8 cm to a total weight of 0.4 kg then bagged, weighed and labelled

- small branchwood (less than 2 cm diameter) should be cut into sample lengths, of approximately 8 cm long to a combined weight of 0.2 kg then bagged, weighed and labelled

- the bole from the 1.3 m mark diameter should be measured both over and under bark every 3 m to a top diameter of 9.5 cm

- a record of stump height and measure diameter of stump 5 cm above ground level

- from the bole cut a sample disk (3-4 cm thick) at the 1.3 m mark, bag, weigh and label

- from the bole cut a sample disk (3-4 cm thick) half way between the 1.3 m mark and the base of the crown, bag, weigh and label

- from the bole cut a sample disk (3-4 cm thick) at the base of the crown then bag weigh and label

- from the bole cut a sample disk (3-4 cm thick) at the mid-point of the crown then bag, weigh and label.

Accuracy in weighing all the samples is important and the following guidelines should be used:

- weigh foliage to nearest 0.001 kg
- weigh branch material to nearest 0.01 kg
- weigh stem disks to nearest 0.1 kg
- oven dry all material as soon as possible after collection.

It has been found convenient in assessing branch numbers and size to lay a tarpaulin on the ground on which each branch with its foliage is laid out in numbered sequence from the top of the tree downwards. Then separate the foliage from the branch wood. Divide the branch wood into that over 2 cm basal diameter from that under 2 cm. Weigh the green foliage and the two branch size categories separately. Aggregate branches for weighing when the total weight is small. Then select the material from the three branches selected for removal of foliage to the laboratory, placing the branchwood and foliage in separate bags.

3.16.4 Samples for root studies

Root mass and dimensions may be estimated from soil samples extracted with a Jarrett borer or soil corer, by cutting out blocks of soil from the soil profile pit or by intersection sampling of roots on three faces of a carefully dug trench within the plot, and extraction of core samples of known volume. One method, still under trial for eucalypt plantations, is described in Appendix 13.

Table 3.1
Organization of field teams

Function	Members of field team			
	Leader	Technicians	Semi-skilled	Unskilled
P1 plots:				
Survey,Plot location	1	-	2	2
Establishing plots	1	2	2	1
Recording site data	1	2	-	-
Measuring tree data	1	2	2	1
P2 plots (additional to above):				
Collecting soil samples	1	1	-	1
Collecting foliar samples	1	1	1	-
D plots:				
Supervisor	1	-	-	-
Establishing plots	-	1	1	-
Cutting branches/felling	-	2	1	-
Sorting foliage		-	2	-
Weighing and bagging	-	1	-	-

3.17 Organization of field teams

The team structures shown in Table 3.1 have been found useful in practice. The numbers and organization should, however, be varied according to local conditions.

3.18 Season and frequency of sampling

3.18.1 Season

Foliage samples should be taken after the end of the actively growing season when it is expected that foliar nutrients are relatively constant. This may be early in the dry season in some tropical climates, or late spring in temperate regions. Soil samples should not be taken at the start of the rains when nitrogen is changing rapidly. It is impracticable to carry out most measurements during the rains without loss of precision and concentration on the part of the observer. It is an advantage if annual remeasurements are carried out at approximately the same time of year. Therefore the recommended time for sampling and measurement in the field is during the first 2-3 months of the main dry or dormant season, if there is one.

3.18.2 Frequency

3.18.2.1 All plots should be inspected annually. Plot labels, marker trenches and access lines should be replaced or renewed as needed. Where appropriate tree numbers should be renewed. If any unplanned felling has occurred the diameters of the stumps of trees removed should be recorded on Form 2 identifying the tree by number, if possible, from the plot plan.

3.18.2.2 P2 plots in which litter fall and litter decomposition are being monitored must be visited at intervals of one or two weeks in order to collect the contents of litter traps and litter bags. This can only be done in a small number of accessible plots. Foliage samples should be collected three or four times in the rotation at least. Where facilities exist this should be done more often. Tree diameters and heights will be remeasured as in P1 plots.

3.18.2.3 P1 plots will be assessed at intervals from a few months up to five years depending on the rotation length, intensity of management and resources available. A short rotation eucalypt stand might require reassessment every 6 months during a 5-year rotation, while a coniferous stand growing saw timber on a 40-year rotation could be remeasured every 3 to 5 years.

3.19 Calendar of Assessments

Table 3.2 gives a suggested frequency for pulpwood rotation of 15 years on average site.

Table 3.2
Calendar of Assessments

(Note: P = year of planting)

Plot TYPE	First assessment	Interval between assessments	Objective
P1	establishment to:		marking trees and plot
	P + 5	once	site description
			tree positions
			tree variables
	P + 7	2 - 5 yrs	tree variables
P2	as for TYPE P1 plus:		
	P + 0	5 yrs	soil samples
	P + 4	2 wks (for one year)	litterfall
	P + 8	"	"
	P + 12	"	"
	P + 15	"	"
D	P + 5	once	allometric relations
	P + 10	"	" "
	at felling	"	" " (inc.bole volumes)

3.20 Recording stems removed in P1 and P2 plots

In order to estimate the cumulative or periodic mean annual volume increment of a stand it is necessary to record all removals during the rotation.

3.20.1 Thinnings

When the measurement interval is short (1 to 2 years) it is sufficient to indicate a thinning by putting 'T' in the code column of Form 2 at the first assessment after the thinning. When the assessment interval is longer than two years thinnings should be recorded on Form 2 and volumes measured if required and recorded on Form 6.

3.20.2 Illegal removals

Diameters of stumps should be recorded (Form 2 can be used with the appropriate coding) as soon as possible after the fellings have been detected. Suitable regressions for estimating total volume from stump diameter will have been obtained from the individual tree volume data and programmes.

3.20.3 Removals before the establishment of the sample plot

Record these as for illegal removals by measuring stumps.

4
data capture and analysis

4 Introduction

This section describes the steps that are involved in transferring the information collected in the field on field forms into a form suitable for inspection and further analysis. Before the existence of computers this process would have always included some form of manual data transfer using summary forms and tables together with the calculation of means and variances of the important stand variables using slide rules, tables of logarithms or desk top calculators. During the 1960s access to computers became possible and computer programs ('software') began to be written to allow the entry of raw field data into a machine that would produce summary tables of inventory data, including that from recurrently measured sample plots. During this period the computers were remote from the field site and the data were usually transferred to the few centres offering a data-processing service, sometimes at great distances and involving long delays, accompanied by the other disadvantages resulting from a loss of contact between the people who needed the data and those who were processing them.

Microcomputers have changed this situation. It is now possible to purchase a computer system for under US$ 2000 that can handle most of the data processing and analyses required by a forestry monitoring organization. In doing so it can provide almost all the results that were previously available only from the main computer centres. Computers are becoming easier to use as more and more interactive programs are made available. The recent trend for compatability between different makes of computer means that software developed for one type of computer can often be transferred to another without difficulty or, at most with only minor modifications requiring the services of a specialist computer programmer.

There are few software 'packages' (that is, a series of programs that together provide a means for solving a defined problem) available that can be used by the non-computer specialist for processing sample plot data. The system of inventory data processing known as FIDAPS that has been developed by FAO is now available for use on microcomputers. It is expected that many other systems will become available in the near future. One such system described in this chapter is designed specifically to assist in the capture of data from permanent sample plots. It has been developed at the Oxford Forestry Institute and is a modification of programs used on mainframe computers for many years.

4.1 Processing of data from sample plot field forms

The objectives are to:

- check for errors and inconsistencies
- archive the data of each assessment
- calculate stand parameters of each plot at each assessment, e.g.means, variances and distributions of diameters, stand dominant height, basal area and volume etc.
- present the data from one assessment as a field form for recording a subsequent assessment
- calculate increment functions for those plots having more than two assessments
- stratify sample plots on the basis of differences in site factors, species and stand treatment
- derive predictive stand growth models for the defined strata.

The processing of data for the construction of predictive yield models has been described by Alder (1980). In this chapter the emphasis is on methods of transferring the data from the field to the computer file using programs available for microcomputers.

Two of the commoner types of commercial software, the spread-sheet and the relational database, can be adapted for use at different stages of the processing of sample plot data. A relational database program such as dBASE III Plus or, from 1988, dBASE IV, can be programmed to provide a convenient interactive system for the input of plot data, for its sorting and archiving. Provided suitable file handling programs are available the files so created can be used as input to programs written in BASIC or other languages that carry out specific functions of forestry application such as, for instance, the summaries of the plot stand parameters, derivation of volume functions and site index curves.

The steps involved in the creation of the plot files, whether in the form of plot forms stored in a filing cabinet or of computer files stored on a floppy disk, are essentially simple and straightforward. In order to provide a system that can be operated without continuous expert supervision and yet be flexible enough to be used for different types of data, elaborate programs have to be developed. The more flexible and comprehensive a program the harder it becomes to run with the correct specifications. A commercial database package may require much time and experience for its proper application, often demanding competence in a specialized programming language.

In order to avoid the problems that may arise in the application of such systems to the handling of forestry sample plot data a series of programs have been written in BASIC to handle data recorded on some of the field forms in this manual. While some specialist knowledge may be required to install the programs on different microcomputers the options open to the user are few and so they are easy to use. It is recommended that the programs are run without modification at first. At a later stage they can be adapted to local conditions and the output modified for particular requirements by someone familiar with BASIC.

4.2 PPR - General description of the programs

Some sample programs have been assembled in the package referred to here as PPR (Permanent Plot Records). Brief notes are given on the objectives of each program and the steps involved in running them, together with examples of the data input and the computer outputs in each case.

Examples of the steps involved in running some of the programs are given in Appendix 14.

The particular examples presented here have been developed for the MS-DOS operating system using an IBM PC and other IBM-compatible machines. They do not require more than the minimum 256K RAM 'online' memory, two disk drives and a dot matrix printer. This is one of the cheapest and most readily available working systems on the market (in 1989). The programs are written in GWBASIC, or Turbo BASIC (except where Turbo BASIC cannot support certain graphical routines). These two versions are similar, though only Turbo BASIC supplies a compiled version of the programs (with file type .EXE) that can be run directly from the operating system.

BASIC is probably the simplest programming language for the 'non-expert' computer user. Very few changes are necessary to enable the package to run on other machines. A version of many of the programs is also available for use with 8-bit micros based on the CP/M operating system.

The latter version can be used in the field and has special applications, for example to look at stem analysis. Details of how to obtain copies of PPR are given in Appendix 10. When run on small portable machines there may be further restrictions on the size of the data input as defined in Appendix 10. These can be relaxed where the programs are mounted on machines with larger memories. However the limitation of the basic plot data to 180 trees per plot is not likely to be a restriction in practice. A more severe constraint is the restriction of the number of remeasurements of any one plot allowing only five increment periods to be analysed. A small program under development allows the splicing of the data files so that the sixth measurement in any plot is transferred to an extension file to which a further five assessments can be appended. This permits an unlimited number of reassessments, with the only constraint being that the calculation of increment is restricted to successive assessments. This permits the conventional calculation of current and mean annual increments in the normal way. PPR comprises three groups of programs.

Group 1: three programs used for entering tree diameters and heights collected in fixed-area sample plots and providing error checks, tree lists and plot summaries for up to six measurements in 'yield table' format.

Group 2: three programs used for the construction of volume tables from data of sectional log measurements of felled trees. These are the well known VOLTAB programs used for many years at Oxford and now modified for interactive use on microcomputers. Output consists of summaries of individual tree volumes, summaries of regression analyses using twelve linear models, both unweighted and weighted, showing the best-fitting model based on the 'furnival index', and a printout of volume tables, if required, for any selected model. A recent addition to this group is a program to process data of ring counts on sectional disks to produce a full stem analysis. This shows the increments in height, diameter and volume growth of the individual tree both by period and position in the tree.

Group 3: sundry auxiliary 'housekeeping' programs including a graph-plotting routine for inspection of bivariate data sets and a number of linear regression models, a histogram program with an estimation of the 'Weibull' distribution parameters, a program for printing a plot map with individual tree positions and the calculation of some simple competition indices, and others under development.

The file structures are consistent within groups one and two. Group 1 uses formatted random access files, whereas Group 2 uses serial files. Group 3 contains some programs with a similar but distinct structure from Group 1, but also contains a Supercalc4 program (for plotting site index curves) and sundry housekeeping programs. Distinct file type names are provided.

Group 1 : random access files with type .RAF and .SUM
Group 2 : sequential files with types .DAT, .VOL and .REG
Group 3 : random access files with type .RDF, sequential files with type .SEQ, and .CAL files used with Supercalc4.

4.3 Brief descriptions of some programs of PPR (Groups 1 and 2)

A general outline of the application of the three programs used for the data capture and summary of standing tree data on permanent sample plots is given in Figure 4.1. A plot file is created by the first run of INDATA. This file is progressively updated by runs of INDATA and UPDATA. The manner of running the programs depends on the form of the field data. At any stage after a plot file has been created a plot summary may be obtained by running SUMDATA. This program creates a summary file of the important stand parameters. At each run of SUMDATA the user has the option of overwriting or amending the existing summary or of placing the summary in a separate file. Some knowledge of the use of random access files is an advantage when running SUMDATA as the user is asked to input the 'first free record' on the file if an existing file has been specified for the storing of the summary. At each print out of a summary file the last record number is always printed and should be referred to in the subsequent run. Notes are given below on the purpose, input, and output of the programs and an indication of the calculations performed in each case. A final section entitled 'without a computer' gives an idea of the manual operations that would be needed to perform the same tasks on the plot data without the benefit of a microcomputer and the appropriate software.

The programs of Group 2 are for the estimation of tree bole volume functions derived from log measurements on felled trees. These have been developed by H.L. Wright. Both weighted and unweighted regressions may be used and the best volume model selected on the basis of the 'Furnival Index'. Volume tables may be printed.

The programs in Group 3 consist mainly of graphical, analytical and 'housekeeping' routines for which many users may have their own programs installed on their particular computer. So only a general description of some of the software available is given as a supplement to a discussion of the manner in which the plot summaries produced by SUMDATA may be processed to provide the information needed by the forest manager for monitoring growth and predicting yield.

4.3.1 <u>INDATA of Group 1</u>

(i) INDATA creates and edits a plot file. Input: plot data including the area, regeneration, and tree data consisting of diameter at breast height (dbh) and total height for numbered trees together with a three-digit code. The order of input is flexible. Tree numbers and dbh may be entered for up to five assessments at one time, or a single assessment may be entered in the file at this stage while permitting it to be updated five times later. Heights are entered against specified tree numbers to avoid zero entries when a small sample of heights is being measured. Heights for one to five assessments may be entered simultaneously as for diameters.

(ii) Output: gives a new or amended plot file. Screen and audio warnings are given for out-of-range data. The plot file is updated automatically after every 20 observations have been entered. The data may be displayed in tabular form on screen and/or printer.

(iii) Limitations: the plot file can contain only six assessments, up to 5 may be entered through INDATA and from 2 to 5 may be entered by the following program, UPDATA. When run on a small 8-bit micro such as the portable Epson PX-8 in the field the maximum number of trees in one plot is restricted to 75, otherwise 100 are permitted.

(iv) Editing: a simple procedure is available for correction of minor errors in the plot file.

(v) Without a computer this stage would require the tabulation of both the indivdual tree assessments and diameters and heights for each plot. These tables would have to be updated regularly and all error checking done 'by hand' - all simple operations but not often well done in the past.

4.3.2 UPDATA of Group 1

UPDATA permits the updating of the plot file with diameters and heights of specified tree numbers; checks for reasonable increments; optionally sorts the plot file in order of tree numbers.

(i) Input: key in tree number to be prompted for entry of dbh, height and code. The previous measurement of diameter and height of the specified tree number is displayed before entry. A code number with up to three digits may be entered for each tree. This could refer to crown class, damage or disease as specified by the user, but preferably using the codes defined in Appendix 2.

(ii) Output: updated plot file which may be given a new name or will overwrite the old file (the normal procedure). A list of 'unlikely' increments will be printed. Program INDATA can be used to make the necessary amendments.

(iii) Without a computer this stage might mean recopying out the tables of plot information including the new assessments. With suitable forms this can easily be done by hand. The checking of unlikely increments is less reliable and data will have been tabulated in order of tree number. The computer allows the trees to be entered in any order which may save time and avoids errors if the field data were not well ordered.

4.3.3 SUMDATA of Group 1

SUMDATA reads one or more plot files, calculates the normal stand means, totals and increments using volume functions previously entered in the program.

(i) Input: file name of each plot file in turn; required volume function for each summary will be selected from a list of the available models.

(ii) Calculations of stand means include:

- age
- number of stems per ha
- dominant height
- 'Loreys' height
- mean diameter
- dominant diameter (the weighted mean diameter of the plot equivalent of the 100 largest trees per ha)
- basal area per ha
- Hart-Becking's spacing percent
- stand volume calculated according to the selected function (e.g. total volume overbark - for different volumes such as total volume underbark the summary must be rerun with the appropriate function)
- number of stem losses (usually due to thinning and recorded as trees present on one occasion but absent on a subsequent occasion) with the mean diameter
- basal area and volume of thinnings
- current mean annual increments of basal area and volume.

(iii) The calculation of stand volume depends on whether a tree or stand volume function is used. In the former case it is necessary to estimate tree heights from a regression for trees not measured for height. The program estimates the linear regression of height on diameter from the trees measured for both height and diameter in the plot. Such a method is not suitable for small sample plots where a stand volume function based on basal area and dominant height may be more reliable. Results of volume calculations must be inspected critically in any particular case to ensure that realistic results are obtained. Suitable volume functions are crucial to the production of accurate plot summaries. The programs in group two provide the procedures necessary for processing data from the measurement of felled trees into volume functions. As volume functions are derived and tested, they are stored within the SUMDATA program for easy retrieval using screen menus.

(iv) Output: essential plot parameters are stored on a summary file and summaries for each assessment for every plot called are printed in yield table form. Optionally the user may call for a printout of summaries previously stored on file. The user is asked to key in the 'last record number' after naming the summary file on which the output is to be stored. For the first run this will be '1'. Each plot summarized occupies n+1 records on the random access file where n is the number of assessments processed for that plot. There is complete freedom to choose between overwriting, appending or creating a new file for the summary output. Overwriting can only be safely performed when storing an amended summary for a plot having the same number of assessments as the plot summary to be overwritten.

(v) Limitations: the number of plot summaries that can be stored in a single summary file for subsequent analysis is limited only by the disk capacity. Individual plot data may be read from as many separate disks as required. The processing time for large plot files may be rather long. However, speed is not an inconvience using modern machines running at speeds of 10 MHerz or more, although it could take up to 10 minutes to summarize five assessments of a plot with 60 trees on a CP/M machine.

(v) Without a computer many hand calculations would have to be carried out on the tables of plot data in order to obtain the following totals and means for each assessment on each plot:

- number of standing trees per ha
- number of trees per ha removed since the last assessment
- quadratic mean diameter of main crop and removals and of largest 100 trees per ha ('dominant diameter')
- dominant height
- mean height (Lorey) weighted by tree basal area
- basal area per ha of main crop and removals
- volume of main crop and removals. Volume functions would be selected to calculate volumes of each species occurring in the plot, both with and without bark and to various timber limits and volume per ha calculated for both main crop and removals for all the required categories
- current and mean annual increment for basal area and volume production.

4.3.4 VOLCOMP of Group 2

VOLCOMP calculates total volume and merchantable volume to different timber limits, both with and without bark.

(i) Input: the number of utilization limits and whether both underbark and overbark measurements are available. Tree number, total tree height, dbh, diameter and height of ends of log sections for each tree also need to be added to the records.

(ii) Output: table of tree numbers, total height, dbh and up to eight volume categories sent to printer and to a disk file.

(iii) Calculations: volumes of logs are calculated using Smalian's formula and it is assumed that the top section is conical.

(iv) Limitations: Data for no more than 200 trees may be processed in one run.

4.3.5 VOLREG of Group 2

VOLREG computes one or more of 12 different functions, with volume as the dependent variable and dbh and total height as independent variables It selects the best fit on the basis of furnival's index.

(i) Input: output table as produced by VOLCOMP (see 4.3.4 above) from the disk file, or from the keyboard.

(ii) Output: summaries of the regression analyses, optionally for all, or for only the best-fitting model to a printer and the constant and coefficients of all, or only the best-fitting regression to a disk file.

(iii) Calculations: linear regression procedures with unweighted and weighted independent variables, and with simple and transformed forms of diameter and height as predictors of tree volume.

(iv) Limitations: restricted to the models defined by the program but these include those most commonly found to give good fits.

(v) Without a computer: calculation of regressions 'manually' is laborious, but many small calculators provide functions for summing squares and products which makes the calculation of the coefficients of a linear regression practicable, though time consuming. Few people would, however, have the patience to test the range of models that can be included in a mirocomputer program.

4.3.6 VOLTAB of Group 2

VOLTAB prints out a volume table based on a regression estimated by program VOLREG.

(i) Input: regression model and coefficients are read from the disk file created by VOLREG, or they may be entered from the keyboard.

(ii) Output: a two-way table of tree volume in terms of diameter and tree height, optionally with a table of confidence limits.

(iii) Without a computer: calculation of volumes for a range of diameter and tree height classes from a given volume function is feasible with a statistical calculator. The volume function by itself has, however, many applications and a table printout is not necessarily essential.

4.4 The programs of Group 3

4.4.1 STAN

STAN summarizes the growth history of an individual tree based on stem analysis. This includes the counting of annual growth rings on sectional disks cut at defined distances from the base of a felled tree bole.

(i) Input: there is considerable input necessary for this program

- tree identifier
- age
- interval in years between rings measured
- tree and stump height
- for each disk analysed
  - number of disk from base upwards
  - number of rings counted on the disk
  - the height above ground level of the disk
- for each ring, or group of rings measured, the diameter in cm.

Field Form 8 should be used to avoid errors in the input of the data which must be strictly formatted. Input may be from file or keyboard.

(ii) Output: underbark ring diameters as input; volumes by disks and sheaths and separate tables giving volumes by inter-disk logs and volumes of the tree at different ages (determined by intervals between rings measured). The final line gives the overbark volume.

4.4.2 CURVIT

CURVIT reads a data matrix from a random access file and estimates the coefficients of a range of linear regression functions relating any two columns selected from the data matrix. The program permits the usual transformations of the selected variables (logarithms, squares, square roots, reciprocal etc.).

Scatter diagrams and selected regressions may be plotted on the screen and printer.

Separate editions of the program would be used depending on the form of the data file. Thus one version would be installed to read files created by the SUMDATA program and another used to plot individual tree growth using files created by the INDATA and UPDATA programs. The reason for this is to ensure simplicity in the application of the program and to save space on small microcomputers.

This program has been superceded by graphical packages such as Supercalc4, Statgraphics, etc, which have flexible graphical routines. CURVIT is no longer included on the PPR disk though it is available on request by those requiring a simple graphing routine for use with small CP/M machines.

4.4.3 HISTPSP for .RAF files (or HISTIBM for .RDF files)

HISTPSP reads a data matrix from a random access file and plots a histogram of the distribution of values in any selected column of diameters in 5 cm classes. Frequencies are plotted as percentages. The program estimates the three parameters of the Weibull distribution function and plots the function over the histogram.

4.4.4 CALSIT

CALSIT reads dominant height and age from plot summaries created by the program SUMDATA and calculates site index curves using the Schumacher equation and nested regression techniques as described by Alder (1980). Plots of the site index curves are overlain on plots of the dominant height at each assessment age for as many plots as desired. Site indices would normally be calculated for a country, region or stratum based on climatic zones. This program provides a method for studying the effect on general site index curves of the inclusion or exclusion of selected plots and for determining to which strata or groups of plots the curves can be generalized. It also provides the first stage in the construction of a stand yield model. This program is not included on current PPR disks but the version written by D. Hughell for Honduras is available on request (in Spanish).

Another version of this is available on a Supercalc4 spreadsheet file called SITEIND.CAL.

4.4.5 MULT

MULT is a program to estimate the parameters of a multiple regression. The data may be input from the plot files (of individual tree data) or from the plot summary files. Up to 19 dependent variables may be entered, though these would include any combinations or transformations of the data variables specified during the running of the program. A facility is provided for the step-wise selection of significant variables. The program is similar to standard multiple regression programs that may already be available for a particular microcomputer. The use of MULT within this package has the advantage of reading the data from files created by the Group 1 programs described above with the minimum 'operator intervention'.

It will be found useful to analyse extended plot summary files that include data of the physical factors of the site together with stand growth data in order to determine how far each are correlated.

4.4.6 MAP (MAPGW for use with GWBASIC interpreters)

A plot map on the screen and a dot-matrix printer is constructed from the data of tree positions recorded on Field Form 4. Versions of this program include estimates of the competitive status of individual trees within the stand based on the size and position of neighbours. Regeneration counts made on quadrats within permanent sample plots may also be plotted on a plot diagram.

4.5 Other programs for processing sample plot data

4.5.1 Database programs

A relational database processing package of programs such as dBASE III is widely available for use with 8-bit microcomputers using the CP/M operating system. This type of package is designed to create, sort, index and manipulate large data files and has many applications in the handling of recurrent inventory data. One application is for the design of the input of data through the keyboard and the design of the file structure, functions partially carried out by the Group 1 programs of PPR above for the particular case of permanent sample plot data. Similar, but more powerful, packages are available for the 16-bit machines that perform these and many other functions. A knowledge of a special set of instructions is, however, required by the user of such programs if they are to be used efficiently. In some cases these instructions are comparable to any other programming language, such as BASIC, in their complexity. Their application at anything more than a superficial level may require the services of an experienced programmer. The PPR package of programs includes a routine for the conversion of dBASE files into files compatible with those of Group 1. Particular applications and extensions of PPR will tend to utilize commercial database programs more in the future.

4.5.2 Spreadsheet programs

Standard software provided by the suppliers of microcomputers now usually includes a spreadsheet program. The spreadsheet is a two-dimensional array. The elements of the array can hold numbers, formulae and labels. Originally designed for financial accounting it is a powerful calculating tool with many applications. One example is given in Figure 4.1. This is a yield table prepared using a typical spreadsheet program on a small portable microcomputer. The only figures input to the program are the ages for which the stand parameters are required and the number of stems per ha at the starting age. All the other values in the table depend on equations or data stored within the spreadsheet. For example the column of dominant height (Hdom) is derived from the Schumacher equation. This equation is placed in every element of the 'Hdom' column though it is not normally visible to the user. Only the result of calculating the value of dominant height from the equation appears on the screen. All this is handled 'automatically' by the program.

4.6 Setting up a data processing system

Although some suppliers and advertisers of microcomputers may sometimes suggest that the machine can be run by a novice with the software provided this is not likely to be true except for standard applications such as a simple accounting system for a small business. No application will fit the standard supplied exactly and it will be necessary to make modifications. The simplest modification can be a baffling task to anyone not familiar with the operating system or programming language in which the software has been written. Modifications are certain to be required for any forest inventory system as the data collected will vary from one forest or project to another. Either the computer is not used in the way intended or a computer 'expert' has to be brought in, probably at a high cost, to make the necessary modifications. Three broad strategies are possible to solve this problem.

(i) Contract the processing of data to another government department, university or commercial organization. This was often used successfully in the past by Forest Departments when computers were expensive and cumbersome and computer expertise less widely available than today. It would probably be expensive and inflexible.

(ii) Install a large and comprehensive program with many options in the way it can be run. The FAO forest inventory processing package known as FIDAPS used this strategy. The disadvantage is the complexity of the specifications needed to select the appropriate options for a particular application. As with dBASE III it is, in effect, necessary to learn a new 'language' in order to run the programs efficiently. Therefore specific training courses are required for the operators of the programs.

(iii) Provide the elements of a data processing package in the form of small programs or modules written in a widely known language such as Basic or Fortran. The installation of the processing system will involve a trained computer programmer, but they will produce a system that is likely to provide exactly what the local organization requires. During the installation stage local personnel will be trained in the operating system and one high level language. A team will be left in charge capable of taking computer applications further within their project.

The third option is examined in more detail as this is the most flexible system to use. The programs to which reference has been made are the modules from which an appropriate system can be constructed. It is not expected, however, that all users will accept the output from some of the programs as providing what is required. Potential users of the programs will include forestry research and management organizations having anything from no computer experience to those with an active team operating several machines. For the former the services of a data processing consultant will be required to advise on the appropriate type of computer and operating system, to install all the necessary programs and to provide training courses. For the latter, programs on floppy disks or as printed listings should be obtained which local staff could install, use and modify as required.

Stand growth model 1 (metric)

Bahamas Yield model - 1s *Total volume ob* *Andros basal areas*

Site Age	class I Hdom m	N/ha	G/ha m2/ha	Diam. cm	M.Crop Volume m2/ha	Thinnings N	G m2/ha	Diam. cm	Thinned Volume m3/ha	Total Volume m3/ha	MAI m3/ha
5	6.6	988	4.5	7.6	28.6					28.6	5.7
10	10.5	988	12.1	12.5	88.8					88.8	8.9
15	13.1	988	15.0	13.9	111.8	618	5.2	10.4	34.1	111.8	7.5
20	15.0	370	12.0	20.3	88.0					122.1	6.1
30	17.9	370	14.5	22.3	107.8					141.9	4.7
40	20.0	370	15.8	23.3	118.1					152.2	3.8
45	20.8	370	16.1	23.5	120.5					154.6	3.4
Site class II											
5	4.4	988	1.5	4.4	4.8					4.8	1.0
10	7.0	988	6.0	8.8	40.5					40.5	4.0
15	8.7	988	9.5	11.1	68.2	618	2.5	7.2	12.8	68.2	4.5
20	10.0	370	8.0	16.6	56.3					69.1	3.5
30	11.9	370	10.0	18.6	72.2					84.9	2.8
40	13.3	370	11.6	20.0	84.8					97.6	2.4
50	14.3	370	12.1	20.4	88.8					101.6	2.0
Site class III											
5	2.2	988	1.1	3.8	1.7					1.7	.3
10	3.5	988	1.5	4.4	4.8					4.8	.5
15	4.4	988	1.9	4.9	8.0	618	.6	3.5	.0	8.0	.5
20	5.0	370	2.0	8.3	8.8					8.8	.4
30	6.0	370	3.0	10.2	16.7					16.7	.6
40	6.7	370	3.6	11.1	21.5					21.5	.5
50	7.2	370	5.0	13.1	32.6					32.6	.7
60	7.6	370	5.4	13.6	35.7					35.7	.6

Figure 4.1
Stand growth table prepared on a spreadsheet

4.7 Training in data processing

The person in charge of the data processing department of a forest organization should, ideally, be a trained computer programmer. The extra training required will consist of a general course on forestry to emphasize the specific problems and issues that they will be handling. Small departments may not be able to afford such a person and consideration has to be given to train staff with forestry qualifications if none are already available. Those selected for training should have passed an aptitude test to indicate their suitability for computer programming, they should be strongly motivated and keen to use computers. It is also important that all participants in a training course be given the opportunity to work with computers for an extended period following their training. Without such practice most computer training courses are of little value.

A six-week course for a numerate forestry graduate might be made up as follows:

Part 1:	elements of programming in BASIC or other high-level language	(2 weeks)
Part 2:	applications of computers in forestry research and management	(2 weeks)
Part 3:	training in the use of particular packages such as PPR, STATGRAPHICS, LOTUS 1-2-3, SUPERCALC or dBASE III, linked with a practical project	(2 weeks)

The components of Part 2 included on a course at the Oxford Forestry Institute included the following topics:

- problem solving techniques
- tools for the job - hardware
- tools for the job - software
- programming - revision of BASIC syntax
- operating system - MS-DOS
- files and drives
- calculating on the micro - statistical programs and packages
- spread sheets - use of LOTUS 1-2-3 and SuperCalc4
- database management - use of dBASE III or IV
- word processing - use of Wordstar or Wordperfect
- graphics - an aid to the interpretation of data
- simulation models - simple examples
- selecting a suitable machine for the job.

(See also Appendix 6).

5

experimental plots for supplementary information

5 Introduction

Growth data obtained from sample plots established in managed plantations are subject to variation due to many factors. Some of this variation may be explained by the influence of site factors such as variation in rainfall, soil depth or nutrient content. A possible source of unexplained variation may be genetic, especially where records of seed source are not available. A further cause of variation may be due to stand management in its influence on stand density, that is, the number of trees established on a given area and the pattern and intensity of removals through thinning and harvesting. An important objective in a monitoring program is to reduce the unexplained variation in tree and stand growth to a minimum.

Replicated experiments on a single site, or on a few key sites, are therefore required to supplement the observations obtained by recurrent measurements on permanent sample plots by providing data for evaluating the effects and interactions of stand density, soil nutrients and genotype on tree and stand growth. Without field trials designed to evaluate growth variation due to these factors, observed growth rates in managed plantations may be difficult to interpret. For example, it may be impossible to compare the growth rates of successive rotations of the same species on a single site when the seed source has changed or the method of establishment and stand treatment has not been identical in each rotation.

The following supplementary information can be obtained from controlled field experiments.

(i) The effect of stand density on:
- the relation between stand and tree growth
- the suppression of weed growth
- the time of onset of competition
- stem form, branching patterns and wood quality
- the economics of establishment and maintenance of stands
- infiltration and run-off
- soil water depletion rates
- light interception.

(ii) The response to soil cultivation and fertilizing.

(iii) The effect of the intensity and frequency of harvesting on the nutrient and moisture relations of the soil.

(iv) The growth interactions of different tree species in mixtures and the interactions between trees and agricultural crops.

A description of the experimental designs suitable for all possible types of controlled growth study is beyond the scope of this manual. In any case the general principles of experimental design are treated in standard texts such as those of Pearce et al. (1988), Cochran and Cox (1957), or Dagnelie (1985).

Reference is made in this section to three of the most important types of field experiment that are recommended for a minimum monitoring programme. These are spacing, thinning and fertilizer experiments with plants of known genetic origin.

5.1 Growth and stand density

Donald (1963) reviewed research on the effects of competition among crop and pasture plants. Even now, a quarter of a century later, the implications of the research done on agricultural and horticultural crops has not been fully appreciated by those working with forest trees. Application of a simple model that relates growth response to available growing space should be the basis of any design for spacing and thinning experiments. Ad hoc experiments laid down to test alternative management practices in a particular forest type appear to offer the simplest path to the solution of a management problem. Owing to changes in management practice, however, the original objectives of the experiment may be outdated by the time results are forthcoming from the longterm experiment. A second disadvantage of the ad hoc spacing or thinning trial is the unreliablitity of extrapolation of the results to other sites and regions.

The reciprocal model of Shinozaki and Kira

$$\frac{1}{w} = A.d + B$$

where w is mean plant weight, d is density and A and B are constants has wide application. It is based on the 'classical' growth function of Verhulst

$$\frac{1}{w}.\frac{dw}{dt} = k(1 - \frac{w}{W})$$

where w is the mean plant weight, W is the asymptote of w (that is the maximum size the plant will reach under the given conditions), k is the initial growth rate and t is time. Apart from the need to account for the accumulation of dead material in the standing crop, the principle on which the reciprocal growth model is based is no different whether the crop is annual or perennial. The relation between stem volume and total tree weight is sufficiently close to justify the use of a modified form of this equation for forest crops. The model of Kira

$$w.d^a = K$$

where w and d are as above and a and K are constants, gives an equally good fit to observed data from spacing experiments in forest stands.

This equation is similar to the model used by Reineke (1933) where plant weight is transformed to tree diameter. Stocking (number of plants per unit area) is used to represent stand density and the axes are reversed, giving

$$\ln(N) = a + b.\ln(d)$$

where N is the number of plants per hectare, d is mean diameter and a and b are constants. Compare Figures 5.1 and 5.2.

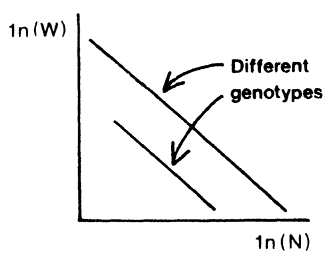

Figure 5.1
Relation between plant weight and density per unit area

These and other similar models suggest that there is a close relationship between plant size and the number of plants throughout the life of the stand, if the stand density is great enough to induce inter-tree competition within the stand. There is a great deal of empirical evidence to support this stand density 'law'.

Self-thinning does not suddenly occur in unthinned stands when the theoretical density represented by the line in Figure 5.1 is reached. The density diagram is better represented by a band limited by two lines one of which represents the **threshold density** at which inter-tree competition begins to be expressed by reduced individual tree growth in relation to the growth of isolated trees on the same site, and the **maximum density** when suppressed trees die. It is this line that is best described by the reciprocal or logarithmic density models described above. The threshold density is best derived from measurements of crown spread and observation of crown plasticity (that is, to what extent a crown can be compressed by neighbours without resulting in growth reduction). The model may be represented graphically as in Figure 5.2.

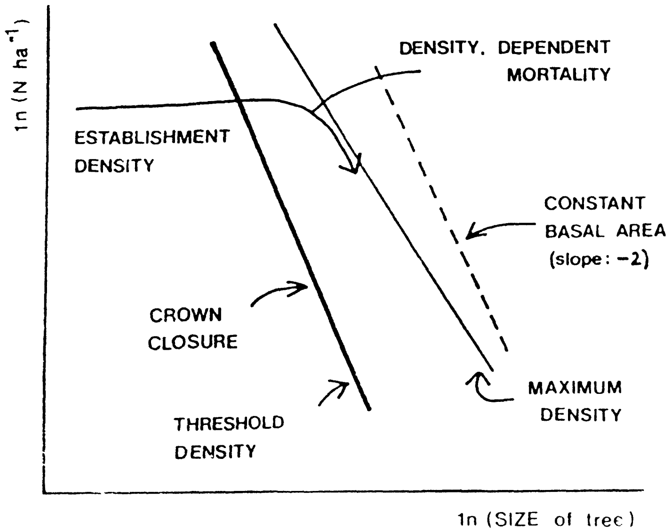

Figure 5.2
A stand density model

Most spacing and thinning trials will be designed to quantify a model of this type. As far as determining the effect of spacing and thinning on growth is concerned the objectives will include:

- determination of the threshold density over time
- determination of the maximum density (usually defined as basal area) over time
- determination of the relationship between growth and density between these two extremes.

Many functions may be derived from such experiments that will be used in the derivation of simulation models of stand growth that will provide the framework for monitoring the growth of stands.

5.2 Spacing and thinning experiments - introduction

Increasingly the decisons made by forest management are investment decisions based on obtaining the objectives at the lowest possible cost or the maximum profit. A basic need of the forest manager is thus information on the effect of initial spacing and subsequent treatment on the growth and yield of the stands. In many countries this information is presented in the form of yield tables which may be applicable to a wide or narrow range of possible treatments. The rapid development during the last ten years of predictive mathematical models of stand growth is an attempt to provide more flexible information for the forest manager. With such a model the cost of various alternative regimes can be calculated. This is extremely valuable for the forest manager.

In the situation existing in many countries where relatively little information is available on the performance of the species being introduced and planted, it is important that the basic data necessary for producing such a model are collected. One of the few coordinated research projects set out with this aim is the Correlated Curve Trend (CCT) trials in South Africa, first defined by O'Connor (1935) and established in 1936-39.

5.2.1 CCT spacing trials

For each site type and species, two series of plots were established. The first series consisted of eight spacing plots with stockings of 2965, 1483, 988, 723, 494, 362, 247 and 124 trees per hectare. All the plots were established at 2965 trees per hectare (1.84 m x 1.84 m spacing) and thinned in advance of competition to their final stocking. This was done to supress weed growth during the early years. The second series of 10 plots was thinned with varying intensity after a varying amount of supression. The aim was to determine the response to thinning and whether this was affected by the degree of initial competition and the intensity of the release. It should be emphasized that it was not intended to test any particular practical or economic thinning regime but to provide the data from which the effect of any thinning regime could be deduced. Accounts of the CCT projects have been given by Craib (1939, 1947) and Marsh (1957). More recently Grut (1970), Burgers (1971) and Marsh and Burgers (1973) have used the CCT data for growth prediction in thinned stands. The methods have been both graphical and by use of regression analysis. Marsh (1957) concluded from a preliminary analysis that the projects are capable of yielding all the results claimed for them by O'Connor, and it would appear that this conclusion is still held.

The type of results given by the CCT method is shown in Figure 5.3. The curves of the mean stand diameter for a range of stockings are plotted over age with each curve diverging from that of free growth at the onset of competition. The hypothesis, successfully tested by Marsh (1957), is that the growth of thinned stands is equivalent to that of unthinned stands of the same stocking (trees per hectare) and density (basal area or volume per hectare) but of equal or younger age. Thus after a thinning from one stocking to another the growth curve follows that appropriate to the new stocking. The effect of any thinning schedule, whether it is heavy, moderate or light, can then be found. Burgers (1971) goes so far as to say "... the need for maintaining a series of thinned plots (except as a check) falls away."

5.2.2 The relation between spacing and thinning

In the following sections spacing and thinning experiments will be recommended based on the general model of Figure 5.2 as described in Section 5.2. They will be dealt with separately for ease of presentation and reference. However, the two are very much interrelated. The model provides the common basis for the interpretation of growth data from the permanent observation plots as well as various types of spacing and thinning experiments.

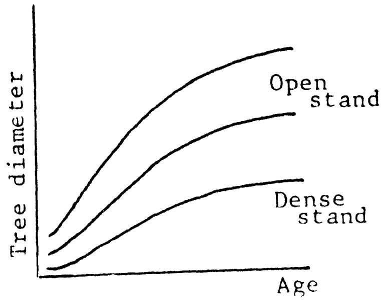

Figure 5.3
Mean tree diameter and stocking

5.3 Design of Spacing Experiments

Most spacing experiments have used a normal randomized block design in which the blocks are made up of plots, each planted at a different spacing. However in any such experiment there is a problem of plot size. To use plots of constant area will result in an unnecessarily large number of trees for the smaller spacings; varying the plot size to suit the spacing can be awkward for the construction of blocks and may result in non-homogenous plots as regards site effects. In addition, with the random arrangement of spacings there is a need for a high proportion of guard rows in the experiment. For example, the four CCT projects in Pinus patula at Nelshoogte in South Africa cover some 40 hectares. To overcome these difficulties a clinal design was used by Pudden in East Africa (Dawkins and Pudden 1960). This consisted of a systematic series of plots with increasing stocking such that adjoining plots were of sufficiently similar stocking for no surround to be required between them. However there is a serious danger of confounding stocking with site, particularly if a wide range of stockings is used.

Nelder (1962) proposed a series of systematic designs for spacing experiments involving vegetable crops. These designs, more generally known as clinal designs, investigate spacing, expressed as the area per plant, and rectangularity, that is, the shape of that area measured as its length/width ratio. Nelder suggested five designs, four based on a polar coordinated grid (that is one made up of the radii and arcs of concentric circles) and the fifth based on a rectangular logarithmic grid. The characteristics of each design, using Nelder's own reference numbers, are:

Ia: - shape constant, area per plant increases
Ib: - area per plant constant, shape changes
Ic:)
Id:) - both area per plant and shape vary simultaneously
II:)

The area per plant increases with increasing distance from the origin. Radial rows of plants are separated by a constant angle. The arcs are spaced by a geometric progression of radial distances. Spacing between plants is the same on the same arc but increases from arc to arc outwards. The rectangularity or shape is constant over the whole design.

The advantages of the designs are the economy in terms of space, the number of guards required, and the flexibility in the choice of parameters. It is also an advantage to be able to test such a wide range of spacings. The disadvantages stem from the lack of randomness which means that a greater prior knowledge of the site is required. In practice one must replicate if possible in such a way as to cancel out any likely clinal effect of site. The designs are not robust and missing trees can cause problems if on a large scale. The selection of sample trees for wood quality or other studies before the end of the experiment is difficult since any removals will affect the spacing. Although clinal designs have been used in forest research few accounts have been published. Smith (1978) working in British Columbia concluded that at age 15 clinal designs give data which compare well with those from conventional half-acre blocks and from replicated plots having 49 trees at each spacing. One of the questions remaining unanswered is whether the distribution of diameter of trees with the same area will be the same as that expected from conventional plots of the same spacing. If differences exist this will have an important effect on the estimates of yield, particularly with regard to the proportions in different size-classes.

The analysis of the data from these designs relies on regression analysis in which some measure of growth is related to the spacing. The techniques of trying to explain the growth of individual trees by means of a mathematical model are well suited to data from a clinal design.

It is recommended that a combination of the Nelder clinal design and a randomized block design be used when no information on growth and stand density is available on a particular species or site. For example:

- a clinal type Ia design is laid out to investigate a wide range of stocking

- a randomized block design is set up alongside the clinal using a limited number of the espacements included in the clinal.

One of the functions of both experiments will be to act as a monitor for one or more associated thinning experiments. The onset of competition at the different spacings can be assessed and used in the timing of operations in the thinning experiment (see Section 5.4).

Specific details of the two types of design are given in Appendix 11.

5.3.1 General treatments for spacing trials

Trees that die in the first year should be replaced, preferably with transplants from an adjacent bed kept for that purpose. Normal weeding and cleaning operations should be carried out. As it will not be possible to use a tractor for all the spacings care must be taken to ensure that the methods have a similar effect. The experiments must not be thinned. Pruning should be restricted to assessed trees, up to breast height (1.3 m), and to any dead branches. Removal of dead branches will make it easier to measure crown length.

5.3.2 Assessment of spacing trials

5.3.2.1 Clinal designs

All the non-guard trees in the experiment must be numbered. This can be done by numbering each radius and each tree within a radius. Thus one can refer to A12-5, meaning the tree level 5 in the 12th radius of the replication (or plot) A. Initially it will be sufficient to have a plan showing the numbering; at a later date the individual trees must be labelled. The radii numbers should be indicated on a stake positioned just before the first tree of each radius, as soon as the experiment is established. A number of assessments are recommended.

(i) Survival assessed annually from the end of the first growing season.

(ii) Height measured on all trees in alternate radii (using a random start) measured for height at monthly intervals during the growing season for the first two or three years. Thereafter total height only.

(iii) Diameter measured annually on all trees at 10 cm above ground level until breast-height measurements can be taken.

(iv) Crown: height to the base of the live crown and crown width to be measured annually on the height trees once the trees are big enough.To reduce the amount of work the width could be measured on half the radii.

(v) Volume estimated for all trees assessed for height on a minimum of two of the radii both over and underbark, once the trees have reached 5 m in height.

(vi) Branch: some measure of branch size may be desirable at a later stage of the experiment.

The heights should be measured on the same radii each year; it is recommended that those radii to be assessed for height are suitably labelled. Annual re-measurement may be unnecessary at a later stage in the life of the experiment. However it is important that the onset of competition is detected as soon as possible for each spacing.

5.3.2.2 Randomized Blocks
All trees in the inner assessment plots must be numbered and the plots clearly labelled. The assessments should be the same as those given above. Height should be measured on twelve trees per plot; on those plots with six rows in one direction (treatments 1-4), two trees are selected at random in each row. For treatment 5, four trees should be selected at random in each of the three rows. The same trees should be measured for height each year.

5.3.3 Analysis of spacing trials

It will be necessary to check, particularly with clinal designs, whether there are any systematic differences due to site or whether the differences can be assumed to be random variation. During the early growth before the onset of any inter-tree competition the trees will be responding only to environmental (and genetic) differences. Consequently inter-arc comparisons of the early height and diameter measurements should show if there are any fertility differences not shared by all arcs within a replication. The analysis of the experimental data will follow a number of steps:

(i) Computation of plot summaries after each assessment, including:

- age
- number of trees per ha
- quadratic mean diameter
- basal area per ha
- mean height (computed as dgh/ dg where d is diameter measured at breast height)
- dominant height (see note below)
- volume per ha for different utilization standards once volume data or tables are available
- growing space per tree
- mean crown length
- mean crown width
- CAI basal area
- MAI basal area
- CAI volume
- MAI volume
- total volume production

(For a clinal design a plot refers to an arc of trees with the same spacing.)

(ii) For a clinal design, inter-arc comparisons after each assessment, up to the time of competition, to test site differences should be carried out. This is particularly important within each half-circle, but also between replications.

(iii) Inter-year comparisons of the diameter statistics to determine the onset of competition affecting diameter growth at each of the stocking levels are necessary.

(iv) A comparison of summaries from the clinal design with those of the randomized block to test for any differences due to design, particularly with regard to the diameter distributions should be carried out.

(v) A comparison should be carried out from the clinal design with those of spacing and age. Determination of maximum basal area for a given stocking, that is the basal area above which the increment is reduced. This is usefully shown on a logarithmic plot of number of trees per hectare against mean diameter (Figure 5.2).

(vi) Regression analysis should be applied to the relationships indicated in (v) on the basis of both individual tree data and plot summary data. Some measure of competition or density should be used to explain differences in growth, again using both individual trees and stand statistics.

(vii) Development of a predictive model for growth in unthinned stands after examination of available methods and functions. During the life of experiments there will undoubtedly be an increase in the published material on this subject.

Table 5.1 gives the areas per plot and arc for the spacing experiments and the consequent numbers of trees required to assess the dominant diameter and height. The calculation of the dominant diameter is straightforward but dominant height involves considerable work in the field. The exact trees to be measured must be decided after the trees have been measured for diameter and the heights taken on a varying number of trees dependent on the particular plot. It is suggested that a regression of height on diameter is computed using those trees regularly assessed for height. The height corresponding to the dominant diameter may then be computed from the regression equation.

A linear or quadratic regression is usually perfectly adequate to express the relationship between height and diameter for this purpose. This technique also has the advantage of smoothing out irregularities in dominant height which can be caused by change of status of the dominant trees and the small number of dominant trees in many of the plots.

5.4 Design of thinning experiments

Thinning, the process of removing trees from an established stand with the object of obtaining an early economic return from the stand, controlling the number of stems on which the total stand growth will be partitioned and removing undesirable trees, has an important influence on many stand growth parameters. It is, therefore, important that the response to thinning, when it is part of the normal stand management, be quantified and understood for the range of species and sites included in the monitoring programme.

5.4.1 Objectives of thinning research

(i) The estimation of the response to varying intensities of thinning timed to occur at or before the onset of competition.

Table 5.1
PLOT AREAS FOR A SPACING EXPERIMENT

Randomized block spacing experiment

Treatment number	Plot area	No. of dominant trees
1	0.016	2
2	0.032	3
3	0.065	6
4	0.115	12
5	0.144	14

A Clinal Design

Stocking level	Plot area	No.of dominant trees
1	0.0045	0
2	0.0057	1
3	0.0071	1
4	0.0090	1
5	0.0113	1
6	0.0143	1
7	0.0181	2
8	0.0228	2
9	0.0288	3
10	0.0363	4
11	0.0458	5
12	0.0578	6
13	0.0729	7
14	0.0919	9
15	0.1160	12

(ii) As for (i) but the timing to be delayed for varying periods such that competition will have begun.

(iii) A comparison of the effects of growth in thinned plots with that in unthinned plots.

5.4.2 Thinning treatments

Examples of treatment specifications are given in the experimental designs included in Appendix 12.

5.4.3 Assessment of a thinning trial

All the trees in the assessment plots must be numbered and the plots clearly labelled. Initially a plan showing the numbering will be sufficient but the individual trees should be labelled as soon as they are big enough. A number of assessments are recommended.

(i) Survival assessed annually from the end of the first growing season.

(ii) Height measured annually on a sample of trees per plot. The sample plan given in Figure 3.4, if used for all plots, will ensure that at least 10 trees for each treatment plot will remain until after the second thinning (except for treatment 9 which will have 8).

(iii) Diameter measured annually at breast height on all trees once they are big enough. Until then at 10 cm above ground level on a 25 percent systematic sample per plot, for example, the trees at the intersections of the even columns and the even rows.

(iv) Crown: height to the base of the live crown and crown width annually should be measured on all height trees from the time of the first thinning.

(v) Volume estimation: annually a minimum of 2 of the height trees should be measured standing for volume, both over and under bark, from the time of the first thinning.

(vi) Wood properties: some assessment of various wood properties may be desirable at the end of the experiment or possibly after the second thinning using the felled trees.

It is very important that the plots are measured at the time of thinning. The trees removed as thinnings must also be measured for height and form as they will provide valuable data for the construction of volume tables. Annual re-measurement may be unnecessary at a later stage in the life of the experiment; however it is essential that the onset of competition is determined for each of the treatment plots with a reasonable degree of accuracy. This will necessitate annual assessment for a considerable time. The use of a computer will obviously reduce the amount of work that this involves.

5.4.4 Analysis of a thinning trial

This should follow a similar pattern to that outlined in Section 5.3.3 for the spacing experiments.

The size of the assessment plot will determine the number of trees that are required to assess dominant diameter and height. (This is done automatically if PPR microcomputer programs are used for obtaining plot means). Since the thinnings are systematic they should represent the standing crop as regards form and diameter distribution. A local volume table for each treatment, based on the data from the thinnings, can be constructed and used for the computation of the plot volumes and the volumes removed in thinning. These regressions (or form factors) should be compared between treatments with a view to using a combined volume table for all the treatments.

The PPR data processing package will be suitable for storing and summarizing the data from both the spacing and thinning experiments.

5.4.6 Replication in space and time

It is theoretically desirable to replicate both spacing and thinning experiments in time to account for the year to year variation in climatic factors such as the length of the dry season or the annual precipitation. However few organizations are likely to have the resources to do this. The results of the spacing and thinning experiments will be interpreted in the light of the recurrent measurements from the observation plots (Chapter 3) that will indicate annual variation in growth rates under management conditions. For example, adjustments may have to be made if exceptional climatic conditions occur during the first few years after planting.

5.5 Fertilizer experiments

5.5.1 Introduction

The use of fertilizers in the establishment of plantation forests is well-accepted practice for many species on many types of soil. Considerable time and effort has gone into research on fertilizers. This has ranged from testing one or two commercial fertilizers to a comprehensive series of experiments involving several individual nutrient elements. The objectives behind this research have been to try and answer the questions: does the addition of extra nutrients increase tree growth; what nutrients are required and in what amount; how, and in what form, should these fertilizers be applied; and what is the effect on wood quality and tree form?

To make rational economic decisions about fertilizers the forest manager needs to be able to predict the growth increase resulting from given data on the effect of the nutrients applied singly, and in combination, in varying quantities.

To detect site change over successive rotations of forest crops it is important to attempt to discriminate between the different nutrient factors controlling growth and to recognize the possible interactions between genotypes, the nutrient status of the site and the management system applied to the crop.

Factors to be monitored could include, the nutrient reserves in the soil and the growth rate of the particular species or provenance (if a plantation) under a specified management regime and the additions of nutrients during successive rotations through mineralization, nitrification, nitrogen-fixation, aerosol deposition as well as through fertilizer addition, and the removal of nutrients through harvesting and leaching. Fertilizer field trials can supply only part of the information required to understand the nutrient cycling processes. They are, however, essential for providing a basis for comparison with the nutrient budgets obtained from permanent sample growth plots of type P2 where chemical analyses of foliar and soil samples have been carried out on successive occasions (Table 1.1 and Section 3.14).

The types of field nutrient experiment required within a plantation monitoring programme will depend on the available knowledge of the soils and crops. Where little background information is available the objectives would be:

(i) the collection of information on the effect on growth of a wide range of levels of the main nutrients

(ii) the detection of nutrients at levels of availability that limit growth

(iii) detection of toxic elements.

This information must be presented in a form enabling the growth response to be predicted for various amounts of fertilizers applied to permit an analysis of the economic costs of sustaining growth rates over successive rotations.

5.5.2 Designs for fertilizer experiments

Most fertilizer experiments, in which two or more nutrients at two or more levels are used, are set out as complete factorials in randomized blocks. The objectives of these experiments are primarily the testing of hypotheses concerning specific main effects and interactions using the appropriate analysis of variance. The analysis will usually include a subdivision of the sum of squares into linear and quadratic components to test whether the response is linear or curvilinear in shape.

A factorial experiment rapidly increases in size as the number of factors and levels of each factor increase. Thus a 3 x 3 x 3 factorial, that is one with three factors each at three levels, requires 27 plots for a single replication. The inclusion of one more factor at three levels would increase this to 81. To reduce the large block size that would be necessary the experiment may be configured in incomplete blocks, whereby not all the treatment combinations are included in each block. However this technique involves the sacrifice of information on the high order interactions.

In recent years interest has centred on the estimation of the relationship between a dependent variable, that is, some measure of the response, and the independent variables (the factors). Such a pattern of relationship is called a response surface and specific statistical techniques have been developed for estimating it. In this situation one is more interested in locating the combination of values for the factors that optimises the response than testing hypotheses about the individual factors and their interactions. An example of a factorial and a response surface design is given in Appendix 12.

5.5.3 General management of fertilizer trials

Trees that die before fertilizer application must be replaced immediately, preferably from a transplant bed kept for that purpose close to the experiment. Trees that have died by the end of the first year should be replaced but excluded from the assessment. It is important that the plots are kept free from weeds and other vegatation. If the experiment is kept active long enough there should be no thinning, and pruning should be restricted to dead branches only.

5.5.4 Assessment of fertilizer trials

Fertilizer experiments are usually relatively short term, hence the small size of plot; it will probably be continued for a year or two after competition has started. It is thus unnecessary to number the individual trees although the plots themselves must be clearly labelled. A number of assessments, on each inner plot, are recommended.

(i) Survival assessed annually from the end of the first growing season.

(ii) Height measured immediately after fertilizing and annually on all trees. It may be desirable to measure the height growth during the growing season, in which case it should be done monthly on the centre row or column of the 3 x 3 assessment plot.

(iii) Diameter measured annually on all trees at breast height once they are big enough.

(iv) Dry-weight production assessed at the end of two years. Two of the replications should be selected at random and all the trees in the assessment plots cut off at ground level for estimation of dry-weights. This should be done at the time of the annual assessment.

(v) Volume production: some estimate of volume will be necessary if the experiment is kept on until the trees are big enough.

(vi) Other measurements: it may be desirable to assess other variables such as foliar nutrient content, ring width and density, crown size, etc., particularly at a later stage if the experiment is still active.

All trees in the inner plot which were replaced after fertilizer application should be excluded from the assessment.

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appendix 1

abbreviations

A. Some general abbreviations used in the text:

CA	-	catchment area
CCT	-	correlated curve trend (type of stand density experiment)
CFI	-	continuous forest inventory
cm	-	centimetre
D	-	destructive sample plot for phytomass estimates etc.
d_{dom}	-	dominant diameter, quadratic mean diameter of 100 largest trees per ha, but see also IUFRO symbols
dbh	-	diameter at breast height (1.3 m above the soil surface) but see also IUFRO symbols below
dm	-	decimetre
E	-	experimental plots - classified in Table 1.2
g	-	gram or tree basal area (depending on context)
gt	-	greater than
kg	-	kilogram
lt	-	less than
m	-	metre
P1	-	conventional permanent sample plot - defined in Table 1.1
P2	-	productivity plot - defined in Table 1.1
P85	-	planting year - in this case 1985

B: IUFRO standard symbols

Symbol	Definition	Explanatory notes
c	circumference	with same indices as for diameter
d	diameter at 1.3m above ground of single tree	state whether measured with tape or calipers. If latter say if based on one or two measurements (at right angles)
d_u	d under bark	
d_g	diameter of tree of mean basal area	$= E\ d^2/n$
$\bar{d}$	arithmetic mean diameter	$= E\ d/n$
d_M	diameter of the median stem	
d_{gM}	diameter of the stem of median basal area	
$d+, d-$	Hohenadl mean stems	$d+ = d + \underline{sd}$; $d- = d - \underline{sd}$ where $\underline{sd}$ = standard deviation
$d_{.05h}$	diameter at half tree height above ground	
$d_{.01h}$	diameter at tenth of tree height above ground	
d_6	diameter at 6 m above ground	
g	basal area at 1.3 m above ground	
h	total tree height from ground to tip	
h_L	Lorey's mean height	$= \frac{g_1.h_1 + g_2.h_2 + \ldots.}{g_1 + g_2 + \ldots.}$
$\bar{h}$	arithmetic mean height	
h_g	height of tree of mean basal area	based on h/d regressions
h_d	height of arithmetic mean diameter tree	"
h_{dM}	height of median diameter tree	"
h_{gM}	height of tree of median basal area	based on h/g regressions

h_{dom}	dominant height (height of 100 trees per ha with largest diameter)	based on h/d regressions
k	form quotients based on relative diameters at half height and at 1.3 m	$= d_{0.5h}/d$
$k_{6/1.3}$	other form quotients are explained by subscripts eg. based on diameter at 6 m relative to diameter at 1.3m	$= d_6/d$
k_A	absolute form quotient	$= (d_{1/2(H+1.3)})/d$
v	total stem volume to tip but excluding branchwood	
v_7	stem volume above 7 cm min. diameter ('derbholz')	
v_b	total tree volume (bole and branches)	
v_{7b}	total bole and branch volume above 7 cm diameter	
f	artificial form factor	$= v\ /(g.h)$
f_7 f_b f_{7b}	other artifical form factors	$= v_7/(g.h)$ $= v_b/(g.h)$ $= v_{7b}/(g.h)$
$f_{0.1h}$	natural form factor of bole	$= v/(h.g_{0.1h})$
i	annual increment of a tree	
I	annual increment per unit area	
$\bar{i}$	arithmetic mean annual increment of a number of trees	the - indicates a mean of trees and not of years
i_{21-30}	periodic mean annual increment between the ages of 21 and 30 years	
i_{21-30}	total increment of a tree in the period between the ages of 21 and 30 years	
i_d	diameter increment	
i_g	basal area increment	

i_v	annual volume increment
i_{v7b}	annual increment of all wood of a tree over 7 cm in bole and branches
$I_{v7b31-50}$	periodic annual increment per unit area (eg.ha) of all wood over 7 cm between the ages of 31 and 50 years
n	number (of trees, years etc.)
n ha^{-1}	trees per ha
p	increment per cent
t	age

Symbols in CAPITALS generally indicate either totals per unit area, or, population totals. Overbark is assumed in absence of subscript u for underbark.

(Modified from Pardé and Bouchon (1988))

appendix 2

coding of variables

Many entries on the field forms referring to non-parametric data will be in the form of numerical codes. This is to standardize the categories, avoid ambiguities and reduce space occupied in the database.

For the general site description data may be recorded in the field on a form following the style of either Form 1 or of Form 1a. For the former the code lists should be carried in the field files for frequent and rapid reference to ensure that the correct concepts are being recorded. However it is possible to enter a verbal description in the field for coding later if preferred. Form 1a should be simpler to use for inexperienced staff as the meaning of the code numbers is given on the form.

The majority of the codes used refer to site variables and so are mainly used with Forms 1 and 1a. The key below follows the order of concepts on Form 1. The next section includes a key to crown and bole classes used for standing trees recorded on Forms 2 and 3.

Note the abbreviations: gt = greater than
lt = less than.

KEY TO CLASS CODES FOR VARIABLES USED WITH FORM 1

GENERAL PLOT DESCRIPTION

FIELD NUMBER	SIZE DIGITS	ITEM	CLASS	CODE
SITE VARIABLES				
15	1	Nature of slope	Linear	1
			Concave	2
			Convex	3
16	1	Catenary position	Meseta	0
			Ridge	1
			Upper-slope	2
			Mid-slope	3
			Lower-slope	4
			Broad valley	5
			Narrow valley	6
			Terrace	7
			Plain	8
17	1	Aspect	Level	0

			North	1	
			Northeast	2	
			East	3	
			Southeast	4	
			South	5	
			Southwest	6	
			West	7	
			Northwest	8	
18	1	Exposure (to wind)	Open on all aspects	1	
			Exposed in one direction	2	
			Locally exposed	3	
			Moderate protection	4	
			Protected	5	
19	1	Soil type	Latosol	1	ferrasols
					acrisols
					luvisols
					nitosols
			Vertisol	2	
			Calcimorphic	3	chernozems
					phaeozems
					rendzinas
			Desert	4	xerosols/yermosols
			Saline/Alkaline	5	solonchak/solonetz
			Gleys,Alluvial,Peat	6	fluvisols
					planosols
					histosols
			Shallow/immature	7	lithosols
					rankers
					andosols
			Temperate	8	podzols
					cambisols
			Not known	9	

NB. Poorly drained soils of valley floors and swamps should be classified under 6 unless there is positive evidence of them being widely cracking black clays, class 2

19	1	Soil depth	lt 10 cm	0
			10 - 20 cm	1
			21 - 30 cm	2
			31 - 40 cm	3
			41 - 50 cm	4
			gt 50 cm	5
23	1	Soil texture	Sand	1
			Loamy-sand	2
			Sandy-loam	3
			Loam	4
			Silt-loam	5
			Sandy-clay-loam	6
			Clay-loam	7
			Silty-clay-loam	8
			Silt	9

			Sandy-clay	10
			Medium-clay	11
			Heavy-clay	12
			Silty-clay	13
24	8	Colour	Use standard Munsell codes Up to 8 digits available: e.g. 2.5YR4/8	
25	2	Mottling	None	0
			Slight	1
			Strong	2
26	2	Soil structure		
		Development (tens)	Structureless	10
			Weak	20
			Moderate	30
			Strong	40
		Kind (units)	Platy	1
			Prismatic	2
			Columnar	3
			Angular-blocky	4
			Subangular blocky	5
			Granular	6
			Crumb	7
27	2	Consistence		
		Condition (tens)	Wet	10
			Moist	20
			Dry	30
		If wet: plasticity	Non-plastic	1
			Slightly plastic	2
			Plastic	3
			Very plastic	4
		If moist:	Loose	1
			Friable	2
			Firm	3
			Very firm	4
			Extremely firm	5
		If dry:	Loose	1
			Soft	2
			Slightly hard	3
			Hard	4
			Very hard	5
			Extremely hard	6
28	1	Gravel content (2-10mm)	None	0
			Low	1
			Medium	2
			High	3
29	1	Stone content (gt 10mm)	None	0
			Low	1

			Medium	2
			High	3
31	1	Drainage	Free	1
			Impeded	2
			Waterlogged in wet	3
32	1	Erosion class	Not evident	0
			Laminar	1
			Rill	2
			Gully	3
			Extreme	4

FOREST CROP

33	3	Species	[see separate Appendix 3]	
34	2	Provenance (define local 2 digit codes)		
37	2	Establishment method	Natural	00
			Seed	01
			Coppice	02
			Artificial	10
			Direct sowing	11
			Planting (pits)	12
			" (ploughing)	13
			Taungya	14
			Other	19
40	1	Plot type	Inventory	1
			Productivity	2
			Phytomass	3
42	1	Understorey type	Woody gt 0.8 lt 1.3 m	1
			Woody gt 0.3 lt 0.8 m	2
			Non-woody	3
			Absent	4
43	1	Understorey density	lt 5% cover, few	0
		individuals	lt 5% cover, several	1
			lt 5% cover, many	2
		cover	5 - 10%	3
			10 - 25%	4
			25 - 33%	5
			33 - 50%	6
			50 - 75%	7
			75 - 95%	8
			95 -100%	9
44	1	Ground flora type	Perennial herbs	1
			Annual herbs	2
			Grass	3
			Ferns	4
			Bryophytes	5

			Bare soil	9
45	1	Ground flora density class (as for Understorey 42)		
46	1	Grazing intensity	Not evident	0
			Light (no damage)	1
			Moderate	2
			Heavy (damage seen)	3
			Extreme	4
47	1	Grazing type	Cattle	1
			Horses	2
			Sheep	3
			Goats	4
			Pigs	5
			Antelope	6
			Other	7-8
			Several	9
48	1	Disease intensity	Not evident	0
			Light	1
			Moderate	2
			Severe	3
			Trees killed	4
49	2	Disease type	None	00
			Stem	10
			Foliage	20
			Shoot	30
			Root	40
			Other	50
			General	60
			Canker	2
			Resinosis	6
			Dieback	8
			Other	9
50	1	Insect damage	Not evident	0
			Light	1
			Moderate	2
			Severe	3
			Trees killed	4
51	2	Type of damage	None	00
			Stem	10
			Foliage	20
			Shoot	30
			Root	40
			Other	50
			General	60
			Borers	1
			Defoliators	2
			Leaf eaters	3
			Leaf miners	4

			Gall formers	5
			Other	9
52	1	Unplanned felling	Yes or No	0 or 1
53	2	Fire damage	None	00
			Light	10
			Moderate	20
			Severe	30
			Some trees killed	40
			Destruction	50
			Ground	1
			Stem damage	2
			Crown	3
54	2	Wind damage	None	00
			Light	10
			Moderate	20
			Severe	30
			Complete windthrow	50
			Crown distortion	1
			Crown damage	2
			Stem distortion	3
			Stem break	4
			Windthrow	5
55	1	Other damage	Yes or No	1 or 0
			if '1' then field 56 will be used...	
56	2	Other damage types	Light	10
			Moderate	20
			Severe	30
			Resin tapping	1
			Forage collection	2
			Branch cutting	3
			or describe	

INDIVIDUAL TREES

Codes used on Field Form 2 - Standing Tree diameters - P1 plots

3	5	Put T	for thinned since last assessment	
		D	died	"
		L	logging damage	"
			etc.	

Codes used on Field Form 4 - Standing Tree Data - P2 plots

5	3	Crown classification	Dominant	100
			Codominant	200
			Intermediate	300
			Dominated	400
			Suppressed (dying)	500
			Dead	600

			Wolf	700
			Normal	10
			Slender	20
			Wide	30
			Asymmetric	40
			Incomplete	50
			Dense foliage	1
			Normal foliage	2
			Open foliage	3
6	1	Bole form	Normal	0
			Leaning	1
			Forked	2
			Curved	3
			Twisted	4
			Multi-stemmed	5

---

appendix 3

species codes for plantation trees

Acacia albida	001
A. auriculiformis	002
A. cyanophylla	003
A. cyclops	004
A. decurrens	005
A. farnesiana	006
A. mangium	007
A. mearnsii	008
A. melanoxylon	009
A. nilotica	010
A. pendula	011
A. salicina	012
A. sengal	013
A. tortilis subsp.raddiana	014
Acrocarpus fraxinifolius	015
Agathis dammara	016
Albizia falcataria	017
A. lebbek	018
Alnus acuminata	019
A. nepalensis	020
A. rubra	021
Anacardium occidentale	022
Anthocephalus chinensis	023
Araucaria angustifolia	024
A. cunninghamii	025
A. hunsteinii	026
Aucoumea klaineana	027
Azadirachta indica	028
Bombacopsis quinata	029
Brachychiton populneum	030
Butyrospermum paradoxum	031
Calliandra calothyrsus	032
Callitris columellaris	033
Campnospermum brevipetiolata	034
Cariniaria pyriformis	035
Cassia siamea	036
Casuarina decaisneana	037
Casuarina equisetifolia	038
Casuarina glauca	039
Casuarina junghuhniana	040
Cedrela odorata	041
Ceratonia siliqua	042
Chlorophora excelsa	043
Cleistopholis glauca	044
Colophospermum mopane	045
Conocarpus lancifolius	046
Cordia alliodora	047
Cryptomeria japonica	048
Cunninghamia lanceolata	049
Cupressus arizonica	050
Cupressus lusitanica/benthamii	051
Cupressus macrocarpa	052
Cupressus torulosa	053
Dalbergia sissoo	054
Delonix regia	055
Eleagnus angustifolia	056
Eucalyptus botryoides	057
E. brockwayi	058
E. camaldulensis (North.Prov.)	059
E. camaldulensis (South.Prov.)	060
E. citriodora	061
E. cladocalyx	062
E. cloeziana	063
E. crebra	064
E. dalrympleana	065
E. deglupta	066
E. delegatensis	067
E. fastigiata	068
E. globulus	069
E. gomphocephala	070
E. grandis	071
E. intertexta	072
E. largiflorens	073
E, maculata	074
E. maideni	075
E. melliodora	076
E. microcorys	077
E. microtheca	078
E. nitens	079
E. obliqua	080
E. occidentalis	081
E. paniculata	082
E. pellita	083
E. propinqua	084
E. regnans	085
E. resinifera	086
E. robusta	087
E. saligna	088
E. salmonophloia	089
E. sargentii	090
E. sideroxylon	091
E. st.-johnii	092
E. tereticornis	093
E. torelliana	094
E. urophylla	095
E. viminalis	096

From: Webb D B; Wood P J; Smith J P; Henman S (1984).

appendix 4

construction of a simple litter trap

Materials required:

- nylon netting with 2 mm mesh, 90 x 90 cm approx.
- 4 wooden stakes 4 x 4 x 60 cm treated with creosote or other preservative
- 4 wooden battens 4 x 1 x 60
- No. 12 gauge wire
- pliers, sailmakers needle and nylon thread

Procedure:

- hammer four stakes into ground at corners of 60 cm square
- cut 90 x 90 cm square of netting with scissors
- fold corners of netting to form tray having 10 cm vertical sides
- tie netting to top of stakes
- twist wire round stakes and netting as in figure
- secure netting to wire all round with nylon thread or plastic ties
- insert battens inside netting to give it ridigity
- hammer four 'tent' pegs near each corner; loop wire from pegs to the four stakes to hold the frame rigid.

Alternatively prepare a box of the same dimensions with a removable base that consists of a wooden frame with the netting battened rigidly to it. The box is supported 25 cm off the ground by four stakes attached at each corner.

Collecting the samples:

The litter should be removed from each trap at weekly or two-weekly intervals. The litter will be divided into foliage, twigs, branches, cones and other material, weighed, dried and reweighed.

****
SECTION 3.14
****

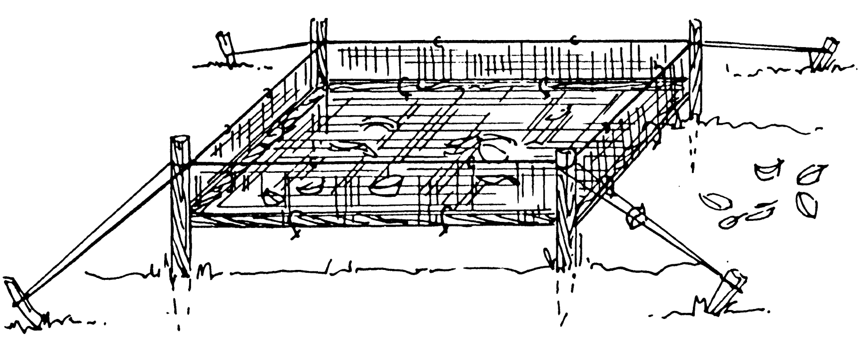


Figure A4.1
Litter trap

appendix 5

measuring a standing tree volume using a telerelascope

See the figure below and the literature (Bitterlich, 1980) for details of the scales on the telerelascope. Each of the four 'tachymetric' units (TUs) equal one diopter (a displacement of one unit at a distance of 100 units). The relascope is used with a graduated staff six metres long marked in centimetres that is placed at the foot of the tree. The telerelascope is mounted at a distance roughly equal to the height of the tree from where the top, breast height point and part of the bole can be clearly seen.

The procedure is simple:

(i) Sight to the graduated staff which is mounted at a known height at the base of the tree.

(ii) Read the width on the staff (W) subtended by the four TUs on the telerelascope scale:

4 TU = W; TU = W/4 = Distance (m) from observer to tree

W/4 is called the "base reading" (BR)

(iii) Sight to required height on tree and read the percent scale (P)

Height = BR x P/100

(iv) Still sighting to required height read the diameter of the bole at that height in TUs (DU), except when sighting to top of tree.

Diameter = BR x DU.

(v) Enter readings on Form 7

(vi) The overbark bole volume can now be calculated using the program TELREL supplied on the PPR disk, or, using an HP-97 programmable calculator, with Bitterlich's program No.10 given on page 229 of 'The Relascope Idea'. (Bitterlich, 1984).

(vii) Repeat 1-6 from a second observation point. If there is a difference in the volume estimate of more than 20% repeat 1-6 from a third observation point.

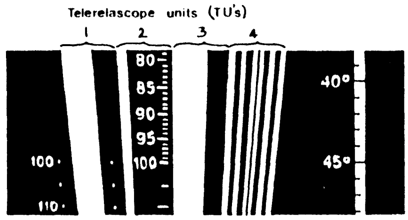


Figure A5.1
Telerelascope scale

****
SECTION 3.11/6
****

appendix 6

notes on training requirements

Training the field teams

It is essential to train and equip at least one inventory team for carrying out the CFI programme in the field. Training for team leaders will include;

- basic mensuration techniques - use of diameter tapes, hypsometers, compasses and linear tapes with slope correction procedures
- advanced techniques to include use of the wide-angle relascope for crown measurements and shrub density estimates, and where appropriate, use of the telerelascope for standing volume measurement
- species identification, not only of the trees but also of the commoner understorey shrubs, forbs and grasses
- establishing correct field drills and communication procedures (such as verbal commands and hand signals)
- methods of recording data
- understanding the instructions and implications of this manual.

Semi-skilled team members should have at least one week of practice under supervision before undertaking field work on permanent plots.

Training in data processing

Training should also be provided in data processing. A data processing team (probably consisting of a programmer and an operator) should be based at a central office for processing the data with the help of a microcomputer. Within a two-week course the following aspects should be covered:

- familiarization with the operation of a microcomputer
- data capture using the package PPR (see Chapter 4)
- production and interpretation of plot summaries
- use of plotting routines
- linear regression programs
- introduction to a simple simulation model and construction of yield tables.

appendix 7

correcting distances for slope

A slope correction table (in this example for use with a circular plot) may be printed using the BASIC program below. This may be found on the PPR disk in file SLOPE.BAS. The first few lines of the output of this program (which should be adapted to local requirements) are:

Corrected plot radius (metres) for slope (degrees)

Plot area:	0.01	0.02	0.03	0.04	0.05	0.06 ha
Radius:	5.64	7.98	9.77	11.28	12.62	13.82 m
--Slope--						
Deg. 4	5.66	8.00	9.80	11.31	12.62	13.82
6	5.67	8.02	9.83	11.35	12.65	13.82
					.... etc.	

```
70 ' Program: SLOPE
80 PI=3.1415927£
90 DIM RAD(10)
100 A=.01
110 FOR I=1 TO 6
120  RAD(I) = SQR(A*10000/PI)
130  A=A+.01
140 NEXT I
150 RK=PI/180
160 LPRINT CHR$(27);CHR$(33);CHR$(17)
170 LPRINT :LPRINT
180 LPRINT SPC(69); " appendix 7":LPRINT :LPRINT :LPRINT
190 LPRINT SPC(35);"SLOPE CORRECTION TABLE"
200 LPRINT SPC(21);"Corrected plot radius (metres) for slopes (degrees)"
210 LPRINT :LPRINT SPC(10);STRING$(70,"-")
220 LPRINT SPC(10);"Plot area:   ";
230 FOR I=1 TO 6
240   LPRINT USING "££.££    ";PI*RAD(I)*RAD(I)/10000;
250 NEXT I
260 LPRINT
270 LPRINT SPC(10);"Radius:      ";
280 FOR I=1 TO 6
290   LPRINT USING "££.££    ";RAD(I);
300 NEXT I
310 LPRINT:LPRINT SPC(12);
320 LPRINT "degrees"
330 LPRINT SPC(10);STRING$(70,"-")
340 FOR I=4 TO 50 STEP 2
350 LPRINT SPC(10)
360   LPRINT USING "    ££      ";I;
370   FOR J=1 TO 6
380     LPRINT USING "£££.££   ";RAD(J)/COS(I*RK);
390   NEXT J
400   LPRINT
410 NEXT I
420 LPRINT SPC(10);STRING$(70,"-")
430 END 'SLOPE
```

appendix 8

equipment lists

Check list 1:
EQUIPMENT FOR P1 PLOT - ESTABLISHMENT AND ASSESSMENT

No.	Item
2	30 m linear tapes (plastic)
2	lengths of rope (12 - 15 m long)
2	diameter measuring tapes (plastic)
1	calliper
1	hypsometer (Suunto)
1	compass (Suunto or other)
2	rods marked at 1.3 m
1	sighting rod with adjustable mark
1	set height measuring rods(young st)
1	folder with previous plot records
1	clipboard with field forms 1, 2 & 3
1	compartment map
1	set number cards
1	calculator
1	ruler
1	set pencils, pens, rubbers etc.
many	spare field forms and paper sheets
1	copy of 'Monitoring Tree Growth', Chapter 3
1	stake or stone pillar (1st occasion)
1	set of plastic number tags and wire OR paint, paint pot and brushes etc
2	machete knives or billhooks
1	spade
1	first aid kit

Check list 2:
ADDITIONAL EQUIPMENT FOR P2 PLOT - ESTABLISHMENT AND ASSESSMENT

Check that all items listed for P1 plots are carried, and, in addition the following:

No.	Item
2	soil augers
4	litter traps (1st occasion)
1	ladder (size depending on crop height)
1	park pruner
1	spring balance and support
many	field forms ....
1	set marker pens
many	plastic bags, labels and ties
	sacks for carrying samples

Check list 3:
ADDITIONAL EQUIPMENT FOR D PLOT - FELLING AND ASSESSMENT

Check that all items listed for P1 plots are carried, and, in addition the following:

No.	Item
1	cross-cut saw
1	axe
1	de-barking knife
1	bark gauge
1	spring balance and support
1	platform balance
	plastic sheet or trestle tables (for sorting sample material)
Many	plastic bags, labels and ties (for foliage and wood samples)
Many	field forms ....
1	set marker pens

appendix 9

choice of type of sample unit

This dichotomous key may be used at an early planning stage in designing a monitoring programme.

If resources are very limited in terms of available finance, personnel or transport availability .... go to 1.5.4

If resources are moderately available or unlimited .... go to 1.5.2

1.5.2 If sample plots cannot be easily relocated, revisited or it is impossible to make occasional checks on their upkeep and maintenance .... go to 1.5.4

If visits and maintenance checks are possible or probable..go to 1.5.3

1.5.3 If the plantation area is very large (e.g. more than 5000 ha) and there are no obvious indications of any growth changes or site deterioration **over the range of sites available**, or there are insufficient resources to undertake more than a conventional forest inventory programme ....go to 1.5.5

If there is concern about possible site deterioration due to one or more of any possible causes, or if the plantation is of medium or small area, or if there are obvious areas of growth check or decline ....go to 1.5.6

1.5.4 **Choose T plots only**

1.5.5 **Choose both T and P1 plots**

1.5.6 If there are sufficient personnel, supervision and competence to undertake biomass studies, coupled with an accessible laboratory to analyse materials ....go to 1.5.7

If one or more of the constraints listed above in 1.5.6 exist ......go to 1.5.8

1.5.7 If there is sufficient competence to set up spacing and density experiments to supplement growth plot data ....go to 1.5.10

If there is difficulty in establishing and maintaining experimental work ...... go to 1.5.9

1.5.8 **Choose T, P1 and P2 plots**

1.5.9 **Choose P1, P2 and D plots**

1.5.10 **Choose P1, P2 and D plots and experimental designs**

---

appendix 10

examples of designs for spacing experiments

A10.1. Clinal spacing design

MODEL EXPERIMENT PLAN No.1 (Supplied by H.L. Wright)

Details of a suitable design are given in Table A10.1. The design is a type Ia in which only the spacing changes, and rectangularity are held constant. It is felt that the shape of the growing space available to a tree will little effect on its growth. Accordingly a value of 1.5 is suggested equivalent to a standard rectangular planting distance of 3 x 2 m as might be found in many plantation projects.

In calculating the parameters of the design it was decided that a range of growing space per tree from 3 m^2 to approximately 80 m^2 should be used. This is equivalent to stockings of 3,333 to 125 trees per hectare. It is unlikely that, in practice, the planting distance will drop below the 3 x 2 m currently used owing to the use of mechanized cleaning operations. Thus it was arranged that an area of 6 m^2 should occur near the beginning of the range. The values of the constant ro, the inter-radial angle alpha, and the number of spacings included (N) were manipulated to take account of several factors. These included the convenience of exactly 10 degrees for the angle, the space available between brushpiles, and the relationship between the various stocking levels. In the latter case it was necessary to try and include the majority of the stocking levels which will occur in an associated thinning experiment. This illustrates the considerable flexibility available when computing the parameters of a type Ia design.

Table A10.1 gives the 15 different levels in terms of their distance from the origin, the area per tree, the stocking in trees per hectare, and the equivalent spacing. It can be seen that the stocking at level 4 is half that at level 1. Similarly level 5 is half that of level 2, et seq. This design was laid out in one area where brushpiles had been laid out in rows following the contour lines leaving planting strips 35 m wide. This kind of restriction on the field layout of experiments is often encountered and the design should be adapted accordingly.

Table A10.1
DESIGN FOR A CLINAL SPACING TRIAL

Angle between radii	10^{o} (constant) (0.1745 radians)
Rectangularity	1.5 (constant)
Number of arcs including guards	18
Radial distance of nth arc	$r_n = r_o$
$r_o = 15.30$	= 1.1232
Maximum radius	69.30 m
Area required	1.51 ha
Number of trees required	342

Level	Radial distance (m)	Difference	Area per tree (m^2)	Number of trees/ha	Equivalent spacing (m)
guard	9.61		-	-	-
		1.19			
guard	10.80		-	-	-
		1.33			
1	12.13		2.99	3345	1.41 x 2.12
		1.49			
2	13.62		3.77	2653	1.49 x 2.38
		1.68			
3(r_o)	15.30		4.76	2101	1.78 x 2.67
		1.88			
4	17.18		6.00	1667	2.00 x 3.00
		2.12			
5	19.30		7.57	1321	2.25 x 3.36
		2.38			
6	21.68		9.95	1047	2.53 x 3.78
		2.68			
7	24.36		12.06	830	2.84 x 4.24
		2.99			
8	27.35		15.20	654	3.18 x 4.78
		3.37			
9	30.72		19.18	522	3.58 x 5.36
		3.79			
10	34.51		24.20	414	4.02 x 6.02
		4.25			
11	38.76		30.53	328	4.51 x 6.77
		4.77			
12	43.53		38.50	260	5.07 x 7.59
		5.37			
13	48.90		48.59	206	5.70 x 8.51
		6.02			
14	54.92		61.29	164	6.40 x 9.58
		6.78			
15	61.70		77.36	129	7.19 x 10.76
		7.60			
guard	69.30		-	-	-

The design should be replicated four times along a strip using half circles of the design with the origin alternately at each side of the strip. A similar layout is illustrated diagramatically in Figure A10.1.

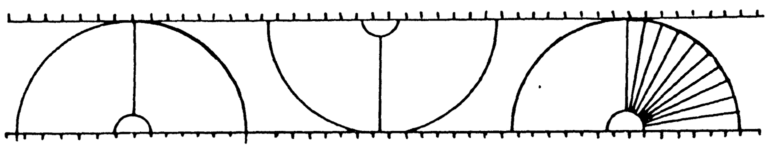


Figure A10.1
Layout for a clinal design with three replications

The 180 degree fan gives 19 spokes which is effectively 15 trees per arc after allowing for two guard spokes at each end. There is thus a total of 60 trees at each of the 15 levels.

When laying out the design in the field a stake is first set up at the origin of the circle which should be as close to the brushpile as possible at the same time allowing a base line of 140 m to run alongside the brushpile. A radius 90 degrees to the baseline is then marked at its intersection with the next brushpile using a theodolite or tripod-mounted compass. The ends of radii at 10 degree angles from this line are then marked at 72 m from the origin using a cord or tape. Once all the spokes are marked the planting spots can easily be found if the distances have been painted or otherwise indicated on the cord. This will be simplified if the cord is made to swivel freely on the stake at the origin. The direction of the first replication should be chosen at random.

A10.2 Randomized block spacing design

MODEL EXPERIMENT PLAN No. 2

Title: Pine Spacing Trial

Location: (This design has been tested in Karnataka, southern India)

Species must be specified, if possible with seed lot number and provenance.

Date of planting must be specified.

Objective:

- to determine the spacing that will give the maximum production of highest quality pulpwood in the shortest time;
- to establish maximum basal area levels for the site and species.

Plant material: 2262 selected healthy first-year transplants.

Design: Randomized block with 7 treatments and 3 replications.

Treatments: Seven initial square planting distances plus one rectangular spacing comparable to current management practice:

Table A10.2
TREATMENTS IN A RANDOMIZED SPACING TRIAL

Treatment number	Planting distance (m)	Assessmt. area sq.m	Surround area sq.m	Stems per ha	Stems assesst. plot	Stems surround plot	Stems Total plot
1	1 x 1	225	400	10,000	225	64	289
2	2 x 2	256	369	2,500	64	59	123
3	2.5 x 2.5	225	400	1,600	36	64	100
4	3 x 3	225	400	1,111	25	64	89
5	3.5 x 3.5	306	319	816	25	51	76
6	3.5 x 1.75	306	319	1,632	50	101	151
7	4 x 4	400	225	625	25	36	61
8	5 x 5	625	-	400	16	-	16
				Total (one block):			905

Plot size: 25 x 25 m = 0.0625 ha. In order to accommodate square planting at the different spacings the treatment plot and surrounds vary in size between treatments as shown in the table above. The surround will be planted at a standard spacing of 2.5 x 2.5 m (1600/ha). In order to avoid the undesirability of assessment plots of different size (introducing the risk of greater site variation between treatments) a circular plot of radius 7.98 m (0.02 ha), or less, located at the centre of each treatment plot is recommended.

Layout: randomized blocks with eight treatment plots within each block. Each main plot will be 25 m square (0.0625 ha). There will be a variable width of surround contained within the fixed area of the main plots. When the overall plan has been marked on the ground lay out the planting positions for the treatment plots from the centre of each plot. The spacing in the outer rows of the main plots, or surround, will be a standard 2.5 x 2.5 m (see diagrams below).

Management: in order to avoid confounding the effect of spacing with weed competition the whole layout should be completely cultivated and kept weed free by frequent harrowing or hand cultivation (at the closer spacings).

Standard fertilizer treatments:

Year	Fertilizer dose		
1	25 g/plant NPK	15.15.15	in hole
2	50 g/plant	"	round plant
3	"	"	"

should be applied, or as specified by local management.
Duration: approx. 5 years by which time detailed assessments should be completed and the value of any extension of the trial assessed.

Assessments:

(i) survival percent;
(ii) in years 1 and 2 measure the heights of all trees on the assessment plots, to the nearest centimetre, once a year in May and June
(iii) in years 3 onward measure diameters and a sample of up to 10 trees for total height within each assessment plot.Selection of trees for height measurement should be made objectively. Height should be measured on the same dates as the diameters.Use Field Forms 2 and 3.
(iv) in year 5 estimate standing volume using the standard procedure for P1 plots.

Parameters:

mean diameter, mean and dominant stand height, basal area, relative basal area, spacing percent (S%), stand volume (total and to 5 cm diameter limit). Each assessment will provide the data to determine the rate of increment of the relevant variables in relation to spacing expressed as growing space, relative basal area and other indices of stand density.

Analysis:

(i) analysis of variance will determine the relative importance of differences between treatments;
(ii) the seven treatments will enable a response surface of various measures of growth to be estimated from which optimum spacing for different management objectives may be determined.

Plan:

```
             <----------------------175 m----------------------->
             <-25 m->
  ----------------------------------------------------------------
 |1      |8      |6      |5      |7      |4      |3      |2      |   25 m
 |       |       |       |       |       |       |       |       |
  ----------------------------------------------------------------
 |7      |2      |3      |4      |6      |8      |5      |1      |
 |       |       |       |       |       |       |       |       |
  ----------------------------------------------------------------
 |5      |1      |6      |3      |2      |7      |8      |4      |
 |       |       |       |       |       |       |       |       |
  ----------------------------------------------------------------
```

Total area = 1.3125 ha

Figure A10.2
Experiment plan for randomized block spacing trial

Example of relation of assessment plot to main plot for treatment 1:

```
   <-------------------25 m--------------------->
   ----------------------------------------------
  |<-2.5m>
  |  *    *    *    *    *    *    *   *    *    * |
  |                                                |
  |  *    *    *    *    *    *    *    *    *    * |
  |        1 m                                     |
  |  *    * x x x x x x x x x x x x x x x    *    * |
  |         x x x x x x x x x x x x x x x          |
  |  *    * x x x x x x x x x x x x x x x    *    * |
  |         x x x x x x x x x x x x x x x          |
  |         x x x x x x x x x x x x x x x          |
  |  *    * x x x x x x x x x x x x x x x    *    * |
  |         x x x x x x x x x x x x x x x          |
  |         x x x x x x x x x x x x x x x          |
  |  *    * x x x x x x x x x x x x x x x    *    * |
  |         x x x x x x x x x x x x x x x          |
  |         x x x x x x x x x x x x x x x          |
  |  *    * x x x x x x x x x x x x x x x    *    * |
  |         x x x x x x x x x x x x x x x          |
  |         x x x x x x x x x x x x x x x          |
  |  *    * x x x x x x x x x x x x x x x    *    * |
  |                                                |
  |  *    *    *    *    *    *    *    *    *    * |
  |                                                |
  |  *    *    *    *    *    *    *    *    *    * |
   ----------------------------------------------
```

(diagram not to scale)

Figure A10.3
(a) Plot plan showing assessment plot at close spacing

Example of relation of assessment plot to main plot for treatment 7:

```
<-------------------25 m------------------>
-------------------------------------------
| <---5 m--->                              |
|  x        x        x        x       x    |
|                                          |
|  x        x        x        x       x    |
|                                          |
|  x        x        x        x       x    |
|                                          |
|  x        x        x        x       x    |
|                                          |
|  x        x        x        x       x    |
|                                          |
-------------------------------------------
```

(diagram not to scale)

* = tree position in surround; x = tree position in assessment plot.

Figure A10.3
(b) Plot plan showing assessment plot at wide spacing

Note: this is a robust design but it only compares square spacing and is confined to one species and provenance. Further experiments are being designed to test the interaction of spacing with genotype and to test the effect of different patterns of spacing.

The next example is a factorial design for testing spacing effects on the growth of a short-rotation crop, the interaction between trees and an annual interplanted crop and soil water uptake.

A10.3 Factorial spacing design

MODEL EXPERIMENT PLAN No. 3

Title: Factorial spacing and intercropping trial.

Location: (This has been tested in Karnataka, southern India).

Objectives:

- to determine the effect of inter-tree competition throughout at least one rotation of short rotation tree crop (e.g. Eucalyptus spp.);
- to determine the effect of stand density on water use;
- to investigate the effect of stand density on stem form and the partitioning of production in the stand between stem, branchwood, foliage and roots;
- to quantify the effect of density of a tree crop on the productivity of an inter-planted annual crop during the first three years of the rotation of the plantation.

Design: Factorial with six spacings times two crop treatments (with and without inter-planting of an annual crop) and three replications. This is an alternative to a clinal design for testing spacing effects and is to be preferred in many situations where there is some risk of loss of individual plants. It is often advisable to install both a clinal and a randomized block, or factorial, design at each site as the experiments then complement each other. A block design has the advantage of providing uniform spacing within the treatment plots, which allows soil moisture measurements to be made and interpreted more easily. It is also a more robust design in which missing trees create fewer problems for analysis and interpretation.
To avoid root interference between neighbour plots there should be boundary trenches between all plots. The plot area is approximately 256 sq. m. of sides 16 m. This gives a central treatment area of 15 x 15 m per plot. Spacings of 1 x 1, 2 x 2, 3 x 3, 4 x 4 and 5 x 5 m, plus one rectangular spacing of 1 x 2.5 m are recommended. If repeated this treatment should be planted at 1.5 x 2.75 m to agree with current management practice. The annual crop should be planted within half the spacing treatments within each replication.

Plot sizes should be constant so the number of trees in each treatment plot will vary from 16 (at 5 x 5 m) to 225 at 1 x 1 m.

Total area of 36 plots, inclusive of trenches is 9216 sq. m.

Trenches 30 and 50 cm deep will be used initially.

Management: keep clean by intensive weeding as necessary. Clean and deepen trenches in reponse to observed root development. When cleaning trenches spread the soil removed evenly over all adjacent plots.

Assessment plots: Circular plots of radius 5.64 m (0.01 ha) at the centre of each treatment plot. (Square assessment plots should be avoided as the limits of the plots may be correspond with rows and give erratic estimated of available growing space). It is recommended to record **all trees** in the treatment plots in order to evaluate edge effects, while carefully discriminating between trees falling within the assessment plots from those in the buffer zone. Each assessment plot will be measured and analysed as a P1 permanent sample plot using the appropriate PPR programs to give the normal range of stand parameters for comparison.

One neutron probe access tube may be located at a random location within the assessment plot area in each of the 36 treatment plots for monitoring soil water content.

appendix 11

examples of designs for thinning experiments

A11.1 Design 1: Triple-split plot. (Supplied by H.L. Wright)

MODEL EXPERIMENT PLAN No.4

This example is taken from a forestry research project in Turkey. The objectives of the experiment are those given in the main text under Section 5.4.

A series of thinning treatments for a thinning trial with a coniferous species is given in Table A11.1. The initial stocking has been set at 1667 trees per hectare which is equivalent to the standard 3 x 2 m planting distance being currently used in many plantations projects. It is unlikely that this will alter for some time and to test the response to thinning for a range of initial stockings would involve too much experimentation. The treatments can be considered as a factorial arrangement with the factors being first thinning and second thinning, each with three intensities. Thus:

First thinning	Second thinning
Remove 25 percent of stocking	No further thinning
Remove 50 percent of stocking	Remove 50 percent of stocking
Remove 75 percent of stocking	Remove 75 percent of stocking

The tree intensities for the first thinning have been chosen to cover the range from a moderate to a very heavy thinning.

The nine treatment combinations will be repeated at three periods in time. These are:

1. at the beginning of competition at the original stocking;
2. two years after competition has started;
3. four years after competition has started.

The treatments have been expressed quantitatively in terms of the number of trees per hectare to be removed. This is much simpler to operate in practice than say basal area. Much of the experimentation in thinning, particularly in Europe, has been concerned with the comparison of qualitative thinning methods, e.g. high, low, crown, etc. However in the U.K. the type of thinning has appeared to be less important than the intensity when concerned with maximum volume production (Wardle 1967). With increasing emphasis on the economic aspects, methods of mechanical thinning have become attractive especially for pre-commercial thinnings. It is suggested that the thinning treatments in this experiment should be carried out systematically. This will also ensure that there is no subjective selection in the populations thus making them more comparable under all treatments. It also enables comparisons to be made with the spacing experiment where, of course, no selection has occurred.

Table A11.1
THINNING TREATMENTS

Plot number	Initial stocking/ha	Stocking after 1st thinning	percent removed	Stocking after 2nd thinning	percent removed
1	1667	1250	25	1250	nil
2	1667	1250	25	625	50
3	1667	1250	25	313	75
4	1667	834	50	834	nil
5	1667	834	50	417	50
6	1667	834	50	208	75
7	1667	417	75	417	nil
8	1667	417	75	208	50
9	1667	417	75	104	75

A11.1.1 Experimental layout

The experiment is best laid out as a triple split-plot in randomized blocks. This has advantages both in the convenience of operations and because there will tend to be less variation within timings than between them. Similarly there will be less variation between plots with the same first thinning intensity. The primary plots will correspond to the timing of the thinning, the secondary plots to the first thinning and the tertiary plots to the second thinning. This is shown diagrammatically in Figure A11.1 for a single block.

The individual treatment plots should consist of 13 x 23 rows of trees giving a plot size of 36 x 46 m or 0.166 ha. This allows an inner assessment plot of 128 (8 x 16) trees (0.0768 ha) which can easily be systematically thinned for all the treatment combinations. The plot with the heaviest degree of thinning (75 percent, 75 percent) will thus end up with 8 trees, a minimum number. A single thinning will need 432 m of plantable strip for its nine plots, equivalent to 1.555 ha. This allows a 2 m blank strip to demarcate each plot. The area required for each block is thus considerable; however it is emphasized that, as in the spacing experiment, one is not interested in comparing specific thinning regimes but in estimating the effects of the treatments. For this reason there need be less concern over reducing the amount of residual variation in the experiment. It is suggested that two replications are established. This will require a total area of 9.111 ha or 2592 m of strip.

A11.1.2 Timing and method of the thinning operations

The clinal experiment can be used to judge when competition should be beginning in the thinning experiment and thus the time for the first thinning. The clinal contains three denser stocking levels before the standard 1667 trees per ha. Competition can be assumed to have begun once the diameter increment at a given spacing falls below that for the wider spacings. Careful monitoring of the clinal experiment should therefore indicate when competition is likely to begin at the different spacings. Data from the spacing experiment and the permanent sample plots in the older plantings can also be used as a check. The timing for the second thinning can be judged in a similar way by use of the data from the spacing experiments. When the first thinning is delayed the second thinning will also be delayed by the same period.

Table A11.2 gives the thinning treatments in terms of the numbers of trees removed per plot at each thinning and the resulting stockings.

Table A11.2
THINNING EXPERIMENT - NUMBER OF TREES TO BE REMOVED

Plot number	Initial stocking	No. removed 1st thinning	Intermediate stocking	No. removed 2nd thinning	Final stocking
1	299	78	221(96)	0	221(96)
2	299	78	221(96)	117	104(48)
3	299	78	221(96)	173	48(24)
4	299	143	156(64)	0	156(64)
5	299	143	156(64)	84	72(32)
6	299	143	156(64)	120	36(16)
7	299	227	72(32)	0	72(32)
8	299	227	72(32)	36	36(16)
9	299	222	75(32)	53	24(8)

(The figures in brackets are the stockings in the assessment plots.)

The trees are to be removed systematically and the schedule for doing this is given below in Table A11.2 for each of the nine treatment plots, using the row and column numbers shown in Figure A11.2.

The fact that not exactly 25, 50 or 75 percent is removed is due to the systematic nature of the thinning; the assessment plots however have the correct stocking. Figure A11.2 is a diagram of a plot showing the individual trees and the co-ordinate numbering suggested as a means of reference. The boundary of the assessment plot is also indicated; this is constant for all the treatments.

It is suggested that for each plot a form such as that in Figure A11.2 is used to indicate which trees must be thinned. A master form for each plot will also serve as a record of which trees have been removed. This form should also show the proposed final crop trees.

trees, if due to be retained, must be replaced by the nearest tree that is marked for thinning.

Table A11.3
THINNING EXPERIMENT - CHOICE OF TREES TO BE REMOVED

Plot number	First thinning	Second thinning
1	Columns 3, 7, 11, 15, 19, 23	nil
2	"	Columns 1, 4, 6, 9, 12, 14, 17, 20, 22
3	"	Columns 1, 4, 6, 9, 12, 14, 17, 20, 22 Odd-numbered rows
4	Even-numbered columns	nil
5	" " "	Odd-numbered rows
6	" " "	Odd-numbered rows Columns 1, 5, 9, 13, 17, 21
7	Even-numbered columns Odd-numbered rows	nil
8	Even-numbered columns Odd-numbered rows	Columns 1, 5, 9, 13, 17, 21
9	Odd-numbered columns Even-numbered rows	Columns 4, 8, 12, 16, 20 Rows 3, 7, 11

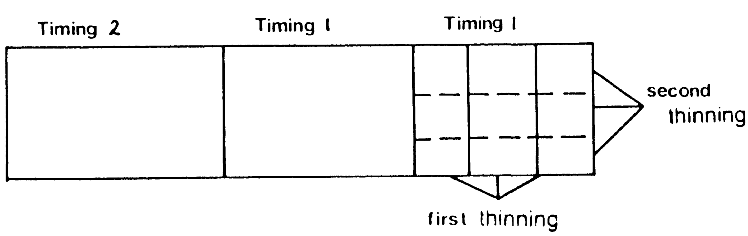


Figure A11.1
Thinning experiment split-plot layout

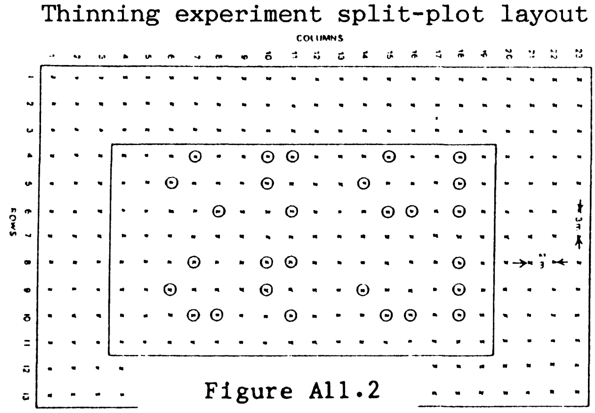


Figure A11.2
Thinning experiment: plot diagram

appendix 12

examples of designs for fertilizer experiments

A12.1 Factorial fertilizer design

MODEL EXPERIMENT PLAN No. 5 (with acknowledgments to J. Riley)

Title: Eucalypt and Pine fertilizer trials

Locations: (These have been laid down in Karnataka, southern India).

Species: Eucalyptus tereticornis local hybrid; Eucalyptus camaldulensis; Pinus caribaea var. hondurensis

Objective:

- to investigate the response to the addition of nitrogen, phosphorus and potassium during the first part of the rotation.
- to evaluate the optimum economic levels of fertilizing.

Design: 3 x 3 x 2 factorial in 2 replicate blocks of 18 plots giving a total of 36 plots. 3 levels of N, 3 levels of P and 2 levels of K will be used. Each plot will be split into 3 to permit extra applications of NPK in years 2 and 3 to the second and third sub plots respectively.

Treatment combinations:

In standard order, treatment combinations are shown in Table A12.1.

Table A12.1
TREATMENT COMBINATIONS FOR A FERTILIZER TRIAL

No.	Factor (Nutrients) N	P	K
1	0	0	0
2	0	0	1
3	0	1	0
4	0	1	1
5	0	2	0
6	0	2	1
7	1	0	0
8	1	0	1
9	1	1	0
10	1	1	1
11	1	2	0
12	1	2	1
13	2	0	0
14	2	0	1
15	2	1	0
16	2	1	1
17	2	2	0
18	2	2	1

where the levels of N and P are 0, 1 and 2 and the levels of K are 0 and 1. These levels should be increasing and equally-spaced to facilitate analysis, should this be done using less sophisticated computer programs or, even, hand analysis.

The standard treatment that has been applied to plantations (eg. MPM 1987) is:

Year 1	25 g per plant	N:P:K (15:15:15)
" 2	50 g	"
" 3	50 g	"

These levels will be spanned by the treatment levels recommended but a luxury treatment should also be tested.

The suggested levels using separate compounds for the three elements are shown in Table A12.2.

Table A12.2
SUGGESTED LEVELS FOR FERTILIZER TREATMENTS

	Grams per plant N	P	K
Level 0	-	-	-
Level 1	15	30	30
Level 2	30	60	-

If, for example, urea (46.4% N), rock phosphate (21.5% P) and muriate of potash (60% K) were to be used then the quantity of compounds required in grams per plant for the levels would be as in Table A12.3.

Table A12.3
COMPOUNDS FOR THE FERTILIZER TREATMENTS

	Grams per plant		
	Urea	Rock Phos.	Mur.of Potash
Level 0	-	-	-
Level 1	32.3	140	50
Level 2	64.6	280	-

The main plots should be split into three sub-plots which should receive treatments differing in time. In year 1 the levels shown above should be applied to all three sub-plots. In the second year the sequence of fertilizer applications should be repeated on sub-plots 2 and 3, but not on sub-plot 1 which will receive the treatments as specified above once only. In the third year of the experiment sub-plot 3 only should receive the extra applications.

Layout: Two blocks of 18 plots with randomized allocation of treatments within blocks. Blocks must be located on homogeneous sites. Blocks should be located according to site.

Plot size, including the surround: 5 rows by 15 rows 2 m apart in both directions with three sub-plots of 5 x 5 rows. Total plot size is, therefore, 300 sq.m. giving a total area for each experiment of 300 x 36 = 1.08 ha.

Assessment plot: within each 5 x 5 sub-plot an assessment plot will be a central sub-plot of 3 rows x 3 rows.

Plant material: 75 plants per plot, 2,700 for a complete layout. The quantities required for this experiment are given in Table A12.4.

Table A12.4
QUANTITIES REQUIRED FOR THE FERTILIZER TREATMENTS
Fertilizer requirements in kg:

	Urea	Rock Phos.	Mur.of Potash
Year 1	8.72	37.8	4.5
Year 2	5.81	25.2	3.0
Year 3	2.91	12.6	1.5
Total	17.5	75.6	9.0

Management: Apply normal management procedures of sub-soiling and soil treatments. Apply the fertilizer round each plant individually.

Costs: a record of costs of materials, equipment and labour used in applying the treatments should be kept.

Plot plan:

```
 2 m spacing;  * and + = tree position in treatment plot;
               +       = tree in assessment plot
 Plot size 30 x 10 m
 Sub-plot:
        1                    2                    3

*   *   *   *   *   *   *   *   *   *   *   *   *   *   *

*   +   +   +   *   *   +   +   +   *   *   +   +   +   *

*   +   +   +   *   *   +   +   +   *   *   +   +   +   *

*   +   +   +   *   *   +   +   +   *   *   +   +   +   *

*   *   *   *   *   *   *   *   *   *   *   *   *   *   *
```

Figure A12.1
Assessment plot in a factorial fertilizer trial

Duration: three to five years

Assessments: Total tree height twice a year
Diameter when any tree reaches 5 cm dbh

Parameters: mean diameter, mean and dominant stand height, basal area, stand volume (total and to 5 cm diameter limit) and stand phytomass.

Analysis:
- analysis of variance will determine the main effects of N P and K and interactions.
- linear and quadratic effects of N and P will be tested.
- cost effectiveness of fertilizing in terms of increased yield will be evaluated.
- pattern of response will indicate range of levels for testing in subsequent trials.

A12.2 Response Surface Designs (supplied by H.L. Wright)

These designs are explained by Cochran and Cox (1957) and by Clutter (1968), written specifically with regard to fertilization experiments. In mathematical terms one may express the response y as a function of the factors x involved.

$$y = F(x_1, x_2, \ldots x_n)$$

The function F is called the response surface. It has been shown that the mathematical form of the function can often be adequately described by first and second degree polynomial equations. Thus, for a three-factor first and second degree polynomial equations. Thus, for a three-factor experiment the most common analysis of a response surface is the estimation of the coefficients in a second order regression of the form.

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x^2{}_1 + b_{22}x^2{}_2 +$$
$$b_{33}x^2{}_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3$$

Where y is the average response associated with a given combination of factor values, x_1, x_2, x_3 denote the values of the controllable factors, and b_0, b_1, b_2 ...... b_{23} are unknown regression coefficients.

In order to estimate the coefficients each X-variable must have at least three levels. The model could therefore be fitted to the data from a 3 x 3 x 3 factorial; however the coefficients of the squared terms would be estimated with relatively low precision and a wider range of levels would also be desirable. To overcome this, designs have been constructed to guarantee certain desirable properties for the estimates of the regression coefficients and for estimates of y.

The designs most suitable for fertilization research belong to a series known as 'central composite rotatable second order' designs. Such a design for three x-variables (say N, P, and K) is made up as follows:

- The eight factor combinations of a 2 x 2 x 2 factorial.
- Six extreme combinations included to form a central composite design. The figure formed by these points is called a star.
- Six points are added at the centre of the design.

This gives a total of 20 points for a single replication and effectively five levels for each factor; a considerable reduction on the 125 that would be needed for a complete 5^3 factorial design. This design is illustrated in Figure A12.2. In defining the actual levels used in an experiment that combinations of X1, X2, X3 are most likely to produce the optimum value of y would correspond to the (0, 0, 0) point at the centre of the design. The values +1 and -1 represent any desired levels which are equidistant from the 0 level.

The method of analysis of the data from such a design is described in the section below which refers to a central composite rotatable second order design with four x-variables.

A12.1.1 Fertilizer treatments and design

The four X-variables are represented by N, P, K and the trace elements. This design requires a total of 31 treatment combinations. The treatment combinations are given in Table A12.6 and are taken from Cochran and Cox (1957 p.370).

For each element it is necessary to decide the actual amount to be applied for each of the five levels -2, -1, 0 +1, +2. This should range from a zero application at the lowest level (-2) through an estimate of the optimum at the 0 level to the maximum at the +2 level.

economic feasibility but, preferably, so that there is likely to be a diminishing response. Suggested quantities of N, P, and K for each level that might be applied in such a trial are given in Table A12.7. These amounts are expressed in grams per tree and also in their equivalent kilograms per hectare both for the elemental quantities and the actual chemical quantities. Most of the published details on fertilization, particularly at planting, do not include such high dosages, but at the same time the responses have not reached a maximum.

The ratio of N:P:K for the 0, 0, 0, level was fairly arbitrarily chosen as 8:5:5; however it will be possible to predict the response to other ratios from the final response surface. For the trace elements a standard combination, used in nutrient solution work, should be assigned to the 0 level and a range around this chosen.

A full factorial experiment with four factors each at five levels would require 625 plots for a complete replication.

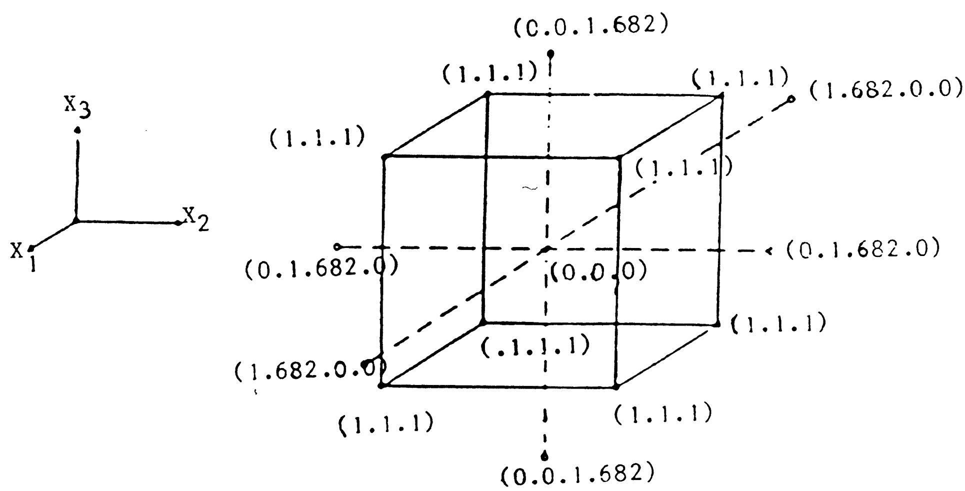


Figure A12.2
Central composite rotatable design

Table A12.5
RESPONSE SURFACE DESIGN : FORMAT FOR ANALYSIS

	X = matrix of x-variables															Y = values of responses			
Plot	x_0	x_1	x_2	x_3	x_4	x_1^2	x_2^2	x_3^2	x_4^2	x_1x_2	x_1x_3	x_1x_4	x_2x_3	x_2x_4	x_3x_4	y_1	y_2	y_3	y_4
1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	1				
2	1	1	-1	-1	1	1	1	1	1	-1	-1	1	1	-1	-1				
3	1	-1	1	-1	-1	1	1	1	1	-1	1	1	-1	-1	1				
4																			
.																			
.																			
.																			
.																			
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				

NB. The column x_0 is completed with 1s. The columns x_1 to x_4 come from the design. The y columns are responses - one column for each replication.

Table A12.6
TREATMENT COMBINATIONS FOR A DESIGN FOR FOUR X-VARIABLES
(N, P, K and trace elements)

No.	N	P	K	TE	No.	N	P	K	TE
1	-1	-1	-1	-1	17	-2	0	0	0
2	1	-1	-1	-1	18	2	0	0	0
3	-1	1	-1	-1	19	0	-2	0	0
4	1	1	-1	-1	20	0	2	0	0
5	-1	-1	1	-1	21	0	0	-2	0
6	1	-1	1	-1	22	0	0	2	0
7	-1	1	1	-1	23	0	0	0	-2
8	1	1	1	-1	24	0	0	0	2
9	-1	-1	-1	1	25	0	0	0	0
10	1	-1	-1	1	26	0	0	0	0
11	-1	1	-1	1	27	0	0	0	0
12	1	1	-1	1	28	0	0	0	0
13	-1	-1	1	1	29	0	0	0	0
14	1	-1	1	1	30	0	0	0	0
15	-1	1	1	1	31	0	0	0	0
16	1	1	1	1					

Nos. 1 - 16 represent the factorial
17 - 24 represent the extra points of the star
25 - 31 represent the points in the centre

A12.1.2 Experimental layout

The experiment will be replicated four times in randomized blocks. Each treatment plot will consist of 6 x 5 rows of trees. This will allow two plots between each brushpile with a blank row dividing them. The inner assessment plot should be of 3 x 3 trees leaving a two-row surround on the brushpile side of the plots. Thus, each plot 0.018 ha. giving 0.558 ha. for a single replication. The blocks should be laid out in random order with 31 plots per block as shown in Figure A12.1.

Table A12.7
RESPONSE SURFACE DESIGN - SUGGESTED QUANTITIES OF N, P and K

NITROGEN	Level Code	-2	-1	0	+1	+2
Elemental N	g/tree	0	40	80	120	160
	Kg/ha	0	67	133	200	267
	lbs/ac	0	60	119	178	238
Ammonium nitrate (34.5 percent N)	g/tree	0	116	232	343	464
	Kg/ha	0	193	387	580	773
	lbs/ac	0	172	345	517	690
PHOSPHORUS	**Level Code**	**-2**	**-1**	**0**	**+1**	**+2**
Elemental P	g/tree	0	25	50	75	100
	Kg/ha	0	42	83	125	167
	kbs/ac	0	38	74	112	149
Superphosphate (17 percent P 0 : 7.4 percent P)	g/tree	0	338	676	1 014	1 352
	Kg/ha	0	564	1 127	1 690	2 254
	lbs/ac	0	503	1 005	1 508	2 010
POTASSIUM	**Level Code**	**-2**	**-1**	**0**	**+1**	**+2**
Elemental K	g/tree	0	25	50	75	100
	Kg/ha	0	42	83	125	167
	lbs/ac	0	38	74	112	149
Potassium chloride (60 percent K 0: 50 percent K)	g/tree	0	50	100	150	200
	Kg/ha	0	83	167	250	333
	lbs/ac	0	74	149	223	297

It is assumed that the planting is at 1,667 trees/ha (3m x 2m)

Allowing a blank row between each plot along the strip will give a block length of 192 m; thus 768 m of plantable strip is needed overall (2.76 ha.). Within each block the relevant treatment combinations must be assigned at random.

A total of 3,720 trees is required for the experiment excluding any spares. If the planting stock is very variable then it should be graded into classes and each class assigned to a block at random. The fertilizers should be applied 14 - 21 days after planting to allow for any trees dying immediately to be replaced. All operations concerned with the experiment such as planting, fertilizing, weeding, assessment etc. should be carried out block by block and not treatment by treatment.

The first step in the analysis is to set up a matrix of x-variables and values of y in the form shown in Cochran and Cox (1957) page 350 and in Table A12.5. Each column of the X matrix is multiplied in turn by the Y columns giving the sums of the products (0y), (iy), etc. The auxiliary total (iiy) is computed and the coefficients b_1, b_{12}, b_{13} etc. found using the equations given above. The analysis of variance can then be computed using the formulae given in Cochran and Cox (1957).

The blocks x treatments interaction may be tested against the within-cell sampling error. Provided that there is no significant interaction the appropriate error to use for testing the first and second order terms and the lack of fit is the interaction mean square. If the lack of fit mean square is significant it may be concluded that the response is too complex to be adequately approximated by the second order response surface equation. A significant interation indicates that the response surface varies from replication to replication.

The significance of individual coefficients in the response surface can be tested using the standard errors of the estimated coefficients in a t-test.

In the calculated response surface equation the coded values of the x-variables have to be used when solving for any specific combination of X values, e.g. (-1, 0, 1, 2). the value of the estimated maximum response can be found by differentiating with respect to each x in turn. This gives the four equations:

$$\frac{dy}{dx_1} = b_1 + 2b_{11}x_1 + b_{12}x_2 + b_{13}x_3 + b_{14}x_4 = 0$$

$$\frac{dy}{dx_2} = b_2 + 2b_{22}x_2 + b_{12}x_1 + b_{23}x_3 + b_{24}x_4 = 0$$

$$\frac{dy}{dx_3} = b_3 + 2b_{33}x_3 + b_{13}x_1 + b_{23}x_2 + b_{34}x_4 = 0$$

$$\frac{dy}{dx_4} = b_4 + 2b_{44}x_4 + b_{14}x_1 + b_{24}x_2 + b_{34}x_3 = 0$$

which can be solved for x_1 , x_2 , x_3 , and x_4. If this combination of values lies outside the range used in the experiment care must be taken in interpretation since a quadratic equation can give very misleading results outside the region from which the data came. The effect on the response variable of varying the values of the x factors can be found by computing for different values of x_1, x_2 etc.

It may be that the second order function does not fit the data. In this case it may be improved by the addition of other variables in the equation such as initial nutrient levels, physical properties of the soil and climatic variables. If this is done then estimation of the response surface has to be one using multiple regression analysis for which a computer is essential.

appendix 13

root system measurements
(by R.B. Matthews)

A13.1 Introduction

A detailed study of roots is essential in a full monitoring programme in order to provide data on the long-term effects of tree plantations on soil water relations, nutrient cycling and soil erosion, and also to estimate rates of root mass turnover for modelling. This Appendix includes a detailed description of an application of a trench technique for determining the structure and weight of the root system under short-rotation plantation trees in Karnataka, southern India.

This particular study was undertaken to determine whether eucalypts are responsible for a lowering of the water table on certain sites; as this could result either from a very deep root system extracting water directly from the water table, or from a very dense surface root system preventing recharge of the water table by rainfall, a knowledge of the root distribution under the plantations was needed. Data on the distribution and density of the root system, along with water uptake data, provides some indication as to whether either of these situations may occur. In Karnataka, comparison with similar data from an agricultural crop (e.g. ragi) at the same site indicates whether eucalypts are any better or worse in respect to water use than alternative species that may be grown. The method outlined here was applied to eucalypt plantations in the 'Fast-growing tree project' in Karnataka. Reference is made to two specific plantations at Devabal and Hoskote.

A13.2 Frequency of observations

It was decided to sample plantations, grown on a rotation of 8 years, at 2-yearly intervals in three age classes.

A13.3. Replications

Within each age class, two replications were made; more than two are desirable, but in view of the total number of samples to be analysed and the time required, it was felt that this was a reasonable compromise.

A13.4 Sampling unit

At each sampling site in each age class, soil samples were taken at a number of representative points within a 3-dimensional unit (Figure A13.1). The length of each side of the unit is variable depending on the following factors:

Side 1: Side 1 of the sampling unit was chosen equal to 2 m in plantations where the spacing range from 1 to 2 m; this includes 2 trees within each row at the former spacing, and 2 trees at the latter.

Side 2: This length is dependent on inter-row spacing which in turn depends on the planting pattern. At a site, the planting pattern consisted of double rows of trees approximately 2 m apart, with approximately 3 m between each double row pair. Thus, the spacing unit is around 5 m, after which the pattern was repeated. The length of side 2 at this site, therefore, is 5 m. At another site where the planting espacement was 2 m x 2 m the length of the side was 4m to give a comparable length at both sites. Thus, three rows of trees at both locations were sampled.

Side 3: The length of this side is equal to the maximum rooting depth, which was determined by preliminary sampling.

Within each sampling unit, soil samples were taken on a 3-dimensional grid pattern. The number of samples along each side of the sampling unit were the same in each case as shown in Table 1. Thus, there was a total of 8 x 4 x 5 = 160 samples in each sampling unit.

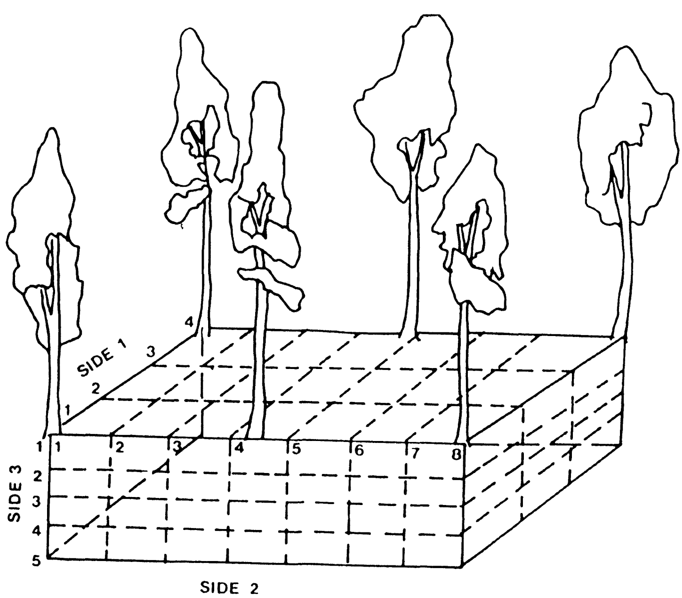


Figure A13.1
Diagram showing the location of the sampling unit in relation to the trees, and the sampling points along each side.

Table A13.1
NUMBER OF SAMPLING POINTS TO BE TAKEN ALONG EACH SIDE OF THE SAMPLING UNIT.

Side	No of samples
1	4
2	8
3	5

Interval between sampling points along each side

Side 1: It was decided that the interval between sampling points for side 1 should be 50cm. Each sampling point along side 1 is also termed a 'face'.

Side 2: The interval (I) between sampling points will be dependent on the actual length (L) of side 2, and is given by

$$I = L / (n-1)$$

where n is the number of sampling points. At Devabal, the length of side 2 is is nominally 5 m (although this may vary due to variations in the bulldozer lines), so that in this case the interval between points will be I = 5/(8-1) = 0.71 m = 71 cm. At Hoskote, the distance between the two rows is 4 m; thus I = 4/(8-1) = 0.57 m = 57 cm. The exact distance between the trees at each end of side 2 should be measured to give L for this calculation.

Side 3: The maximum rooting depth should be determined by preliminary investigation and rounded up to the nearest 50 cm. For example, if the maximum rooting depth was found to be 160 cm then the depth of sampling should be 2 m. For the following maximum sampling depths, samples should be taken at the given depths:

Maximum sampling depth (m)	Sampling intervals (cm)
1.0	0, 25, 50, 75, 100
1.5	0, 25, 50, 100, 150
2.0	0, 50, 100, 150, 200
2.5	0, 50, 100, 150, 250
3.0	0, 50, 100, 200, 300

For maximum sampling depths greater than 3 m, the sampling intervals should be 0, 50, 100, 200 and the maximum depth.

A13.5 Selection of sites

The sites to be sampled should be as representative as possible of the age class; obviously there will be an element of subjectivity in this, but it should be minimized. Trees of poor growth should be included as well as those doing well. In the Devabal II plantations, where Acacia is planted with Eucalyptus, a site should be selected where there is only Eucalyptus, and the nearest Acacia is some distance away. The study at the moment should concentrate on Eucalyptus; it is anticipated that species comparisons should be made in the future. If possible, the site should be clear of undergrowth, as it is almost impossible to differentiate between roots of different species; however, this is not essential, as we are comparing Eucalyptus plantations as 'systems' - undergrowth is all part of the 'system'. Sites should also be selected in a nearby ragi crop for comparative root studies.

A13.6 Collection of samples

It is proposed to use the advancing trench technique; the advantages of this are that it is possible to use the initial trench to determine the maximum rooting depth, and secondly, although labour-intensive, it requires no sophisticated equipment apart from a simple corer and digging implements. In addition, it also enables sampling positions in the profile to be determined very accurately, and accurate sample volumes to be extracted. Finally, it allows a 'feel' for the root system to be developed, as the size and distribution of the roots can be clearly seen, which vertical coring is not able to do.

Much of the following methodology is taken from Bohm (1979); there has, however, been some modification to suit particular resources available.

An initial trench is dug to enable access to the first face, which corresponds to the first sampling position along side 1 of the sampling unit (see Fig 2). The width of this initial trench should be approximately 1 m; this is not critical, only that there should be enough room for a person to stand comfortably in the trench.

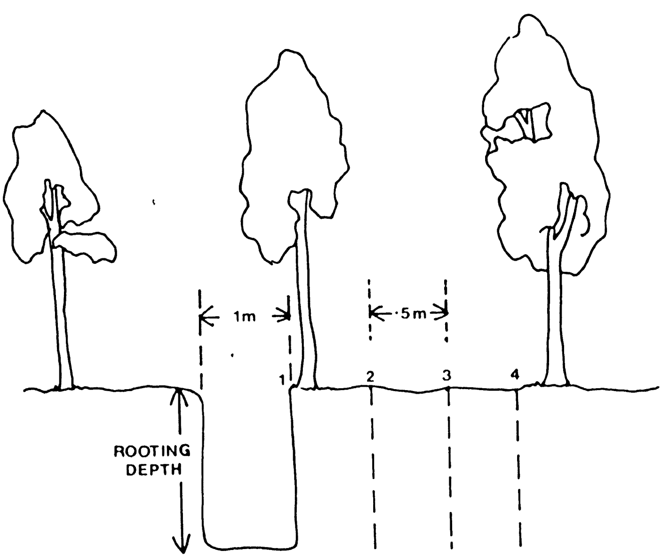


Figure A13.2
Diagram showing position of the initial trench in relation to the four faces.

Using the corer (Figure A13.3), eight soil samples should then be taken from the surface layer, along a line between the first two trees (corresponding to sampling position 1 on side 2 of the sampling unit). These will be spaced at the intervals calculated as shown above. The corer should be hammered into the soil until the the outside ring reaches the soil surface - this ensures that the sample is exactly 10 cm deep. Using the bar, the corer should then be rotated to shear the soil at the bottom of the sample to ensure a flat surface; simply pulling the corer out straightaway can result in the bottom of the sample being irregular, causing inaccuracy in its volume. The corer can then be removed using the bar. If this is difficult due to the compaction of the soil, the soil around the outside of the corer can be loosened. The sample is then removed from the corer and placed in a plastic bag, making sure that none is lost. A label as described below is used to identify the sample.

Once the surface line of samples has been taken from the face, a 'step' should then be dug to 5 cm less than the next sampling depth (eg. if the next depth is 50 cm, the step should be dug to 45 cm). This ensures that the centre of the core sample (total length 10 cm) is at the correct depth. The width of the step should be such that it does not interfere with the next face to be sampled; a distance of 25 cm from the first line of samples is therefore recommended. When this step is completed, eight more samples can be taken at that depth. The procedure should then be repeated until all the depths in that face have been sampled, giving 40 samples (5 x 8) in all.

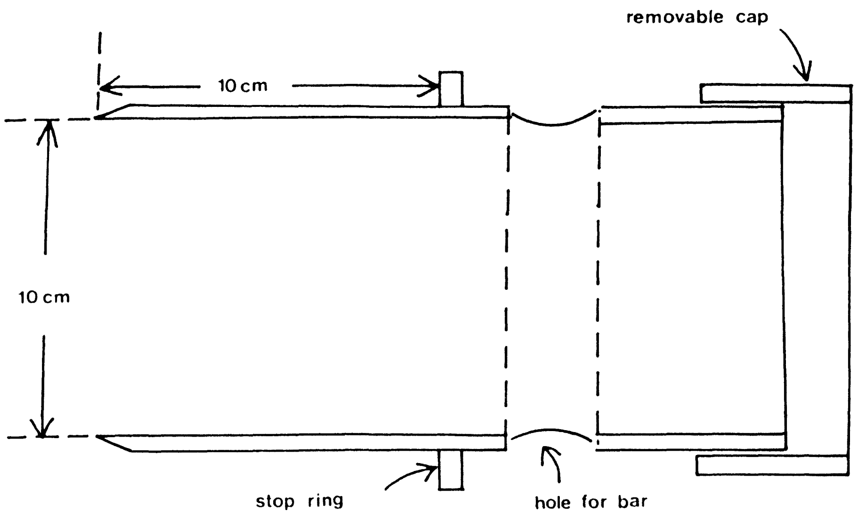


Figure A13.3
Diagram showing construction of soil corer.

Once the first face has been sampled, the next face should be marked out (corresponding to sampling position 2 on side 1) and the whole procedure repeated, and so on until four faces have been sampled.

As a rough guide, it was found that approximately 12 samples per hour (at Devabal) could be taken, although this will depend on the soil hardness, depth of sampling, quantity of labour available, etc.

The trees within the sampling area should be felled, and DBH and height measured. The leaves should then be removed, dried in an oven for 24 hr and their dry weight measured. If the tree is small, the stem dry weight can be measured in the same way; if large, the stem should be allowed to dry in the sun and then weighed. All measurements should be recorded alongside the position of the tree in the sampling unit.

Equipment: spades,shovels,pick-axes, etc. for digging.
tape measure
corers (to be made)
hammers
smoothing implement.

A13.7 Transport/storage

Samples should be transported to the laboratory in strong plastic bags labelled with the face number, position across side 2 of the sampling unit, and depth number. For example,

F2-4-3

refers to a sample from face 2, 4th position in a horizontal direction, and at the third depth. A note should be made in a field book of the actual distances involved between faces (usually 50 cm), horizontal positions, and depths.

At the laboratory, samples should be transferred to plastic buckets and allowed to soak in water overnight. Buckets should be filled approximately 1/2 full, so that the soil samples are covered. Samples should not be left in the water for longer than 4 days or root decay may occur.

Equipment: plastic bags, marker pens, labels.
plastic buckets (40)

A13.8 Washing and separating

The next day, the soil and water mix should be stirred and sieved. A series of sieves of different mesh sizes should be used to recover different sized roots; it is suggested that 5mm, 2mm, 1mm and 0.5mm are used, although this may be altered through experience. Roots can be removed from the sieve using forceps. In particularly clayey soils, a water softener (eg. sodium pyrophosphate, CALGON) can be used to aid dispersion, although at both Hoskote and Devabal this was not found to be necessary. It is very important to separate all soil particles from the root tissue; if not, root weights will include a soil component.

Equipment: stirrers
sieves: 5mm, 2mm, 1mm, 0.5mm (preferably 2 of each)
adequate water supply
forceps, Petri dishes

A13.9 Sorting into size classes

The separated root tissue should be then sorted into 6 size classes using forceps:

Size class	1	2	3	4	5	6
Root diameter (mm)	1t0.5	0.5-2	3-5	6-10	11-20	21+

It was found that two people could sort an average sample from the Petri dish containing the total roots recovered from the sample into six separate Petri dishes in about 5-10 minutes.

Equipment: Petri dishes
forceps,needles
well-lit flat table, chairs
water

A13.10. Measuring root length

Within each size class, the total root length should be measured using the intersection method. For this, a transparent dish is placed over a grid. The wet roots are then poured into the dish with some water, and positioned randomly over the grid with forceps or needles. If necessary, long branched roots can be cut into smaller pieces. Finally, counts are made of the total number of intersections of the roots with the vertical and horizontal grid lines. The use of a tally counter facilitates the counting procedure. A 1-cm grid should be used. If there are a large number of roots (eg. in classes 1 and 2) the sample can be divided into 2 sub-samples, counted separately, and the counts recombined for recording on the data sheet. Root length of the sample can be calculated from the number of intersections (N) using the equation:

$$\text{Root length (R)} = \pi/4 \cdot N \cdot G$$

where G is the grid unit (1 cm in our case), and π (pi) is 3.1416. Thus, the root length can be calculated in our case as

$$R = 0.785 \times N$$

A source of error can be the counting of curved root segments. Accurate results have been obtained by recording single counts when the edges of curved roots touched a line, and recording double counts in cases where roots were lying along a grid line.

If the total root length in the size class is small (ie. less than 20-30 cm) it could be measured directly using a scale or ruler. On the data forms, these figures should be enclosed in brackets to differentiate measurements in cm from counts.

Equipment: petri dishes
forceps, needles
blotting paper
graph paper with 1-cm grid
ruler
pencils,pens

It was found that with 6-8 persons, a minimum of 15 samples per day could be washed, sieved, separated from the soil, sorted into size classes, and counted. It is recommended that 4 persons should wash, sieve and separate the roots from the soil, 2 persons should sort the material into the size classes, and 2 should count the intersections.

A13.11 Measuring root weight

Once the lengths of each size class have been determined, each sample should be placed in a small paper bag and labelled with the sample label from the field, as well as the size class and count or length in cm. Each sample should then be dried in an oven at 105°C or 24 hours, after which it should be weighed and the weight recorded.

Equipment: blotting paper
small paper bags
oven for drying plant material
balance

Figure A13.4 illustrates the root distribution observed in one study using this method.

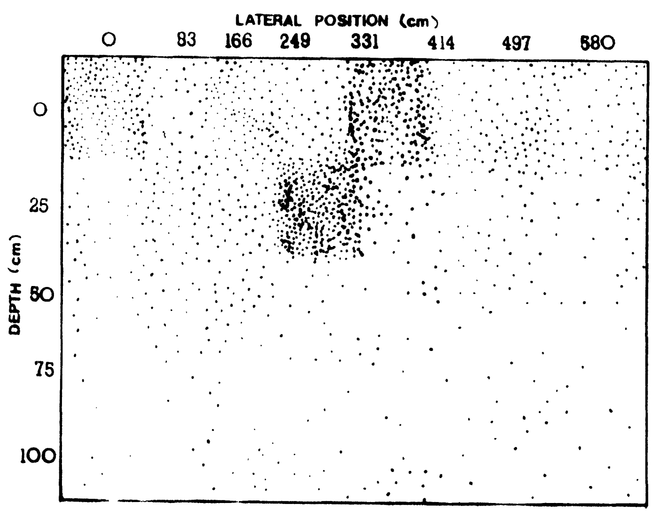


Figure A13.4
Schematic diagram of root distribution in Devabal II
1987A Face 1. Each quadrant represents data from one soil sample.

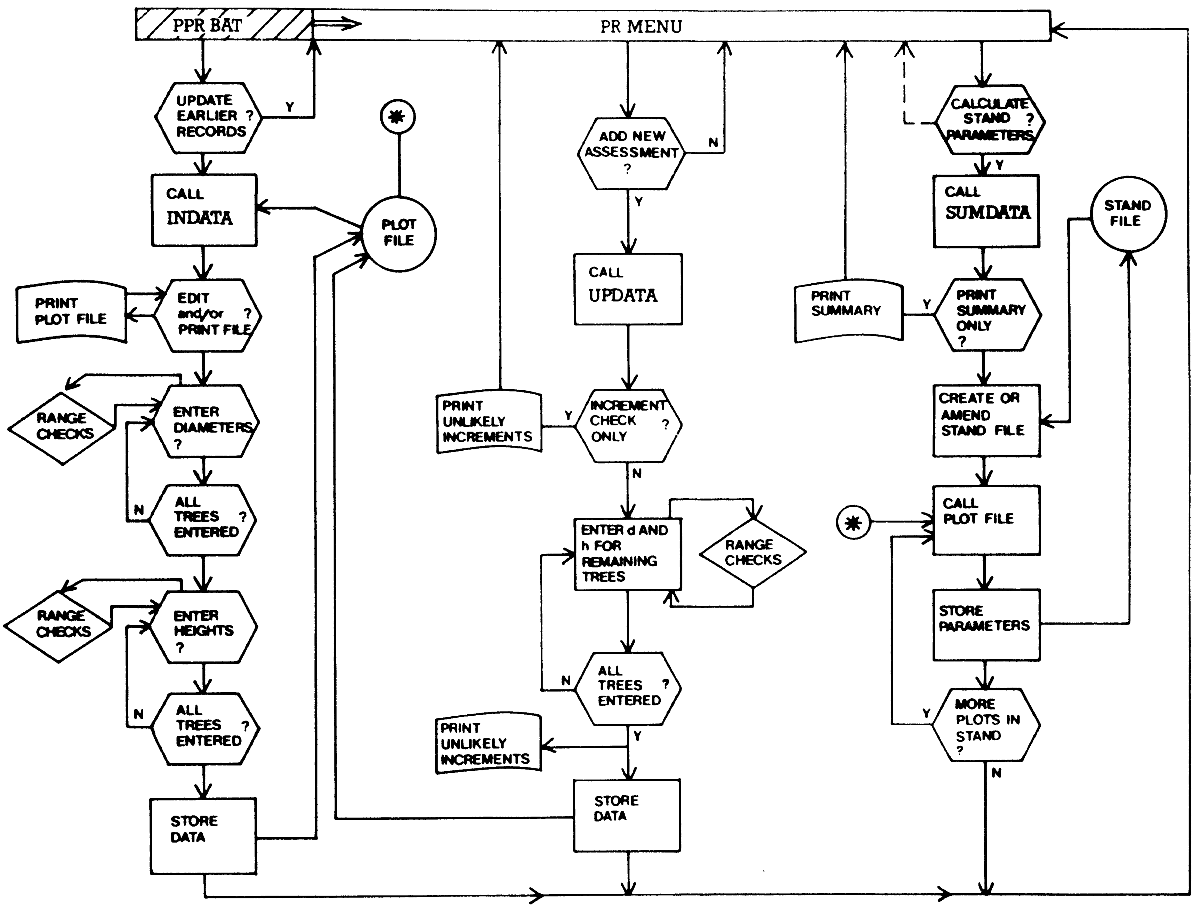


Figure A14.1
Flow of data from a permanent sample plot

appendix 14

PPR - selected menus and options

This appendix gives an overview of the facilities available in most of the programmes supplied on the PPR (Permanent Plot Records) disk. All programs are menu driven, with explanatory notes provided on screen. It should be possible for those familiar with IBM-compatible microcomputers using MS-DOS to run the programs without further instruction. Those familiar with the BASIC programming language may modify certain programs to their own needs. This could apply to the format of the printed output from the summary files in SUMDATA for example. However, facilites are provided for exporting some files in ASCII format for further analysis or editing using other programs, spreadsheets or word processors. The programs are not suitable for use by those with no computer experience without an appropriate training course (Appendix A6). The flow of data using the tree data capture programs is shown in Figure A14.1.

```
-------------------------------------------------------------------
|              PRMENU - MENU FOR THE PPR PACKAGE - page 1       1/2 |
-------------------------------------------------------------------
|   Key in the appropriate letter to select program. (RETURN to quit) |
|                                                                     |
|  A:  INDATA   - for input of existing assessments and file editing  |
|  B.  UPDATA   - for adding subsequent assessments and increment checks |
|  C.  UPDATANP- as B but all output to screen                        |
|  D.  SUMDATK - for summarizing plot growth data and printing the results |
|  E.  SUMDATNP- as D but output to screen and file only              |
|  F.  VOLCOMP - for input of felled-tree volume data                 |
|  G.  VOLREG  - for estimating best-fit volume regressions           |
|  H.  VOLTAB  - for printing  volume tables                          |
|  I.  INFILE  - for entering data to sequential file                 |
|  J.  MULT    - for general multiple regression                      |
|  K.  READATA - to input data for MULT and other programs            |
|  L.  ......... to turn to page 2 of the menu                        |
|                                                                     |
-------------------------------------------------------------------
```

```
---------------------------------------------------------------------
|              PRMENU - MENU FOR THE PPR PACKAGE - page 2          2/2 |
---------------------------------------------------------------------
|    Key in the appropriate letter to select program. (RETURN to quit) |
|                                                                     |
|   M.     - MAP  for plotting tree positions                         |
|   N.     - SETPR to set up a dot-matrix printer                     |
|   O.     - HISTWEIB for histograms and WEIBULL for READATA files    |
|   P.     - HISTPSP for histograms and WEIBULL for PSP data          |
|   S.     - STAN for tree growth summary from stem analysis          |
|   T.     - STEM PROFILE from TELERELASOPE 5-POINT method            |
|   R.     - RETURN to page one                                       |
|   Q or X- EXIT (other programs are to follow)                       |
|                                                                     |
---------------------------------------------------------------------

---------------------------------------------------------------------
|                              INDATA                            1/5 |
---------------------------------------------------------------------
|  This program is used for storing and editing permanent sample plot data. |
|  From one to six assessments of a plot can be saved on a disk file, for a |
|  maximum of 180 trees per plot in this edition. Tree heights are entered  |
|  separately from the diameters. The stored data can be listed on the      |
|  screen or printer and edited if required.                                |
|                                                                     |
|  The program options are:                                           |
|     1.  Enter data from the keyboard to create a disk file.         |
|     2.  List and edit a disk file to overwrite existing file or to an |
|         amended file including addition of heights.                 |
|     3.  Quit                                                        |
|                                                                     |
|  Select option ...                                                  |
---------------------------------------------------------------------

---------------------------------------------------------------------
|                              INDATA                            2/5 |
---------------------------------------------------------------------
|  The default drive is set to C: but other drives may be selected.   |
|  The filename of entering or amending the data is entered. The file must |
|  be in random access format of type .RAF on the chosen drive. A list of  |
|  files is displayed.                                                |
|  There is an option to convert imperial to metric units.            |
|  Selected plots or the whole file may be read.                      |
|                                                                     |
|  The options are:                                                   |
|     1.  List and edit the file                                      |
|     2.  Add heights and a code to the file                          |
|     3.  Restore file, with same or new filename                     |
|     4.  Add diameter to an incomplete file                          |
|     5.  Return to the status quo                                    |
|                                                                     |
|  Select option ...                                                  |
---------------------------------------------------------------------
```

```
--------------------------------------------------------------------------
|                              INDATA                               3/5  |
--------------------------------------------------------------------------
|  The output may be sent to printer or screen.                          |
|  The editing options available within the program are:                 |
|    Type:-: I(nsert), E(dit), D(elete) or C(ontinue);OP$                |
|    e.g. E(dit):                                                        |
|     Line number to edit ?                                             |
|     (Put 0 to change column names and/or units)                       |
|     Column number ?                                                   |
|     Old value was ...  New value ?                                    |
|    or the headings and units may be amended:                           |
|     Old name and units were ... New name and units ?                  |
|    and D(elete):                                                       |
|     Deleting row(R) or column(C) ?                                    |
|     First and last columns to be deleted ?                            |
|     First and last line numbers to be deleted ?                       |
|    The regeneration year,plot area and plot identifier can be amended  |
--------------------------------------------------------------------------
```

```
--------------------------------------------------------------------------
|                              INDATA                               4/5  |
--------------------------------------------------------------------------
|                                                                        |
|  Before entering data it is necessary to ensure that a disk is mounted in
|  the chosen drive ready for storing the data. Data files on the selected
|  drive are displayed before the file name for storing plot data is     |
|  entered. The data will consist of:                                    |
|                                                                        |
|     Plot identifier (30 chars)                                         |
|     Number of assessments being entered now                            |
|     Dates of each assessment                                           |
|     Number of trees in plot                                            |
|     (optional: you may terminate data with '-9' in tree number column) |
|  The observations:                                                     |
|     Tree number                                                        |
|     Dbh (in cm ddd.d)                                                  |
|     One integer code - this must be the SPECIES CODE when dbh is first |
|     entered                                                            |
|     Tree heights should be entered using the special edit option later |
|     Plot identifier                                                    |
|     Number of trees in this plot (enter '-9'if '-9' is used as terminator)
|     Number of assessments (<6)                                         |
|       Must be five or less; use UPDATA for sixth assessment.           |
|     Assessment dates as MM/YY                                          |
|     Plantation date (MM/YY)                                            |
|      (enter the dates in the form 06/55, (representing June, 1955).    |
|     Plot area (ha)                                                     |
--------------------------------------------------------------------------
```

INDATA	5/5

Entering the observations: (put tree number = -9 to finish)
Observation: (i)
Last tree number entered is displayed.
Indicate whether this tree is multistemmed coppice or low-branched

Minimum and maximum values for diameter, height and codes may be defined, or default values accepted. If values are out of range in column they can be corrected.

Do you want to overwrite existing data file ;

Give the name of the data file for storing amended data

Messages:

Press Q to QUIT, any other key to continue
WARNING .. 'END' not read
End of disk: plot not found

UPDATA	1/5

This program is used for adding further assessments to an existing permanent sample plot data file. A data file can include a maximum of six assessments with 180 trees per assessment in this edition. Heights and diameters are entered together.

The program checks for annual increments >10 cm in diameter (over bark) and > 10 m in height and prints out any anomalies. These may be altered as desired. The data are sorted according to tree number and then stored on disc in a data file with any previous assessments of that plot.
Default drive for the data is C: but other drives may be selected.
The filename of the data file to be updated is entered.
The file must be in random access format of type .RAF on the indicated drive.
The list of *.RAF files is displayed.

UPDATA	2/5

There is an option to only test increments already on file.

The program checks for annual increments >10cm and <0.5cm diameter and >10m and <0.5m height but these limits may be altered.

```
---------------------------------------------------------------------------
|                              UPDATA                                 3/5 |
---------------------------------------------------------------------------
| Entering the data:                                                      |
|    Enter date of assessment as MM/YY.                                   |
|    Previous diameter =                                                  |
|    New diameter      =                                                  |
|    Previous aggregate diameter = ... on ... shoots                      |
|    Previous height   =                                                  |
|    New height        =                                                  |
|    (If height to be calculated from field obs., key (Y)es)              |
|    Enter  code                                                          |
|                                                                         |
| Last tree number entered is displayed.                                  |
---------------------------------------------------------------------------
```

```
---------------------------------------------------------------------------
|                              UPDATA                                 4/5 |
---------------------------------------------------------------------------
| The file may be sorted in descending order of diameters.                |
|                                                                         |
| For multistemmed-tree or coppice the entry display includes:            |
|    Enter data for tree no. ...  on ...                                  |
|    What is the total number of stems at b.h. (Previously ... )?         |
|    Enter the number of shoots <5 cm dbh                                 |
|    Enter  - - ------- >5 & <10                                          |
|    Enter the ... stems >10 cm dbh separately: Diameter bh (cm)          |
| After entering data for one coppice stool or multi-stemmed tree the     |
| following meassage is displayed:                                        |
|    Number of shoots is ... which have an aggregated (total) sectional   |
|    area of  ... sq.cm giving an equivalent diameter of ...cm.           |
| If an error has occurred the data for this tree may be re-entered.      |
---------------------------------------------------------------------------
```

```
---------------------------------------------------------------------------
|                              UPDATA                                 5/5 |
---------------------------------------------------------------------------
| Heights may be calculated from field observations:                      |
|    % to top                                                             |
|    % to breast height (-ve below horiz.)                                |
|    % Slope                                                              |
|    Distance in metres                                                   |
|                                                                         |
| Messages:                                                               |
|    WARNING *** 'END' not read correctly.                                |
|    File ;DD$; read into memory.                                         |
|    File not found. (Rerun after checking file and filename).            |
|    Assessment date must consist of five characters e.g., 06/55 for June,|
|    1955                                                                 |
|    Put -9 for tree number to finish.                                    |
|    Tree number not found. (A new tree must be entered using the INDATA  |
|    program.)                                                            |
|    List of improbable values:                                           |
|             Tree £    Date       Now       Before    Interval           |
---------------------------------------------------------------------------
```

No.	Tree No	DBHob 11/65	Hght. 11/65	Coppc shoot	DBHob 07/72	Hght.	Coppc shoot	DBHob 10/79	Hght.	Coppc shoot	DBHob 05/84	Hght.	Coppc shoot	Code.... 1	2	3	4
1	1	21.1	0.0	0	22.8	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
2	2	16.8	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	0
3	3	25.4	0.0	0	27.4	0.0	0	28.4	0.0	0	28.4	0.0	0	1	0	0	4
4	4	25.9	0.0	0	31.7	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
5	5	23.9	0.0	0	31.7	0.0	0	34.3	0.0	0	0.0	0.0	0	1	0	0	3
6	6	33.0	14.8	0	43.4	28.2	0	47.6	32.3	0	51.9	36.2	0	1	1	0	4
7	7	24.6	0.0	0	28.1	0.0	0	29.5	0.0	0	0.0	0.0	0	1	0	0	3
8	8	22.1	0.0	0	23.8	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
9	9	21.6	0.0	0	24.8	0.0	0	26.8	0.0	0	28.3	0.0	0	1	0	0	4
10	10	23.1	0.0	0	27.6	0.0	0	30.9	0.0	0	0.0	0.0	0	1	0	0	3
11	11	29.0	14.8	0	34.7	31.2	0	39.3	31.8	0	42.7	34.1	0	1	1	0	4
12	12	22.9	0.0	0	28.1	0.0	0	30.9	0.0	0	0.0	0.0	0	1	0	0	3
13	13	22.1	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	0
14	14	24.9	0.0	0	30.2	0.0	0	32.9	0.0	0	33.9	0.0	0	1	0	0	4
15	15	25.6	0.0	0	31.4	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
16	16	20.3	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	0
17	17	19.6	0.0	0	21.3	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
18	18	21.8	0.0	0	24.3	0.0	0	24.6	0.0	0	24.5	0.0	0	1	0	0	4
19	19	21.8	0.0	0	25.6	0.0	0	28.7	0.0	0	29.8	0.0	0	1	0	0	4
20	20	34.3	14.8	0	39.8	30.8	0	44.4	33.8	0	46.4	34.1	0	1	1	0	4
21	21	25.9	0.0	0	29.2	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
22	22	24.1	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	0
23	23	16.8	0.0	0	20.5	0.0	0	24.0	0.0	0	26.3	0.0	0	1	0	0	4
24	24	24.1	0.0	0	35.0	0.0	0	42.0	0.0	0	45.5	0.0	0	1	0	0	4
25	25	24.1	0.0	0	27.4	0.0	0	29.3	0.0	0	32.2	0.0	0	1	0	0	4
26	26	43.9	0.0	0	22.6	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
27	27	26.4	0.0	0	31.7	0.0	0	35.2	0.0	0	37.3	0.0	0	1	0	0	4
28	28	16.5	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	0
29	29	26.9	0.0	0	34.7	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
30	30	23.4	0.0	0	23.6	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
31	31	33.3	14.8	0	42.4	32.1	0	47.9	34.3	0	53.4	0.0	0	1	1	0	4
32	32	25.9	0.0	0	33.2	0.0	0	38.2	0.0	0	41.7	36.6	0	1	0	0	4
33	33	25.4	0.0	0	0.0	0.0	0	35.3	0.0	0	37.7	0.0	0	1	0	0	4
34	34	17.0	0.0	0	19.5	0.0	0	0.0	0.0	0	0.0	0.0	0	1	0	0	2
35	35	26.4	0.0	0	37.5	0.0	0	46.0	0.0	0	49.7	0.0	0	1	0	0	4

Figure A14.2
Output from programs INDATA and UPDATA

SUMDATA 1/5

This program computes and summarizes various permanent sample plot parameters from assessments made on successive occasions and saved on disk by use of INDATA and UPDATA programs. Stand means and increments are calculated for each plot and assessment and saved on disk in a results file that can be printed out when required.

The first menu options are:

- create or add to a results file
- print out an existing results file
- transfer results to a serial file
- quit

SUMDATA 2/5

The default drive for the data is C:, but other drives may be selected.
List of data files on drive is displayed.
List of summary files on drive is also displayed.
Type in the file name for storing the results.
Type in the number of the first free record on file.
(If you're creating a completely new file the first record number = 1)
The last record number used is printed at the end of the last summary
A warning is displayed:- YOU CAN OVERWRITE PREVIOUS RESULTS!
The list of data files on current drive is re-displayed.
The name of plot file to be summarized is entered.
Put 'END' if finishing.

Messages:

- Turn printer on.....and start again!...PRESS ANY KEY
- FILE EMPTY...Rerun after checking file
- WARNING -END not read correctly

SUMDATA 3/5

You can restrict summary to one species.
Key in numerical code for species required (0 for all).
Select the coefficients for the volume functions.
The volume models included are listed.
Choose one......and then <RETURN>...;
Select or enter coefficients for model ...

The coefficients of the regression H=ba0+ba1(log(DAP)) are displayed on the screen temporarily.

Program SUMDAT run on 07-27-1988

Summary of measurements of permanent sample plots

	AFTER THINNING											THINNINGS					
Age(Yr)	N/ha	SP%	Hdom	Ddom	H(L)	Diam(e)	SumCS	MNCS	MDcop	G	SumV	N rem	D rem	G rem	V rem	V mean	Plot No.
	INCREMENT																
	CumG	CumV	CAI(G)	CAI(V)	MAI(G)	MAI(V)											
10.83	875	25	14.8	36.4	14.8	25.1	0	0	0.0	43.4	294.015	0	0.0	0.00	0.0	0.0	K270
	43	294	0.00	0.0	4.01	27.1											
17.50	725	13	30.3	40.8	30.5	30.1	0	0	0.0	51.6	689.823	150	21.1	5.26	35.2	0.2	K270
	57	725	2.01	64.7	3.25	41.4											
24.75	500	14	33.5	46.5	33.1	35.6	0	0	0.0	49.7	736.865	250	26.5	13.81	183.1	0.7	K270
	69	955	1.65	31.7	2.78	38.6											
29.33	400	15	35.3	50.4	35.3	39.2	0	0	0.0	48.3	755.493	100	31.4	7.77	114.4	1.1	K270
	75	1088	1.38	29.0	2.56	37.1											

Volume function used in the above summary was 4

KEY FOR VARIABLE NAMES

N/ha = number of trees per ha
SP% = Hart-Becking's spacing percent
Hdom = Dominant (Loreys mean) height of 100 largest trees per ha
Ddom = Dominant quadratic mean diameter
H(L) = Loreys mean height
Diam(e) = Quadratic mean diameter of stand
if MNCS > 0 this is diameter (e) corresponding to total basal area of all shoots on a stump
Total number of coppice shoots per ha
MNCS = Mean number of coppice shoots per stump
MDcop = Mean coppice shoot diameter
G = Basal area per ha
MAI(V)= Mean annual increment of volume

N rem = No. of trees removed
D rem = Mean diameter of trees removed
G rem = Mean basal area of trees removed
V rem = Total volume of trees removed
V mean= Mean volume of trees removed
Cum G = Cumulative mean basal area increment
Cum V = Cumulative mean volume increment
CAI(G)= Cumulative annual increment of basal area
CAI(V)= Cumulative annual increment of volume
MAI(G)= Mean annual increment of basal area
MAI(V)= Mean annual increment of volume

***** LAST RECORD NUMBER USED ON FILE c:FRCSUM.raf was 5 *****

Appendix Figure 14.3
Example of summary of data from a P1 plot
(Output from program SUMDATA)

SUMDATA	4/5

Type in a title for output (<40 chars.).
Type in name for the transferable (serial) file, (if this option has been selected).

```
N/ha   = number of trees per ha
S%     = Hart-Becking's spacing percent
Hdom   = Dominant (Lorey's mean) height of 100 largest trees per ha
Ddom   = Quadratic mean diameter of 100 largest trees/ha
H(L)   = Lorey's mean height
D      = Quadratic mean diameter.
           if MNCS > 0 diameters of coppice shoots are included as
           equivalent diameter of all shoots on a stump.
MNCS   = Mean number of coppice shoots per stump
MDcop  = Mean coppice shoot diameter
G      = Basal area per ha
SumV   = Total volume
N rem  = Number of trees removed
D rem  = Mean diameter of trees removed
G rem  = Mean basal area of trees removed
V rem  = Total volume of trees removed
V mean= Mean volume of trees removed
Cum G  = Basal area of main crop and thinnings
Cum V  = Volume of main crop and thinnings
CAI(G)= Periodic annual increment of basal area
CAI(V)= Periodic annual increment of volume
MAI(G)= Mean annual increment of basal area
MAI(V)= Mean annual increment of volume
```

SUMDATA	5/5

Some coefficients for most volume models are included in the program and may be selected from a screen menu. In all cases the operator may insert the coefficients manually.

VOLCOMP	1/5

This program calculates total volume and merchantable volume to different limits both with and without bark. Smalian's formula is used to compute volumes of each log. It is assumed that the top log is conical and interpolated diameters assume a parabolic form. The computed volumes are printed and may be recorded on disk. Maximum number of trees that can be entered at one run is 200.
You can convert height and diameter measurements on entry. If required the conversion factors for height and for diameter are entered.

```
--------------------------------------------------------------------------
|                              VOLCOMP                               2/5 |
--------------------------------------------------------------------------
| The operator is then asked:                                            |
|                                                                        |
|    1. Are the complete data already saved on disk?                     |
|    2. Do you want to append felled-tree volume data?                   |
|    3. Are you creating a new data file now?                            |
|         Key in 1, 2 or 3                                               |
| Choose the default drive.                                              |
|                                                                        |
| The operator is asked whether a formatted file for transfer to other   |
| software is required, and if so the transferable filename must be      |
| entered.                                                               |
| There is an option to transfer either:                                 |
|    1) height and diameter                                              |
|    2) total height, DBH and volume                                     |
|    3) both                                                             |
| The height and diameter measurements will be stored in file ...        |
| The height,dbh, and volume measurements will be stored in file ...     |
|                                                                        |
--------------------------------------------------------------------------
--------------------------------------------------------------------------
|                              VOLCOMP                               3/5 |
--------------------------------------------------------------------------
| Enter the title for this set.                                          |
| Enter the number of utilization limits required ( <=9 for ub vol; <=4  |
| for both ub and ob vol.) or put '0' if only total volume required.     |
| For determination of merchantable volume the data must extend beyond the
| height on the tree of the diameter limit specified.                    |
| Enter:                                                                 |
|    (1) length from ground level of each section (m),                   |
|    (2) one or more diameters over bark in CENTIMETRES                  |
|    (3) the bark thickness or under bark diameter.                      |
| Enter how bark is measured:                                            |
|    (1) Double bark thickness                                           |
|    (2) Single bark thickness                                           |
|    (3) Diameter under bark measured directly                           |
|    (4) No bark thickness measured                                      |
--------------------------------------------------------------------------
```

```
---------------------------------------------------------------------
|                            VOLCOMP                            4/5 |
---------------------------------------------------------------------
| Enter the data:                                                   |
|    Tree number (0 to finish)                                      |
|    Total height (m)                                               |
|    Diameters at breast height (max. 4) (cm)                       |
|         Key RETURN if all dbh entered.                             |
|    Key in the sectional measurements from ground level upwards    |
|         Height of measurement (m)                                  |
|           (key -1 when all entered)                                |
|         Height of section excessive                                |
|         Diameters over bark (cm) at height ...                     |
|            (key -1 when all entered)                               |
|         Bark thickness (mm), or Diameter under bark (cm)           |
|    There is the option to re-enter the data if there are keying errors. |
|                                                                   |
| Final menu:                                                       |
|    1. Write the results on disk                                   |
|    2. Continue                                                    |
|    3. Finish                                                      |
---------------------------------------------------------------------
---------------------------------------------------------------------
|                            VOLCOMP                            5/5 |
---------------------------------------------------------------------
| Messages:                                                         |
|                                                                   |
| The data will be stored on drive C file ...                       |
| The printer must be connected and switched on......!              |
|    (Press Q to quit, any other key to continue)                   |
|    (Set the printer and adjust the paper)                         |
| File not found                                                    |
| The results will be written to file ...                           |
| File exists - overwrite it (Y/N) ...                              |
| The data have been written to file ...                            |
| Error occurred on line ...  was error code ...                    |
---------------------------------------------------------------------
---------------------------------------------------------------------
|                            VOLREG                             1/4 |
---------------------------------------------------------------------
---------------------------------------------------------------------
|                                                                   |
| This program fits volume functions to data of felled tree sectional |
| (log) volumes. It will compute one or more of 12 different functions and |
| select the best fit using Furnivals's Index. The regression parameters |
| may be written to disk for use by VOLTAB in printing out volume tables. |
| The data may be entered from the keyboard or read from a file created by |
| VOLCOMP.                                                          |
| All results are output to the printer so the printer must be connected |
| and switched on.                                                  |
|                                                                   |
---------------------------------------------------------------------
```

```
--------------------------------------------------------------------------
|                              VOLREG                              2/4    |
--------------------------------------------------------------------------
| The title for the current run is typed in and then data may be entered |
| from the keyboard or read from a disk file.                             |
|                                                                         |
| The data will consist of a matrix of P trees and M variables per tree.  |
| There should be at least two columns, for volume and  for diameter.    |
| The number of trees in the data set may be entered in, if known, or -9 |
| entered. The data are terminated with a -9.  A screen menu then asks for:
|    How many trees ?                                                     |
|    How many variables ?                                                 |
|    Variable names: ?                                                    |
|         Tree number:          -9 terminates data entry                  |
|         Variable 1:                                                     |
|         Variable 2:                                                     |
|         Variable 3:                                                     |
|         Variable 4......etc:                                            |
--------------------------------------------------------------------------
--------------------------------------------------------------------------
|                              VOLREG                              3/4    |
--------------------------------------------------------------------------
|                                                                         |
| The data will now be printed - make corrections later.                 |
| Any corrections (Y/N) ?                                                 |
|                                                                         |
| To make a correction enter the row number, variable number and the new |
| value in the form dd,d,dd.d.                                            |
| The data will now be written to disk if the data have just be entered  |
| from the keyboard. The data may be read from disk in any future run.   |
| If the data are already on disk:                                        |
|    Enter the file name of the *.VOL (sequential file).                 |
|    A message is displayed giving number of trees and variables, with   |
|    their names, on this file.  If incorrect call another file.         |
|    The file may be printed.                                             |
| New variables may be derived and added to current file.               |
| The columns of the data file to be used in this calculation must be    |
| specified:                                                              |
|    Column number for volume                                             |
|    Column number for diameter                                           |
|    Column number for height (put '0' if it is not measured)            |
--------------------------------------------------------------------------
```

VOLREG 4/4

The regression models are displayed (see panel 3 of VOLTAB below).
The number of models to be investigated are entered and the required model numbers keyed in, or all are tested.
All or contiguous parts of the data may be included by specifying the first and last rows of the data.
One may choose:

1. All regressions, or
2. Only the best-fitting regression.

The message COMPUTING IN PROGRESS is then displayed until the results are printed.

The final menu is:

1. Write the parameters of the regression to a file
2. Analyse another set of the same data
3. Terminate the run

Messages:
Press Q to quit, any other key to continue
FILE ALREADY EXISTS!
Do you want to overwrite the file (Y/N)
The parameters of the best-fitting regression (or, all regressions) have been written to disk.

VOLTAB 1/4

Welcome to this volume table program. The tables are derived from regressions of volume on diameter, or on diameter and height. The parameters may be read from diskfile created by VOLREG or entered at the keyboard. Confidence limits can be computed if the necessary data are available.

All results are sent to the printer. Switch it on!":BEEP
Press Q to quit, any other key to continue"

Are you entering the regression parameters from:

1. a file
2. the keyboard?

Select 1 or 2

```
-----------------------------------------------------------------------------
|                               VOLTAB                                  2/4 |
-----------------------------------------------------------------------------
| If 1 is selected:                                                         |
|    Default drive is C: "                                                  |
|    The files on  the selected drive are then displayed.                   |
|    The appropriated filename (omitting the type i.e.'.REG')               |
|                                                                           |
| A message describing the contents of the file is given,                   |
|    and the question "Is this correct? " appears.                          |
| The operator must then choose the model to be tabulated and then enter a  |
|    title for the volume table.                                            |
-----------------------------------------------------------------------------

-----------------------------------------------------------------------------
|                               VOLTAB                                  3/4 |
-----------------------------------------------------------------------------
| If 2 is selected:                                                         |
|    The operator enters a title for the volume table.                      |
|                                                                           |
|    The models available are:                                              |
|                                                                           |
|     1. V     = D*D                                                        |
|     2. LN(V)= LN(D)                                                       |
|     3. V     = D*D weighted by D*D                                        |
|     4. V     = D*D*H                                                      |
|     5. V     = D*D + H + D*D*H                                            |
|     6. V     = D*D + D*H + D*D*H                                          |
|     7. LN(V)= LN(D) + LN(H)                                               |
|     8. V     = D*D*H weighted by D*D                                      |
|     9. V     = D*D + H + D*D*H weighted by D*D                            |
|    10. V     = D*D + H + D*D*H weighted by D*D*H                          |
|    11. V     = D*D + D*H + D*D*H weighted by D*D                          |
|    12. V     = D*D + D*H + D*D*H weighted by D*D*H                        |
|                                                                           |
| Choose one and enter the constants and the coefficient for the function   |
|   selected. If you need the confidence limits you have to give also:      |
|   (a) mean of each independent variable                                   |
|   (b) the variance and covariance of each coefficient                     |
|   (c) residual mean square and the total number of observations           |
|                                                                           |
| What is the total number of observations                                  |
-----------------------------------------------------------------------------
```

VOLTAB 4/4

The tables can be divided into a number of pages

Each page of a table can have 8 height columns with normal letters or 14 columns with compressed printing. There is no limit to the number of diameter classes.

The following message then appears:

Do you want:
1. Normal
2. Compressed output ?

Key 1 or 2 and <RETURN>.

Further instructions include:

How many pages of height columns?

Then enter:

Mid-point of the lowest diameter class (cm)
Mid-point of the largest diameter class (cm)
What is the width of the classes (cm)
Mid-point of the lowest height class (m)
Mid-point of the highest height class (m)
Height class width (m).

Do you want confidence limits?

The final menu:

1. Do you want to print another table, or
2. Finish

MAP 1/1

- TREE POSITION INPUT AND PLOTTING PROGRAM -

This program processes tree position data
The data must have been entered to file using the READATA program with following format:
There must be SIX DATA COLUMNS and up to 100 observations:

COL:	1	2	3	4	5	6
	Tree number £	Species code	Dbh cm	Bearing degrees	Slope %	Distance m

Press Q to quit, any other any key to continue
Default drive for data is C: This can be amended during the run.

Now enter the name of the data file and the area of the plot (circular).
Do you want map of tree Symbol (S), siZe (Z) or Both ?

```
------------------------------------------------------------------------
|                              READADATA                           1/2 |
------------------------------------------------------------------------
|                  READATA - GENERAL FILE INPUT PROGRAM                |
|                                                                      |
|  This program selects, lists and edits data (max.12 cols and 150 rows).
|  Have the data been recorded on disk?                                |
|   - answer N if entering data now,                                   |
|   - or <RETURN> to edit existing file                                |
|   - or Q to quit....                                                 |
|  The default drive is set to C:                                      |
|  If drive A: or B: wanted then type A or B else <RETURN>             |
|  Name of disk file (omit the file type)......                        |
|  Do you want to read down all the data (you may select parts) ?      |
|  Type 'key' to identify a data section (* to finish):                |
|                                                                      |
|  The message: "end of disk: section not found.....Start again"       |
|     may appear.                                                      |
|  Are there more data to be read from the disk?                       |
|                                                                      |
|  Do you want to edit the data ?                                      |
|  Output to screen (S) or printer (P) ?                               |
|  Is this correct ....?                                               |
|  If not the file may be edited:                                      |
|    Select....1. Insert                                               |
|              2. Edit                                                 |
|              3. Delete                                               |
|              4. Continue                                             |
|    Which....?                                                        |
------------------------------------------------------------------------
------------------------------------------------------------------------
|                              READATA                             2/2 |
------------------------------------------------------------------------
|                                                                      |
|  Entering new data from the keyboard:                                |
|                                                                      |
|  Data identification (maximum length = number of columns * 10 chars.)
|  Number of observations (but -9 TERMINATES at any time)              |
|  Number of data columns?                                             |
|  Column names and units (max:8 chars):                               |
|  Enter the minimum and maximum values for each column of data.       |
|  Type values  - each 'observation' or 'record' is numbered sequentially.
|  If a value is out of range a message appears:                       |
|  Value out of range in column ...... - is this all right?;           |
|   and the value may then be re-entered if so desired.                |
|  The data may overwrite the existing file or be saved on a new file. |
|                                                                      |
------------------------------------------------------------------------
```

```
------------------------------------------------------------------------------
|                                   STAN                              1/2    |
------------------------------------------------------------------------------
|                               Stem analysis                                |
|                                                                            |
|  This program needs a printer from the start.........                      |
|  Press Q to quit, any other key to continue                                |
|  The program calculates tree volume increment by period and position       |
|  in the tree from data of periodic growth-ring diameters measured on       |
|  stem disks.  The data must be recorded in the correct format at the       |
|  screen prompts. See the attached sample Field Form.                       |
|  Are the data already on disk ?                                            |
|    If not they are entered now from the keyboard.                          |
|                                                                            |
------------------------------------------------------------------------------
------------------------------------------------------------------------------
|                                   STAN                              2/2    |
------------------------------------------------------------------------------
|  Entering data from the keyboard:                                          |
|                                                                            |
|  Drive for filing data to be input now is C:                               |
|              .........and the filename ?                                   |
|  Tree identifier...                                                        |
|  Age of tree in years...                                                   |
|  Interval between rings measured...                                        |
|  How many disks measured...                                                |
|  Total height of tree in m...                                              |
|  Stump height for volume in m                                              |
|  The tree data may be corrected if required on the prompt:                 |
|  Are these correct (N if not) ?, followed by the message:                  |
|  Re-enter all data for this tree....                                       |
|  Disk no. ?                                                                |
|  No.of rings on disk ?                                                     |
|  Height a.g.l. in m                                                        |
|  The disk data may be corrected if required on the prompt:                 |
|  Are the above data correct (put N if not) ?, followed by the message:     |
|  Re-enter data for disk....                                                |
|  Enter diameters in mm sequentially FROM PITH outwards                     |
|  Enter a negative number to escape.                                        |
|  When measurements for each disk are complete corrections may be made.     |
|                                                                            |
|  Reading the data from a disk:                                             |
|                                                                            |
|  Drive on which the data are stored is now C:                              |
|                   .........and the filename ?                              |
|  Do you want to see the data ?                                             |
|  If yes they may be displayed or printed and the message                   |
|  "Any corrections to the tree diameters?"  appears.                        |
|                                                                            |
------------------------------------------------------------------------------
```

```
------------------------------------------------------------------------
|                              TELREL                             1/1  |
------------------------------------------------------------------------
|                                                                      |
| TELERELASCOPE - 5 POINT METHOD OF VOLUME ESTIMATION ON STANDING TREES|
|                                                                      |
|   Method adapted from Bitterlich's program for HP97 PROG 41 by PGA   |
|                                                                      |
|   The printer should be attached and switched on                     |
|   Press Q to quit, any other key to continue                         |
|                                                                      |
|   The data required are:                                             |
|                                                                      |
|   Tree identifier: (0 to finish)                                     |
|   Distance (horizontal equivalent) in metres                         |
|   Percentage angle and TUs at levels 1 to 4 where TU = telerelascope unit|
|   Percentage angle to tip of tree                                    |
|                                                                      |
|   Further % heights within the crown may be taken for plotting       |
|     the crown profile, if required ('0' if none).                    |
|                                                                      |
------------------------------------------------------------------------
```

Figure A14.4
Example of use of field form for stem analysis

STEM ANALYSIS - form used with PPR program STAN

PLOT IDENTIFICATION HYPOTHETICAL EXAMPLE
(Number /country /forest /stratum /compartment

SPECIES EZ STAND BASAL AREA 21 m² DATE XX/YY

PLANTING YEAR '86 DOMINANT HEIGHT 10.5m RECORDED BY PGA

The following entries are those called for by program STAN:

Tree number	1	
Age of tree	5	years
Interval between rings measured	1	years
Total height of tree	10	m
Stump height (for vol.calc.)	0.5	m

DISK			Diameter at age cm											Notes
Number	No. of rings	Height a.g.l.m	1	2	3	4	5							
1	5	1	2	3	4	5	6							
2	3	7			2	3	4							
3	1	9					2							

Figure A14.5
Sample output from STAN program

STAN - Stem analysis run on 09 -14 - 1989 at 11:19:03 reading from file

Tree number	:	1
Age	:	5 years
Height	:	10 m
Total volume ob.	:	0.019 cu m

Volume by interdisk logs

Age Years	Height m	Diam ob cm	Volume ob cu dm
5	0.5	6.5	1.659
5	1.0	6.5	14.726
3	7.0	4.5	2.081
1	9.0	2.5	0.164

Volume by periodic cores

Age yrs	Height m	diam 1 3 cm	Volume ub cu dm	PMAI ub cu dm	MAI ub cu dm
1	2.0	2.0	0.262	0.26	0.26
2	2.5	3.0	0.707	0.45	0.35
3	8.0	4.0	5.445	4.74	1.82
4	8.5	4.9	9.346	3.90	2.34
5	10.0	3.5	15.341	6.00	3.07
5	10.0	6.5	18.630		3.73

Last line gives overbark volumes

Figure A14.6 Stem analysis with STAN
Example to illustrate method of volume calculations
(Scale: Vertical 1 cm = 0.5 m; Horizontal 1 cm = 1 cm)
Figures in diagram show volume of segment in cubic decimeters

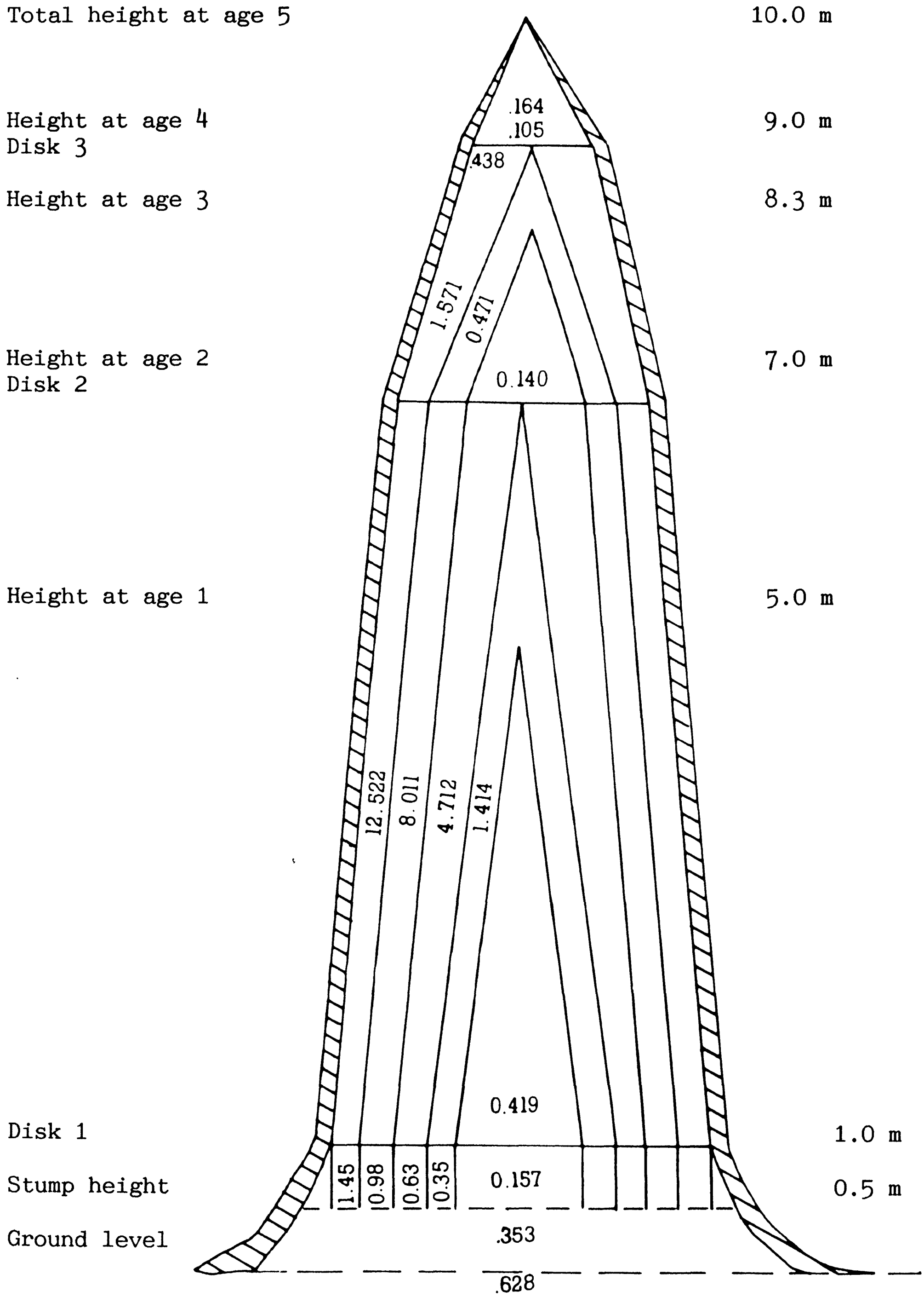
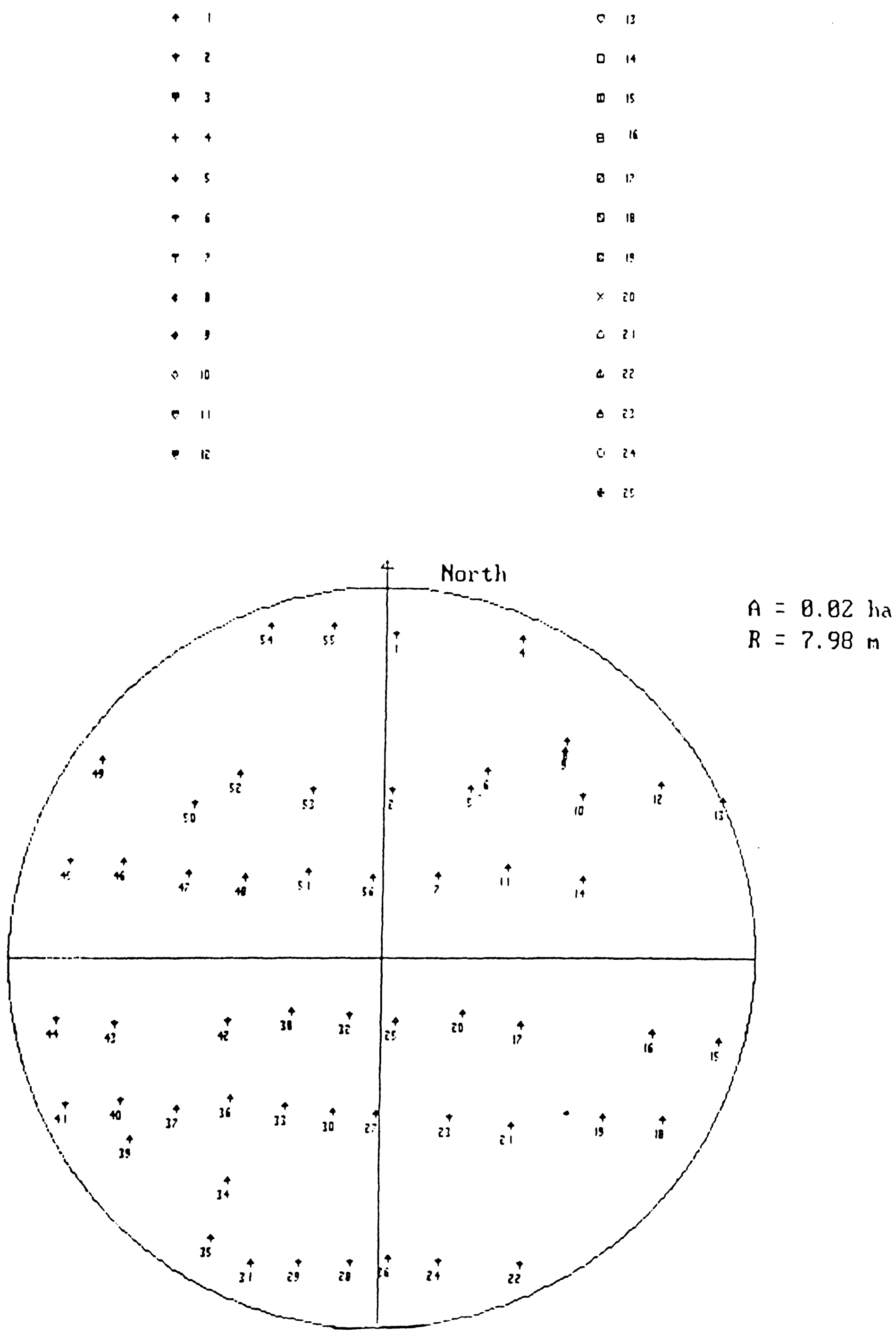


Figure 14.7
Sample output from program MAP or (MAPGW)

SYMBOLS FOR SPECIES CODES
See local manual for key to code numbers



field forms

This section includes a number of formats for the recording of data in the field. These may used as they are, or used as check lists for the types of data that have been found necessary to collect in many continuous forest inventory programmes.

Data of the standing crop covered by forms 2 and 3 can be entered directly on to portable computers if the relevant PPR programs are used.

The forms included here are:

1 General plot description and history sheet
2 Standing tree diameters
   2a Coppice shoot diameters
3 Standing tree heights
4 Standing tree data from P2 (Productivity) plots
5 Branch and foliage measurements in D plots
6 Stem volume measurements
7 Standing volume measurement with a telerelascope
8 Stem analysis
9 General experimental data plot form

1 GENERAL PLOT DESCRIPTION — FIELD FORM 1: PAGE 1 OF 3

PLOT IDENTIFICATION

Code ....

Plot /country /forest /stratum /compartment

Item	Unit	Verbal description	Coding
1 Date recorded	dd/mm/yy		
2 By whom (initials)	XYZ		
LOCALITY			
3 Map reference			
4 Latitude	degrees		
5 Longitude	degrees		
6 Access point	describe		

CLIMATE	J	F	M	A	M	J	J	A	S	O	N	D	Total
7 Mean monthly rainfall													
8 Max. monthly temperature													
Min. monthly temperature													
9 Mean monthly temperature													

Item	Unit	Verbal description	Coding
10 Koppen's classification			
11 Thornthwaite's PE			
12 Other			
TOPOGRAPHY			
13 Altitude	metres		
14 Slope (principal)	percent		
15 Nature of slope	code		
16 Catenary position	code		
17 Aspect	code		
18 Exposure	code		

SOILS	sample no.	1	2	3	4		Coding
19 Soil type	code						
20 Depth of litter	cm						
21 Depth of humus layer	cm						
22 Effective rooting depth (or > 50 cm)	cm						
23 Texture	code						
24 Colour	Munsell						
25 Mottling	code						
26 Structure	code						
27 Consistence	code						
28 Gravel	code						
29 Stones	code						
30 Reaction (pH)	units						
31 Drainage	code						
32 Erosion class	code						

FOREST CROP	Unit	Verbal description	Coding
33 Species	code		
34 Provenance	code		
35 Seed lot number	no.		
36 Planting date	mm/yy		
37 Establishment method	code		
38 Thinning dates (up to four)	mm/yy	| | | |	
39 Plot area	ha		
40 Plot type	code		

PLOT IDENTIFICATION NUMBER	DATE OF RECORD	FIELD FORM 1: PAGE 2 OF 3

UNDERSTOREY

41 Understorey height	m			
42 Understorey type	code			
43 Understorey density class	code			
44 Ground flora type	code			
45 Ground flora density class	code			

DISTURBANCE

46 Grazing intensity	code			
47 Grazing type	code			
48 Disease intensity	code			
49 Disease agency	code			
50 Insect damage intensity	code			
51 Insect damage agency	code			
52 Unplanned felling	code			
53 Fire damage	code			
54 Wind damage	code			
55 Other damage	0 or 1			

GENERAL COMMENTS:

PROFILE OF TOPOGRAPHY:

Along slope

Across slope

SOIL PROFILE:

DOMINANT SPECIES OF UNDERSTOREY

DOMINANT SPECIES OF GROUND FLORA

SERIAL NUMBERS OF SOIL SAMPLES COLLECTED

Point no.		1	2	3	4
Litter					
Depth	5 cm				
	15 cm				
	30 cm				

PLOT IDENTIFICATION NUMBER	DATE OF RECORD	FIELD FORM 1: PAGE 3 OF 3

HISTORY SHEET RECORD OF OPERATIONS AND ASSESSMENTS

Date	Details	Recorded by

SUMMARY OF SUBSEQUENT SAMPLING IN PLOT

Date	Details	Recorded by

2 STANDING TREE DIAMETERS - P1 - Conventional Permanent Sample PLots

PLOT IDENTIFICATION

....
(Number /country /forest /stratum /compartment)

SPECIES
PLANTING YEAR
ASSESSED BY

DATE OF LAST THINNING
DATE OF ASSESSMENT

Tree no. £	Dbh cm	Species code	Tree no. £	Dbh cm	Species code	Tree no. £	Dbh cm	Species code	Tree no. £	Dbh cm	Species code
1			16			31			46		
2			17			32			47		
3			18			33			48		
4			19			34			49		
5			20			35			50		
6			21			36			51		
7			22			37			52		
8			23			38			53		
9			24			39			54		
10			25			40			55		
11			26			41			56		
12			27			42			57		
13			28			43			58		
14			29			44			59		
15			30			45			60		

Regeneration:

North

SCORE:..........

Notes:

2a: COPPICE SHOOTS - CONVENTIONAL PERMANENT SAMPLE PLOTS - TYPE P1

Stool Number	No.of Shoots	Code	Diam. Class	Tally / Diameter	Total
			-5		
			-10		
			10+		
			-5		
			-10		
			10+		
			-5		
			-10		
			10+		
			-5		
			-10		
			10+		
			-5		
			-10		
			10+		
			-5		
			-10		
			10+		
			-5		
			-10		
			10+		

Note: -5 = 0.5 - 4.5cm class; -10 = 4.6 - 9.5cm class; 10+ = diameters greater than 9.5cm.

3 STANDING TREE HEIGHTS - P1 - Conventional Sample plots

PLOT IDENTIFICATION

....

(Number /country /forest /stratum /compartment)

SPECIES

PLANTING YEAR DATE OF LAST THINNING

ASSESSED BY DATE OF ASSESSMENT

HEIGHT TOTAL of: ALL / SAMPLE TREES (delete as necessary)

Tree no.	% to top t	% to dbh b	Slope % s	Dist.(m) d	Height * h	Tree no.	% to top t	% to dbh b	Slope % s	Dist.(m) d	Height * h

*

[h = (t-b).d + 13

where d(istance) is corrected for s(lope),

h and d are in decimeters (dm) and

percentages (on scale 0 - 1) below horizontal are negative]

4 STANDING TREE DATA - Productivity Sample Plots

PLOT IDENTIFICATION

....
(Number /country /forest /stratum /compartment)

SPECIES

PLANTING YEAR DATE OF LAST THINNING

ASSESSED BY DATE OF ASSESSMENT

Tree no.	Dbh ob cm	Total Height m	Height to crown m	Crown class code	Bole form code	Tree position Bearing °	Distance m	Slope °	Whorl height m	Foliar sample ref.no.	Notes

N.b. use columns 1, 2, 7, 8 and 9 for recording tree positions in all plot types.

5 BRANCH AND FOLIAGE MEASUREMENTS - PHYTOMASS PLOTS - TYPE D

PLOT IDENTIFICATION

....

(Number /country /forest /stratum /compartment

RECORDED BY DATE

TREE NO: DBH: HEIGHT: CROWN HEIGHT:

Whorl Number						
Whorl height						
Number of branches						
Diameter at whorl height						
Branch No.						
Orientation						
Branch diameter						
Branch length						
Stratum (A,B or C)						
Foliage green weight g						
time/date						
Foliage sample: label						
total green weight g						
total dry weight g						
time/date						
current foliage green wt g						
" " dry wt g						
time/date						
Branchwood green weight g						
time/date						
Branchwood sample: label						
green weight g						
" dry weight g						
time/date						
Cones number						
dry weight g						
Other						
dry weight g						

6 STEM VOLUME MEASUREMENTS - D PLOTS

PLOT IDENTIFICATION ....

(Number /country /forest /stratum /compartment

SPECIES PREVIOUS VEGETATION

PLANTING YEAR RECORDED BY DATE

TREE NO PAGE OF STAND DOMINANT HEIGHT

Species code	No logs £	Dbh cm	Tree Ht. m

Distance from base m	Diameter over bark cm	Bark thck Diam ub * cm	Disk sample.......................... label	green wt. g	dry wt. g	dry wt. g	dry wt. g			Notes:
										One disk must be
										collected at the___
										base of the crown

* Delete as appropriate (bark may be measured single or double thickness, or diam. under bark may be measured directly). Record diameters (ob and ub) in cm to nearest mm. Record bark thickness, using a bark gauge, in mm.

7 STEM VOLUME OF STANDING TREES WITH TELERELASCOPE

PLOT IDENTIFICATION

....

(Number /country /forest /stratum /compartment

SPECIES TREE NUMBER

PLANTING YEAR DOMINANT HEIGHT

RECORDED BY DATE

BEARING TO TREE DISTANCE		

	HEIGHT		DIAMETER		HEIGHT		DIAMETER		HEIGHT		DIAMETER	
	%	m	TU	cm	%	m	TU	cm	%	m	TU	cm
Bottom												
1.3 m												
25%												
50%												
75%												
Top												
Volume												
1st br.												
Base of crown												
Crown radius												
*												
*												
*												

Sketch of crown profile		

8 STEM ANALYSIS - form used with PPR program STAN

PLOT IDENTIFICATION ....

(Number /country /forest /stratum /compartment

SPECIES STAND BASAL AREA DATE

PLANTING YEAR DOMINANT HEIGHT RECORDED BY

The following entries are those called for by program STAN:

Tree number		
Age of tree		years
Interval between rings measured		years
Total height of tree		m
Stump height (for vol.calc.)		m

DISK			Diameter at age mm										Notes
Number	No. of rings	Height a.g.l.* m											
													*above ground level

9 GENERAL EXPERIMENTAL RECORDING FORM

EXPERIMENT NO: .... DATE..............

LOCAL IDENTIFIER : ..../............/.........../............
(number district forest compartment)
or (" " village owner)

EXPERIMENT BLOCK NO: DESIGN :
TREATMENT NO: VARIABLE RECORDED :
OTHER NO: UNITS :

* COL.		1		2		3		4		5		6		7		8	
ROW		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1																
	2																
2	3																
	4																
3	5																
	6																
4	7																
	8																
5	9																
	10																
6	11																
	12																
7	13																
	14																
8	15																
	16																

SKETCH OF EXPERIMENT LAYOUT: ORIENTATION:

*Use part or all of 8 by 8 or 16 by 16 matrix as required; delete as appropriate.
Note: Row 1 Col: 1 will normally be the top left hand point on sketch. Mark clearly if this is not so.

index

ORDER FORM FOR THE PERMANENT PLOT RECORD (PPR) SOFTWARE

The computer software for handling the permanent plot records may be obtained on request from the Oxford Forestry Institute. This is a collection of programs written in BASIC for use with IBM compatible personal computers. Every effort has been made to ensure that the programmes are error free, but this cannot be completely guaranteed. It is recommended that some training in the use of the software is gained before its implementation.

Cost per copy:

United Kingdom	£ 25.00
Overseas	US $ 40.00

Delivery is by airmail.

Payment:

To be sent with order either as crossed cheques/ bank draft/ money order made payable to the **Oxford Forestry Institute.**

Name : ______________________________

Adress : ______________________________

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Enclosed herewith a cheque / bank draft / money order for /$________ for ________ copy/copies of the PPR software package. Order form to be sent to Dr S Dury or Dr C Lines, Oxford Forestry Institute, South Parks Road, Oxford, OX1 3RB or by fax, (0865) 275 074.