THE BASIS OF SELECTION, MANAGEMENT AND EVALUATION OF MULTIPURPOSE TREES

- AN OVERVIEW

by

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The Basis of Selection, Management and Evaluation of Multipurpose Trees - An Overview

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I. INTRODUCTION

The term "Multipurpose tree" (MPT) in this paper refers to all woody perennials that are purposefully grown so as to provide more than one significant contribution to the production and/or "service" functions (e.g. shelter, shade, land sustainability) of the land use systems they occupy. They are, therefore, so classified according to the attributes of the plant species themselves as well as the plant's functional role in the system under consideration. Many woody perennial species can be "Multipurpose" in one kind of system and "Singlepurpose" in another.

There are many similarities between the methodologies involved in the selection, management and evaluation of MPT's for agroforestry land use systems* and of trees and shrubs used in forestry or agriculture. There are, however, some differences that arise from the need to consider multiple outputs and/or services in agroforestry, as well as from the complexity of the plant associations commonly found. In the latter case, for example, arising from the differences in the spatial and temporal complexities of the woody plant component(s) as compared with the short-statured, short-duration associates. This paper concentrates on outlining the effects of these differences.

Ecologists and those familiar with investigating or managing natural or integrated forms of land use are well-used to and well-able to conceptualize the characteristics of complex systems involving species mixtures of one kind or another that include woody perennials. And, if applicable, to evaluate suitable management techniques designed to optimize particular chosen output characteristics. There are, however, many scientists and technologists trained in "conventional" agriculture or "industrial" forestry, who have now become interested in agroforestry in one or another of its various forms who may not be quite so familiar with the problems involved. It is mainly to this audience that this overview is addressed.

There is a very wide range of uses for MPT's (von Carlowitz, 1984) and a great diversity of types of agroforestry land use systems (Nair and Fernandes, 1984). The selection, management and evaluation of MPT's for any one of these always, of course, involves a consideration of the tree itself, sometimes the tree as a crop plant and, often but not always, its association with other species

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* For a definition see Lundgren, B. (1982).

(the "tree/crop" mixture). Thus the resolution of management alternatives and any research objectives require answers to the following questions: "What species are most suitable for any *particular* agroforestry land use system?" "How many of them are required per unit area of land?" "How should they be arranged and managed?"

The subject areas concerned with finding the answers to these questions are noted in Table 1 and discussed in the sections that follow: in brief where they have already been addressed elsewhere, and more fully where they have not and are considered to need urgent attention. The question "How best do we evaluate MPT's as trees, crops or in mixtures of species has been addressed in a "Manual of Research Methodology for the Exploration and Assessment of Multipurpose Trees" 'Huxley (Ed), 1984) and some of the issues are noted in the appendix to this present paper. Many of the other contributions that follow in this Conference add significantly to the further development of the subject.

II. KEY ISSUES IN SELECTING, MANAGING AND EVALUATING MULTIPURPOSE TREE SPECIES

A. Some Characteristics of the genotype to consider

Chosing a MPT genotype for a particular agroforestry application may often involve difficulties due to the need to rank, in some way, the relative importance of required outputs, as well as to consider potentials for environmental resource-sharing with other kinds of crop species. As yet some of the basic information on which to base a choice is, indeed, little known for many, if not most, MPT species.

Some important characteristics to consider are as follows.

- General growth, flowering and fruiting attributes, which include:-
  - specific morphological attributes
  - dry matter distribution as affected by genotype and environment. (source-sink relationships with regard to fruiting).
  - phenological characteristics
- Adaptability, which includes
  - overall genetic fitness or flexibility
  - ecophysiological considerations
  - genotype and environment (GxE) implications

Ledig (1983) has already critically summarized many aspects of dry matter distribution as affected by genotypic

	WHAT SPECIES?	HOW MANY PLANTS?	HOW ARE THEY TO BE MANAGED?
A. TREE	1. Specific morphological attributes 2. Overall genetic fitness or Flexibility 3. Ecophysiological considerations 4. G x E interactions 5. Selection index procedures 6. Source-sink relationships and fruiting	Attributes contributing to land sustainability	Some tree management considerations: 1. Pruning and the manipulation of vegetative growth and fruiting 2. Pruning practices
B. TREE AS A CROP	Ideotypes	Plant density rectangularity arrangements	The effects of the removal of plant parts on sustained yields
C. TREES IN MANAGED SPECIES MIXTURES	Space-time considerations: 1. dimensional opportunities 2. the tree-crop interface	Choice of optimum populations and degree of intimacy.	Management in tree-crop mixtures: 1. Manipulating plant stress 2. Entrainment

Table 1: Factors to be taken into account when considering the selection, management and evaluation of multipurpose trees. Within the table, in each column any factor listed in sections above need to be considered also is, in the rows, do any factors listed in sections to the left.

and environmental factors. Only some aspects of source-sink relationships and fruiting are taken up here. Similarly, the value of matching the growth of the component plant species to the environmental resources available and, in particular, of understanding both the natural and managed responses in time, for MPTs, has been discussed elsewhere (Huxley, 1983a). Some practical issues are raised in other sections.

1. Specific morphological attributes

Although general descriptions of growth and form are available for all MPT species there is often, still, inadequate information at the provenance level. Furthermore, no really detailed investigations have yet been carried out to provide an understanding of the anatomical/morphological basis for growth and development of individual MPT species in the way that has been so helpful for some of our more important tree cash crops. For example, in coffee, the early studies on the structure of the axillary bud series and the behaviour of buds in particular parts of it, (see Fig.1) laid down a sound, predictive approach to any form of shaping and pruning of the coffee bush. There is little that is needed to obtain this kind of information other than careful visual observations combined with simple dissecting techniques,and it should be undertaken for all MPT species as soon as possible.

2. Source-sink relationships and fruiting

In woody perennials the onset of a development cycle (floral initiation, bud growth, ovule development, fertilization, pollination, zygote development, seed and fruit growth and maturation) has effects not only for the current season's vegetative growth activities, but also for the level of subsequent seasons' growth and development. It has long since been known that the presence of fruits can enhance carbon assimilation (Neales and Incoll, 1968); fruits (and especially seeds) are highly competitive sinks and can take preceedence over all others (Cannell, 1971).

The manipulation of flowering and fruiting is, therefore, a powerful tool for "shaping" the distribution of dry matter in a MPT where, for example, from year to year a change in the proportions of product outputs can, under intensive management at least, be achieved by encouraging, regulating or eliminating the flowering/fruiting process.

With the exception of some edible pod-bearing leguminous trees (Prosopis, Acacia) there are relatively few species of MPTs that have been subjected so far to any intensive breeding programme in which fruiting capacity has been a criteria. Most MPT genera, have been selected through simple species and provenance trials for survival and general vigour. Leucaena has for some time been subjected to fairly rigorous selection and, latterly inter-species crossing, in order to select for mainly fuelwood or fodder types (Brewbaker, 1980,1981) or for adaptability to acid soils (Hutton, 1983). A

characteristics of Leucaena is its early and prolific flowering with the consequence that large numbers of pods are produced. These can be used as a cooked vegetable when very young (in limited quantities) but when mature, they are not readily eaten by domestic animals. Leucaena is not widely grown for its fruits, in other words, and the litter of pods and seeds that form under Leucaena plants provide mainly a "service" function which could better be served by leaf litter, particularly as seedlings are usually not wanted and have to be removed. Leucaena, in fact, provides an example for the plant breeder, of a case where genotypes providing a smaller fruit load would be advantageous

Apart from the potential level of fruiting, which can be over 70% of the annual dry matter increment in some woody perennial species, there is another, as yet scarcely-studied aspect, of source-sink relationships with regard to fruiting that would repay some consideration. This is the spatial relationships between carbon assimilation source (leaves or bracts) and the fruiting sites. In particular, the disposition of leaves in relation to flowers and/or inflorescences. Cannell (1970) showed in Coffea arabica, that even small vegetative laterals could be important sources of assimilates to nearby developing fruits. Also a number of Carbon - 14 tracer studies with woody plants have shown that newly-formed carbon assimilates can be transfered to floral structures and the developing fruits, not only from subtending leaves, but also from adjacent ones both up and down the stems (e.g. for coffee, Cannell and Huxley, 1969).

The extent to which this occurs no doubt varies with species, the numbers of developing fruits at any site and the stage of fruit growth. However, it seems a reasonable working hypothesis that flowers and/or inflorescences that are more adequately provided with source leaves, either at the site or in closely-adjacent regions, will be less of a drain on stored carbohydrate reserves and main canopy leaf sources. And that processes of flower and fruit growth that might otherwise be restricted by limited carbon source accessibility will be better and more continuously provided for where well-leafed rather than sparsely-leafed fruiting branches (or even inflorescences) are present.

If we are chosing MPTs for their ability to reliably provide fruits and/or seeds this might be a possible selection characteristic to consider (Fig. 2a-h). There is an urgent need to collate existing general knowledge about tree form and morphology and possible relationships with functional attributes in order to facilitate MPT selection procedures.

3. Overall genetic fitness or flexibility

Environmental selection pressures will, through eventual genetic change result in different degrees of adaptation to a range of ecological niches ("flexibility") or, in other

cases, to a more rigid adaptation to a specific set of environmental variables ("fitness") (Stebbins, 1950). In selecting MPT germplasm we need to consider very carefully whether the objective is to satisfy a generally adaptive set of criteria in a range of various types of agroforestry land use systems situated, perhaps, in an environmentally somewhat diverse area, or whether the aim is to select critically for a particular system in either one or a closely comparable set of systems.

Ecological flexibility is an attribute of a particular pool of germplasm and individual genotypes may or may not have the capability to flourish outside the immediate environment in which they are discovered to be well-adapted (see also Pickersgill, 1983). Individual genotypes within a particular taxon (species, cultivar) may exhibit a narrow or broad adaptive capacity, irrespective of how heterozygous they are. The ability of a single genotype to grow in a range of different environments will depend on how far particular adaptive anatomical, morphological and physiological characters of the phenotype can be modified in response to changes in particular environmental variables. That is the extent to which it has retained some "buffering" responses within any set of broad genetic instructions. Table 2 indicates the combinations found.

TABLE 2: Degree of adaptability depending on the characteristics of the genotype and the capacity of individual genotypes within it to have maintained "non-specialized" adaptive traits.

Type of adaptation of germplasm (genepool) to environment	Controlled by mechanisms which are	Adaptation limits
Fit	Genetical and highly specialised.	Only grows in one (or a restricted number) of ecological niches for which its form and function is highly specialised
	Genetical, but some non-specialised traits remaining.	Grows usually in a restricted number of niches (where it has evolved), but has maintained some capacity to be moved to others by retaining sufficient "non-specialisation" in terms of anatomical, morphological and physiological traits.
Flexible	Genetically diverse	A wide range of genotypes available which enable some to grow in a number of different kinds of habitat (each genotype restricted to one or similar habitats though)
	Genetically diverse and many non-specialised traits.	A wide range of genotypes available from different ecological niches but many of these (i.e. are individually capable of considerable morphological, anatomical and or physiological modification in response to environmental change.

4. Ecophysiological considerations

(a) Survival and resource-sharing mechanisms

Many of the attributes for adaptive change, and the capacity a plant has for either limiting or expressing these in response to changes in the environment, will have evolved during evolutionary history both from a need to ensure survival as well as an ability to develop competitively in plant associations. These two objectives may overlap in some cases, but not in all.

The balance has been resolved in an infinite number of ways by plants achieving some level of compromise in the size form and physiological behaviour of particular organs. Once an evolutionary trend has established some specialized plant modifications, in the form of either a survival mechanism or an enhanced ability to compete or to develop a "resource sharing ability", and where these are achieved by different plant modifications,then the plant's capacity to adapt to another set of environmental conditions may have been diminished.

As an example, and to make this clearer, we might look at one aspect of the evolution of the plant leaf. Various adaptive structures have evolved to reduce water loss from leaves in arid environments; thicker, fleshier leaves, smaller stomata; hairs; etc. and without these (or alternative mechanisms)the plant would be unable to survive the inevitable prolonged drought periods imposed by such a climate. Such leaves are very different in character from those of many plants which have evolved in moister conditions, where species can grow relatively closely together, and where the major limiting resource to be shared in such a plant community is not water but light. In such circumstances leaves are aggressive organs and shading out another plant is an adaptive strategy to achieve a greater share of available light. Under these conditions leaves have evolved so as to respond rapidly to the reduction of light by increasing their specific leaf area (unit leaf area per unit leaf weight). In other words as the plant is shaded, leaves still in a formative stage quickly grow bigger in area but, to conserve assimilated carbon they also grow thinner. This is seen to a high degreee, for example, in many Cucurbitaceae but it is, clearly a feature which puts them to a disadvantage if water becomes in short supply.

The arid land plants with thick leaves might well grow vigorously if moved to a situation where water becomes more plentiful. But the type of leaf structure to which they are by now genetically restricted will not be of much use in a plant association where the other species have leaves which will respond to shading. Equally, the survival of the latter, if moved to a desert fringe, would depend, at least in part on the extent to which they had retained the capacity to respond to dry environments by producing thicker, waxier leaves.

General adaptability therefore becomes a matter of being relatively non-specialized. As distinct from specific

adaptability which derives from morphological, anatomical and physiological specialization which are the result of evolution towards genetic fitness. In chosing MPT species we used to be aware of their "adaptability" and, ideally to have some idea of the structural and physiological mechanisms to achieve this which they have evolved in natural communities.

(b) Potentials for exploitation

"Success" in any particular community can be expressed as the ability of a genotype to increase in numbers. It may depend more on a plant's capacity to acquire, through a whole variety of strategies, a greater share of the available environmental resources than co-habiting species which happen to find themselves there, than on more positive plant modifications to fit it to the specific environment. The implications of this in terms of selection for particular products or attributes are rather important, and we need to apply the lessons learnt with other crop plants to MPT's.

For example, Coffea arabica, at its centre of origin, (Ethiopia), is found as a successful understorey shrub producing, under relatively shady conditions, only a modest number of fruits per tree; but sufficient to ensure its survival. Removed from its natural habitat, and grown by man for its seeds it has been found to yield much more prolifically if grown in full sun. As long as it is provided with a high enough level of plant nutrients to enable it to do so on a regular season-to-season basis. The physiological reasons for this are now well understood and supported by the results of several decades of detailed study (Cannell, 1971). There are, of course, many other examples of a similar nature in which the attributes for ecological success tend to obscure the potentials for exploitation by man.

(c) Implications for selecting MPTs

If we understand sufficient about the genetic background of our MPT species, and have at least a basic understanding of its anatomical, morphological and physiological adaptive behaviour when exposed to environmental change, we will be better able to chose the correct species for a particular ecozone or site. And to be able to propose appropriate management techniques to optimise the products we require.

In selecting multipurpose tree species for various uses we are likely to find a whole spectrum of adaptive strategies. Both in terms of genetic pools of varying degrees of flexibility, and as a consequence of an individual genotype's ability for antomical and physiological "buffering". However, the task of unravelling the evidence for either (or both) is made more difficult because of the multiplicity of "products" (in its widest sense) for which we may select any one species or provenance. There is therefore, a need to know and understand, however marginally, the growth and development processes involved in the achievement of

"adaptation" to the particular habitats where we propose to grow that species. Also the management to be imposed. In addition, we must clearly define its uses. It is to be grown primarily for its leaves? for fuelwood? for building materials? for fruits and/or seeds? And so on. To be productive the species or provenances we chose for a particualr ecozone must be either generally or specifically adpated to grow vigorously in that particular environment and also to be suited to it in a way that will maximize the products (or services) that we require.

5. Genotype x environment interactions

If the limits of and reasons for adaptive behaviour in MPT species or provenances need to be understood a common set of critically-evaluated MPT species/provenance trials conducted throughout a suitable range of environments are required. Experience to date with the major agricultural crops (wheat, maize, rice, potatoes, cotton etc. etc.) and with provenace testing of industrial forest tree species, establishes both a clear indication of the necessity and the magnitude of this task. Some attempts to undertake this are, fortunately, under way (Nitrogen Fixing Tree Association Trials, Brewbaker; National Academy of Sciences Fast-growing Nitrogen fixing Tree Trials, Gritzner; FAO's MPT Germplasm Conservation Project, Palmberg, and so on, personal communications). Sommonds (1981) indicates the benefits to be gained by taking G x E effects into accounts with agricultural crops.

With MPTs there is the added difficulty that a significant G x E interaction may be established for one yield output, but not for others. Or, at least,not the same kind or magnitude of G x E interaction; for example, if two kinds of harvests come from competing sinks rather than the same sink (honey and fruit/seeds, roundwood and fuelwood, fodder from leaves and exudates will, in each case, be from the same sink, in any pair, but not between pairs). Another example, might be where a particular MPT species responds only minimally in terms of overall vegetative growth to a small change in environment, but the flowering/fruiting processes are markedly affected by a critical response to e.g. night temperature, Huxley and Summerfied, 1976).

At present the selection ofsuitable MPT germplasm for a particular task involves a choice mainly at the species level. Selection on the basis of provenance trials is increasing rapidly, however, and tree breeding programmes to exploit the huge genetic gain that is potentially available will be needed (Felker et al, 1983, Burley and Owino, 1984). The objectives of such programmes need to be very clearly considered because of the multipurpose nature of the plants. How do tree breeders see the best approach?

The breeding programmes for Leucaena leucocephala (mainly in-breeding, unlike most MPT species) have provided two types of plants - mainly fuelwood types (e.g.cv "K8") and mainly fodder types (e.g. cv."Peruvian") (Brewbaker, 1980 etseq.). The extent of any seperation of yield imporitives in a breeding programme clearly has a number of implications

that are not found with agricultural crops. One example is that the rates and degree of genetic gain for particular outputs may be different. Another, already mentioned, is that G x E interactions may be of different kinds for different outputs.

6. Selection index procedures

Whatever breeding strategies are adopted a major problem for MPT breeders is to devise rapid and simple selection procedures so that these can handle the extremely wide range of genetic variability that exists in many MPT species.

Such procedures were introduced as a refinement in the approach to selecting agricultural crops. (e.g. cotton breeding) in the 1950's (Manning, 1956; Walker, 1960). Instead of examining relatively large amount of germplasm in the early stages of selection by somewhat crude and subjective methods Manning argued that it was better to measure the yield and its components in small numbers of progeny grown in replicated plots. The data could then be used to establish genetic variation so that a selection procedure could be used that could lead to maximum genetic advance within the material studied. A "selection index" was evolved (Arnold and Innes, 1976) encompassing 4 traits of cotton yield (which were lint yield and its 3 components). Originally the assumption was that a phenotypic trait (e.g. "lint per plant", which equalled "net worth") was the additive outcome of genotypic and environmental effects. A selection index of the form $I = b_1x_1 + b_2x_2 \ldots b_nx_n$ was used in which the weighting coefficient ($b_1 \ldots b_n$) were calculated so as to maximize the relationship between, for example I and G_w (the genetypic effect for the trait "net worth"). This was done by taking into account the phenoptypic variances and covariances of the traits as well, as their genotypic covariances, with net worth. Optimum values of b arise from the simultaneous solution of the derived set of equations. Arnold and Innes (1976) describe the procedure in more detail and point out that because G x E interactions limit the usefulness of heritability estimates derived from a single experiment, what is wanted is the magnitude of genetic difference in relation to the G x E interactions encountered in the production area.

In cotton, a plant which can be selfed, the selection index procedure was adapted because of the difficulties of defining criteria for visual selection, and in order to undertake an objective selection procedure. With MPTs in their initial stages of selection there is no doubt that considerable progress will be possible on the basis of mere visual assessments and, wherever possible, quantitative measurements of phenotypic traits. The desirability of ultimately dealing objectively with the selection of several outputs simultaneously may suggest that we look into a "selection index" procedure even if G x E interactions considerably raise the mathematical complexities of doing this.

Very simple (non-mathematical) selection procedures can be used now for MPTs. These need to utilize sets of comparison in which , say, end-uses are listed against climatic designations of ecozones. Such two-way tables or matrices can include simple within-table ranking schemes, but they will have limited value where there is a high level of G x E interaction for particular traits, unless these can be investigated and the outcome taken into account. Furthermore, it must be remembered that the users themselves will establish a different ranking order according to land use system for which any particular MPT is being grown. Therefore, a simple ranking scheme for user requirements will have to be incorporated. This could be made at least partially objective through the decisions made about the systems requirements using a field diagnostic procedure (such as ICRAF's "Agroforestry Diagnosis and Design" Procedure, Raintree, 1983).

The favourable possibilities for vegetative and micro-propagation that exist are likely to assist the rapid dissemination of many MPT species and provenaces. Although foresters are wary of clonally-established industrial tree plantations it should be remembered that the bulk of all the world's temperate and tropical tree fruit industries has been based on selected clones. For temperate fruits, starting from extremely diverse germplasm in seedling material that was widely distributed in the 14th and 15th centuries onwards. The future of MPTs may be much more directed towards low-input land use systems but, as many of the species of interest are fast-growing, and mature rapidly, there is an opportunity to establish MPT breeding centers which can provide a successive range of suitable germplasm (including pest and disease resistance) as it is needed to replace that which becomes outdated.

7. Conclusions

The present fragmentary state of knowledge about MPT's together with the large numbers of species (let alone provenaces) involved and the need to get trials started quickly, will all militate against any in-depth evaluation of factors underlying the adaptability and suitability of particular selections. Nevertheless, where some considerations can be given to this, however scantily, it may not only save resources but assist in the more rapid selection of species for particular end-uses in selected ecozones. Certainly, there has to be a more elaborate process of judging the relative value of different MPT species than is usually the case for single-product forest tree or agricultural crop species.

B. Attributes contributing to land sustainability

1. Soil changes at the microsite

Species of woody perennials can differ very considerably in the extent to which they modify the immediately adjacent soil (the microsite). For each species we need to know what soil changes occur, and the time taken to bring these about on any particular kind of site. The tree's capability to change the microsite will itself be modified by management, particularly training and pruning, and by any removal of plant materials. For example, yield harvests, and mulch or litter which is used elsewhere. To estimate changes in the complex space-time arrangements of a mixed cropping agroforestry system involves the consideration of a great number of variables and their interactions. Table 3 indicates a possible way of grouping the factors concerned in order to estimate the overall time trends, and so as to include the effects of management.

TABLE 3: Factors affecting the nutrient budget of a land use system involving MPTs, (modified from Huxley, 1982)

		Natural		Man-Manipulated
ENVIRONMENT	(A)	Soil nutrient availability Topography climate (Rainfall)	(A')	Soil management practices Soil conservation practices Water conservation practices
PLANT	(B)	Characteristics of species used in the system - Potential useful biomass - Growth (habit/rate) - Rooting characteristics - Nutrient content of plants Canopy effects (on temperature, throughfall)	(B')	Harvesting Programme and techniques Plant management Fertilizer and externally transferred mulching practices Training/pruning/harvesting of leaves/wood)
SYSTEM CHARACTERISTICS	(C)	Space - Plant cover Time - Crop succession (land occupancy)	(C')	Layout and arrangement of plant species (position and dimensions) Cropping sequences and timeliness of management operations

Taking the groups of factors listed above the Nutrient Budget (N) can be estimated from the best approximations of accumulated inputs less accumulated losses for all major nutrients, and any minor elements (if likely to be deficient). Projections to t_1, t_2, t_3 etc. (in, say 5, 10, 15 years time) can be calculated from

$$N_t = \left(\left((A'(A))_{t_1} - (A'(A))_{t_0}\right)\left((B'(B))_{t_1} - (B'(B))_{t_0}\right)\left((C'(C))_{t_1} - (C'(C))_{t_0}\right)\right) N_0$$

where N_0 is the current nutrient status of the soil, and $A'(A)$, $B'(B)$, $C(C)$ represents estimates of the overall effects of the groups of factors categorized above (E.g. economists "production functions"). The consequences of heterogeneity in space may also need to be taken into account in an agroforestry system because of localised microsite enrichment by MPT's.

Tropical broadleaved MPT species generally possess a potential for benefitting the microsite but, again, to various degrees. They may, therefore, be of differing values in agroforestry systems where land sustainability has a high priority. As yet little is known about the particular characteristics that bring this about. For example, in India, the indigenous species of Prosopis (P. cineraria) is commonly found on farmers' fields in Rajastan, where it is nutured because of its favourable effects on the microsite. Whereas the introduced species (P. juliflora) is not nearly so beneficial. In African Acacia albida is similarly well-known for its favourable effects (Felker, 1978) and in central and South America genera such as Inga and Calliandra behave similarly. Other examples are species of Gliricidia, Erythrina, Acrocarpus and Sesbania, as well as numerous other leguminous species. And also, for example Grevillea, Terminalia and Alnus among non-legumes.

Not all woody species improve the status of soil around them. Many gymnosperms, for example, as we well know, produce a resinous and slowly decomposing leaf litter that can severely lower soil reaction. Eucalypts also deposit a litter of resinous leaves that can form a close-lying mat that may inhibit understorey growth and, on sloping land, encourage run-off. A few species of higher plants are known actually to produce root secretions that inhibit associated plant (e.g. guayule (trans-cinnamic acid (Bonner and Galston, 1944). More obscurely, there are many different kinds of organic compounds that can accumulate from the decomposition of plant residues which have adverse effects on associated species (Friedman,1983; Koslowski and Huxley 1983; Shang-Shyng and Hsi-Hua, 1983). Brunig and Sander (1983) give a detailed account of the analyses of different peats from two phasic communities in a natural swamp forest in Sarawak. Nutrients and physical conditions alone were not considered to have brought about the differences in physiological responses and growth changes that subsequently occurred in test plants grown on them. There may also be specific replant problems following the cultivation of certain species; and these have been reported, for example, for fruit trees, Stylothanthes (a perennial fodder plant) and arabica coffee.

Agroforestry systems are often promoted because of their implicit land sustainability characteristics (Lundgren, 1982). It seems essential, therefore, to establish, as soon as possible, the relative potentials for achieving this possessed by the 50 or 60 woody species that, at present, are considered to be highly promising candidates for different ecozones (from among more than 2000 species that have so far been listed as possibles; Burley and Owino, 1984). Also to establish any possible allelopathic effects where MPT's are to be used in crop mixtures as well as any replant problems

2. MPT's and land system sustainability

The generalities and, sometimes, illusions that "trees improve the soil" need to be replaced, for individual MPT species, by critical experimental evidence of the kind that facilities extrapolation to other sites and management conditions (Young, 1984). In this respect we will, where trees are grown as crops or in mixtures, need also to assess very carefully the outcome of removing relatively large amounts of biomass from the site; because this is often implicit in many proposed agroforestry production systems.

Woody species are often (but not always) deeper-rooted than forbs or grasses and may, therefore, be extracting nutrients from lower soil levels and re-cycling these in litter. This process has very significant ecological effects over long periods of time. And there is much evidence for this available from the studies of the dynamics of natural ecosystems such as tropical forests (e.g. Golley et al, 1975) and also from the wealth of data on shifting cultivation (e.g. ter Kuile, 1983). However, unlike natural ecological situations, the time-scales for any required improvements in most managed agroforestry systems are very much shorter, nor are such managed systems closed. There is, also considerable evidence in the tropics of the inexorable decline of soil fertility under both continuous agricultural cropping and plantation forestry which suggests that any high output system (unless it is on an extremely fertile soil), cannot provide sustained yields without the addition of nutrients. Agroforestry schemes which purport to be able to remove, annually, very large amounts of biomass from the sites without the addition of nutrient inputs need to be treated with some scepticism. The amounts, location and rates of off-take and replenishment of nutrients need to be carefully studied in relation to the environmental and physical site factors, and of the MPT species concerned, before such systems can be considered viable in the long-term.

Depending on the climate, the intrinsic growth rates of the species or species mixtures, and the inherent level of soil fertility it might be reasonable to expect quite modest limits, of biomass removal (say, 5 to 10t ha^{-1} per year?) before many land use systems in "difficult" environments become non-sustainable. Despite the difficulties involved, the need to obtain relatively precise information about this is clearly a key issue if the design of new sustainable agroforestry systems is to be undertaken scientifically. And a key issue in assessing the input side to the situation is the potential rate of microsite enrichment that any particular MPT species is capable of.

Continue below

3. Dealing with sustainability in mixed cropping with MPTs

In designing agroforestry systems where appropriate MPT's are to be used on farmer's land in mixtures with agricultural crop species there will, therefore, be a compromise between the level of productivity (the results of multiple outputs from all contributing species) and the sustainability of the system. Bearing in mind that, in any particular system, the latter may well depend prodominately on the tree species being used and their number per unit area. How then can we consider what proportions of tree and agricultural crops will be necessary in order to predict any particular productivity/ sustainability "trade off"?

A precise answer to this question can only be found after some considerable on-site research, but a means of producting the outcome from a combination of theoretical approximations based on existing analagous data (what we already know about the effects on soil of other tree species on the sites) will but least, give us a start. Figs. 3 & 4 from Huxley, 1983b) shows the changes with time that can be expected

in the soil status with a paired tree/agricultural crop combination. A similar response surface can be predicated using some information (or guesses?) about production output. Such a model can provide only conjectural solutions at present, because the information about changes with time in soil status and plant productivity, particularly with multipurpose tree species, is unknown. Nor do we know anything about the shape of the curves representing the effects of such a species mixture on the soils. However, the absence of required data which is exposed by this model helps to establish a set of priorities for research with MPT's.

C. Some Tree Management Considerations

Cannell(1983a) has discussed a whole range of management options and their effects. What follows here is confined to some aspects of pruning.

1. Pruning and the manipulation of vegetative growth and fruiting.

Woody perennials lend themselves to relatively precise forms of structural manipulation which are usually undertaken to (a) change or moderate stature and form, and (b) regulate the proportion of different parts. In the latter case, there are two main objectives. First to adjust the balance of sources of carbon assimilation (i.e. the green, actively photosynthetic parts) and the sinks (those other parts of the plant which utilize fixed carbon) so as to maximize total biomass production; plants will otherwise be "source-limited" or "sink-limited". Second is to optimize the production of those plant parts that are to provide the wanted yields - fruits and/or seeds, leaves, trunks or other stems, roots, exudates etc.

All this has to be done with a knowledge of what state the vegetative condition and fruitfulness of the tree are in as a consequence of previous growth and fruiting activities. There must also be a predictive assessment of future climatic benefits or stresses, in both the shorter and longer terms, so that vegetative growth, dry matter partitioning and plant development processes can be harmonized within the possible limitations of the seasonal weather patterns that are to be expected.

The proportion of the annual dry matter increment that may be allocated to fruits/seeds can be from zero to a recorded 70% or so (e.g. coffee, Cannell, 1971). Some extremely fruitful MPTs (e.g. Prosopis spp. grown for pods for animal fodder) may well perform similarly (Felker, pers. comm.).

Where MPTs are not purposefully grown for fruits or seeds the flowering process may just be ignored or fogotten about. However, if flowers, fruits and seeds are not wanted their production represent a waste of the plant's resources. In either case a better understanding of the development processes may well suggest ways of regulating them. For most MPT species there seem to be only references to flowering and fruiting in the ecological or taxonomic literature which is not usually of the kind to lead to practical management strategies.

The investigational requirements are not onerous. The first is to observe and record on what type of stems flowering takes place ("new" or "old" shoots, i.e. current or previous season's stems), and to note in what sequences flowering and shoot-flushing occurs. (Does flowering occur prior to, concurrently with or after a vegetative growth phase?). These can be related in as much as flowering prior to a vegetative flush must ipso facto be on the wood (stems) producted in a previous season. Such information is essential for an effective pruning programme, as all fruit growers know.

When flowering occurs on "old" wood it may be form residual axillary buds which have remained dormant and are still capable of forming flowers or inflorescences. More likely it will be on some form of "short shoot" -usually an axillary shoot with highly compressed internodes. Flowering on "new" wood is not restricted to the periphery of a tree, of course, as shoots can grow out from older stems. However, the supply of potentially active buds may rapidly be used up and whole areas of older stems become relatively free of axillary shoot formation and, hence, are barren. Species or cultivars may exhibit a range of types from those that flower mainly on old wood to those that mainly, or additionally, flower on new wood (e.g. in the apple "tip-bearers"). Where plants are not fruiting only on short shoots a regulated supply of new fruit-bearing stems is, again, one of the aims of a pruning programme. Short shoots themselves will eventually age and need to be replaced at other sites in the tree.

To remove unwanted flowers and/or fruits may often be impractible, but where a MPT is, at least in part, to provide browse, then it may be feasible to impose browsing of newly developing shoots around the time at which flower initiation is occuring in order to reduce their number.. If flowers (or inflorescence buds) have a dormant period, as in arabica coffee, this may be some time before anthesis occurs. To check the time, or part of the season, at which flower buds are intiated requires only a sequenced programme of bud dissection and examination with a binocular microscope.

An appreciation, however anecdotal, of the carbohydrate source/sink relationships of a MPT species can be of use in determing its proper management. For example, by trying to attain a appropriate source/sink balance by regulating the amount of leaf todeveloping fruits. However, there is an outstanding need to investigate the ways of

doing this through some relatively simple approaches. Perhaps by finding morphological "Keys" to physiological functions. It involves not only a consideration of the relative "size" of the fruit sink, but of the potential activity and position of source leaves in relation to this.

There are experimental data on the capacity of plants to provide recently-assimilated carbon to various sinks, including developing flowers and fruits. In general, young expanding leaves do not export carbon (except to the apical bud), mature active leaves can export both upwards (e.g. to fruits) and downwards (e.g. to roots) depending on the strength of sinks in these regions and the exact position of any leaf; old leaves do not export newly acquired carbon, which is retained and presumably respired. Actively expanding leaves adjacent to or actually substending fruiting sites usually supply all their surplus carbon to these sites and may therefore, be a major source of carbohydrate supply to the developing fruits.

There can be considerable variability in the "leafiness" of fruiting regions Figs.2a-h even between closely related species but, even if well-studied agricultural and horticultural crops this particular aspect has not, as yet, been well-studied. The characteristics may be a useful one in selecting MPT genotypes required for fruiting should a relationship between "leafiness" adjacent to fruiting sites and stability of fruit yields be proven experimentally. Similar rapid selection criteria are required with MPT's in order to relate form to function.

2. Pruning practices

There are many forms of pruning (e.g. Cannell, 1983a, von Carlowitz, 1984) but only two basic pruning operations - "thinning-out" (Fig. 5) and "heading-back" (Fig. 6). Their skilled application can be used to change the overall size and shape of trees/shrubs, to manipulate the source/sink relationships so as to regulate growth and fruiting, and so to modify the output of all plant parts, within limits. The two operations can be carried out on stems of differing order: main stems, primary branches, secondaries tertiaries, and so on. Coppicing and pollarding are forms of heading-back carried out on the main trunk.

Although the overall effect on different species of either operation will be similar the precise response will depend very much on the growth characteristics of the species concerned, the time at which the pruning operations take place (with regard to both the physiological condition of the tree and climatic factors), and the care and understanding with which the pruning operator selects which process to use in respect of individual trees and parts of trees. Because skilled pruning involves numerous decisions it has to be recognized as an art as much as a science, and it has reached a high degree of sophistication in many tree species grown for their fruits and/or seeds. This kind of knowledge about plant responses now needs to be transferred for use with

MPTs where, however, relatively simple forms of pruning are likely to be more readily adoptable than complex ones.

The effects of using the two basic processes on branches of different orders are shown in Figs. 5 and 6. Even when fruits and seeds are not required as useful products a knowledge of the location and magnitude of the numbers of fruiting sites is important so that a conscious reduction of the future fruit "sink load" can be undertaken if this is feasible, at the same time that the potential leaf canopy and the general form and size of the tree are regulated. An ability to balance pruning operations so as to predict the appropriate degrees of "leafiness" and fruiting required is what makes the more complicated pruning schemes even more of an art.

III. MULTIPURPOSE TREES AS CROPS

A. Ideotypes

Up to the 1960s, as Donald (1968) pointed out, plant breeders had confined themselves, basically, to two types of breeding programees: "defect elimination" and "selection for yield" (on the basis of yields). The development of crop physiology as a branch of plant science led Donald (and see also Donald and Hamblin, 1976) to propose that if enough was known about the attributes that formed the basis of any set of breeding objectives then a "model" could be established, and this could be used tomake selection processes much more exact. The term "ideotype" ("ideal plant type")was derived to describe this set of "model" plant characteristics which include, for example, attributes not only of stature and form but of functional efficiency, such as the intrinsic factors affecting growth (leaf area ratio, net assimilation rate, leaf area ratio, leaf-to-total-growth ratio, etc.) and fruiting (known influences of climate on flower initiation,fruit set and fruit maturation.

Three types of ideotypes were envisaged:

A. Those that do well as spaced individuals ("isolation" ideotypes);these are often widely-branched broad-leaved and have other "aggressive" growth attributes.

B. Those that do well in varietal mixtures ("competition" ideotypes). These can flourish in a plant community of their own kind and they have characteristics that tend to dominate less aggressive varieties.

C. Those that do well in crops consisting of single cultivars ("crop" ideotypes). These have a form and functional abilities that tend to enable them to share environmental resources in a community of their own kind. In cereals, for example, short-statured, upright, narrow-leaved kinds.

The validity of Donald's ideas has been well-substantiated by agricultural crop breeders in the last two decades or so, particularly with regard to the selection of "isolation" and "crop" ideotypes. More recently the concept has been taken up by forest tree breeders (e.g. see Cannell, 1979, 1982).

In agroforestry, and in systems consisting of mixtures of plant associates, we will mainly be concerned with "associative" ideotypes. That is those plant selections (species, provenances, cultivars) of either woody perennials, or perennial or seasonal forbs or grasses, each of which, although of different plant stature, habit and functional characteristics, is contributing to the fulfilment of the system's, design objectives whilst maximizing environmental resource-use by integrating and sharing in both space and time (in other words, "non-competition" ideotypes). Each kind of plant in such a system could be idealized in terms of a "specification" based on a combined set of requirements derived by considering the needs of the system and the technical requirements of available plant types that can fulfil them.

ICRAF's procedures for "Diagnosis and Design" of agroforestry systems (Raintree, 1983, ICRAF, 1983) relates technical components to the requirements of the landuser and the land use system as a whole. It now includes a process of deriving a prioritized "specifications" of plant components as part of the process of defining any research needs, and this can be considered as establishing a set of ideotypes for MPTs (Huxley and Wood, 1984). Such specifications might include not only a set of required attributes associated with natural growth, but those achieveable under some form of management. Fig. 7 shows, diagramatically, some examples of "isolation", "competition" and "crop" ideotypes for MPT's plus a set of "associative" tree ideotype forms that might be suitable for different types of agroforestry systems. For the latter there would be a parallel set of "associative" agricultural crop ideotypes also. The detailed specifications would include an outline of attributes not only of stature, form and phenology, but of desired functional characteristics also.

B. Plant density and rectangularity arrangements

The effects of manipulating plant density and rectangularity for trees and herbaceous crops have been well-summarized and discussed by Cannell (1983a & b) and I intend only to make some additional relevant points here.

1. Some general concepts noted and extended

(a) The enthusiasm that has greeted the possibilities for improving the productivity and sustainability of land use systems by using MPTs has sometimes led to unthinking optimism

with regard to the possible level of outputs. At all times it pays to remind ourselves of the information that is available concerning potential biomass production in different ecozones, the data available for dry matter partitioning and harvest indices, and the published information about actual yields of different species under optimum management conditions (Table 4, see next page).

The very large differences between the potential and mean yields that always exist may encourage us to hope that a better use of the available environmental resources might ensue if a suitable MPT species is incorporated where there were non previously, or that more efficient selections of MPT's can be used in place of any less productive woody species already present. But it is just as well to remember that as one gets closer to the potential biomass production limit economic gain gets harder and harder to achieve, sometimes starting well below it. The possibilities of improving the harvest index of MPTs is a less practical reality because we are dealing with multipurpose plants and, hence, the outputs may often represent the results of competing sinks.

These comments are relevant when considering a choice of MPT density because, despite the large accumlation of published information and practical experience in developing the theory and testing of plant density/yield relationship

TABLE 4: Rough ranges of net biomass production for different ecozones and expected ranges of plant dry matter ratios.

		Semi-arid	Seasonally-arid	Highland tropics	Lowland wet tropics
A. Likely net biomass production ($t\ ha^{-1}\ yr^{-1}$)		5 to 15	15 to 25	25 to 35	35 to 45
B. Expected range of plant dry matter ratios		Roots	Stem*	Leaves	Fruits
(% of total)	a) non-fruiting	15 to 30	25 to 40	20 to 35	Nil
	b) fruiting	11 to 22	16 to 30	15 to 26	up to 35

* of which 80% or so could be useable fuelwood.

For any ecozone and product likely values of (A) x (B) give an estimate of potential yields for MPT's that incomplete ground cover, poor management, pests and diseases, bad weather etc. will reduce. Bear in mind, also, the following "good" seasonal yields: maize (1.5 to 3.0 . ha^{-1}); cassava (15 to 20 . ha^{-1}); grain legumes (0.5 to 1.0 . ha^{-1}); sugar cane (40-60 . ha^{-1}, c. 10% is sugar); oranges (10-20 . ha^{-1}, fresh weight); cashew (1.0 to 1.5 . ha^{-1}); coffee (1.0 - 2.0 . ha^{-1}, seeds); tropical hardwood plantations (25-35 $m^3\ ha^{-1} yr^{-1}$; tropical pines (15-45$m^3\ ha^{-1}\ yr^{-1}$).

- See Elsevier, (1981), Evans (1982).

(see Cannell, 1983b; Huxley, 1983c) there is still an insufficient awareness of what to expect on the part of many concerned with planting MPTs.

(b) The curve for the plant density/yield relationships will normally be approximated by a reciprocal yield equation. That commonly used being:

$$\theta/\text{weight per plant} = (a+b\ (\text{plants}^{-ha}))$$

This can result in, basically, either an asympototic (for biomass) or a parabolic relationship (for plant parts).

There are a number of practical issuses relating to the choice of plant density with MPTs. The results of under-populating a unit of land with herbaceous crops that reach full structure during a single season, and that are grown for biomass, will be some loss of potential yield in average climatic years but no effective loss in below- or above-average climatic years (because in below-average years the attainment of the curve's plateau is shifted to a lower plant population). Similarly with herbabeous crops grown for a plant part (= a parabolic yield/plant density relationship)) there will be little or no loss when climate is below-average (as long as this is not severe), but there may be some loss in average or above-average years. As weather in sub-tropical and, especially, tropical regions, as distant from temperate ones, is marked by its disparity from the climatic mean, the difficult of not only establishing an "optimum" plant density, but of, regularly achieving optimum yields by adhering to it, are obvious.

Even if there were a normal frequency distribution of years in which the growing conditions (either generally, or for a particular crop) were optimal, or nearly so, as compared with those in which they were detrimental, most farmers in developing countries would be more concerned with avoiding crop failure than in optimising yield. They will fear the effects of a severe drought, when it is better to have plants relatively widely spaced, more than they covet the extra (say) 10% yield resulting from having a higher plant population in a slightly wetter year. The distribution of "wet" years is usually positively skewed, anyway.

With tree as compared with herbaceous crops the investment in planting is greater and the risk consideration therefore involves more serious consequences. Furthermore, the results of plant stress in stands that are too closely planted is, as with herbaceous crops, to increase the proportion of small ("dominated") plants. However, with woody perennials this effect is then maintained throughout the duration of the stand over several or many years, with adverse effects on both management and yield. Fortunately, trees do not reach their full structure in one season and the often-used practice of over-planting and sequential thinning allows an opportunity to remedy the effects of previous minor climatic disasters. Although this will not

be the case where a completely regular espacement is required, as in fruit orchards or in some agroforestry systmes (e.g. hedgerow or border plantings) where the intention is to maintain continuous lines of trees or shrubs.

2. Effects of plant density on the harvest of plant parts over time

With MPTs it is necessary always to consider the projection of the effects of plant density on yields over time. In Fig. 8 this is done for hypothetical situations relating to mean annual increment of woody biomass and merchantable timber from Cannell, 1983a) and for total biomass, fruits/seeds and leafy shoots or fodder (from Huxley, 1983c).

3. Rectangularity

Crop plants which have the same stature share available evironmental resources most equitably when they are evenly-spaced. In row-cropping this is represented by a rectangularity (the ratio of between-row to within-row spacing) of 1. However, large rectangularities are often used to facilitate management practices (e.g. drilling, interrow weeding, spraying etc.). With MPTs grown as crops in the tropics (as in fuelwood lots) there may be similar reasons for increasing the rectangularity above 1, and generally similar trends will obtain to those expected from herbaceous plants. (Fig. 9). But different MPT species have a different capacity for branching and, also, there will be different effects of increasing rectangularity on the yield of different plant parts. So that we need to explore more fully the consequences of rectangularity changes on MPTs, at least at a few experimental sites and on a selected range of different types of MPTs.

C. The effects of the removal of plant parts on sustained yields

The effective handling of trees demands a clear perception of the way various management treatments will affect dry matter distribution. In particular, with MPTs, how harvesting the various products will influence future growth and development in terms of total biomass production, plant allometry and the entrainment of subsequent growth and flowering sequences.

It is not possible to deal with this subject in any depth here. The background to factors affecting dry matter distribution has been discussed by Ledig (1983) and Cannell (1983a), the need to study entrainment sequences is noted and discussed briefly in Section IVC. From an understanding of what a particular management procedure does to the tree itself we can proceed to a consideration of the added effects of population density stress. (Section IIIB).

Fig. 10a-e present some hypothetical cases for:

a) the general growth and dry matter distribution pattern of a free-standing MPT (Fig. 10a);

b) similar plants subjected to different kinds of pruning (Figs. 10b,c and d) and

c) the MPT grown as a crop (Fig. 10e).

Other scenarios are clearly possible with other management treatments and/or the combined effects of density stress. The diagrams are intended only to stimulate a more detailed approach to the consideration of plant responses to management and to provide some rough , practical guidelines for these general non-specific cases.

IV. MULTIPURPOSE TREES IN MANAGED MIXTURES OF SPECIES

A. Space-time considerations

1. Dimensional opportunities

The term "Multipurpose Tree" is commonly used to describe woody perennials of several kinds and of varying plant habits and stature: for example large to small trees, shrubs and bushes, palms, woody vines (lianes) and bamboos. Thus the range of choice of natural dimensions and form available when chosing MPT species are much greater than one finds with agricultural plants, or industrial forest tree species. Further, MPTs can be, and often are, greatly modified by training and pruning.

(a) One group of agroforestry research workers is very much concerned with the study of the structure and dynamics of natural vegetation, and the transposition of the basic concepts learnt from such plant associations to the design and management of simulated "artificial" plant communities. In these MPT species provide specifically required outputs The first stage in this process is, indeed, just the partial replacement of existing vegetation by chosen MPTs to fit particular ecological niches.

A parallel approach is the detailed study of complex man-made systems that involve multistoried mixtures of many species, such as Indonesian Home and Forest Gardens (Michon, et al, 1983). This is done in order to learn more about how groups of plants, including MPTs, can be associated and managed even more efficiently. This type of work is now moving from the purely descriptive phase into experimental approaches (e.g. Olderman, 1983).

(b) A characteristic of the process of improving or designing agroforestry systems (and especially of the more complex ones) is a requirement to understand sufficient about how the

associated plants can best share the available environmental resources in order to optimize their growth and development as individual species in a way that provides the correct proportions of different outputs needed from the system as a whole. Such problems have been addressed by those concerned with intercropping herbaceous, low-statured agricultural species in recent years with some success, but with intercropped land use systems that include MPTs there is a need both to extend and add to our approach. The spatial dimensions are greater, the time duration over which the system produces is markedly longer (from one harvest to many sequential harvests of different kinds), and the product outputs are more numerous.

The more "permanent" nature of the MPT in such a system has a range of biological, economic and managemental implications, one set of which are related to the time at which events occur. In particular, there is a need to understand the phenological behaviour of the woody species and to chose those kinds of MPTs that can best match with the resource requirements of the lower-storey plants; or can easily be entrained to do so by appropriate management practices (pruning or lopping at different times). This implies that we must have detailed information on the phenophases in relation to climatic change for the MPT species in its indigenous location; we must include phenological studies in all trials of species (or provenances) introduced into other locations (or ecozones); and we should if needed, assess the extent to which phenophases can be manipulated by management treatments. Of course, if the MPT is an introduced species we must check that its phenological behaviour in the new location is, itself, indicative of climatic suitability.

These aspects have already been discussed more fully elsewhere (Huxley, 1983a) but it is worth re-emphasizing that successful association in plant mixtures will depend very much on the stature, form and phenological behaviour of the MPT species. In general, we have at present far too little information about the phenology of most MPT species, but tropical woody species as a whole are characterized by a considerable diversity of phenological behaviour that can, undoubtedly, be used to great practical advantage.

2. The tree-crop interface

Combinations of MPTs with other plant species must optimise the sharing of environment resources to the best advantage of the mixture but, in practice, what can be done to discover how best to do this? With complex systems at least a first approximation of choice of plant association can be made on the basis of considering all available pairs of combinations and examining the mutual interactions at their interfaces, (Fig. 11).

With MPTs even a "simple" one tree/one crop association requires a large experimental area in order to test the range of management variables likely to be of interest. And this, again, can be approached most cost-effectively by examining

what happens at the interface (Huxley, 1983d). This can have considerable implications in simplifying the design of field experiments, and this is discussed more fully in the appendix.

B. Choice of 'Optimum' Populations and Degrees of Intimacy

1. Choice of plant density and intimacy in MPT-crop mixtures

The choice of plant density for MPTs in crop mixtures, apart from other considerations noted in Sections III B, must involve decisions on how they are to be managed. That is, whether they are to be pruned or lopped in some way, and when. The level of intimacy of the mixture can then be controlled, as needed, by manipulating plant density, plant arrangement (i.e. whether species are arranged in some kind of mixture, or zonally, so as maximize or minimize tree/crop interfaces), by sequential thinning and by pruning. And such forms of pruning are much more akin to those used by fruit tree or tree cash crop specialists then foresters (see Section III C).

Because we are concerned with the level of outputs from the whole mixture of species, any pruning regime must take into consideration not only what may be best for MPTs but what the environmental resource requirements for the understorey crops will be, and what pruning the MPT in different ways and/or at different times will do to satisfying these. That is, what do we need to know about how to prune the MPT so as to maximize the tree outputs required without detriment to its long-term multi-yield capacity, and how do we estimate the environmental resource needs of the other species in the mixture. For example, are periods of water stress to be avoided? How should we partition the light between upper - and lower-storey plants. What nutrient limitations might occur and how can we best dealy their onset? and so on. These are not easy questions to answer separately, let alone resolve in terms of complete system's behaviour.

The understanding and design of such systems requires considerable scientific background and an aptitude for systems thinking. Their practical management similarly demands considerable aptitude and an ability to perceive future events before they occur. Unless such practical skills are inherently available, or can be easily taught, there is every reason to compromise in proposing agroforestry systems that involve mixtures with MPTs, so that simplicity of management is not sacrificed in order to maximize the efficiency of the system.

2. Rectangularity

The effects of increasing rectangularity was briefly described in Section IIIB. There is now a growing interest in hedgerow intercropping ("Alley croppings") as a feasible way of introducing MPTs into tropical mixed cropping situations. There are various reasons for doing this which needs to be briefly explained as they effect whether or not we are concerned with rectangularity ratios in which the MPT hedgerows can still be considered as close enough to interact in some way with one another, or not.

In most hedgerow-type situations the MPTs will be maintained at a low height by some form of pruning/pollarding, which may or may not be accompanied by side-pruning. This is done both to limit the aggressivity of the trees in the hedgerow as well as being a consequence of the need to take harvests of leafy shoots, woody mulch materials and/or fuelwood. If the hedgerows are being grown for other purposes (fruits/seeds, plant exudates, nectar sources etc.) then the pruning procedures will be different.

We may be dealing with hedgerow intercropping in wet tropical regions, where it is already becoming well-established or in semi-arid areas, where there is still a need for further investigations. In the latter case, high rectangularity ratios might be a necessity due to the need to obviate competition for the most limiting environmental factor, i.e. available soil water, although this can be achieved by coppicing at the start of, or during, the growing season, although only with fairly drastic consequences on the yield of vegetative materials from the hedgerow.

Where a hedgerow is being grown in order to provide woody mulch with a view to improving the sustainability of the land use system, or because of soil and water conservation requirements, then the rectangularity choice may not entirely depend on attempts to optimize yields (of both the hedgerows and the inter-hedgerow crop plants).

Bearing these points in mind we can limit ourselves here to discuss breifly the underlying principles of adjusting rectangularity in hedgerow intercropping to those ecozones where water is not particularly limiting. In such situations manipulating the rectangularity is the key to successful intercropping of MPTs and agricultural crops. The first step is to consider the choice of MPT plant population per unit area in relation to environmental resources (Section IIIB) and to re-estimate any effects that may predictable from the management (pruning, lopping, coppicing, pollarding etc.) that is intended (Section IIIC). If the latter is not possible there is no alternative but to find out through appropriate experimentation (see Appendix). Consideration of the factors influencing the decision about rectangularity that are mentioned below will also mean that the effects of shading from the hedgerow have be taken into account, and hence orientation, and thus the height at which the hedgerow is to be maintained when mature is important.

Fig. 12 shows what effects changes of between-row spacing will have on an initially chosen plant density (at rectangularity 1) assuming that no adjustment to compensate for in-row spacing is made. In fact rectangularities greater than about 6 have little subsequent effect on plant population per unit area. Depending on the original plant population chosen, and the basic in-row spacing for this at rectangularity 1, also on the maintenance height of the hedgerow, relatively little interaction between hedgerows is to be expected at such rectangularities, anyway.

In some circumstances in the wet tropics, such as on hill slopes where hedgerow intercropping is inteded to raise soil fertility through the provision of nitrogen-rich mulch, and/or for soil and water conservation, rectangularities of lower than 6 will often be of interest. In these circumstances the next step is to consider how, as rectangularities, change we may adjust the basic in-row spacing so as to re-establish the plant density optimum. The way to approach this is shown in Fig.13.

A factor that limits the choice of very close in-row spacings is the need to consider the effects of plant competition in the row during times of drought, especially during early stages after planting out, when close in-row spacings can be highly detrimental.

3. Orientation

With MPT strips or hedgerows orientation has to be considered, even in the tropics. Fig. 14 shows the results of using a model of light interception* (Jackson, 1983) for a site in Malaysia (3°N, ° E) to establish the distribution of diffuse and direct incoming short wave solar radiation (expressed as a percentage to full daylight) at ground level in 50 metre-wide strips of cropland alternately situated between 50 metre-wide strips of fuelwood trees (taken in this case as a solid object allowing no light diffusion. The model can allow for both different orientations and strip (or hedgerow) dimensions, including height, as well as different latitudes. Although originally produced for hedgerow fruit tree crops this and similar computer models (as well as later approach using a light panel and a physical simulation measuring model with selenium cells) are likely to be extremely useful for agro-forestry research and design.

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* I am grateful to J.E. Jackson for producing these results.

C. Management in Tree-crop Mixtures

Unlike scientists, who are usually trying to contain variability so as to be able to comprehed the complexities of systems containing biological entities, a tropical peasant farmer is out to exploit the heterogeneity inherent in his land use system in both space and time (Huxley, 1982). The opportunities to do this in agroforestry are even greater than in less complex systems and in relation to the choice and management of MPTs for such systems, in must necessarily demand a good appreciation of exactly what the environmental opportunities will be, and a clear understanding of how best to fill them.

For example, attributes of trees that enhance thier "site capture" ability such as an appropriate growth form in relation to that of associated species, rapid early growth even under shaded conditions, efficient light-interception features, high wateruse efficiency, and so on, will not necessarily make them the best choice for mixtures with low-storey agricultural crops. Indeed, there will not be a complete set of attributes that can commonly be seen as "desirable" for all MPTs, because their place in any one kind of agroforestry land use system may not be the same as in another, and the possibilities for managing them in different ways is very large. This can not be dealt with in any depth here and only two subjects will be briefly disucssed: the need to understand and manipulate the system to obviate plant stresses, and the possibilities for entraining a desired sequence of growth and development in the MPT's.

1. Manipulating plant stress

(a) Connor (1983a) has considered the ways in which different stresses will occur between the woody and herbaceous components in agroforestry systems. He describes the characteristics of the "resource pools" (light, water, nutrients) and emphasizes the predictable differences with which sub-optimal levels occur and can be replenished. An understanding of this is essential for the good management of MPTs in mixtures.

Conner reminds us that, with light preferential access relies on canopy display in which stature is the most advantageous attributes differential response can be quantified in terms of the leaf photosynthesis/light response functions of different species. For water and nutrients in the soil preferential access depends on relative root profiles, with differential responses depending on efficiencies of extraction per unit of rooting volume. In fact, with relatively immobile nutrients, such as P, access depends less on root efficiency and more on continuing root growth into non-depleted soil volumes. Complementary uses of resources is the key to successful co-habitation of a site and the reader is referred to Connor's paper for more detailed discussion and examples.

(b) Agroforestry systems are supposedly more sustainably productive than many purely agricultural land use systems found in the tropics. If they are so then it is because they are better able to share the available environmental resources, or that they are less "leaky" with regard to some, or all, of the resources pools, or both. The hard evidence in terms of experimental data in the form of light interception measurements, leaf area indices, light intensity/photosynthetic response curves, water use efficiencies, details of root volumes and water and nutrient extraction rates, nutrient growth responses, the differential effects of environmental stresses on associated plant species, and even a summary of biomass production, is either unavailable or, at least, anecdotal for agroforestry systems. This is largely because these are, in the main, both subsistence-oriented and complex, so that they have neither attracted the experimental resources nor been seen to be so easy to study as sole food or cash crop species such as rice, maize, grain legumes, fodder crops, coffee, tea, etc.

Without a deeper appreciation of the plant environment reponses it is not going to be easy to be able to predict how best to associate and manage species so that they will share environmental resource pools in both space and time in a way that minimizes the onset of stresses. We need answers to some apparently difficult questions such as "How do we want to portion out the incoming photosynthetically active radiation?". What are the relative water use requirements of the various plant components?". "How should we best try, spatially, to distribute existing nutrients in the biomass (litter, mulch materials or, if used, fertilizer inputs?"). And so on.

The answers to such questions are likely to demand a complex series of investigations for any particular agroforestry system if anything more than crude estimates are wanted. It may well be that approximations will have to suffice, and combination of a pragmatic "trial-and-error" approach, combined with existing conceptual eco-physiological "models" will take us a long way (Loomis and Whitmann 1983; Connor, 1983b). Certainly, for some time to come, and because we do not have nearly sufficient research resources available, we may have to test, under representative site conditions, the practical outcome of associating groups of agroforestry species (or provenances/cultivars) without fully understanding the ways they are interacting.

3. Entrainment

Woody perennials must proceed through a cyclic series of phenophases. The later steps of these are, as with seasonal herbaceous plants, consequent upon the completion of earlier ones and the time of commencement of each subsequent cycle can be influenced by both exogenous and endogenous controls (e.g. the state of the leaf canopy, Huxley and van Eck, 1974).

The sequences of growth and development that normally occur under natural conditions can vary very greatly among tropical woody perennial species. Within this wide range of plant

behaviour further variability can occur due to weather variations about the climatic norm. Even individual trees can be affected by site conditions and, not the least, by man-managed influences such as pruning, irrigation and fertilization, or by other biotic influecnes such as pest and disease attacks (causing defoliation, fruit drop etc.), and by browsing animals. Any or all of these can promote or retard plant grwoth and/or development processes. And, as these are sequentially linked any one of them may be set in train as a doninat plant activity.

Figs. 15 and 16 give some examples of the way certain management practices have been shown to influence normal patterns of growth and development. In order to optimise both the design and management of MPTs in agroforestry it is necessary to know both the natural sequence and the expected time of onset and duration of individual phenophases, as well as what opportunities there are to manipulate these by approparate management practices.

V. RESEARCH PRIORITIES

There are many, hut perhaps the most urgent that arise from the aspects considered here can be summarized as follows:

- Simple description of the location of buds of different kinds and a account of what growth and/or flowering potentials they possess
- Some information about the effects of fruiting on vegetative growth.
- Dry matter distribution.
- Experimental evidence to ascertain the relationship between morphological characteristics and functional performance so as to aid selection processes (e.g. "leafiness" of the fruiting traits and fruit yield).
- A knowledge of the range of adaption possessed by species and provenances of MPTs. For the mor important of these some understanding of the mechanisms underlying adaptive responses.
- MPT breeding strategies (actual schemes for individual species), including the establishment of objective selection index procedures and GxE assessments (mathematical or non-mathematical?).
- Data on the capacity of individual MPT species to enrich the microsite (and under what particular circumstances).

- Testing the prediction model of the effects of tree-crop mixtures on soil change; and plant productivity.

- Descriptions of the flowering characteristics of MPT species (flowering on new wood, old wood, short-shoots etc.?) - Additional information on flower initiation times for important species.

- Responses to pruning/lopping/browsing at different times and intensities.

- Simple source-sink investigations of the free-standing plant in order to look into the interactions between vegetative growth and flowering/fruiting.

- Practical trials to optimize pruning practices.

- The effects of changing plant density and plant rectangularity on growth and yield of desired parts.

- Modifications to "normal" source-sink relations brought about by pruning and/or spacing.

- Studies on the "tree-crop" interface in order to discover about resource-sharing, plant stress effects, and so as to regulate the "intimacy" of mixtures. Also to help with the design and management of agroforestry systems.

- Experiments on MPT's in hedgerows (including orientation aspects).

- Simple studies on the phenology of MPT species both (a) grown untouched (in different ecozones) and (b) after management by, say, pruning including observations on "entrainment".

Some of the research areas relating to managemental aspects will be, as yet, inappropriate for some species of MPTs where so little is known that simple species/provenances elimination trials may be appropriate.

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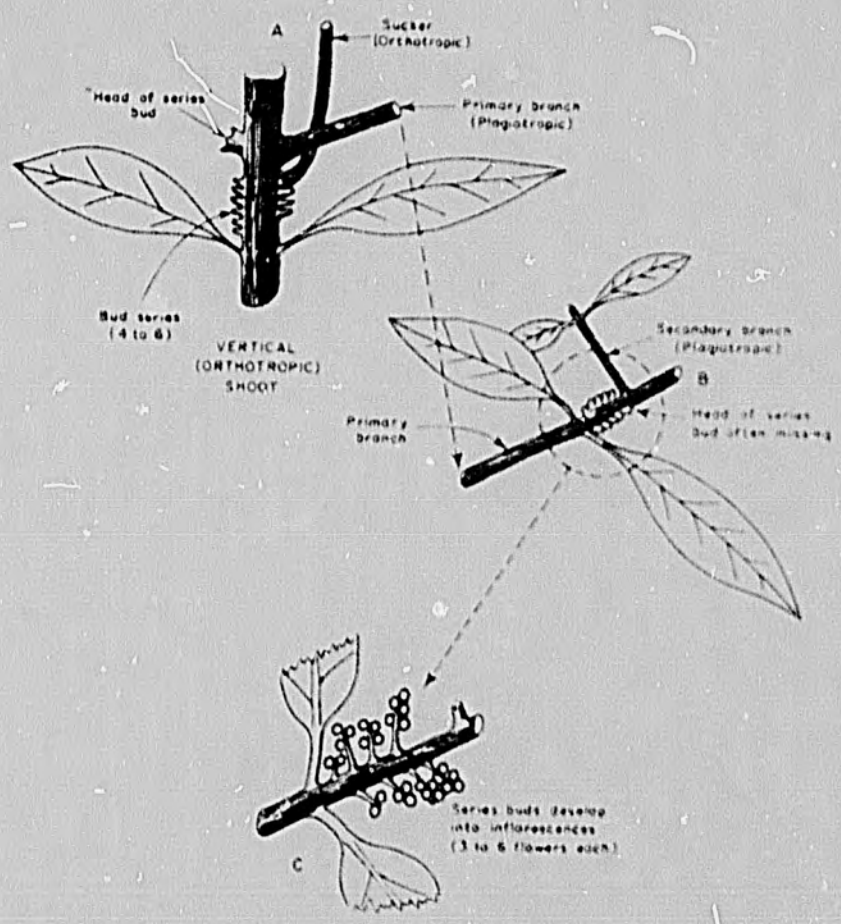


Fig. 1: The bud series that occur in the axils of leaves of Coffea spp. (from Van den Meulen, 1939).
Similar studies were required for MPT species of the bud morphology in relation to brancing, pruning response etc.

Fig. 2: Different examples of "leafiness" of the inflorescence in relation to assimilate source-sink relationships of developing fruits (diagrammatic)

A. Shoot apex ends in inflorescence without leaves

B. Shoot apex vegetative, lateral inflorescences (single flowers) subtended by numerous leaves.

C. Single terminal flower, supplied by whole of leafy shoot below.

- (a),(b), (c) and all found in, for example, different genera in the Rosaceae.

D. Single flower arising from a lateral and supplied from leaves above and below a main shoot (after Monodora myristica, Annonaceae).

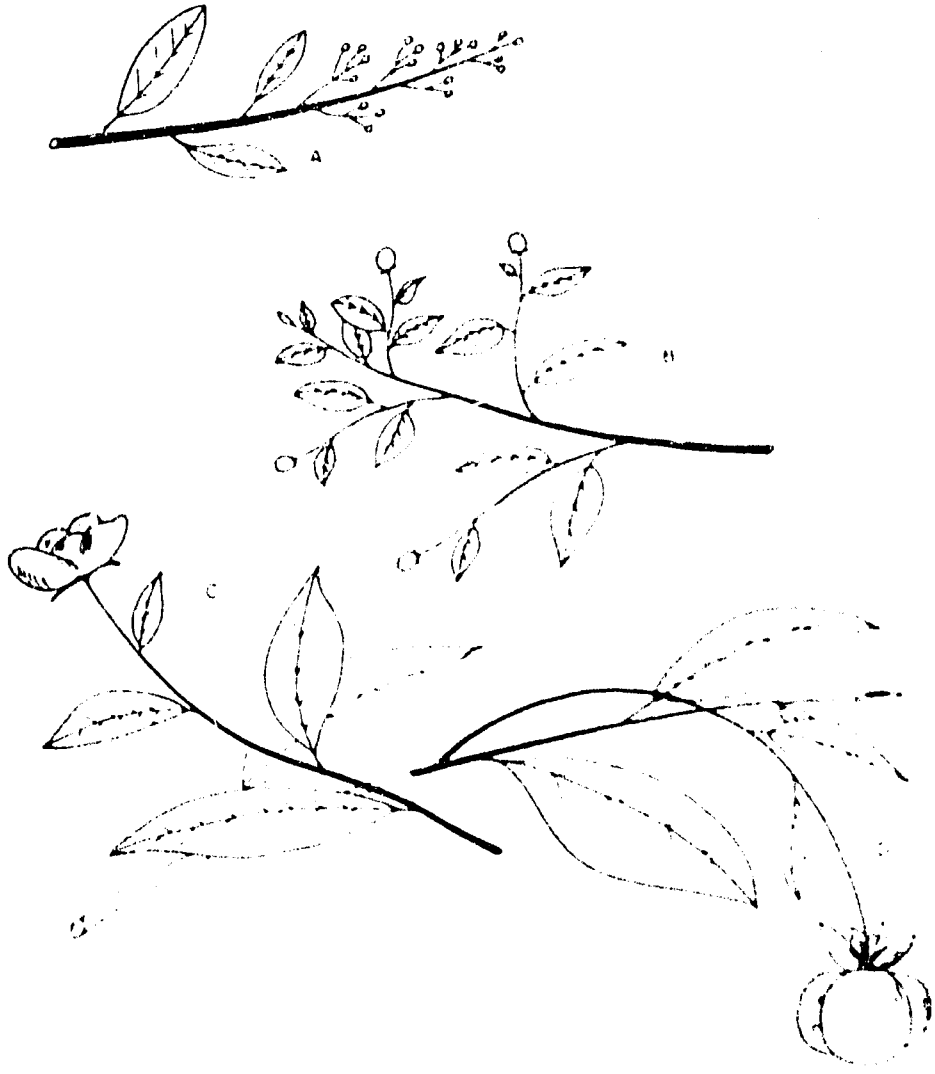


Fig. 2(cont'd):

E. Shoot apex vegetative, inflorescences many-flowered and lateral, each subtended by a single leaf only. (after Combretum tenuipetiolatum).

F. Single - or few - flowered lateral inflorescences on lateral shoots that, themselves, remain vegetative (cf. B) - after Grewia (Tiliaceae).

G. Inflorescences borne on "short-shoots" among leaves (after Terminalia (Combretaceae)

H. Inflorescence borne alone on "short-shoots" leaves borne on other short shoots. (after some species in Anacardaceae, Burseraceae).

E
F
G
H

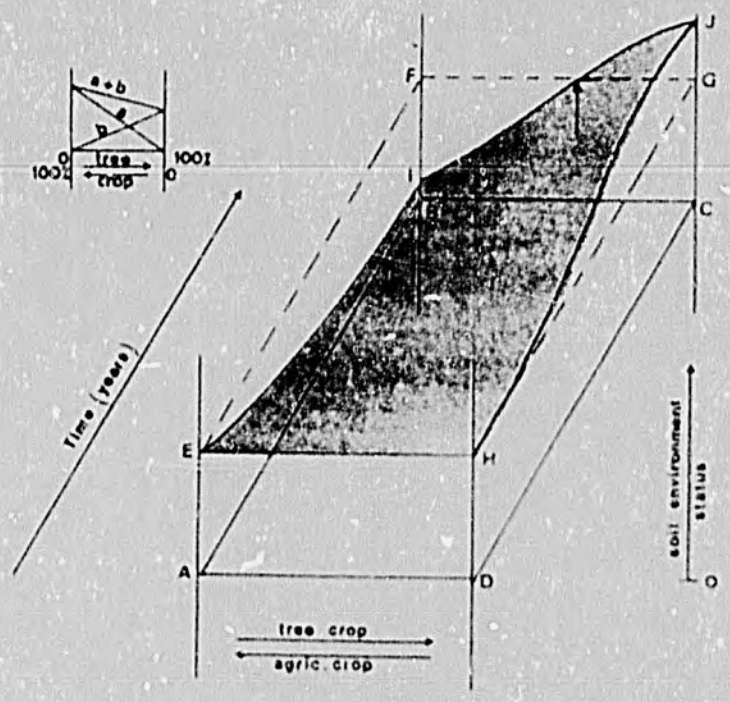


Fig. 3: Response surface showing the hypothetical effects of a tree-crop mixture on soil status with time.

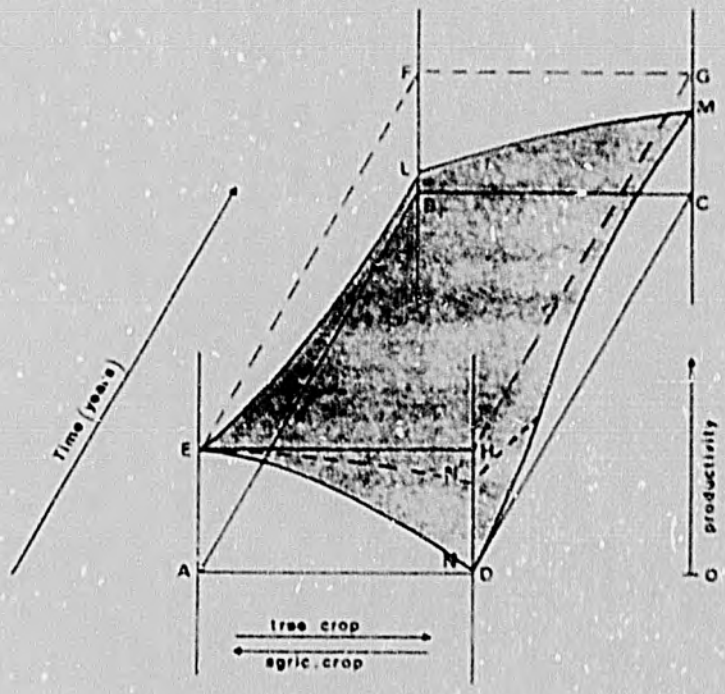


Fig. 4: As for Fig. 3 but showing plant production trends.

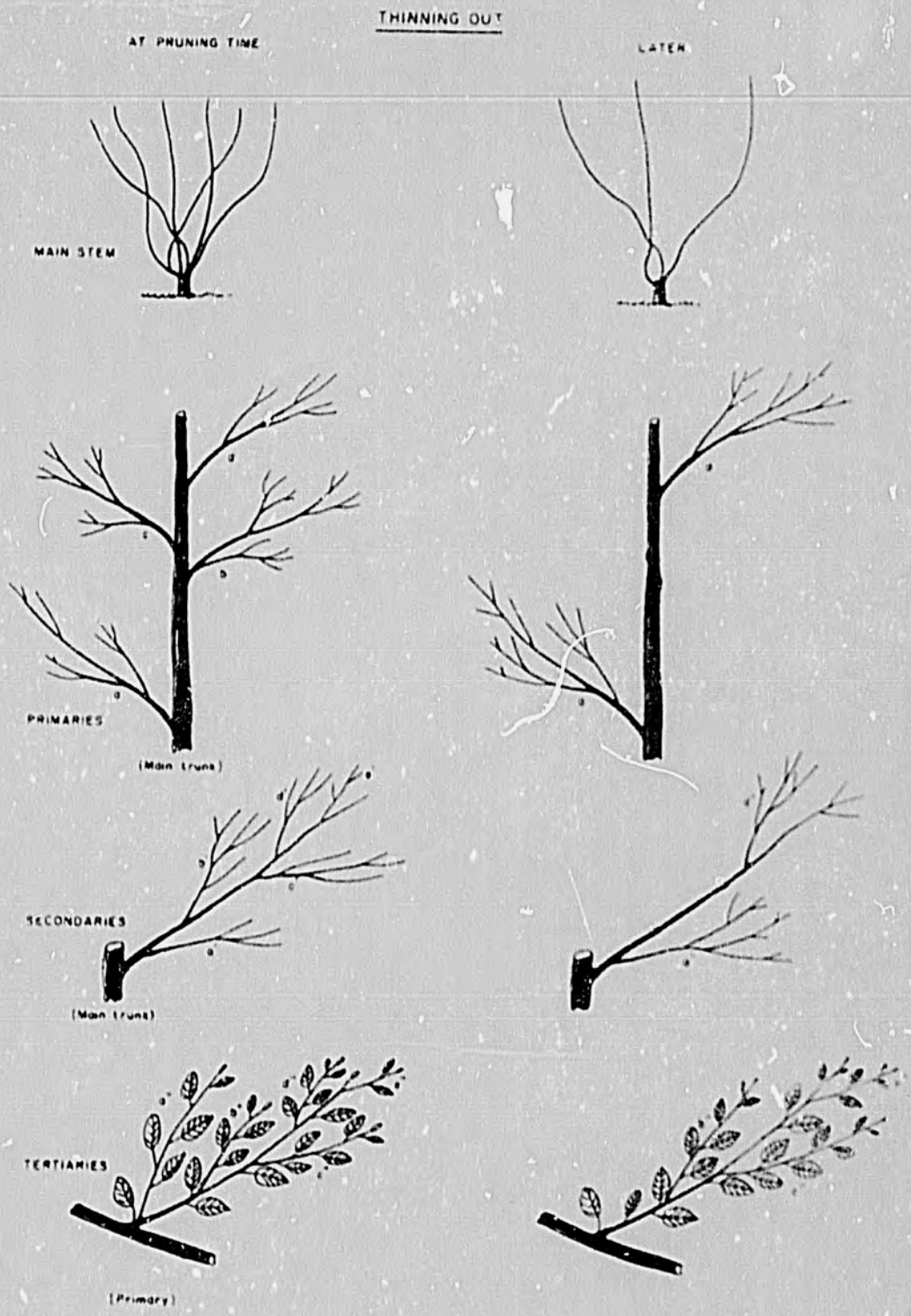


Fig. 5: "Thinning out" as a pruning practice - see text for explanation.

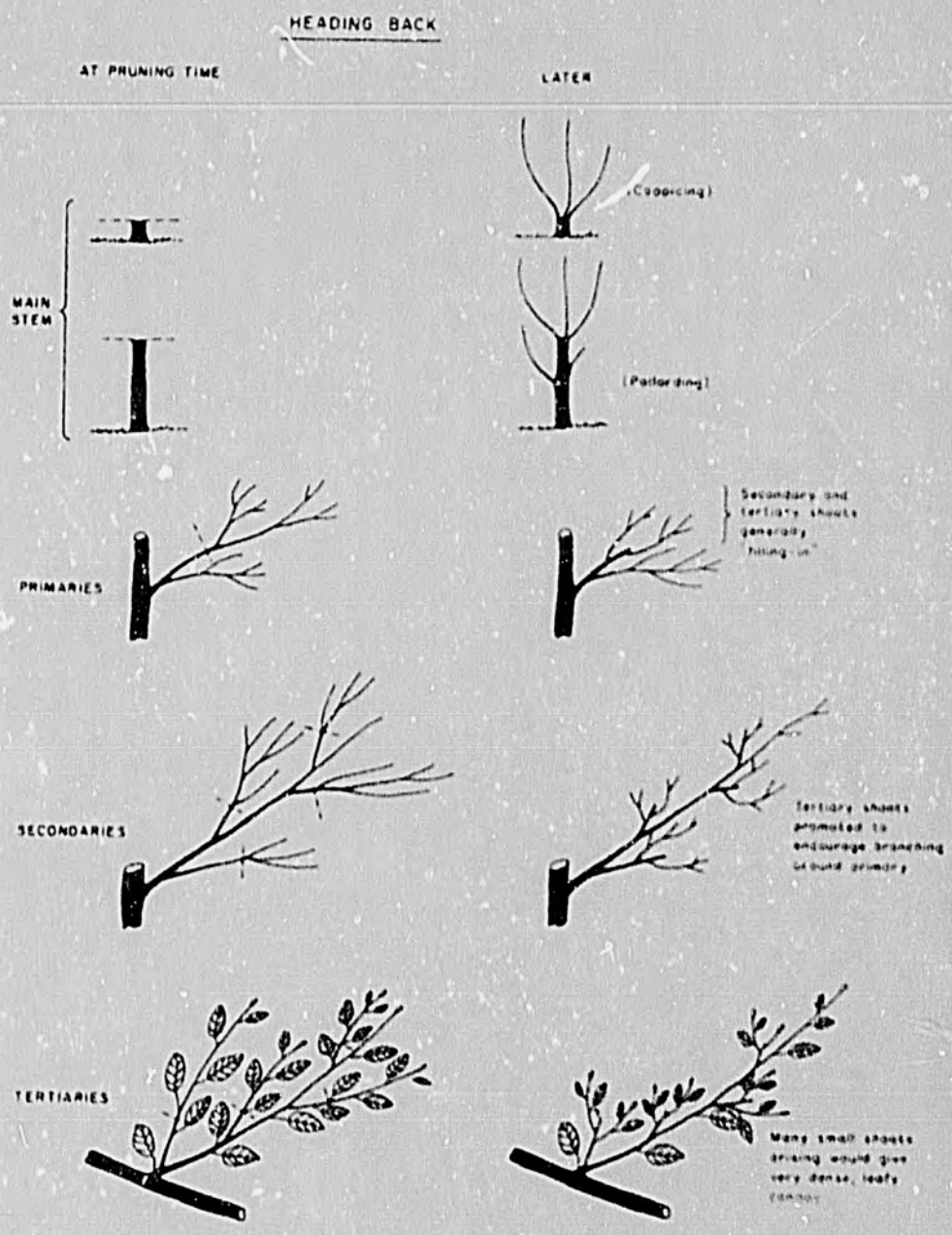


Fig. 6: "Heading-back" as a pruning practice - see text for explantion.

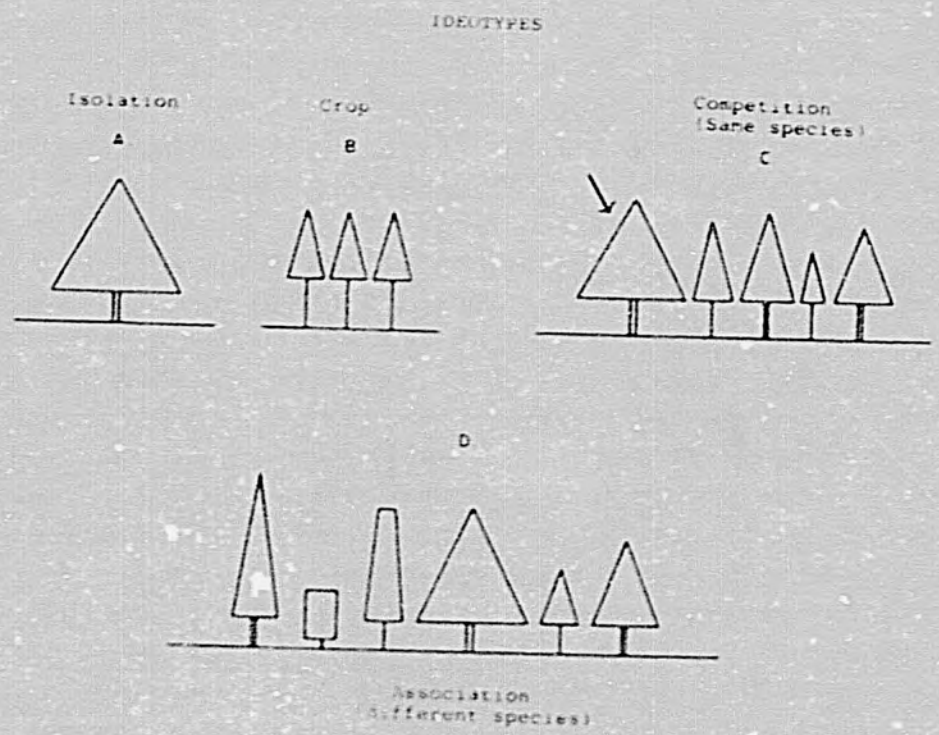


Fig. 7: Different kinds of ideotypes. For agroforestry landuse systems a range of selections fitting particular sets of specifications are needed, and these may have to be grown in the natural habits and/or under some form of tree management.

(a and b) Effects of planting density on the mean annual increment (MAI) of trees grown for woody biomass (a) (branches and stems of any diameter) and merchantable timber (b) stems above a given diameter). Note that there is an optimum density for woody biomass as well as timber production, and that thinning will move the population in the direction A to F. Remember that closely spaced trees will be small in diameter, but not necessarily height, and that, in unthinned stands, the number of trees at harvest will be less than at planting owing to self-thinning. From Cannell, M.G.R. 1981. Plant population and yield of trees and herbaceous crops, pp. 489-502 in P.A. Huxley (Ed) "Plant Research and Agroforestry", ICRAF, Nairobi.

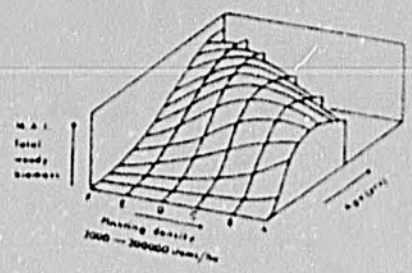
(c) Changes with time of total biomass accumulation per unit area of land for different plant densities of a woody perennial species. Eventually the net annual increment due to carbon fixation and mineral uptake will be exceeded by losses (parts shed, total respiration and this will happen sooner at high plant densities.

(d) Changes in annual fruit yield with time for a woody perennial species planted at different densities. Small amounts of fruit per plant can give substantial yields per unit area at very high plant populations early on, but increasing densities (and the development of pests and diseases) can make such unpruned stands rapidly unproductive. Mid-level populations will attain maximum yields per unit area later but possibly become unproductive less quickly. Low levels of plant population will give longer individual tree yields but too wide a spacing will limit yield per unit area (although it may make management easier). Pruning at any time will shift the response to the left.

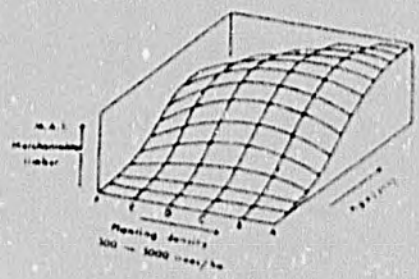
(e) Changes with age in the yield of leafy shoots in hedgerows with different within-row spacing. Assuming no over-browsing or excessive lopping and that hedge height is restricted to that achieved after 4-5 years. A decline in the numbers of active vegetative buds available may sometimes occur with some species (e.g. tea) after continued pruning of leafy shoots.

Fig. 8 (see opposite)

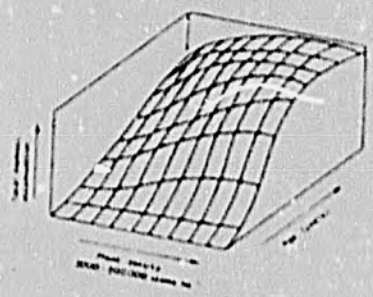
(a)



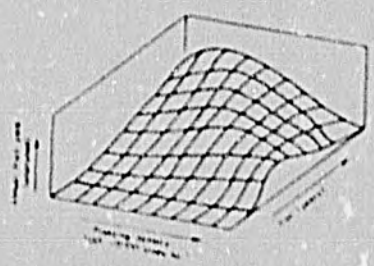
(b)



(c)



(d)



(e)

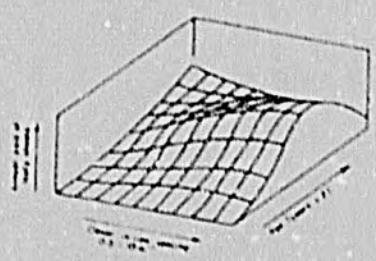


Fig. 8

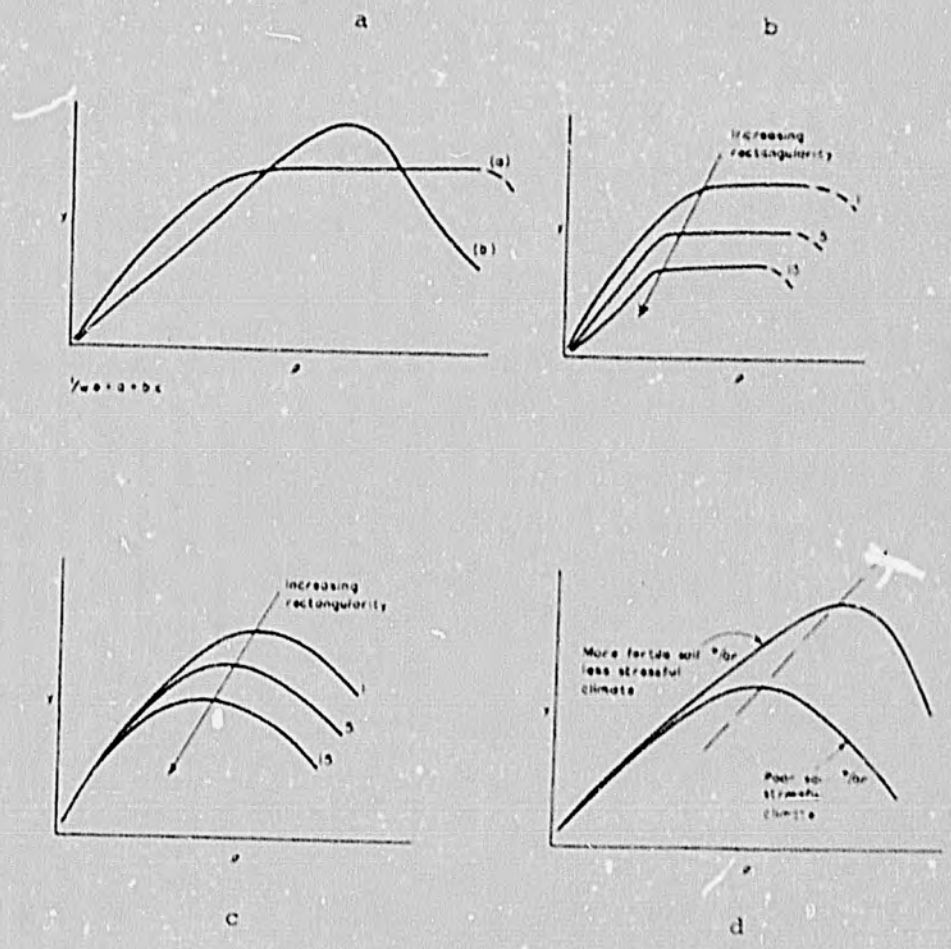


Fig. 9 (a) Basic yield per unit area (y) plant density (ρ) relationships
(b) (c) The effects of increasing rectangularity on an asymptotic and parabolic relationship, respectively.
(d) The general trend in a parabolic yield/density relationship brought about by changing soil fertility and climatic stress.

Fig. 10a: Hypothetical growth and dry matter distribution pattern over time (steps 1-6) of an untouched free-standing MPT. Left-distribution of total dry matter as percentages in various plant parts (R=roots, S=Stems, L=Leaves, F=Fruits) Right relative annual dry matter increment per unit of total biomass: (a) gross (b) net (i.e. less shed parts and respiratory load).

1	2	3	4	5	6
Seedling	Young tree (juvenile)	Early maturity	Maturity	Late maturity	Senescent
Initially fast root development - efficient photosynthetic system	development of branching structure - ageing pattern develops in canopy	re-allocation of dry matter due to fruiting and increase in photosynthetic rate (and respiration of fruits)	maximum allocation of dry matter to fruits at this stage - some shedding of plant parts starts	noticeable decline in rate of dry matter increase: stem cambium relatively large, fruit load declining due to tree structure ageing	inefficient canopy, parts being shed, little fruiting

FIG. 1[illegible] Hypothetical growth and dry matter distribution pattern over time of a free-standing MPT, stage 1-6 as in Figure 11

Not lopped, then left unpruned

1

Topping prevents fruiting allometry re-instated and dry matter allocated mainly to stems/leaves and little to roots. Total biomass small but plant efficient photosynthetically

4

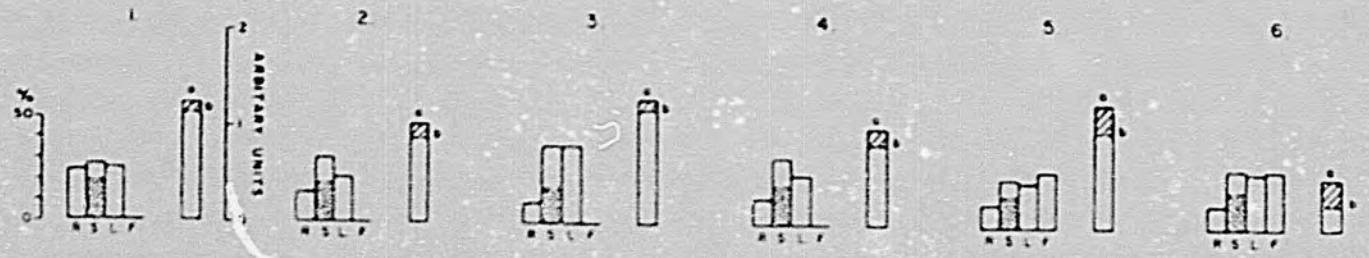
Onset of fruiting delayed (more so if plant fruits on old wood); ageing developing in new canopy structure, re-instatement of dry matter allocation to new roots has started, may be residual effects of diminished root system on growth vigour

5

Maximum fruiting capacity, this increases photosynthetic rates (more than increase in fruit respiration) so less dry matter available for roots, stems, leaves although normal allometric proportions maintained

6

Senescence delayed Stage 6 here would be similar to stage 5 in unlopped tree.



[illegible] pruned annually - by "heading back" or by regulated browsing

(Actual effects will depend on browsing intensity and time)

3

fruiting eliminated* total biomass increment reduced increased allocation to young stems and leaves at expense of trunk and roots.

4

fruiting can be controlled by pruning/ browsing (shown as eliminated here), continued attempts by plant to restore allometry by allocating more of dry matter increment to stems and leaves.

as before
- but main stem [illegible] time is increasing with time.

6

Annual biomass increment shown as declining with continued heavy annual pruning/browsing
- this could be adjusted with better management.

* assuming fruiting is not on old wood

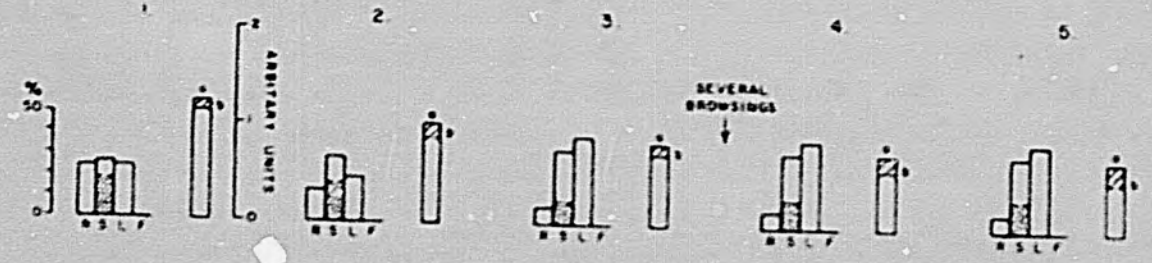


Fig. 16a. Pruned annually - by "thinning out".

1. Reduced total biomass increment, fr'ting load less than in untouched plant; greater proportion of dry matter increment to stems and leaves as plant restores basic allometry. Efficient canopy due to better light penetration gives greater dry matter increment per unit of initial total biomass.

4. Plant's photosynthetic efficiency is maintained by 'thinning out' annually*. Gradual build-up of older stem tissue occurs.

5. As before, and a regular supply of fruiting sites is maintained by renewal of new stems

6. Senescence delayed and fruiting maintained.

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* this would be even better if both "thinning out" and "heading back" occurred.

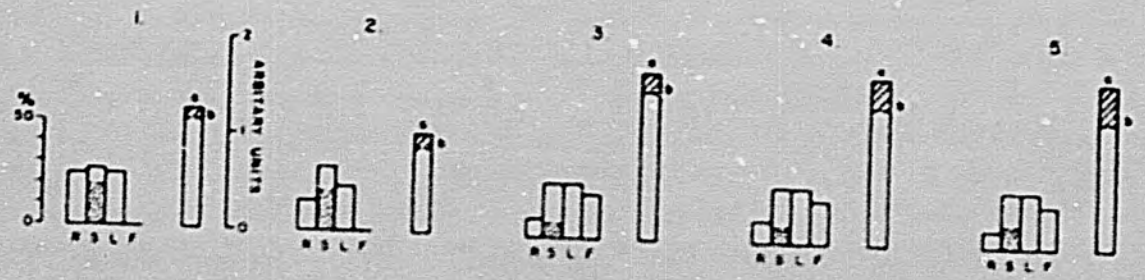


Fig. – Hypothetical growth and dry matter distribution patterns over time for a MPT grown as part of a crop with low thinning.

Thinned

1

Total plant biomass is less than free-standing plant at this age class. Density stress has reduced root growth, increased dry matter allocation to stems (especially trunk), reduced leaf growth and lowered fruiting potential for the individual plant.

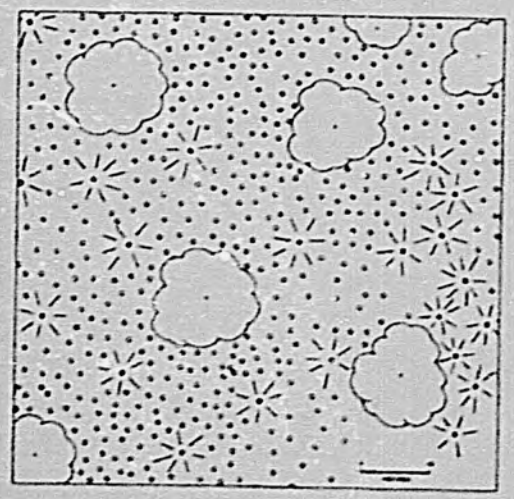
4

Opening crop canopy increases plant biomass production. Is less dry matter partitioned to stem tissue and slightly more to roots, leaves and fruits.

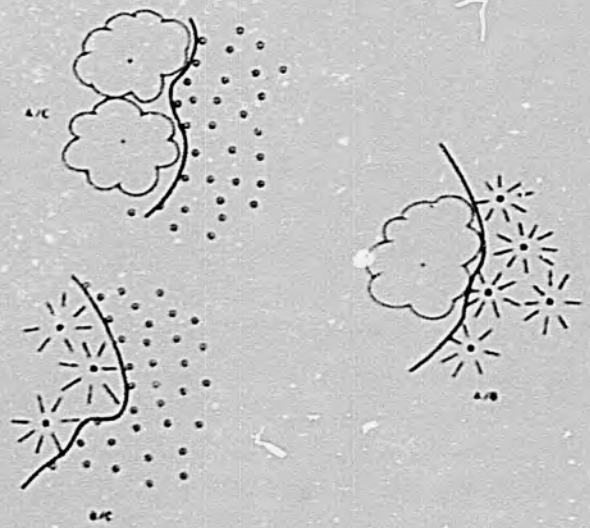
6

Canopy closure again individual annual plant biomass increment slightly decreased drymatter partitioning to stems again increased (particularly old stems perhaps also to fruits as more fruiting sites now available), less proportionally to roots and leaves.

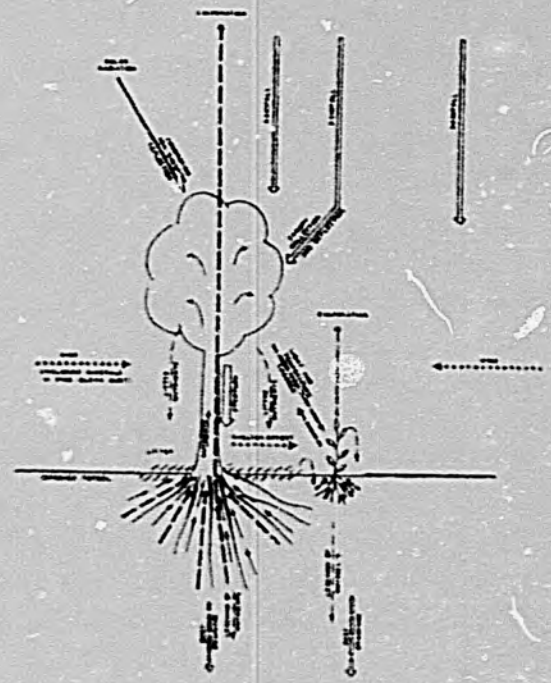
Reduction in total annual biomass increment with high level of respiration due to ageing and large amounts of stem tissue. Continued high proportion of available dry matter increment to stems (especially trunk), reduction in fruiting due to self-shading(by canopy permits a greater allocation to leaves (but density stress promotes only a short leaf life so is high turnover of leaf litter).



(a) Plan view of a [illegible] ecosystem. Varying distances are combined between tree [illegible] species and between any two components species in this relatively complex form of land use.



(b) The key to understanding the complex agroforestry system shown. The interfaces between pairs of component species. It may also be of interest to examine the sole crop interactions A/A, B/B and, certainly, C/C.



(c) Tree-crop interactions will result in, and be a consequence of changes in environmental resource pools, shelter effects etc.

Fig. 11: Tree-Crop Interface

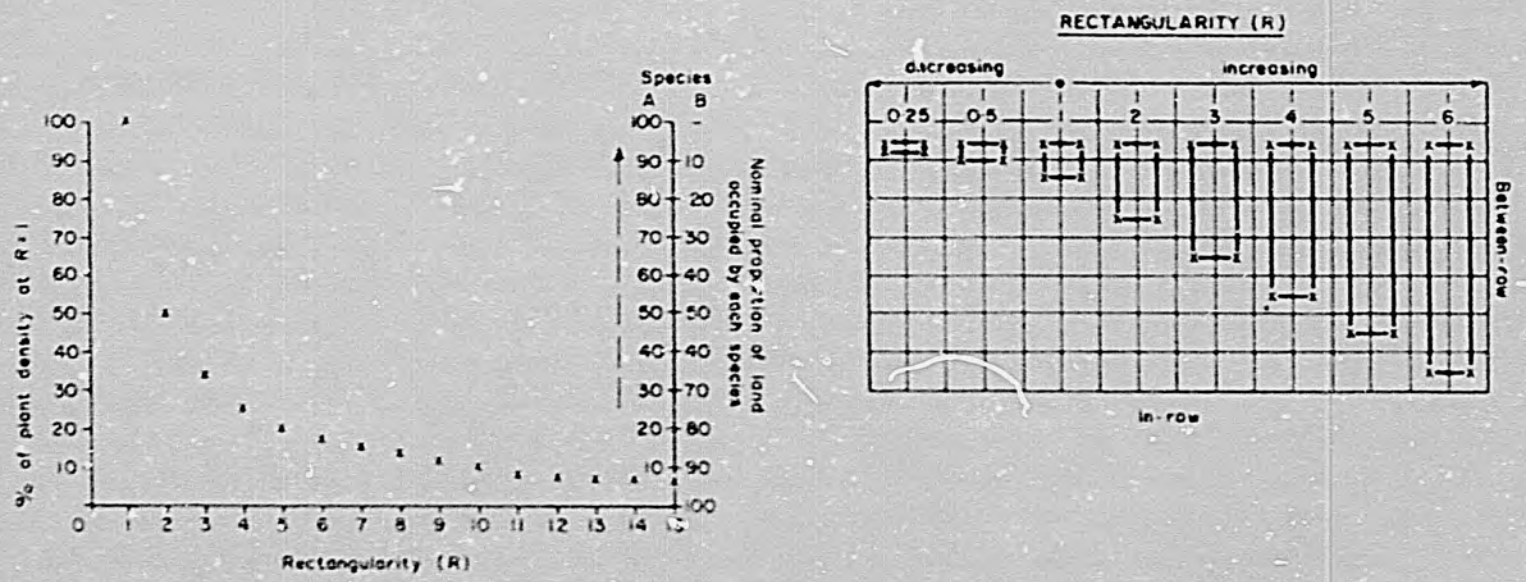
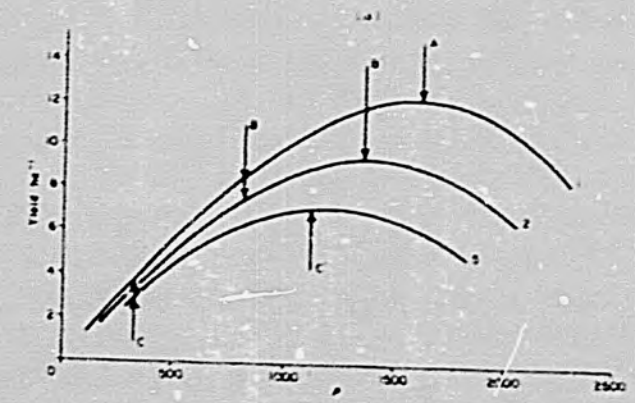


Fig. 12 Different rectangularities (right) and the way in which plant population per unit area changes with a change in rectangularity if the in-row spacing remains the same (left). Changes in the nominal allocated area (assuming the species A is a tree and it occupies all the land at its optimum plant density at rectangularity 1) are shown on the right-hand axis, but the actual area utilized by each species will be more in the direction of the dotted arrow as the tree matures and its canopy and roots spread to the between-row space. (From Huxley 1983c).



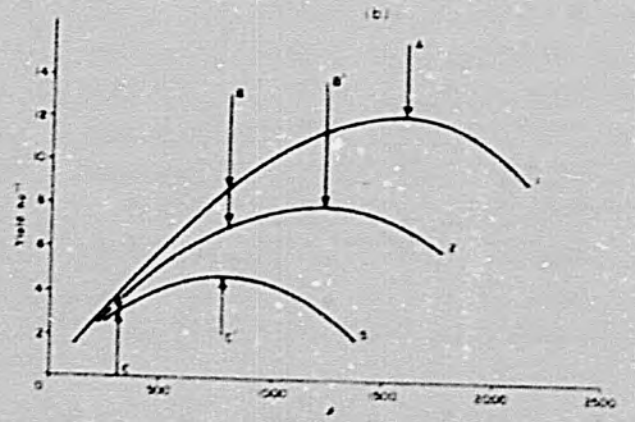
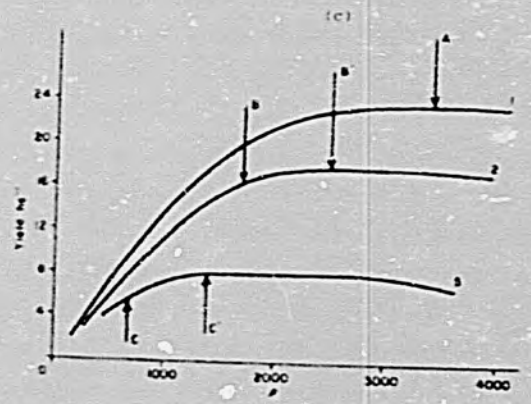


Fig.13. The sets of curves show some postulated yield responses to changes in plant density at different rectangularities (1, 2 and 5). In (a) the effects of increasing rectangularity are less than in (b) but, in both cases B and C indicate the yields obtainable when the plant population is reduced to a half or a fifth, respectively when the in-row spacing is just changed to compensate for the increase in rectangularity (continued over).



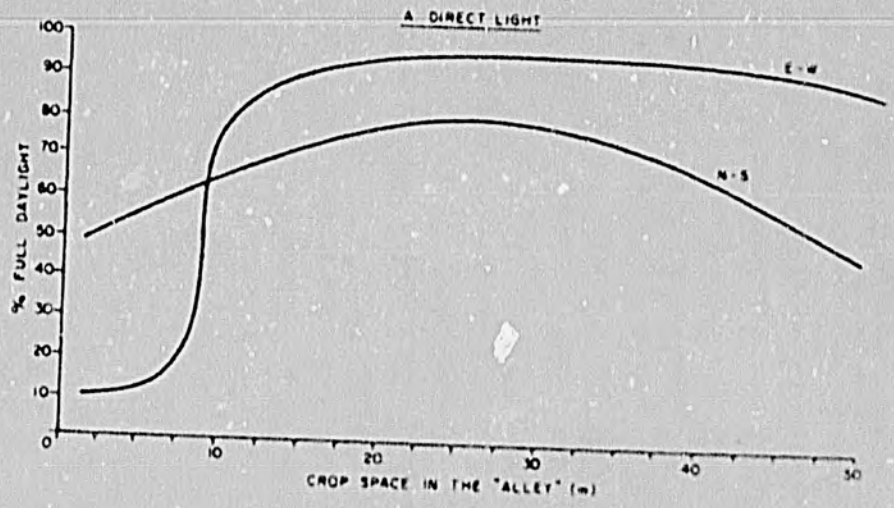
		Plant density	Rectangularity	Nominal area (%)	Revised optimum plant density	Estimated yield (t ha⁻¹)
						Plant pgm
1	A	600 (optimum)	1	100	-	12.2
	B	800	2	50	(B') 1350	9.6
	C	320	5	20	(C') 1100	7.1
2	A	1600 (optimum)	1	100	-	12.2
	B	800	2	50	(B') 1250	8.0
	C	320	5	20	(C') 875	4.75
3	A	3400 (optimum)	1	100	-	Biomass 24.0
	B	1700	2	50	(B') 2500	17.5
	C	680	5	20	(C') 1400	8.0

Fig.13 (continued)

B' and C' indicate on the appropriate curves what scope there is, in this hypothetical situation, for such compensation.

In (c) the same situation is demonstrated for an asymptotic (total biomass) response curve, with less opportunity for compensation in this case. Unless the relationships such as these shown here are known, the effects of manipulation of rectangularity and plant density can only be conjectured.

(From Huxley 1983c)



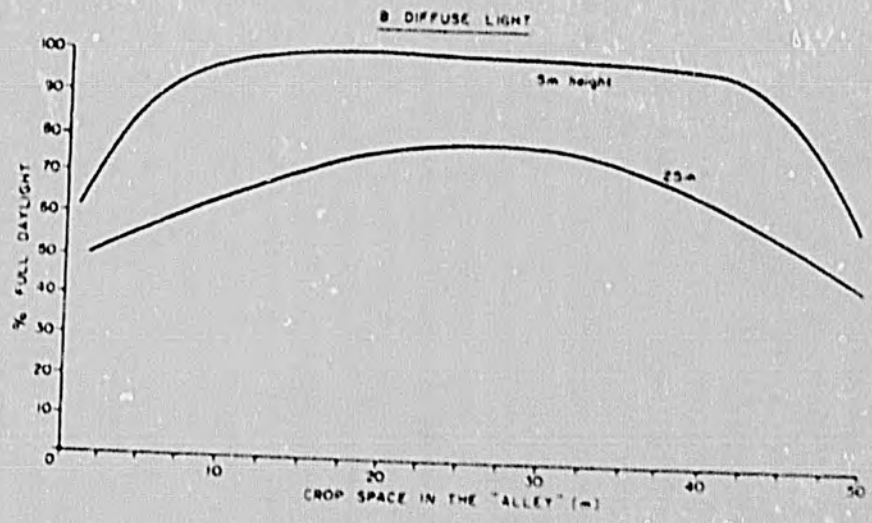


Fig. 14: Distribution of (A) direct light E-W and N-S orientations and (B) diffuse light for different tree heights (both as % full daylight) across 50m cropped "alley" between 50m-wide blocks of fuelwood trees (assumed to allow no canopy light diffusion). Part of the output of a computer model run by Dr. J.E. Jackson for a site in Malaysia (3°N) - see Jackson (1983), examples of the output only.

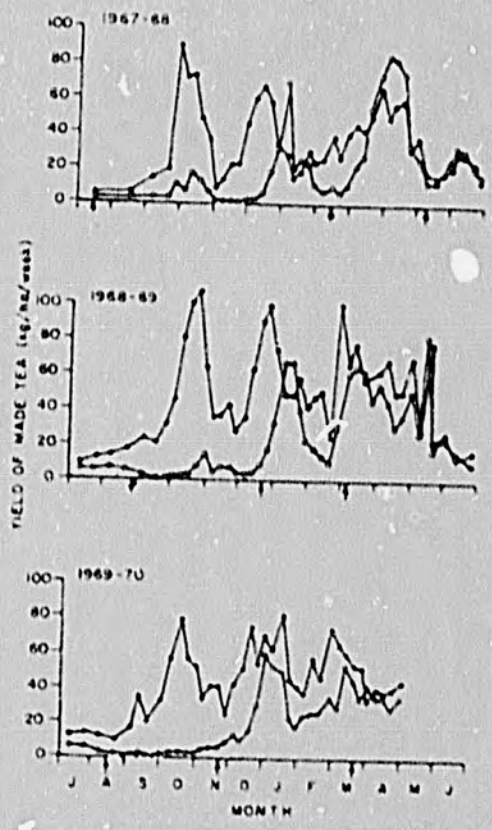


Fig. 15: Distribution of crop for tea grown frequently-irrigated (closed circles) and under natural rainfall (open circles) in Southern Tanzania. - re-drawn from Carr (1974)

Note the "entrainment" of cropping peaks in both treatments and the differences in crop levels due to irrigation. (Arrow indicates when fertilizers when applied. Dec.-April is the rainy season. See original paper for details).

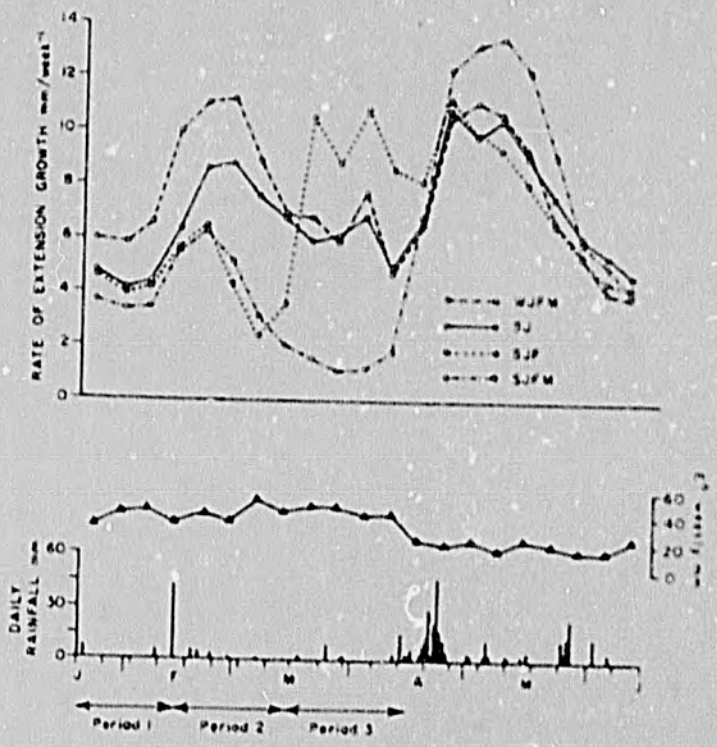


Fig. 16: Extension growth of shoots of Coffea arabica under different irrigation treatments, (re-drawn from Browning and Fisher, 1975). All these treatments had roots protected from rainfall but then (WJFM) was irrigated weekly:(SJ) no irrigation mid- Jan to mid-Feb, (SJF) similarly, mid Jan to mid-March; (SJFM), similarly, mid-Jan to mid-April, 1983.
Note the effect of treatment SJF (water withheld for two months) when subsequently irrigated. See original paper for details.

APPENDIX ON THE EVALUATION AND ASSESSMENT OF MULTIPURPOSE TREES

by

Peter A. Huxley

APPENDIX

THE EVALUATION AND ASSESSMENT OF MULTIPURPOSE TREES

The reader is referred to "A Manual of Methodology for the Exploration and Assessment of Multipurpose Trees" (Ed. P.A. Huxley; compiled by P.A. Huxley, J. Burley, P.J. Wood and P.J. Robinson) for a much fuller exposition. All that is intended here is to comment on a few aspects.

A. Evaluation of multipurpose trees as trees.

The types of field and/or laboratory experiments required to study the potentials of MPT species as trees can be drawn from, and are paralleled by, many decades of work on "conventional" timber, fruit and tree cash crop species For these there is an extensive amount of field work on species, provenances or cultivars which has also elicited supportive laboratory studies of product quality, relevant physiological and biochemical analysis, and microbiological investigations (e.g. for Rhizobia and mycorrhizas). All this is part of the "armoury" that exists to support an attack on our present ignorance about many MPT species.

When investigating MPT's as trees the main problem is not related to "what field layout will provide a suitable investigational structure" (these are unlikely to differ from those used for studying other kinds of trees), but rather "what kinds and levels of assessment are actually needed?" We must be stringently selective if procedures are to be feasible but still useful. Huxley and Burley (1984) have compiled an extensive checklist of characters that may be considered for assessment depending on the objectives of an experiment and the purpose for which any MPT is to be grown. Table 1 gives some suggestions for a minimum programme of assessment and some indications of how this might be enlarged when more precise research objectives become defined. Fig. 1 indicates some of the very simple kinds of measurements that can be made on branches so as to provide a considerable amount of information about the behaviour of the tree.

B. Trees as crops: trials of spacing and other management practices

1. Spacing trials

A knowledge of yield/plant density relationships obtained from experimentally derived data fitted by the receiprocal yield equation (θ/weight per plant = a+b (plant per hectare)

TABLE 1: Suggested minimum and useful additional assessments for MPT trials. Detailed management trials will require a greater range of assessment techniques than simple species/provenance trials, and experiments undertaken for specific purposes may have specific assessment conditions (see Huxley and Burley, 1984).

	PLANT	PHYSICAL ENVIRONMENT: CLIMATE	PHYSICAL ENVIRONMENT: SOIL
MINIMUM ESSENTIAL IN ALL CASES	Survival/Dimensional variability between specimens Then: Form Height Crown dimensions Branching (photographs) Dbh (and/or base diameter) Phenology Leaf fall Leaf flowering times Flowering time Fruit ripening	Rainfall (Weekly totalizing) Max/min temperatures (recording thermograph)	Prior to trials: Basic soil description and classification (Texture, colour, depth drainage PH. During trials: Liter Total OM in topsoil pH.
EXTREMELY USEFUL	Details of apical and axillary bud behaviour (phyllochron) Nodulation/fine root growth. Records of pests and diseases	Daily values of: Rainfall Evaporation (or estimate) Air humidity Max/Min. Temps. Wind-run (m) Calculate "Day-degrees" Eo & ET	N.P.K Mg,Ca, Na Organic C, CEC., base saturation rates. Bulk densities, Field capacity/wilting point and pF curve.
CAN BE USEFUL	Estimates of fruit/seed set (where fruits are used) Wood quality (timber) and/or calirific value (fuelwood). Analysis of leafy shoots (for fodder).	Incoming short-wave solar radiation.	Run-off plots or wash traps.

is a rational way to approach any decision about crop spacing. Although this must, of course, be conditioned also by other issues such as requirements for cultivations and harvesting, and so on. Differences in weather from the climatic norm during the test seasons will make an exact relationship difficult to uncover because the "optimum" plant density will vary according to the capacity of the environment to provide physical resources, as well as of a species to utilize these in the most effective crop arrangements.

The precision with which it is possible to assess yield/plant density relationships for any MPT species grown as a sole crop will be even less than that for many agricultural crops because of the expected genetic variability of most MPT germplasm. Most species of MPTs are highly heterozygous because they are outcropping, and it will be difficult to reconcile the influence of successive and different (often very different) seasons of the growth and yield of a woody perennial providing multiple harvests of different kinds and grown at different plant densities.

Nevertheless, an appraisal of the yield/plant density response for one particular experimental site is helpful even if it is not very precise, because it is possible to use it to predict at least the trends to be expected in other sites, depending on whether these are more or less environmentally stressful. (See Cannell, 1983b and Fig.9, main paper).

In theory (Willey and Heath, 1969) the yield/plant density relationship can be estimated from experiments that contain only 3 plant density levels. But because of the difficulties with MPTs mentioned above it is probably better to extend the range of plant densities under test to as to attempt to establish the relationship with at least as much precision as possible. Another reason why a suitably wide range of plant density levels is required is that the optimum spacing for the yield of one output is unlikely to be the same as that for another, and such differences may not be as clearly observed when only a few plant densities are tested.

To try to establish yield/plant density relationships using conventional plot layouts can be very wasteful of experimental resources. This is because of the relatively small fraction of such layouts that can reputably be used for collecting actual experimental data after adequate guard plants have been discarded (Fig. 2). Indeed, with the increase in scale that results from testing MPTs it is doubtful whether single guard rows are adequate anyway.

A now well-proven and cost-effective alternative experimental layout that handles the spacing variable very well is a systemqtic design, and more particularly for MPT species, the parellel row layout proposed by Bleusdale (1969) - see Fig. 3. Some of the problems with systematic designs have been listed (Huxley, 1983) but, with careful experimental management the advantages for systematic trials usually outweigh their disadvantages. And they provide excellent demonstrations. Systematic layouts can also serve to

establish the effects of differences in rectangularity whilst maintaining a constant or selected density (in log/log designs these two variables can be tested together).

2. Management trials

MPTs can be manipulated through pruning and bending but because these alter, considerably, the size and form of the plant, it is not possible to consider optimizing the output of different products without eventually dealing with spacing and pruning simultaneously. However, the response of the introduced tree at different plant densities and rectangularities, and the plant behavioural responses to, for example, pruning or lopping without any density stress, are the two points of departure from which to consider the variously-manipulated plant under different levels of density stress.

Experiments on MPT management need to be kept as simple as possible, starting with a study of the changes in response to natural growth and development of the introduced single plant before progressing to their behaviour when treated in the same ways, but grown as a crop. The steps to consider when undertaking a field investigation are listed and described in the Manual of Methodology for the Exploration and Assessment of MPTs (Huxley, 1984) from which Fig.4 is taken.

D. The assessment of tree-crop mixtures

1. General concepts - inadequacies for studies with MPTs

(a) Early work on species mixtures and competition/interference were carried out with replacement series experiments where a stated total plant population was manipulated so as to give varying proportions of each component species. In practice, in intercropping, the populations of both sole crops and the mixture can be varied and the expected and actual yields of any mixture density (for any proportions of crop mix and levels of intimacy) can be compared with any relevant sole crop densities (usually the optimum for that site).

Where species yield differently the comined yield of mixtures is highly dependent on the proportions of the different species used. Nowadays, when making comparisons bwtween mixtures containing different species mixed in various proportions this evaluation problem can be approached by comparing the separate yields of the two intercrops and their combined yield, in terms of the relative land areas under sole crops, (at a stated plant density) that are required to produce the yield achieved in intercropping, the "Land Equivalent Ratio" (LER). These are equivalent to "Relative Yields" and the "Relative Yield Totals" of earlier workers. The LER is always less than or greater than 1.0 with mutual inhibition, and mutual co-operation, respectively. And it

can be either when one species dominates the other but some level of compensation is apparent.

Thus:

$$LER = L_a + L_b = \frac{Y_a}{S_a} + \frac{Y_b}{S_b}$$

Where: L_a and L_b are the LER's for the individual crop species in the mixture.

Y_a and Y_b are the actual yields of the intercrops, and

S_a and S_b are their yields as sole crops.

Because a change in crop proportion in a mixture will itself change the calcultated LER's and the Total LER of the mixture, there is not only an "optimum" Total LER for a particular mixture but a set of "Effective LER's" for different crop proportions (Mead and Willey, 1980). Furthermore, an LER involves a comparison with sole crop yields of component species (very likely at plant densities that are different from one another, also), so that these must all be clearly stated (Huxley and Maingu, 1978). This tends to make between-site and between-year comparisons of LER's (or "Effective LERs which allow calculations for pre-determined crop proportions) less fundamental than they might seem because the optimum sole crop density will itself change with the level of available environmental resources. As will the individual and total crop yields in the mixture (and hence the individual and total LER's) as mixture intimacy is changed.

Recently, a "competitive Ratio" (CR) has been proposed (Willey and Rao, 1980) to serve as a more universal measure of comparative "aggressivity" of species used in mixtures grown under different cirmustances, where:

$$CR = \frac{\text{Actual yield of (a) when intercropped}}{\text{Expected yield of (a) when intercropped}} \div \frac{\text{Actual yield of (b) when intercropped}}{\text{Expected yield of (b) when intercropped}}$$

or

$$\frac{Yab}{Yas \times Zab} \div \frac{Yba}{Ybb \times Zba}$$

When: Yab = yield per unit area of (a) intercropped with (b) (at the plant density and intimacy of the mixture).

Yaa = yield per unit area of sole crop "a" presumably at its opimum and Ybb for "b" likewise.

Zab = proportion of intercropped are initially allocated to crop "a"

Zba = proportion of intercropped area initially allocated to crop "b"

$$\text{In fact} \quad CR = \frac{LERa}{LERb} \times \frac{Zba}{Zab}$$

and it is simply the ratio of the individual LERs of the two component crops but correcting for the proportions in which the crops were originally source.

Riley (1984) has extended the concept of the LER and proposed a general LER that can deal with several intercropping systems and sole crops at the same time, as have Chetty and Reddy (1984) in proposing on "Staple LER" where a fixed yield of a particular crop for a given land area is required.

(b) When we come to try to express the results of intercropping experiments in which one of the components is a tree or bush the usual problems (as mentioned above) exist over specifying sole crop yields for LER or CR so as to make the comparisons most apt in terms of relevant plant densities. There are, also, several additional problems to consider.

In mixed agroforestry schemes the normal plant density (numbers per unit area) of trees and of agricultural crops are of a completely different order. So that it is much more meaningul to consider the "area occupied" by any plant unit (or group of similar units) in mixtures of trees and agricultral crops, because the tree component will not add to the plant population total of the mixture in a way commensurable with its occupation of space.

MPT trees/bushes will provide, by definition, several products (fodder, fuelwood, timber, food, mulch, medicinal products,honey etc.) as well as "service functions" that can be difficult to evaluate (shelter, soil improvement etc.) And yet some of these may well be modified when the tree or bush is grown in a mixture. This "yield" of widely disparate outputs may not be easily compared between sole crop and mixture if the ratio of outputs is changed in the latter.

Trees and bushes may provide harvests at different time intervals depending on the part being harvested. For example, there may be several intermitent within-season harvests (browse), a seasonal harvest (fruit /seeds), harvests at several-year intervals (fuelwood, building poles) and/or a final harvest after many years (timber). Some form of averaging (or discounting , if monetary values are of interest) will be needed, therefore, if comparisons from mixtures with MPTs are made with the yields of seasonal crops.

The very considerable differences in stature between mature trees and bushes and most agricultural crops is, in itself, a condition that can markedly affect "aggressivity" in either positive or negative ways, depending on circumstances and bearing in mind the comparative phenology of the component species. There are, therefore, likely to be very large observable differences between the growth performance of a tree in a sole cropping situation with its fellows, as compared with its likely performance in a mixture with (say) a dominated agricultural crop. Much more so than where different species of a similiar stature are being compared. This raises issue as to whether intercrop experiments using mixtures in plots are really necessary in the preliminary stages of an investigation, or whether some simple examination of the "tree-crop interface" is sufficient. If this can be followed by a study of sole crop yields of both the MPT and the agricultural crop species at different plant densities to provide sufficient information for formualting design and management features. This is discussed more fully below.

Woody perennials occupy the land for several to many years. Where a long tenure crop (a tree or bush) is concerned with yields may be accumulated over a much more complete partof the accumulated growing seasons than a series of seasonally-sown annual crops could achieve. Although this need not obviate the use of, say, LER or CR as a tool for comparing different plant mixtures involving trees/shrubs, there is a need to bear it in mind if the comparisons are to be meaningful. Even with annual species there is a case to treat comparisons of LERs between long- and short-season crops with caution. Particularly in situations where differences in the duration of land occupancy do not make the most of the environmental resources available; that is where some part of the potential growing season is "wasted" by an agricultural crop. Futhermore, if there is a possibility to manipulate time-of-planting, and/or the length of the growing season through choice of cultivars then <u>different</u> cultivars might, in practice, be better-suited to either the sole crop, or the mixture, but not both.

Trees/bushes (even fast-growing ones) are in the ground for considerably longer than any herbaceous, seasonal or perennial crops. During their occupancy they progress from the juvenile stage (when they may be dominated plants) to maturity (when they will be dominants or co-dominants), and they can be subjected to various forms of training in their early growth, and of plant management during their production stage. Experiments in intercropping must have clearly -stated objectives relating to which growth stages are to be studied. Furthermore the development of the trees or bushes themselves will also be dependent upon the plant associations, soil mangement etc. that are imposed in previous years.

Many agroforestry systems exist that have more than two plant components. Some of the most productive man-managed association involve woody perennials and contain large numbers of species mixed together. Conventional intercropping experiments will not encompass the range of variables inherent

in such systems. Bivariate and multivariate methods have been suggested for the evaluation of intercropping experiments (Pearce, 1982, Dear and Mead, 1983), but the added complexity of agroforestry intercropping is likely to cause problems of data evaluation (see also Chetty and Reddy, 1984; Riley, 1984).

Bearing these comments in mind it seems likely that some relatively elementary factors aboutthe growth complementarity and environmental resource-needs of the proposed partners in tree/crop mixtures will be required before one embarks on field investigations through more elaborate intercropping trials. The most cost-effective way of obtaining this information for field trials is through tree-crop interface assessment.

2. Tree-crop interface trials

This approach has been discussed more fully in Huxley,(1983). The tree-crop interface is the key to understanding, and hence designing and managing, complex agroforestry systems where MPT's are associated in some way with other kinds of plants. Such interfaces can be studied whereever they occur or can be arranged (Fig. 5a). However, in any kind of row-crop arrangement (e.g. hedgerow planting) the effects of one plant associate or another will be considerably influenced by the orientation of the rows, because this will affect the extend of shading, shelter and rainfall diversion. If the system in mind is to include any zonal arrangements of plant components the tree-crop interface effects must be investigated so as to take orientation into account and a cheap and single arrangement for doing this is shown in Fig. 5b, for investigating zonal plantings of MPTs with an agricultural field crop. Such a design can be utilized to study hedgrows per se and even combined with a systematic set of hedegrow lopping treatments (Fig. 5c).

The interface in such designs will be examined by taking transects through suitable parts of the layout, replicated within each arm, if possible, and by recording environmental conditions and the response of the associated plant species at a standard degree of intimacy. A list of possible measurements to make is given in Huxley (1983b).

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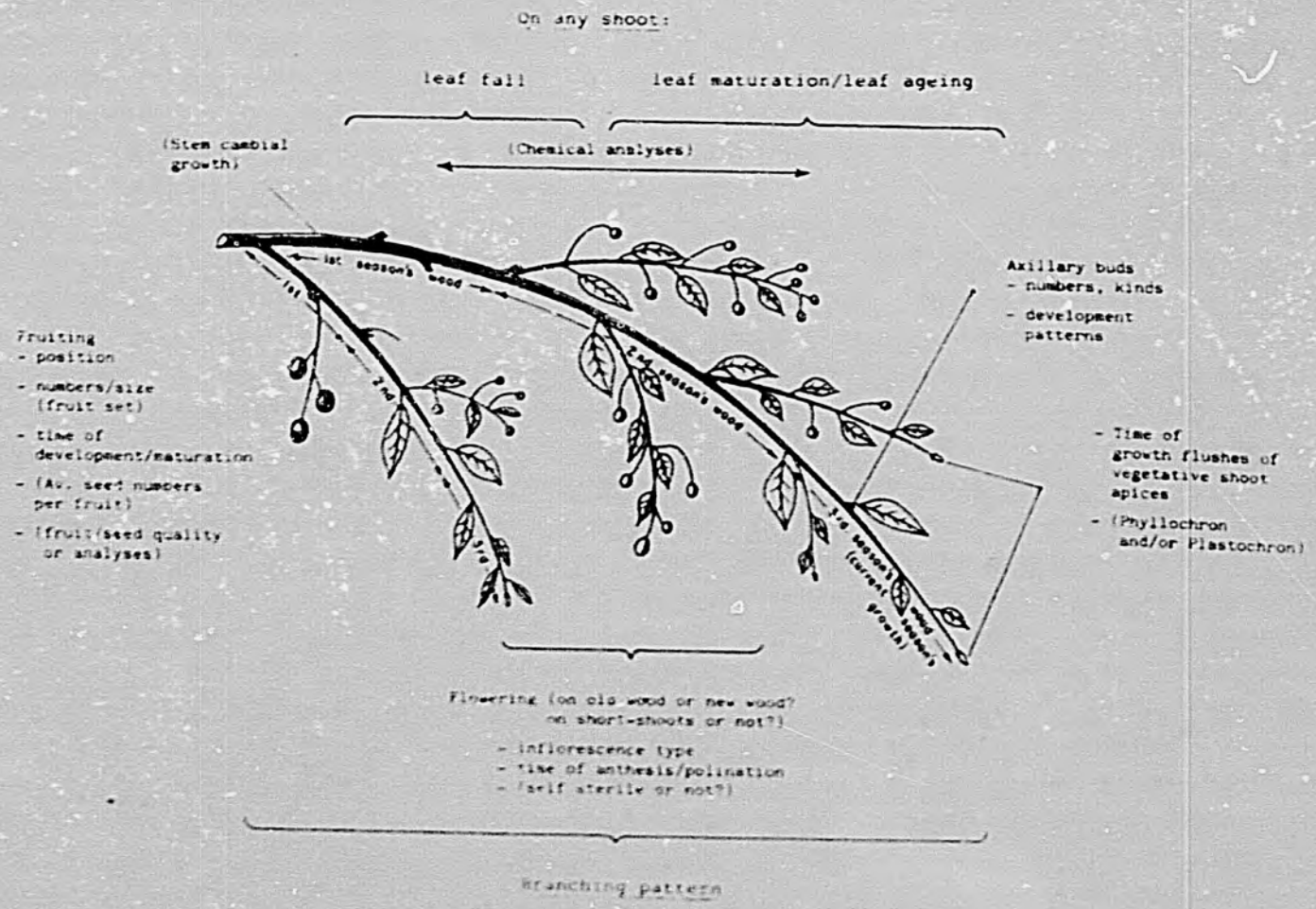
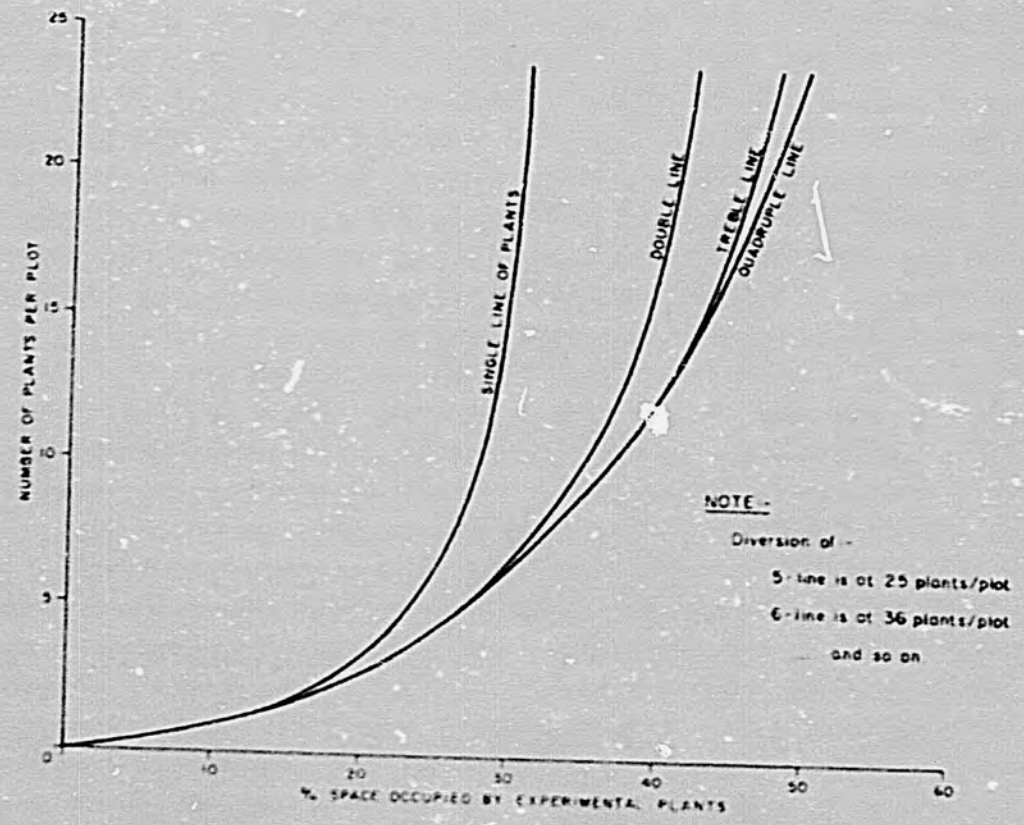
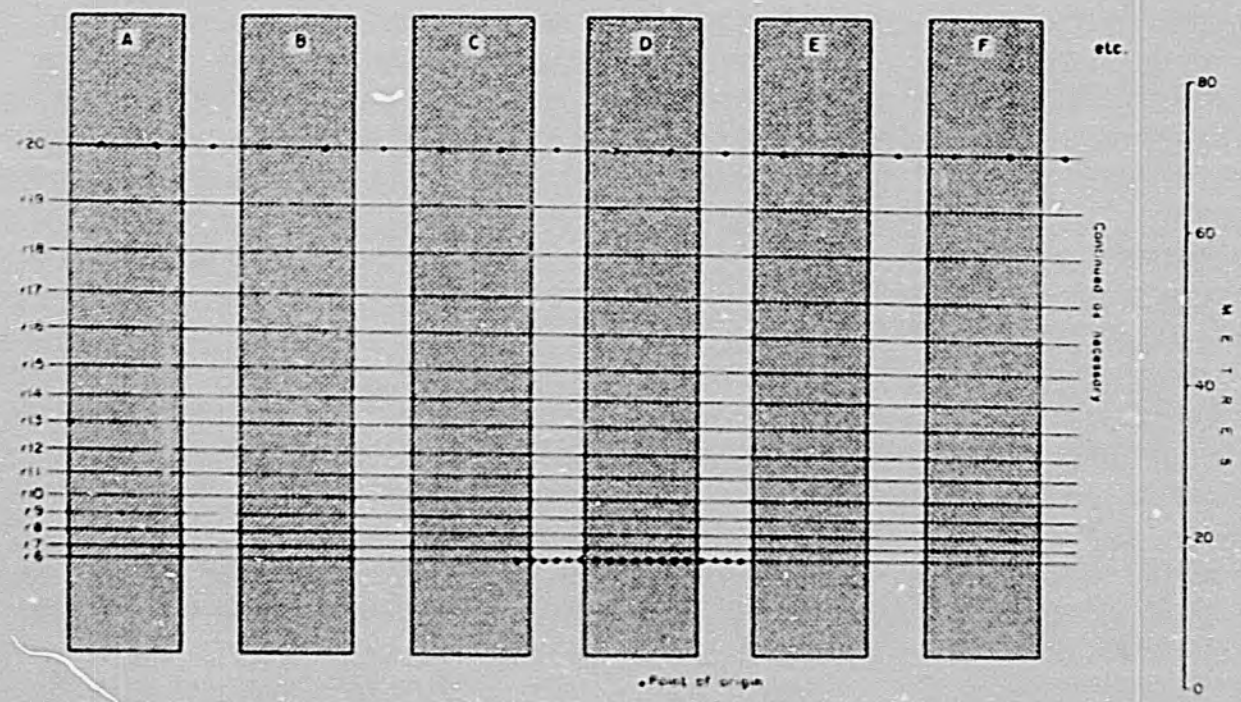


App. Fig.1: Suggested kinds of assessments to be made on branches using mainly simple observational techniques. More detailed assessments requiring analytical techniques are in brackets.



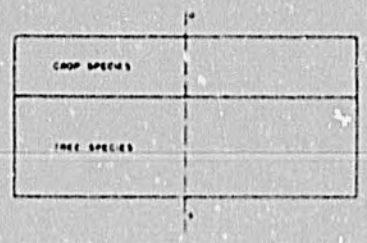
App. Fig. 2: Percentage useful experimental area when a single row of guard plants are used round each plot, and these are shown as single,- double-rows etc. for varying numbers of total plants per plot.



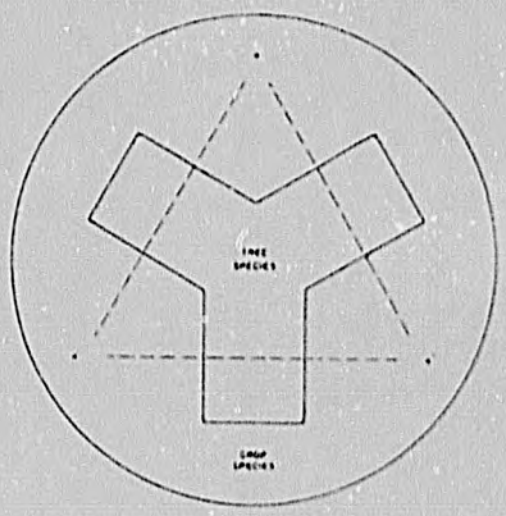
App. Fig. 3: Experimental treatments (e.g. lopping, pruning etc.) superimposed on a parallel row design. The treatments could also be different crop species (at standard spacings) for investigating mixed cropping combinations - (from Huxley, 1983a).

Steps	Process	Results
1 - 5	Information and germplasm acquisition →	Selected choice of indigenous and exotics.
6 - 9	Decide on experimental objectives and match to available resources →	An experimental plan
10-12	Commence field trials to test MPT species and provenances in a logical and properly phased manner →	Sufficient research information concerning survival, adaptability vigour and productivity in relation to site and chosen levels of management
13	Evaluation of the MPT information and experimental evidence to data →	Decision to go on to mixed cropping trials or acquire more information about the MPT's first.
14-17	Examine and update, if necessary, information about other crop components and likely between plant component interactions. Carry out screening trials with mixtures, then more detailed management trials →	Determination of suitable MPT crop species mixtures and a knowledge of how to manage them so as to optimize required outputs
18	Feasibility and acceptability trials with landuse systems →	Leading to adoption

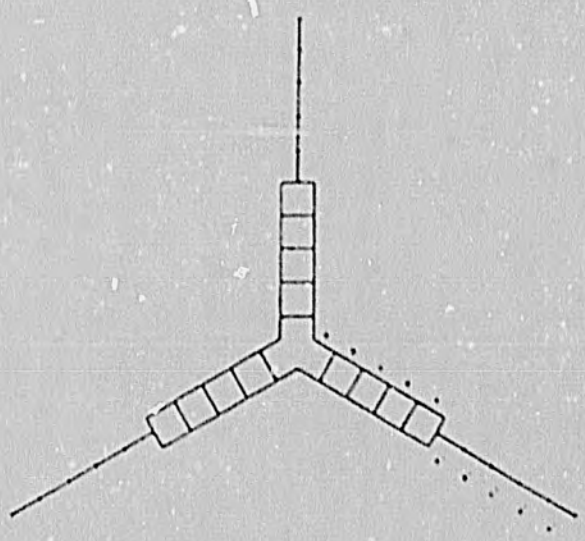
App. Fig. 4: Outline of the steps in evaluating MPT's (from Huxley (Ed), 1984).



(a)



(b)



(c)

App. Fig. 5: Geometric field layouts for assessing the tree-crop interface.

(a) an interface can be studied wherever it occurs
(b) a suggested layout where orientation is important
(c) a layout for use with hedgerow trials which combines a systematic set of treatments

((a) and (b) from Huxley, 1983b)