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RATIONALISING RESEARCH ON HEDGEROW INTERCROPPING: AN OVERVIEW

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PREFACE

This Working Paper is not intended as a review. It is, rather, an attempt to select some examples of information and issues that I consider to be fundamental to the advancement of the subject of hedgerow intercropping in particular, and agroforestry experimentation in general. I started putting it together during 1985 and, some of the comments, suggestions and proposals go back to in-house memos and publications about experimentation for agroforestry circulated or produced in 1979-80. Others are to be found in "Source Materials and Guidelines for Research Methodology for the Exploration and Assessment of Multipurpose Trees (initially circulated in 1984).

Necessarily, it deals with a rather wide range of subject areas which support and illustrate the topics chosen to sustain the arguements and ensuing proposals. Some of these topics have been, or are being more throughly dealt with by others in ICRAF. For example, soil aspects has already been the subject of a Workshop (Mongi and Huxley, 1980) and of the first issue of the "Science and Practice of Agroforestry" booklets ("Soil Productivity Aspects of Agroforestry, by P.K.R. Nair, 1984). Also Young, is preparing an in-depth review on "The role of agroforestry in soil and water conservation". "Windbreaks" are being reviewed by Darnhofer; and various participants at the WMO/ICRAF Workshop on "The Application of Meteorology to Agroforestry" will certainly discuss some of the issues of climatic amelioration and the use of mulch. Woody plant management has been much more thoroughly discussed in papers in "Plant Research and Agroforestry", published by ICRAF in 1983 as the proceedings of a meeting held in 1981. Also more recently, in "Trees as Crop Plants" published by the Institute of Terrestrial Ecology (UK), 1985, as the proceedings of a meeting held in Edinburgh in July, 1984.

In general, the suggestions and proposals concerning experimental approaches are presented as topics for consideration and discussion among those who are actively engaged in hedgerow intercropping research, or who are currently planning to be. There are, as yet, no sets of "rules" or "principles", or even firm "guidelines", until the issues raised have been further discussed and evaluated. At present the contents of this Working Paper represent mainly my own views and suggestions derived from personal research experience and the opportunities I have had at ICRAF over the last seven years or so, to observe and discuss what is going on in experimental agroforestry with the keen band of foresters, agronomists etc. who have been busily and enthusiastically converting themselves into "experimental agroforesters".

Peter Huxley

ACKNOWLEDGEMENTS

References are given where any figures and tables have previously been published elsewhere, or where they are re-presented here in a modified form. Grateful thanks are due to authors/publishers for permission to reproduce in appropriate cases. References supporting data in such tables are not included in the list at the end of this Working Paper but are to be found in the original publication.

I am grateful to Anthony Young for useful suggestions to improve the text made on an earlier draft, and to Dirk Hoekstra for some comments on the "Lanmodel" approach.

CONTENTS

ABSTRACT

The paper discusses some of the background issues to the plant-environment interactions that affect hedgerow intercropping in particular, and agroforestry in general. Putting forward various sets of conclusions that indicate where critical research problems lie.

Hedgerow intercropping is one form of zonal agroforestry in which plant residues (from the hedge) are utilized to sustain crop product on. Some comparative examples from tropical agriculture research are given of the effect on crop yields of applying organic matter to the soil. The need to main a balance of soil available nutrients is emphasised. In many systems this has involved using some fertilizers. Relatively large and consistently applied amounts of plant residues are usually needed in order to improve the normally measured soil chemical and physical parameters.

A summary of three extensive reviews of tree planting in the tropics is given. These highlight the fact that continuous cropping on most tropical soils brings about "long term" soil deterioration. Tree clearing can cause major problems, but even in the "maximum production phase" nutrients are lost from the system. Any kind of cropping which removes a high proportion of the plant biomass can degrade soils. However, hedgerow intercropping in high rainfall areas (>1000 mm. p.a.) and in reasonably fertile soils (Alfisols) does, so far, appear to maintain crop yields. It is suggested that we need to know more about the "short-term" environmental effects of using plant residues that can help bring this about if we are to be able to extend the practice to other environments. In dry regions, hedgerow intercropping may have an important function in preventing soil erosion and rainfall run-off.

The ability of individual tree species to enrich their microsite is discussed, but the rather slow rate at which this occurs should be noted. Factors involved are commented on. When trees are grown in some spatial arrangement to cover just a portion of the ground (as in hedgerow intercropping) their effects on the yield of adjacently-grown crops appears to be much greater than that resulting from the "equivalent" coverage in time when trees/bushes are used to improve soil fertility through a fallow phase, or by growing plot of trees in a rotation. A computer model available at ICRAF ("LANMODEL") helps to expose this paradox. Again, mixing trees and crops may offer a greater opportunity for the short-term environmental benefits, both aerial and adaphic.

Pasture leys, and the use of perennial grasses, are established methods for improving tropical soil and/or providing fodder/mulch. They must not be overlooked. There is a need to compare both woody species and grasses at the same sites in order to establish a better appreciation of their resource-use capabilities, also vis-a-vis hedgerow/grassrow intercropping.

A section is devoted to examining some of the tropical work on mulch, litter and green manures. Cover crops have not proved extensively popular as they are difficult to eradicate. Grown under trees, however, can benefit the soil and are eliminated when the tree cannopy closes. They may, therefore, have a place in some hedgerow intercropping schemes. Examples are given of various kinds of responses to mulch (from the Amazon and from East Africa). These, again, illustrate the large amounts of plant residues that are required in order to change long-term soil characters, but various examples illustrate the benefits of short term effects. Timely beneficial changes in topsoil water states and, hence, nutrient availability are key issues that are well documented. The influence of mulch in increasing fine root growth, level of activity and longevity are mentioned, with examples. Data on the biomass and nutrient content of closely associated soil fauna are difficult to find but, as this may be an important contribution to the nutrient cycling process, and total nutrient pool, we need to investigate the processes, rates and times of what is happening under the relatively small amounts of plant residues derived from hegerow intercropping, especially in semi arid regions. As mulch can enhance internal plant nutrient levels this can, again, contribute to the timely availability of nutrients at different stages of plant growth and development. Complex bi and tri-partite symbiotic associations can also be encouraged by mulching.

Litterfall can be a very important contribution to the whole nutrient turnover in a system, supply a wide range of nutrients (according to the tree species). Examples are given which emphasise the need to consider high biomass turnover and litter nutrient balance in relation to soil characteristics, rather than just to concentrate on nitrogen fixation potential. Recently revised views on the proportion of carbon assimilates fruit are transferred below-ground suggest that these can be much higher than originally thought. This is discussed and the possible limits in hedgerow intercropping of the contributions from both litter and the fine-root function are noted.

Shelter is dealt with very briefly in order to point out its possible contribution in hedgerow intercropping and, hence, the need to consider orientation as an experimental factor. The increased water use of windbreaks or hedgerows, may however offset any benefits to the system as a whole, depending on the enviroemental situation.

The relevance of the concept of "environmental coupling" is mentioned, particularly with regard to experimental situations where an understanding of plant-environment interactions is being sought.

Hedgerows will normally be closely coupled and, hence, factors such as water loss will be modified by plant control mechanisms. Again, spatial arrangements and become important.

The effects on subsequent growth of lopping woody perennials is briefly discussed, and some supportive examples of data from the literature are given. As lopping woody perennials can diminish the effects of other treatments (e.g. mulching) hedgerows may seem to be less affected by these than the adjacent crop. Fruiting hedgerows have great potential, but precise forms of intensive pruning may have to be investigated, as there is a need both to optimise fruit yields and limit competition with nearby crops.

Some ecological concepts relating to "disturbance", "competition" and "stress tolerance" are outlined. The importance of understanding how plants have developed particular sets of characteristics under major environmental pressures that can make them more or less suitable for different types of agroforestry systems, including hedgerow intercropping is noted. Different ecological strategies have led to common sets of plant attributes, in terms of both form and function, and the recognition of this could be most helpful in the selection of multipurpose tree species. In agroforestry systems we are trying to exploit heterogeneity in both space and time even when, as in hedgerow intercropping, the number of plant components are assembled in a fairly "simple" arrangement. Understanding this heterogeneity is the key to managing it.

The various possible lines of research that emerge from the discussion points in this paper so far could lead to a confusing number of proposals for research. Instead, a simple scheme for considering all research under 5 headings (for agroforestry in general) is put forward. A key issue, of considerable importance in simplifying hedgerow intercropping experimentation, is the need to study the "tree/crop interface". For this very simple field layouts are all that is needed ("Geometric designs). Systematic designs can be used to study problems relating to the management of woody species (e.g. response to lopping, when these are previously unknown). Soil aspects, including investigations of the effects of plant residues on the crop and the soil itself, can be studied separately using micro plots.

Such a simplified approach, which, at least, initially, identifies and separates the experimental factors involved, is probably necessary where new plant components are being considered. Investigations can be done on small plots, and so limit unwanted locational variability. This approach will establish, quickly and cost-effectively, what the most important variables and levels are. The more complex investigations of interactive processes can then be carried out, subsequently, in statistically appropriate, robust, plot trials in a much more focussed way. Simple layouts and cheap but effective assessment methodologies resulting in minimum data sets, are what we first require. However, small plots can suffer from problems of "fetch" and a knowledge of the extent of environmental coupling is needed if environmental/physiological measurements are to be taken.

Hedgerow intercropping can certainly be seen as a potential alternative to shifting cultivation or degraded cropping systems in the tropics. It can further evolve to a system whereby "alley cropping" alternates (with no removal of the hedgerow plants) with a "rotational tree plot" phase. The latter functioning mainly as a soil fertility restorer. There are, indeed, numerous possibilities including having hedgerow intercropping sensu stricto, or "rotational alley cropping", or either, with a litter-forming higher canopy. Leading eventually, of course, to designed multi-strata systems. "Prototype" research on these possibilities is also seen to be required, but it will only be effectively carried out when we understand more fully some of the ways the components in the system are interacting, and we can have clearly identifying the processes by which environmental resource sharing can be optimised, both by selection of species with appropriate characteristics, and by suitable management practices. Without this knowledge the design and management of hedgerow intercropping schemes (or any agroforestry schemes) reverts to a process of trial and error.

Rationalising Research on Hedgerow Intercropping

An Overview.

by

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A. INTRODUCTION

Hedgerow intercropping (or "Alley cropping") is one form of zonal agroforestry. That is a landuse system where woody and non-woody plants are grown in some geometric arrangement of rows, strips or plots which will limit, to some extent, the intimacy of the mixture. In the case of alley-cropping there are single or sometimes multiple rows or strips of the woody plant, which is managed so as to restrict its growth in the form of a hedge.

A wider choice of woody species may be feasible in zonal as compared with mixed agroforestry systems, because the spatial arrangement of plant components limits intimacy more. An additional feature of zonal systems, including hedgerow intercropping, is that they facilitate management. For example, alley-cropping systems can be mechanized (as at IITA), if this is required.

Hedgerow intercropping has arisen, in humid and sub-humid tropical regions (i.e. >1000 mm annual rainfall), as potentially a more productive and economically more feasible alternative to natural bush fallow under land-limiting conditions (Getahun, 1980; Kang, et al, 1985; Ssekabembe, 1985; Wilson, et al., 1986). And it often appears to be proposed as an annually cropped and indefinitely-sustainable alternative. In seasonally-arid regions there is, as yet, less evidence of its successful implementation, but some research is in progress (Singh and Van den Beldt, 1986; arap Sang, 1986; and Lulandala, 1986).

If we are fully to appreciate the possibilities for its further extension and development there is a need to consider the implications of all the relevant research available to date, and to evaluate what still has to be done.

Some relevant evidence on tropical soil management

A great deal has been written with regard to tropical soils on the pros and cons of shifting cultivation systems and the nature of rotational bush fallows (e.g. FAO, 1974; Ruthenburg, 1980; Lanly, 1984; ter Kuile, 1984); on cover crops and "living mulches"; and on the benefical effects of dead plant residues used either by incorporation into the topsoil and/or as mulch (e.g. Fuggles-Couchman, 1939; Pereira and Jones, 1954; Robinson and Hosegood, 1965; Lal, 1975; Lal et al, 1978; Sanchez 1982; Sanchez et al., 1982; Wade and Sanchez, 1983; Stigter, 1985). Both Nair (1984) and Young (1985, 1986) have gone over the factors concerned with soil productivity aspects of agroforestry systems, and a good account of the aims and objects of plantation forestry in the tropics is given by Evans (1982).

As Sanchez et al (1985) point out, the kind of evidence for soil improvement by trees and shrubs has to be scrutinized carefully, and it falls into two categories: information from sites at which sequential sampling has been taken; and comparitive data from several sites at which plant cover has been established for various periods of time. There are rather few data of the first kind and great care has to be taken that inherent site differences do not invalidate the credibility of the second. Furthermore, the situations studied often relate to plant associations which achieve a "closed" canopy (including dense woodland) and not a partial coverage of the land area, as in hedgerow intercropping.

Other relevant data are available from investigations of the effects on tropical soils of perennial fallows of different kinds e.g. perennial herbaceous grasses and legumes, and of the effect of transported mulches. However, in this latter case, there is comparatively little information in the literature about the effects of woody mulch (Huxley, 1983a).

Compost/manure and soil changes

There is, of course, a very considerable amount of relevant work on soil management and crop production on tropical soils which it is impossible to consider in detail here. Two examples chosen from work carried out in Northern Tanzania (Ukiriguru) and the Amazon (Yurimagus) can, however, serve as useful reminders.

Fig. 1 shows the long-term residual reponses to only a one-time application (3 and 7 tons acre^{-1}, which equals 7.5 and 17.6 tonnes ha^{-1}, respectively) of "compost" or farmyard manure (FYM) on a deep sandy soil at Ukiriguru, Tanzania. Even longer-lasting for cotton than finger millet, because individual crops respond differently to soil changes.

Fig. 2 shows the significant relative yield increases with 5 consecutive crops (on a well-drained Amazonian Ultisol) achieved by adding and/or incorporating various plant residues, where fertilizers were not being used. It also reminds us that when chemical additions are made they can easily cause nutrient imbalances (K deficiency occurred after adding lime and phosphate). Nevertheless, an undoubted improvement can be achieved in the chemical properties of the topsoil after eight years of using a complete fertilizer regime to maintain crop production on the same soil (Table 1); although a very complicated fertilizer programme was required to achieve this (Table 2).

Lastly, Fig. 3 (Ukiriguru, again) reminds us about the kinds of interactions that are often found to occur when studying the outcome of fertilizer and/or plant residue additions. In this case the interactive effects of adding nitrogen fertilizers with or without the additions of compost and phosphate and lime applications. On this soil, reaction (pH) had been lowered and available calcium had been seriously depleted after 9 years of continous cropping, which "compost" or FYM applications of 15 tonnes per hectare every three years could not offset. Phosphate and compost enhanced the responses to nitrogen, especially when applied together.

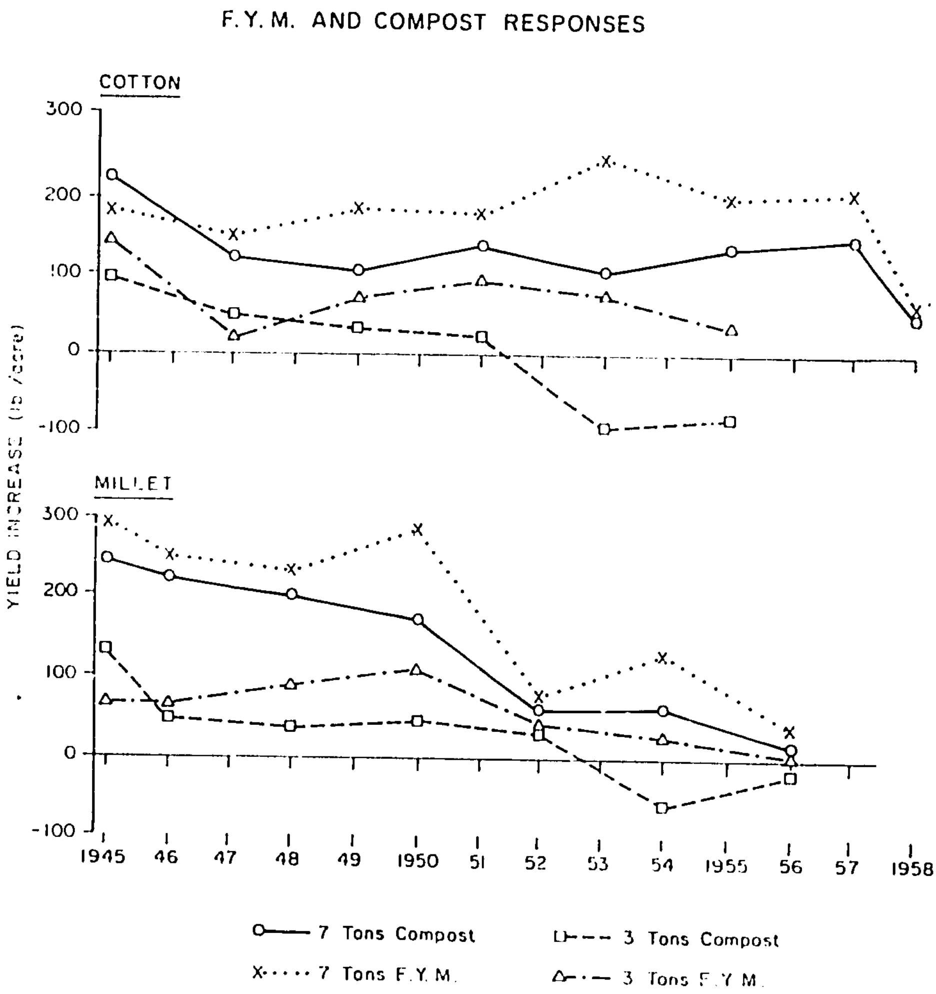


Fig. 1: Long term responses from single application of FYM and compost applied late 1944. Cotton and millet were planted alternate years.

Reproduced by permission from:
Peat, J.E. and Brown K.J., 1962. The yield responses of rain-grown cotton, at Ukuriguru in the Lake Province of Tanganyika. I. The use of organic manure, inorganic fertilizers and cotton seed ash Emp. J. Expl. Agric. 30, 215-231. Cambridge University Press.

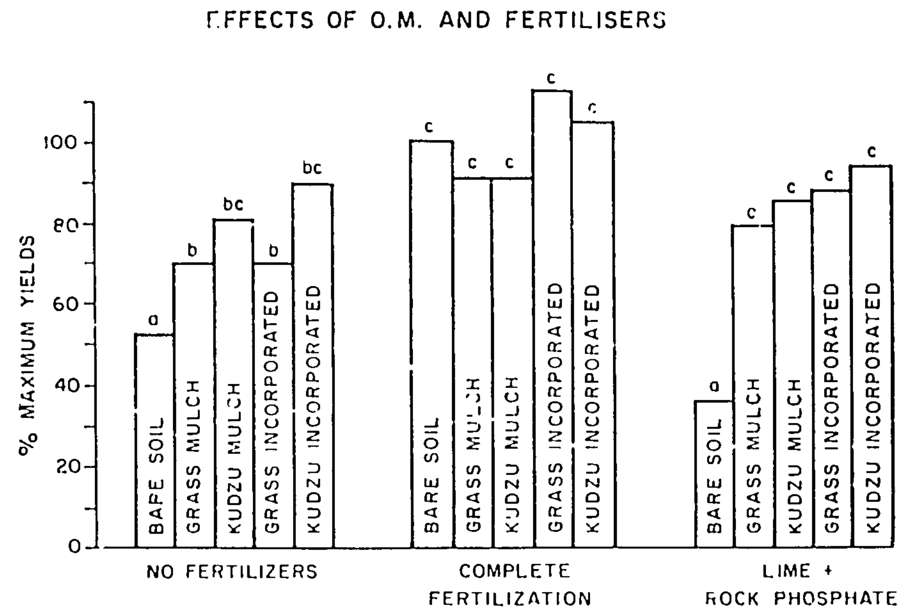


Fig. 2: Relative yields (means of 5 consecutive crops) as affected by organic additions and fertilization. Yields of the bar completely fertilized treatments =100

Table 1:

Changes in topsoil (0-15 cm) chemical properties after 8 years of continuous production of 20 crops of upland rice, maize and soybean *with complete fertilization* in Yurimaguas, Peru 1/

Time	pH	Org. matter	Al	Ca	Mg	K	Eff CEC
			Exchangeable				
		%	---------meq/100 cc	-------------			
Before clearing	4.0	2.13	2.27	0.26	0.15	0.10	2.78
90 Months after clearing	5.7	1.55	0.06	4.98	0.35	0.11	5.51

Available

	Al Sat'n	P	Zn	Cu	Mn	Fe
	%	--------------	g/cc	-------------------		
Before clearing	82	5	1.5 2/	0.9 2/	5.3 2/	650 2/
90 months after clearing	1	39	3.5	5.2	1.5	389

1/ Source: Sanchez et al., 1982

2/ 30 months after clearing.

Table 2:

Lime and fertilizer requirements for continuous cropping of a three crop/year rotation or rice-groundnut-soybean 4/ on an ultisol of Yurimaguas, Peru
- from Nicholaides et al. 1984.

Input 2/	Rate per hectare	Frequency
Lime	3 tons $CaCo_3$ equivalent	Once per 3 years
Nitrogen	80-100 kg N	Rice and maize only
Phosphorus	25 kg P	Each crop, split applied
Potassium	165 kg K3/	Each crop, unless dolomitic lime is used.
Magnesium	25 kg Mg	Once/year or two years 4/
Copper	1 kg Cu	Once/year or two year4/
Zinc	1 kg Zn	Once/year or two years 4/
Boron	20 g B	Mixed with legume seed during innoculation

1/ Source: Nicholaides et al., 1982

2/ Calcium and sulphur requirements are satisfied by lime, single superphosphate and Mg, Cu and Zn carries

3/ Potassium application may go to this rate depending on soil test.

4/ Depends on soil test analysis and recommendations.

COTTON YIELDS AND SOME INTERACTIVE EFFECTS OF NITROGEN

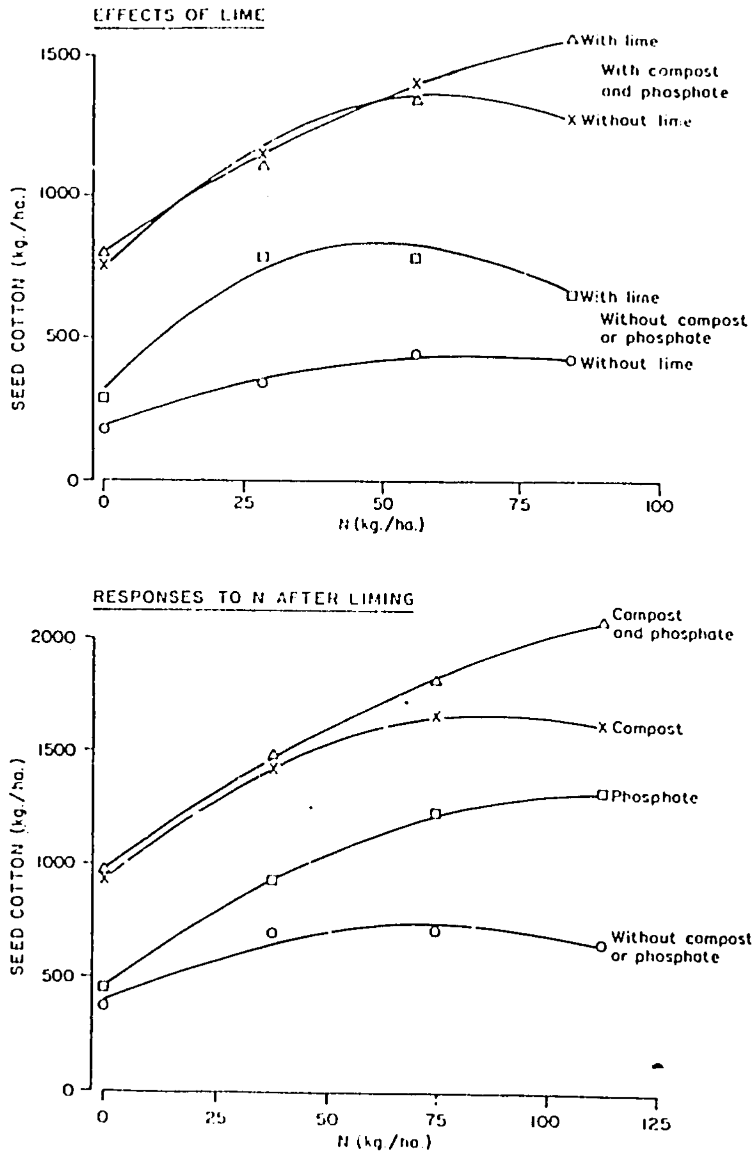


Fig. 3: above, Effects of lime, with and without compost and phosphate in response to nitrogen, 1965.

below, Effects of compost and phosphate, after liming, on response to nitrogen; means of 3 seasons 1966–8.

Soil fertility experiment at Ukiriguru, Tanzania.

Reproduced by permission from:

Le Mare, P.H., 1972. A long term-experiment on soil fertility and cotton yield in Tanzania. Expl. Agric. 8, 299-310. Cambridge University Press.

These two examples illustrate some generalizations that are relevant to an appreciation of the extent to which we can expect applications of plant residues in hedgerow intercropping to be effective.

- The direct beneficial results of applying plant residues to tropical soils, can be considerable when soils are poor to start with, particularly if incorporated rather than applied to the surface, and they can be long-lasting even on sandy soils.

- Sustained yields can be obtained by consistently applying fertilizers alone, but only in carefully regulated and monitored programmes. Also positive interactions are commonly to be expected when applications of fertilizers and plant residues are made together.

- Although quite small amounts of plant residues can have some immediate beneficial effect, rather large and regular amounts are required, depending on the soil and climate at any particular site, to halt soil degradation under continuous cropping schemes. And much larger amounts might have to be used in other circumstances to bring about persistent long-term improvements in soil chemical and physical conditions. The equivalent annual rates of application in the examples given above were 5 tonnes ha^{-1} of compost at Ukiriguru and 4.5. to 5.0 tonnes ha^{-1} d.m. of mulch at Yurimaguas.

- Combined applications of plant residues and fertilizers may, therefore, often be the best compromise. Certainly a great deal of care is needed if only one or the other is to be used continuously without checking that the amounts and kinds of either are adequate.

- The use of plant residues in hedgerow intercropping schemes must be done in such a way as to address all the usual problems of maintaining the fertility of tropical soils - there really are no new factors to consider - only more critically focussed explanations of the outcome of known processes.

Tree plantations and soils changes (summaries)

Several recent papers on the effects of tree cover draw sets of conclusions: e.g. Lundgren (1980), Chijioke (1980) and Sanchez et al (1985). It is worthwhile summarizing these as they represent an analysis of a great deal of work.

From Lundgren (1980) for tree plantations* (see Fig. 4):-

- If fast-growing tree species are grown on latasolic soil types with continuous "cropping", and normal forestry management practices, **soil deterioration will occur** (i.e. decreases in soil organic matter and nutrient levels, loss of topsoil structure and porosity). "Normal" forestry management practices implies no use of fertilizers; and some lopping during the "establishment phase", which invariably involves exposure of bare soil.

* Emphasis **(in bold type)** is mine

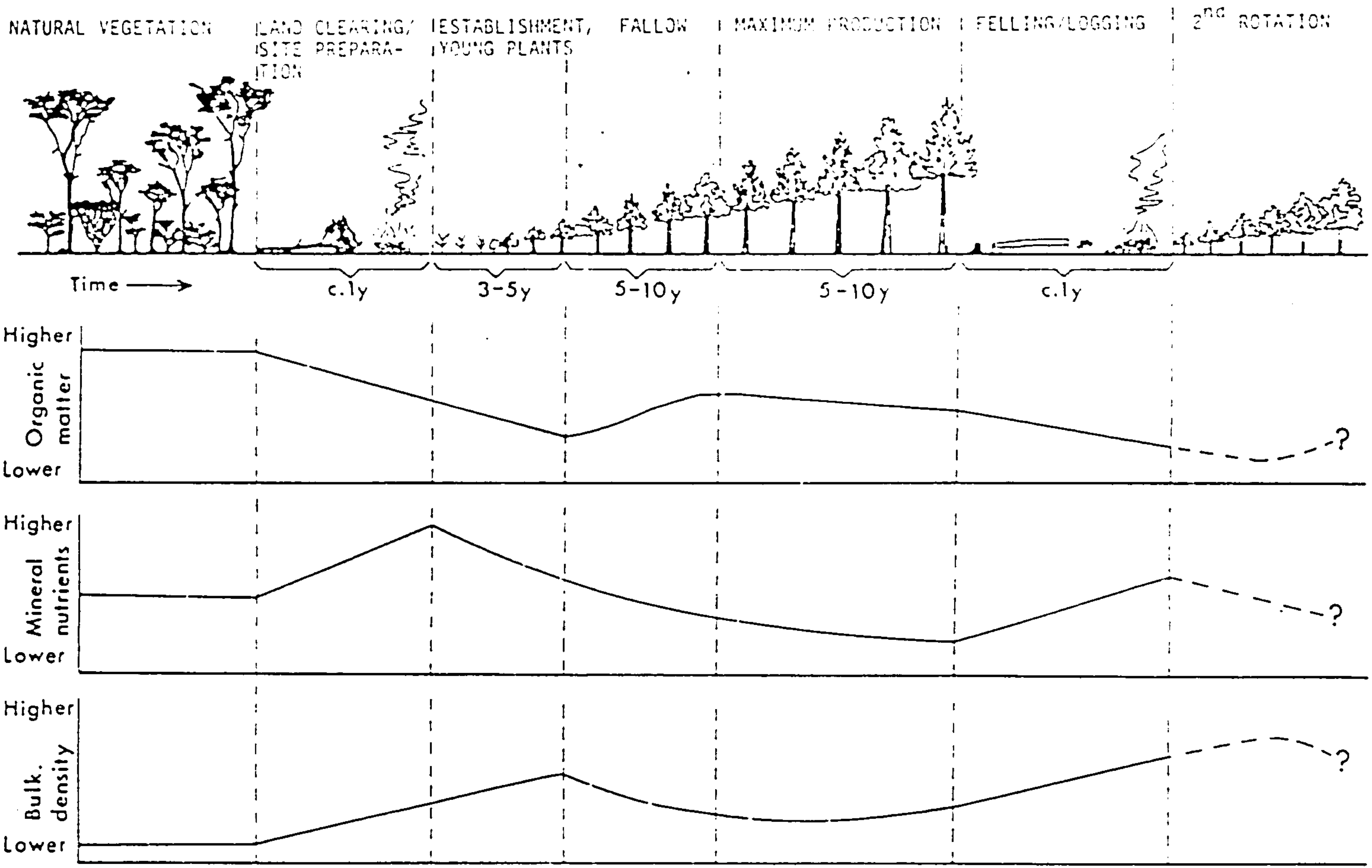


Fig. 4: Different ecological and management phases in the conservation of natural forests in short-rotation plantations.

- from Lundgren, 1980

- Clearing methods (including burning) can greatly affect the site depending on soil, climate and slope. Soil structure and nutrients, soil reaction and organic matter are all affected.

- **During the "tree establishment phase" losses by leaching and erosion are much greater that losses by crop removal** where taungya is practiced.

- In the "fallow phase" there are often large additions of organic matter (from litter and roots) which improve soil structure but, except for nitrogen, **soil nutrient levels will continue to decrease, largely because nutrients are being incorporated into biomass.**

- **The "maximum production phase" shows all soil characters deteriorating, compared with natural forest,** due to a lower rate of litter fall and less soil organic matter, although the depth of the litter layer may increase. **Even the extensive root systems found in tree plantations may not prevent some leaching out of the soil profile.**

- At "clear-felling", nutrient removal in the harvest, and changes in soil conditions due to site clearing activities, are likely to prevent a restoration of soil status to that at the initial forest clearing.

- Second and third rotations will then result in progressive deterioration of soil physical and chemical conditions unless soil amelioration is undertaken.

From Chijioke, (1980).

- Basic nutrient elements and nitrogen are mostly immobilized in the above-ground organs of the trees. 70-80 percent of the nutrients so immobilized are lost by the harvesting of stemwood and bark.

- Contrasting soil changes are brought about by different species (*Gmelina arborea* and *Pinus caribaea* in this study).

- On light-textured soils (*Gmelina*) faces a geater risk of yield decline in subsequent rotations (than on heavier soils). This is from excessive leaching of meagre nutrient resources following increased soil porosity and lower bulk densities. Yields decline on medium and heavy-textured soils also.

- Up to 25 percent of the nutrient loss due to whole tree harvesting could be avoided if the slash was left on the site. A further 5-10 percent could be saved if the bark was returned.

- Total nitrogen in every situation - in natural forest or plantation - was present in more than optimal levels despite the large amounts immobilised (by *Gmelina* and *Pinus*).

From Sanchez, et al. (1986)

- Closed tree canopies tend to improve soil structure and decrease top soil bulk density (and so increase percolation rates); but this effect varies substantially with tree species.

- Closed tree canopies do not go on increasing topsoil organic matter content, but the effect (again) varies with species. When products are harvested during growth the soil organic matter decreases to reach a new equilibium level.

- Closed tree canopies tend to increase topsoil Ca and Mg (through slow decomposition of tree trunks, stumps and roots). However, K levels often decreases to very low levels and woody species differ in their ability to alter soil reaction (pH).

- Leaching losses appear to be less than expected in tree plantations (as for rainforest) except in the establishment phase. The nutrient cycling mechanisms of many perennial tree crops, when the canopy, is closed appears to be very efficient.

- However, expectations that sustained tropical forestry is possible on acid soils of the humid tropics without fertilization is likely to be erroneous.

o Trees generally maintain or improve soil properties in the tropics only after they have established a closed canopy. The main advantages of trees over annual crops or pastures seem to be related to the longer period of time that trees can exert their influence on soil properties.

Some conclusions

From such work on plant residues and trees a number of relevant issues which relate to what might be expected from hedgerow intercropping can be set down, as follows.

- o The severe problems (loss of nutrients, organic matter and soil structure) occasioned by site clearing in plantation forestry will be avoided in hedgerow intercropping.
- o We are not, however, dealing with anything like a closed canopy.
- o Even if we were, the net effects on long term soil changes will depend on:
  - the woody species used;
  - the amount and kind of biomass removed from the site; and
  - the "leakiness" of the whole system (c.f "establishment" and "fallow" and even the "maximum production phases" in forest plantations).

o Even where there is a long rotation time, and large amounts of biomass are retained on-site, all these authors are unanimous in not expecting to be able to "crop" trees continuously (2nd, 3rd and subsequent rotations) without some absolutely necessary forms of soil amelioration (fertilizers or large additional quantities of organic matter, or both).

Clearly, climate and the initial soil conditions are highly relevant to the rates of changes to be expected. But these kinds of studies are really only concerned with long-term soil productivity changes. Certainly, we need to go into the points listed above but, in addition, for hedgerow intercropping also to examine any possible short-term effects. Moreover, we should more closely examine the comparative benefits or otherwise of spatial woody/non woody plant arrangements (e.g. hedgerow intercropping) versus rotational woody plots) for a range of climates and, ultimately, for any particular site. This is discussed briefly in Section B below.

Claims for hedgerow-intercropping

In the next section of this Working Paper, I want to look more closely at the effects of relative amount of tree cover. But before doing so let us look briefly at the proposed benefits suggested for hedgerow intercropping ("alley-cropping").

The following is extracted from the IITA Alley-cropping brochure (Kang et al. 1985), although it can be assumed that all potential benefits would not necessarily be claimed for all sites and situations. I have added some questions or cautionary comments.

Alley-cropping may:

- o **Provide green manure or mulch - which recycles plant nutrients from deeper soil layers.**
  - But what about areas with very acid subsoils? Nutrients have to be there if any are to be recycled, and tree roots have to penetrate deeper soil layers.
- o **Provide prunings and shade to suppress weeds.**
  - How effectively? Exactly what biomass and/or hedgerow cover is needed in any particular set of circumstances?
- o **Provide favourable conditions for soil macro- and micro-organisms.**
  - Yes, but can this important aspect be quantified?
- o **Provide biologically-fixed N to the companion crop.**
  - If the woody species is a N-fixer, but why the emphasis on nitrogen?
- o **Provide prunings for browse, stakes and fuelwood.**
  - What about the "trade-off" between all the above and the amount of biomass remaining that is required to improve the soil?

- **Provide a barrier to control soil erosion (when planted along contours)**
  - In drier regions is the necessarily wider between row hedgerow spacing any limitation to achieving this and can the in-row spacing be made close enough?.
- **The main advantage is that cropping and "fallow" phases are concurrent - so that a farmer can crop for an extended period without returning the land to bush fallow.**
  - Is this "something for nothing" then? Or does this not emphasize the need to compare exactly what is happening in alley-cropping vis-a-vis a bush fallow?

There is no doubt that some or all of these claims can be effected under many humid or subhumid regions i.e. above 1000mm annual rainfall, and under particular sets of management conditions (Kang et al. 1981; Kang et al, 1985; Wilson, et al., 1986; Yamoah et al 1986a and b). However, both the nature and extent of the processes and interactions between plants-soil-environment that can be manipulated for alley-cropping need to be more critically examined and understood, because they are, indeed, fundamental to all agroforestry systems.

Alley cropping can certainly also provide a means of preventing soil erosion and, indeed, in semi-arid regions this may be of greater importance than any contribution of the relatively restricted amounts of plant residues made available which are applied to the soil (particularly any hoped for long term effects on soil characteristics). In a review of the potential of agroforestry for control of soil erosion Young (1986b) has pointed out that alley cropping designs have the apparent capacity to combine two methods of erosion control: checking runoff through the barriers provided by the tree rows, and providing a ground surface cover through litter from prunings. These *a priori* reasons for supposing that alley cropping could be designed to control erosion are at present supported only by very scanty data, and research is needed. It is now recognized also that erosion can cause serious losses of soil organic matter and nutrients, and thus there is an interaction with the potential for maintenance of fertility.

We should, therefore, benefit from the advances already made in alley-cropping research to widen and deepen the scope of investigations. Particularly those on the effects and interactions of woody perennials on soils and other adjacent plants; on factors affecting biomass production and nutrient re-cycling in relevantly managed systems; on soil water status where plant residues have been applied; on shelter/shade effects and environmental resource-sharing; and the effects of all these on tree management techniques, and so on.

B. PRODUCTIVITY AND SUSTAINABILITY OF LANDUSE SYSTEMS

Microsite enrichment

Perhaps the most obvious example of the soil improving capacity of woody perennials that one most frequently sees in the field is that of site (or micro-site) enrichment under single trees/bushes, or small clumps. A whole range of factors affect both the real and apparent changes in the growth and apperance of ground-level vegetation in this situation.

Real positive effects can be due to:

- o an increase in topsoil nutrient and soil physical conditions brought about by litter-fall;
- o nutrients in through-fall;
- o re-direction of rain;
- o mist-collection;
- o dust collection;
- o animal excreta (birds and cattle resting, or roaming wild animals);
- o insect faeces, excretions and dead insect biomass;
- o lower day and higher night soil surface temperatures;
- o changes in soil surface humidity;
- o changes in topsoil/subsoil soil water status;
- o shelter effects from wind, high insolation and rain impact (although "drip" can also be detrimental);
- o the long-term changes in the soil due to any or all of the above.

Negative tree effects can result from:

- o competition (for water, light and nutrients).
- o allelopathy.

Apparent enhancement of ground storey vegetation under trees can be caused by:

- o the purely plant morphogenic changes brought about by shading;
- o protection from browsing animals (e.g. by thorny lower branches);
- o an accumulation of plant propagules "trapped" under the tree or bush.

Precise soil data from single tree investigations are, unfortunately rather scanty, although they present a good opportunity to obtain a great deal of information very cost-effectively. Kellman's study (1979) offers a clear insight into the comparative soil benefits accrued by small clumps of five mature savanna species in Belise. All five species accomplished a preferential enrichment of the soil about them. This differed between species and, in some cases, reached levels approaching or exceeding those found in nearby rainforest soil (Fig. 5). Effects were achieved without deep-rooting. Changes involved amounts of Ca,K,Mg, and Na, available P and total N, as well as improved cation exchange capacity and percentage base saturation.
The ecological implications of these findings are exciting as these trees, or clumps of trees, enriched their microsites to the point where other species not adapted to the level of soil fertility in the open savanna could find a "niche" in which to become established. However, it seems that this enrichment process may take some time, in agricultural terms.

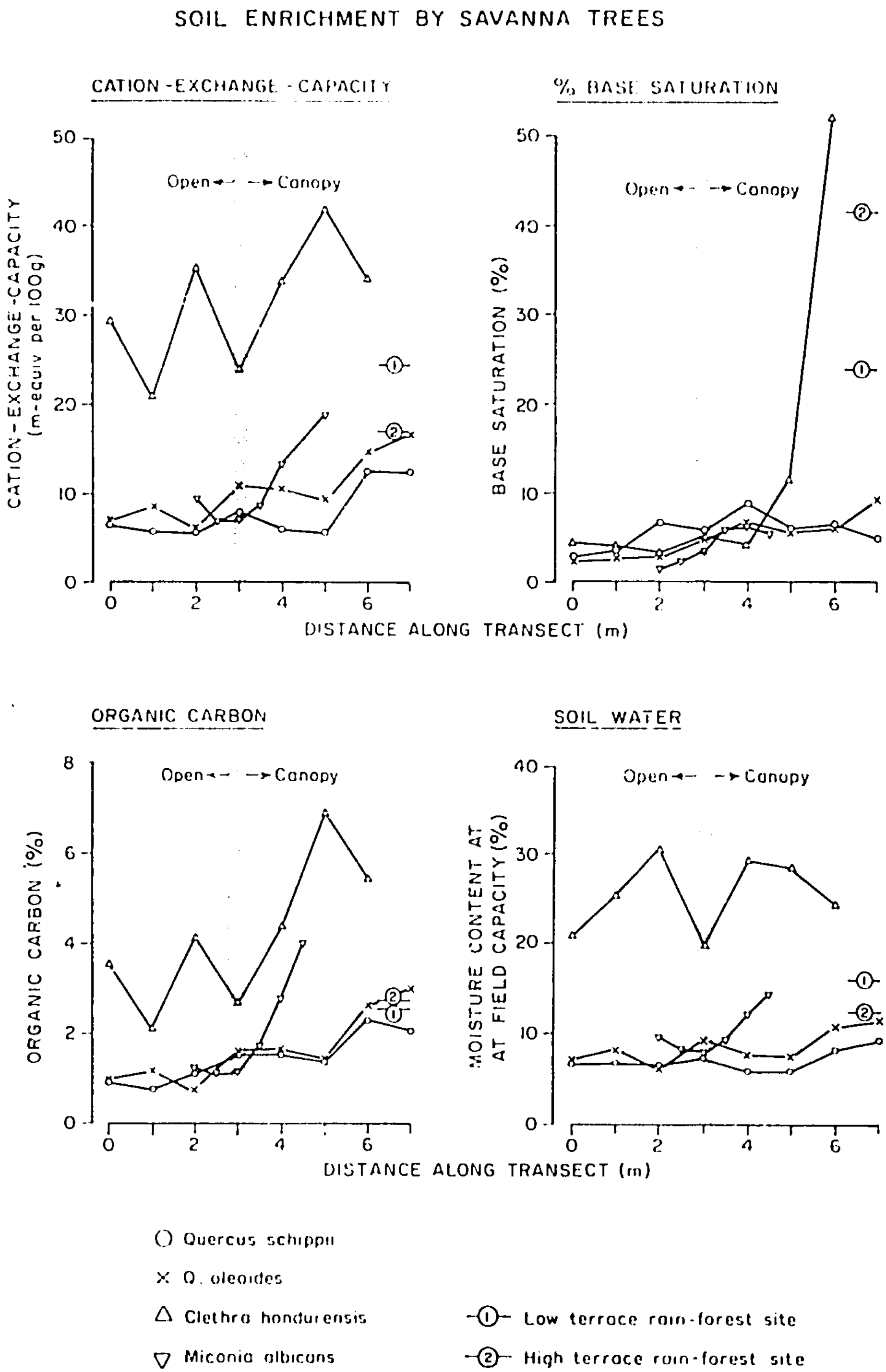


Fig. 5: Changes in various surface soil properties along sample transects under 4 species of trees.

- From Kellman, 1979.

Harcombe (1977- quoted in Kellman) estimated that the total nutrient capital of rain forest in Costa Rica could be accumulated in 250 years by complete capture of rainfall inputs. Furthermore, the addition of nutrients is not, in itself, enough unless the whole capacity of the system is concurrently increased so as both to capture and store them (Connor, 1983).

Trees and shrubs even act as "traps" for insects etc. above ground and so enchance nutrient re-cycling in the system (143.5 and 4.8 kg.d.m. ha^{-1} for faeces and dead insect bodies, respectively,) in a dry evergreen forest in Thailand, for example - see Watanabe et al, (1984).

In agroforestry systems it may be necessary to provide some nutrient inputs (fertilizers, manure and/or "borrowed" plant residues from another site) in order to "lift" the system to an enhanced level, and then to keep it from declining by all means that make it less "leaky" (extended plant cover in space and time, increased rooting volume and activity, reduced leaching, increased soil organic matter to improve the cation exchange capacity, high soil base saturation, larger plant biomass).

Modelling the situation

A "replacement series" model

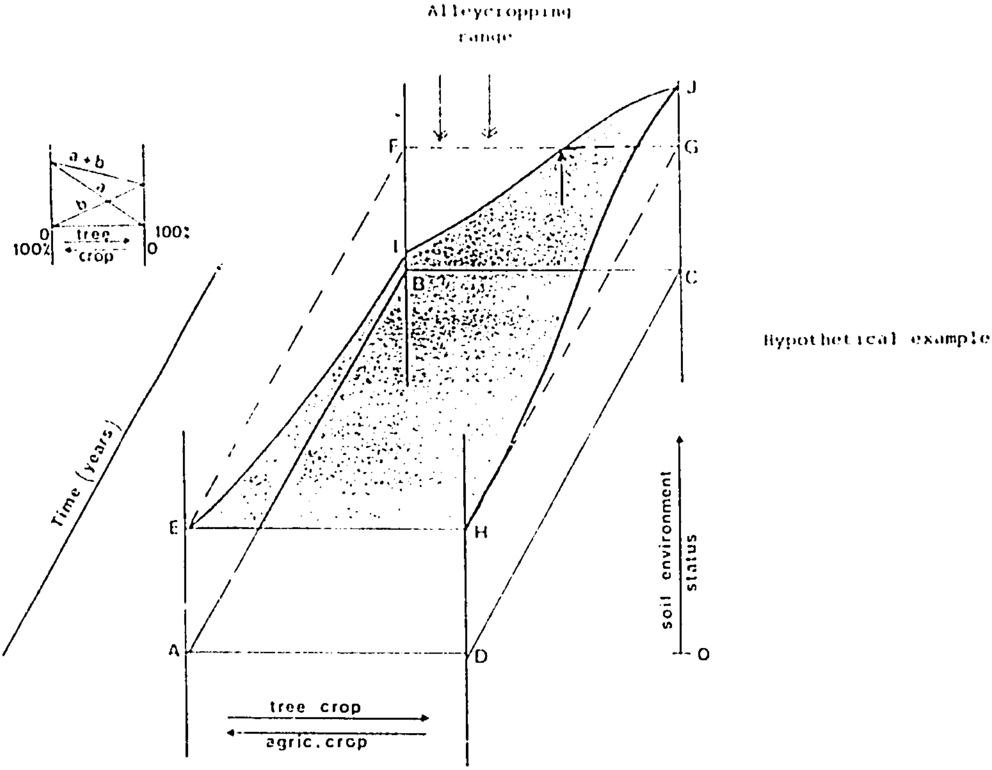
One approach to making a comparison of different forms of landuse systems involving a mixture (or mixtures) of woody and non-woody plants is to consider what happens over time to the system for different ratios of the mix.

Likely long-term changes in soil factors for (a) a sole agricultural crop and (b) a sole tree crop are a place to start, followed by the form of the response surface for the mixture. This can form the first part of the model (Fig.6), and be repeated with regard to solely plant considerations (crop weediness, the incidence of pest/diseases, the growth of the tree component). Then, the two aspects, "soil" and "plant" can be summed together to form a model of overall land productivity which predicts the outcome of any ratio of a mixture of a woody and non-woody plant components in time (Huxley, 1983b, 1986a).

Like all such models this one poses more questions than it answers. But in our case it is these very questions that will provide a further insight into the relative importance of some of the processes concerned when comparing, say, hedgerow intercropping with rotational plots (bush fallow, fuelwood, fodder plots etc.).

Hedgerow-intercropping: should it work?

One puzzle about alley-cropping is that if it takes a certain number of years of bush-fallow to re-establish soil fertility so that annual cropping can once again take place at a satisfactory level, why do we expect to cover only a fraction of the land with a woody species, and yet be able to sustain cropping on it annually? For various reasons we might not expect there to be complete equivalence between the time it takes to restore soil fertility under a bush fallow and the amount of space that needs to be occupied by woody species in a permanent or semi-permanent system (see Table 3). There are indeed, a number of points of difference which are discussed more fully in Huxley, (1986b).



This is from a 3-dimensional computerized model ("Lanmodel" - see Huxley, 1983b and 1986a) which shows the changes with time of the output trends as influenced by changes in soil factors for the crop or crop mixture (left hand side), when the land unit is covered entirely by a tree species (right hand side), and for all proportional mixtures of these. The first stage of the model deals with soil factors, the second with plant factors and the third sums these to give land productivity. Inputs can be real or conjectured. However, we do not have (any?) data to describe, for the self-same site, the shape of even the extreme boundaries of the model. Nor are data sets as yet available to indicate the precise shape of the response surface (the mixture). We can, however, very usefully consider the various conceptual problems involved, and list the research that has to be addressed to get the information we need (see papers listed above).

The model is considering a situation which is an intercropped mixture. To use it for a hedgerow intercropping situation one could merely utilise any information to derive the left hand (alley) and right hand (hedge) trends - but this would not be making full use of the model's potential to consider the interactions in a mixture. To consider what is happening in alleycropping a simpler approach, which includes analysing what happens at the "tree/crop interface" (see Fig.17 below), would be better.

FIG.6

Comparison of status of potentially beneficial processes due to woody-perennials where they occupy (a) a "permanent" spatial fraction of the land or (b) a complete cover rotated in time

	(a) Hedgerow-Intercropping	(b) Rotational Tree Fallow
A. Shelter	Possibly some mutual shelter of hedgerows and some shelter of crop - but depends on orientation and distances between hedgerows.	No crop to benefit from shelter. Young tree seedlings may be rather exposed if wide spacings are used.
B. Plant Residues etc.		
	Amounts. Biomass production of combined hedge and crop relatively lower than during tree fallow phase, but relatively higher than in sole cropping phase.	Relatively larger biomass production in tree fallow period, but relatively smaller in cropping period.
	Effects. If hedgerow loppings retained on-site can be major beneficial effects on water, nutrients, soil physical conditions (water infiltration and soil surface temperatures) i.e. mainly "short term" effects unless large amounts of biomass produced are retained (c.7-10 tonnes d.m. ha^{-1} yr^{-1}).	Net accumulation of organic matter in litter and soil depends on site factors and kind of plant canopy established (rate of gain due to leaf turn over, leaf nutrient content etc. loss by degradation and leaching etc.). Clearing methods very important in maintaining soil fertility. Very rapid soil fertility loss after cropping begins.
	Litter fall. Very little and effect will be minor, at most	A major factor and "litter" could be increased by lopping, but this is rot usually done. - annual increments are accumulated (although sum of annual losses can be high) so that net gain can be reduced.
	Fine root fraction. Small effect due to size, amount of cover and management of woody plants (lopping of hedgerow).	Possible large effect.
	Canopy leachate. Very little.	Quite an important contribution to soil nutrients at the site.
C. Soil fauna	Relatively higher level of increase for smaller additions of plant residues.	High level of increase, but with large additions of plant residues.
D. Soil water	Infiltration rate increased (under hedgerow mainly and this helps prevent run-off); total soil water status of whole profile raised somewhat, but topsoil water status markedly improved throughout crop growing season.	Whole plot infiltration rate markedly increased (depends on tree species). Amount of deep drainage increased and run-off considerably reduced. Increased infiltration may accentuate nutrient losses through leaching.
E. Soil fertility	Increased only slowly, if at all in some situations; mainly in surface soil layer which quickly achieves several transient beneficial states: e.g. - more available soil water for crop plants at a time they need it - greater availability of small amounts of plant nutrients (especially P) proximal to current fine-root growth. - reduced soil surface temperatures (important at crop germination and early seedling growth stages.)	Increases rapidly but then more slowly (eventually reach an equilibrium). Occurs rapidly in upper soil layers but, depending on time duration, lower layers can be improved too. Can have major effects on CEC, base saturation, pH soil O.M., and physical factors such as bulk density etc. i.e. "long term" effects.
	Seasonal nutrient losses (due to leaching and denitrification etc) are regular but small.	Season nutrient losses for the system increase with increasing depth of litter.

Table 3

The model shows the parodox quite clearly for a selection of examples involving different rates of soil fertility decline under seasonal cropping, and different potential rates of fertility increase under a tree cover (Table 4). In none of the "scenarios" will a 20 to 30 per cent cover of a woody perennial maintain long-term soil fertility with the model inputs used. Either these are unrelated to what is actually happening, or the woody/non woody mixture is behaving in a more positive way than can be assumed from a linear response surface, or both. But alley cropping is proving successful in certain circumstances. That is soil fertility is maintained or even improved and crop yields have proved to be sustainable. Thus, land occupancy by woody perennials in space would seem to have a greater effect than "equivalent" land occupancy in time, and we must understand exactly why.

Certainly, the intimate association of woody perennials with crops will supply mulch (organic matter and nutrients), shelter, shade, and give less run-off etc. in a way that is likely to make the whole system rather less leaky overall (for light, water and nutrients - see Huxley, 1980a). It may also make better and more timely use of small, but vital additions of water and nutrients to the system. We will consider these and other factors, briefly, later on. However, we can appreciate that the alley-cropping system does not ensure anything like a continuous closed canopy, also it is doubtful whether much, if any, of this improved use of the environment has anything to do with "wonder trees".

The first lesson to be learn from the model is that we are much more likely to realize the full environmental and production benefits from

Type of System	Changes in Soil Fertility Potential (in kg maize ha^{-1} equivalents			Mixture (% of tree)				
		Crop	Tree	10	20	30	50	60
A. Crop decline rapid, tree a good soil improver	a) at start	1000	1000	-	-	-	-	-
	b) after 10 years	500	1500	600	700	800	900	1000
B. Crop decline cataclysmic, tree a remarkable soil improver	a) at start	750	750	-	-	-	-	-
	b) after 5 years	250	1500	375	500	625	750	875
C. Crop decline slow, tree only improves soil a little with time	a) at start	1500	1500	-	-	-	-	-
	b) after 10 years	1000	2000	1100	1200	1300	1400	1500

Table 4. Some simple, postulated "typical" examples of soil fertility changes under various proportions of a tree/crop mixture. Calculated from "Lanmodel" using only linear relationships (the model will handle curvilinear ones if they are known, or can be reasonably assumed, including curvilinear form for the response surface, see Huxley and Muraya in App.1.) In these examples a 20 to 30 per cent tree cover will not, in most cases, anywhere near maintain soil fertility at its original level. The model assumes a mixed intercropping situation, but even if all the plant residues from the hedgerow space were to be moved into the 'alley' (and the areas occuped by each adjusted accordingly) achievement of sustainability of crop yield would necessitate a greater degree of benefit from the mixture than that obtaining from a linear response.

various forms of agroforestry if we begin to know more about the processes involved, rather than merely pin our faith on a favourite multipurpose tree species, or just copy systems which seem to work in some other region.

Another computer model ("SCUAF") predicting the changes in soil carbon under different landuse system is now also available (Young et al.; 1986). This can also be used to test the kinds of hypothesis outlined above.

Pastures and perennial grasses as soil improvers

The current interest in woody plants should not cause us to neglect the decades of research done on tropical grasses and grass/legume mixtures. To give but one example, information is available about the effects of legume-based pastures on the properties of tropical soils (e.g.Sanchez, 1982 - reporting on CIAT's Tropical Pastures Program). Well-managed pastures (on an Alfisol) maintained soil organic matter over 16 years at the same level as before clearing rainforest or, at two other sites reported,they increased soil pH from 4.5 to 6 - 7, eliminated Al-toxicity and maintained Ca, Mg, nitrogen and organic matter at fairly high levels for some 13 years "with only minimum additional fertilizers".

Grass strips have often in the past, of course, been advocated as soil - maintaining features, but less emphasis has been put on their use as providers of plant residues for mulch in spatially-seperated cropping systems. Certainly the maintenance of grass strips is sometimes difficult and/or arduous; and they can get very weedy; but then so can woody hedgerows.

The biomass production from pastures can be similar, in the early years at least, to that produced by any other vegetation from a particular site. However, one of the problems of comparing the productivity of woody and herbaceous plant associations e.g. from world biomass data, is that for our purposes the data need to be from areas with identical soils and climates, and I have not been able to find any example in the literature where this has been the case.

From a theoretical point of view, as Kira and Kumura (1983) state, "forest communities tend to have greater gross production (i.e. dry matter accumalation) rates than their herbaceous counterparts in the same natural environment, owing to the greater leaf area held by their canopies. Smaller leaf area indices and lower rates of gross production are characteristic of natural herbaceous communities, but this drawback is counterbalanced by larger values of net production: gross production ratios which are the outcome of the smaller portion of supporting tissues in the total community biomass".

Whilst the theoretical possibility that either tree or grass communities have the greater potential for biomass production is important to pursue, in practice other considerations are like to be overiding. The summaries of data on biomass production of different types of vegetation are not, indeed, particularly helpful. The often quoted table from Leith and Whittaker (1975), or the more recent detailed review by Leith (1978) show greater maxima for tropical evergreen forest than for tropical grasslands, but the range of values for these, and other types of plant communities, are very wide indeed (as we might expect). Because of the greatly differing strategies that plants adopt in order to establish themselves in any particular ecological niche, individual tree and grass species have to be considered very much on their merits for a place in any man managed system. So, in practice, we will find that particular species of trees/shrubs may or may not be better, on any particular site and for any particular purpose, than particular species of perennial grasses. The important issue is not to ignore the possibilities of either.

We can however, remark on some rather obvious and fundamental characteristics when comparing trees/shrubs and perennial (herbaceous) grasses that will directly affect our choice of one or the other for an agroforestry system. Some of these we know more about than others. Below ground trees and shrubs (unless vegetatively propagated) will often possess a tap-root as distinct from a fibrous (monocotyledonous) root system. Although this will not, as mentioned above, necessarily make them deeper-rooted than a suitably-adapted perennial grass species.

Certainly, some grass species on particular soils have been shown to be very deep rooting indeed (e.g. Pereira et al, 1967, found that a Cynodon dactylon pasture depleted soil moisture to wilting point to a depth of 10 feet each year on a high altitude Kenyan site). And we should not just assume that trees exploit a deeper soil profile than grasses.

Second, and most important, as leaves are organs of aggression in the competitive plant world, many tree or even shrub species can, eventually, produce a canopy above that achievable by grass species. They will also, in general, age less rapidly (depending very much on the species), and their phenological behaviour can be such that leaf growth, leaf duration, and flowering and fruiting processes can occur and be differently spread (cf grasses) over parts of a single season, or even occupy several seasons. Thus their whole pattern of resource use and especially the uptake and distribution of nutrients, and even their water-use strategies (Helsa, et al., 1985), can be different from that of grass species, or of the grass communities surrounding them.

Indeed, trees and shrubs lend themselves to a much wider range of manipulation than perennial grasses, and it is this that makes them particularly useful in agroforestry intercropping situations. Provided, that is, that we fully understand exactly how it is we need to manipulate them in order to optimize outputs of products or services.

In conclusion, we can say that in order to make a wise choice of alternatives when considering plant species for mulch production and/or soil improvement the existing information about the use of grass species must not be ignored. There is, indeed, a wealth of knowledge about deep-rooted, perennial fodder grass species that can be used in exactly the same way as hedgerows, and the comparisons need to be made.

Some effects of crop residues for mulch or for soil incorporation

Mulch/Litter/Green manure

As the addition of plant residues is probably a key factor in the success of hedgerow intercropping I want to spend some time on the topic. The importance of plant residues in enhancing yields and improving soils in the tropics has been fully recognised of course (e.g. Lal, 1975). Various materials including woody residues, are often relatively easily available close to tropical cultivated lands yet, certainly, woody mulch is not consistently used by tropical farmers - and perhaps we should ask ourselves why? (Huxley, 1983a).

Kang *et al* (1981) give an evaluation of leucaena prunings as a nitrogen source for maize, and reached the conclusion that they are more effectively used when incorporated into the soil. Probably due to some N loss by volatilization when they are applied on top. Organic carbon compounds have a high variable (pH-dependent) charge (Mehlich, 1960), and so can be important in binding cations which remain readily available to plants. Thus soil organic matter can enhance the number of nutrient transfer sites proximal to fine roots, and this is probably as important as the actual amounts of plant nutrients held.

The results of 3 year's trials comparing applications of mixed grasses or mulch for woody species (cut from nearby "bush") at Morogoro, Tanzania, indicated little difference in the benefit to maize or sorghum yields between the two (see Table 5). But residues from particular species of either grasses or woody perennials can affect the outcome in markedly different ways (see photos of tea surface root systems grown under 6 different grass species in Willson et al, 1975). The degree of lignification is one factor that will certainly influence the rate of residue decomposition (see Figs. 7 and 8) and hence the availability and kinds of degradation products.

Green manuring as well as mulching (mainly with grasses) has been advocated for the amelioration of degraded tropical soils (e.g. Sanchez, 1976). Green manuring more for increasing available soil nitrogen (if its C/N ratio is low enough) rather than to enhance soil organic matter levels (Russell, 1973).

Cover crops (e.g. "live mulches") could well be used to enhance the "tree fallow" stage of rotational alley cropping schemes (see Fig. 16 below). Watson (1983) records the success, and gives details, of the use of legume cover crops (e.g. Pueraria phaseoloides) in rubber and oil palm in Malaysia (and see Weng, et al., 1979). Both commodity crops grew better along with the legume cover crops which, after about 5 years, died out as the tree canopy closed; although their beneficial effects lasted up to 10 years. With arable crops, competition for nitrogen can occur, however, (see e.g. Mulongoy and Akobundu, 1984). The labour-free elimination of the cover crop under tree stands is an

Table 5: Experiment 1. 1975-1977. Effect on maize yield (kg ha^{-1} at 12% m.c.) of grass or woody mulch applied either (a) at the beginning of the rainy season or (b) both then and two or three weeks later.

– from Huxley, 1980b

Mulch treatment		1975			1976			1977	
– Nil –		1089			2103			2503	
Grass (a)	1600	1521		2885	2862		272[illegible]	2702	
Grass (b)		1679			2908			2741	
			1511			2737			2789
Woody (a)	1422	1493		2588	2487		2857	2785)	
Woody (b)		1351			2689			2929	
S.E. of a Mean (Single treatment)		± 83.3			± 94.8			± 97.0	

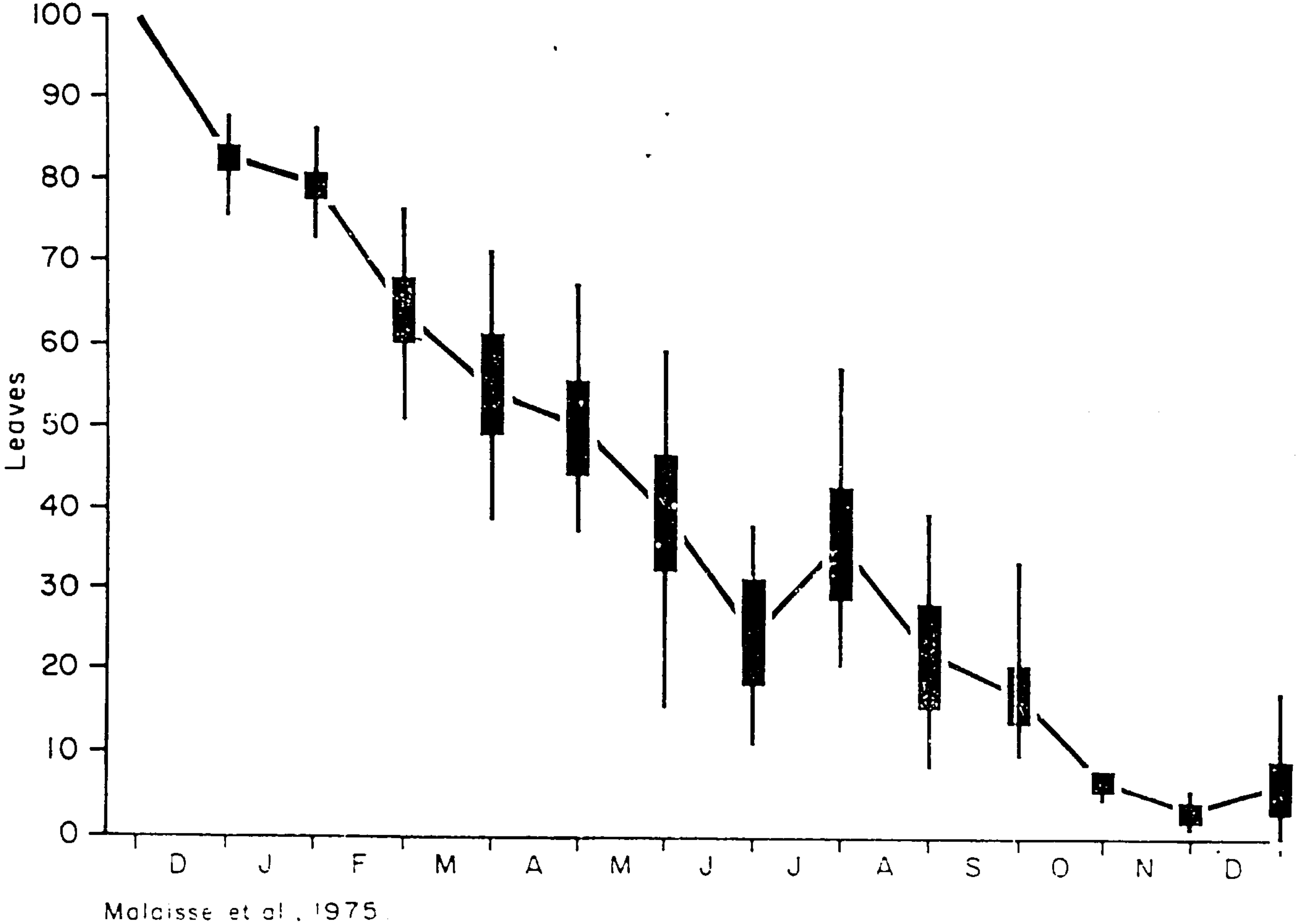


Fig. 7: Breakdown of leafy litter in a miombo (Brachystegia) woodland site with time.
- From Malaisse et al, 1975 by kind permission of Springer-Verlag.

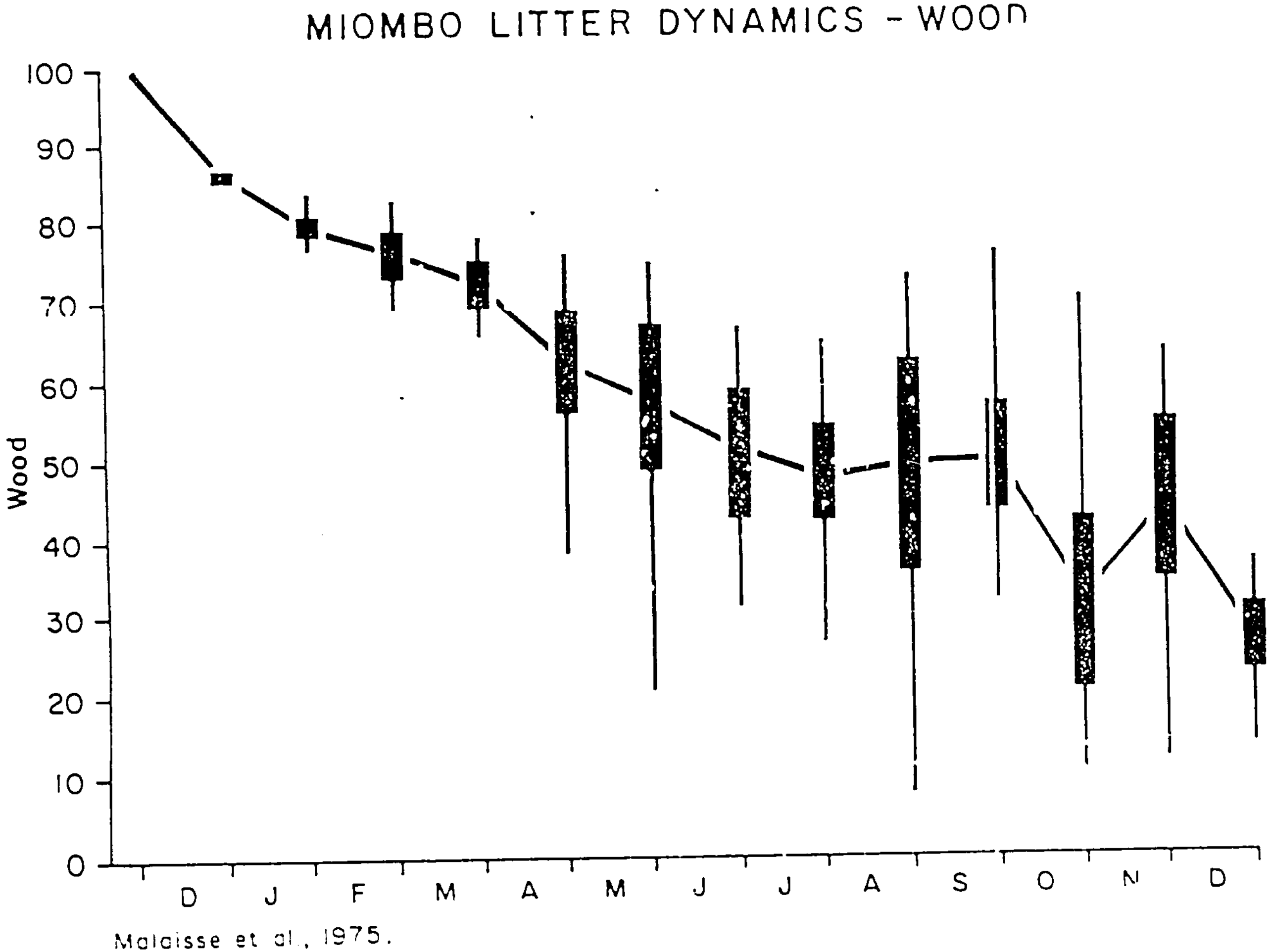


Fig. 8: Breakdown of woody litter in a miombo site with time.

- From Malaisse *et al.*, 1975 by kind permission of Springer-Verlag.

important issue, as eliminating and incorporating them is what has often prevented their more widespread use in arable systems. Cover crops can readily provide up to 10 ton ha $^{-1}$ d.m. or more in the first year, and minimum or zero tillage soil management combined with addition of some form or another of crop residue has proved highly successful in many cropping situations in the tropics (see Wilson, 1979; and other papers in Lal (Ed) 1979b). Dommergues (1981) points out that green manuring is the most efficient way of transfering N_2 to the soil as long as the N_2-fixing system is very active with, consequently, a minimum period needed for the growth of the green manure (cover) crops.

Mulching and cover crops are often claimed to suppress weeds (e.g. Weerakoon and Senerivatne, 1983), but the effective suppression of weeds by mulches obviously depends on many factors: climate, soil, weed seed "load" in the soil, weed species, amount and kind of plant residues applied (and if weed seed free), and time of application. Grass residues, especially, may introduce weed seeds and woody mulch materials do not normally introduce this hazard but, structurally, they form a less compact mulch cover if twigs are used, and so are less effective at weed suppression (Huxley, 1983a).

Mulching can be effected by using plant residues in situ, in which case the amounts applied are limited to the biomass present in the non-harvested residues, and/or it can be a process of "borrowing" plant biomass from adjacent areas (in hedgerow intercropping, from the tree rows). The variable results that Lal (1979a) obtained in one of his earlier general trials that involved several crop species and a range mulches (some inert), and of type of seed bed preparation (see Table 6), illustrates the need to investigate more precisely, and certainly more widely, the factors involved in the physical and chemical changes that occur in mulched soils. For example, the beneficial effects of mulch on reducing adversely high topsoil temperatures in the tropics have been investigated at IITA (Fig. 9). Many practical field trials as well as critical investigations under careful controlled conditions (e.g. Ong, 1983) have shown the advantages of limiting high soil temperatures, especially for grain legume crops (e.g. Fig. 10 for cowpea). The influence of residue mulches (and tillage) on soil structure and infiltration rate (Lal, 1978) have also been studied at IITA indicating that levels of 4 to 6 ton ha^{-1} (with no tillage) were effective.

Some possible adverse effects of applying plant residues must not be overlooked. For example, allelopathic reactions (e.g. Brunig and Sander, 1983; Cheng, 1983) and the possibilities of waterlogging, even for transitory periods, where deep layers of mulch are used in high rainfall areas on heavy soils (Koslowski, 1984).

An example from the Amazon

On an Amazonian Ultisol Wade and Sanchez (1983) have reported that mulching, with *Pueraria phaseoloides* and *Panicum maximum*, had little effect on increasing the availability of N.K.Ca and Mg. And the use of mulches (8 tons per hectare of green materials), without extra chemical inputs, produced 80% and 70% (legume and grass, respectively)

. Table 6:

Crop response to mulches and methods of seed bed preparation

(a) First season 1977

Treatment	Maize	Cowpea	Soybean	Cassava
	----------	---------- t/ha	----------	----------
Black plastic	5.35	0.64	1.93	-
Clear plas'ic	4.73	0.67	1.23	-
Straw mulch	6.90	0.73	1.73	-
Ridges	4.85	0.46	0.23	-
Bare flat	5.50	0.62	1.60	-
Aluminium foil	6.53	0.85	2.10	-
LSD (.05)	1.32	0.26	0.67	

b) Second Season 1977

Treatment	Maize	Cowpea	Soybean	Cassava
	----------	---------- t/ha	----------	----------
Black plastic	2.18	0.60	1.30	7.9
Clear plastic	2.33	0.76	1.32	9.7
Straw mulch	1.93	0.38	1.57	8.6
Ridges	1.73	0.45	1.41	2.3
Bare flat	1.55	0.60	1.50	3.2
Aluminium	2.43	0.65	1.46	1.1
LSD (.05)	1.05	0.38	0.36	2.9

- from Lal, 1979

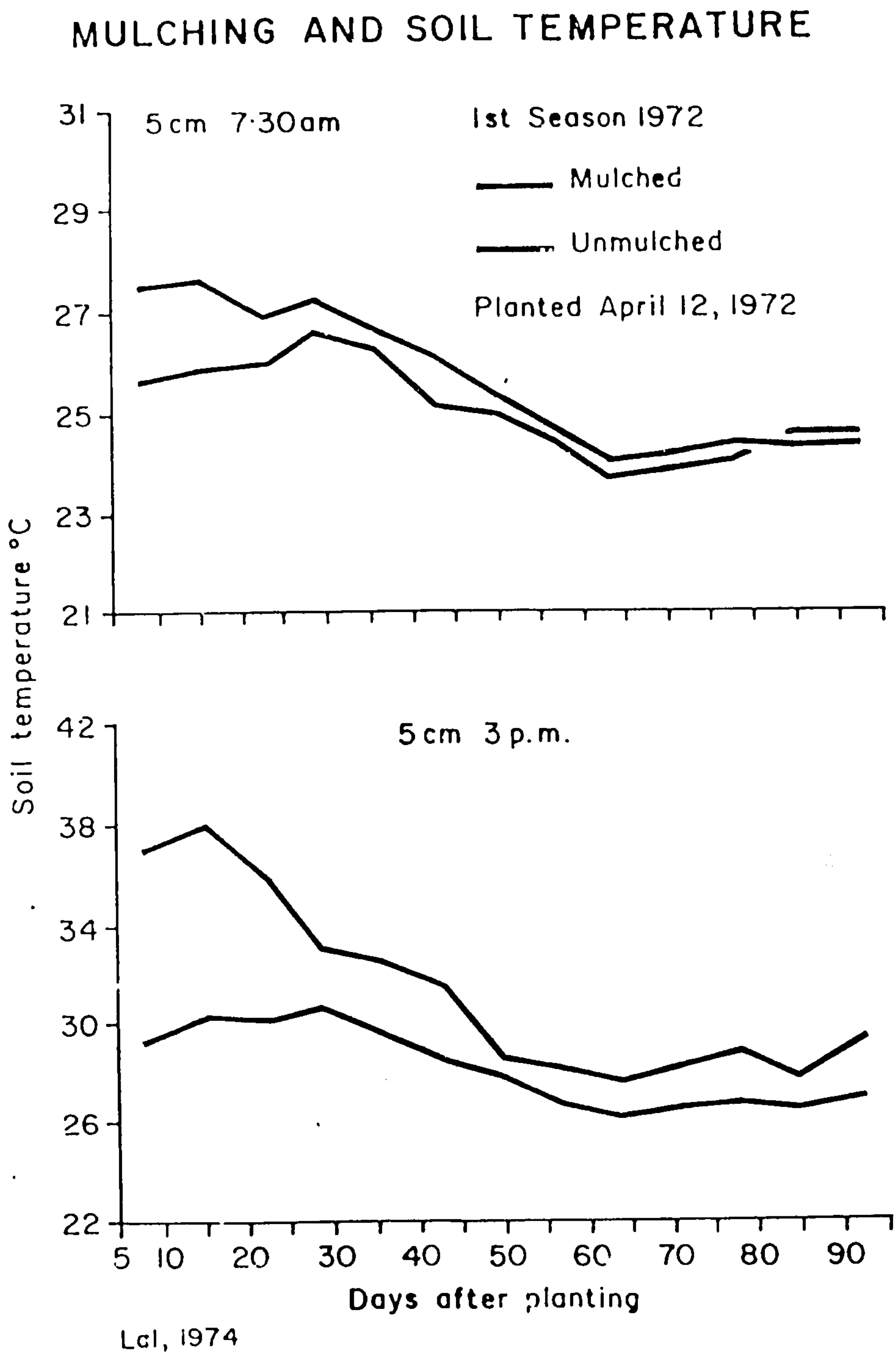


Fig. 9: Effects of mulch on soil temperature at 5cm depth (Nigeria, IITA).

Reproduced by permission from:

Lal, R. 1974. Soil temperature, soil moisture and maize yields from mulched and unmulched tropical soils. Plant and Soil, 40, 129-143.

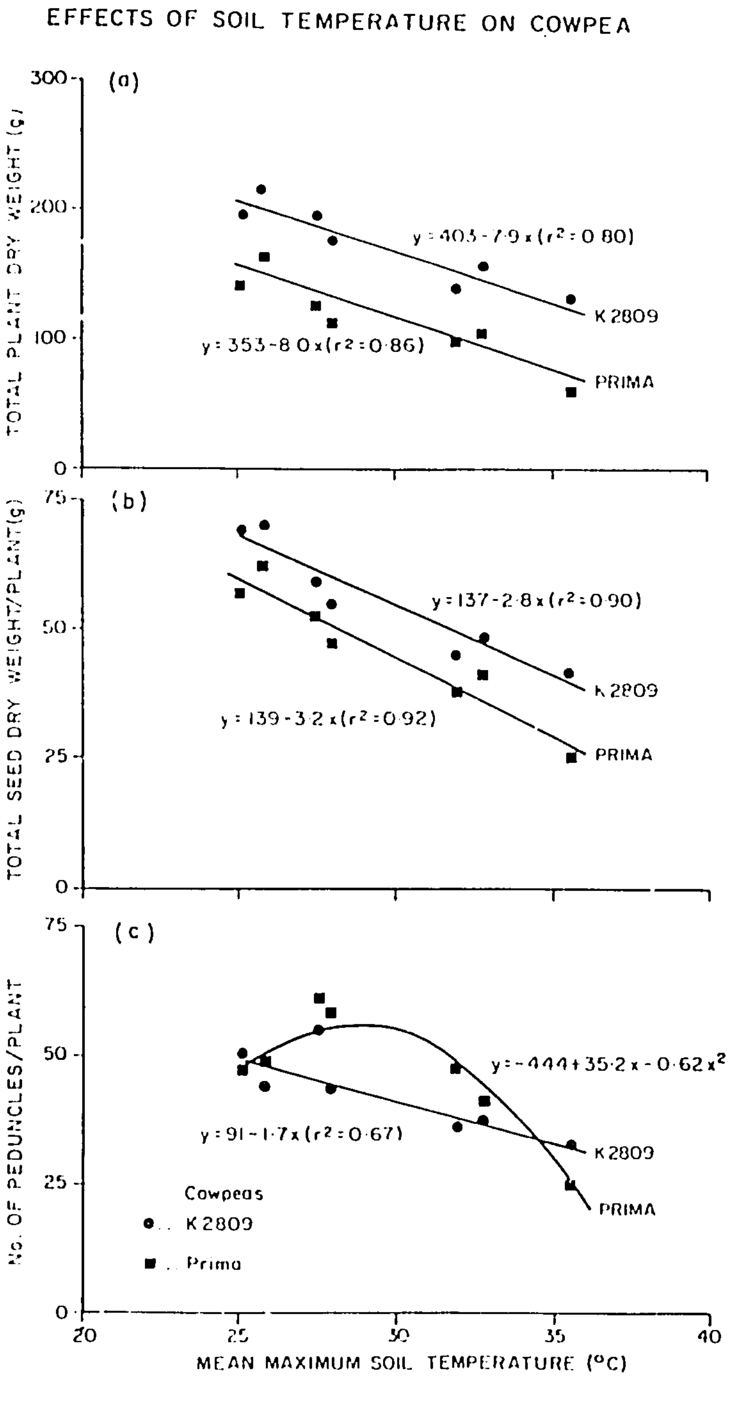


Fig. 10: Effects of soil temperature on cowpea cv. K2809.

Reproduced by permission from:

Minchin, F.R., Huxley, P.A. and R.J. Summerfield, 1976. Effect of root temperature on growth and seed yield in cowpea (Vigna unguiculata). Expl. Agric. 12, 279-288. Cambridge University Press.

of the crop yields achieved with completely fertilized bare plots (originally cleared from secondary forest and 5 consecutive crops taken in 21 months). Incorporating the residues gave better results (90%) for the legume, but still only 70% for the grass mulch (see Fig. 2, above).

On Oxysols and Ultisols (acid soils with low clay activities) in the Amazon the utilization of compost from crop residues, e.g of Pueraria phaseoloides as incorporated green manure, resulted in crop yields being maintained at 80% and 100% of that using complete fertilizer (Bandy and Nicholaides, 1979; and Wade, 1978; respectively); although compost alone required additional K fertilizer after the sixth and subsequent crops. Alternatively, rotations with a Pueraria phaseoloides fallow (1:1 or 2:2) slashed or burnt in situ, with some additional K fertilization, is suggested as a successful yield-maintaining treatment on these soils. (Bandy and Sanchez, 1981).

Mulch and Coffee

A review of early mulch literature, and a report of the results of three experiments with mulched young arabica coffee (corral compost or grass) on a fine sandy loam in Brazil, are reported by Medcalf (1956). Linear yield improvement and leaf P content occurred with increasing amounts of mulch applied, and three and a half times more roots were found under mulch (top 10 cm) than in bare soil. In the latter, the roots found were brown and suberised.

The effects of using grass mulch (mainly *Pennisetum purpureum* K. Schum) on coffee (*Coffea arabica* L.) in East Africa has been reported from various studies which go back over 40 years (e.g. see Bull, 1963 for early work). In Kenya's East Rift Coffee growing areas the application of mulch (about 18-20 t ha^{-1} yr^{-1} of air dried materials) to alternate inter rows, an established practice, has been shown to result in increases in both yield and quality (Table 7). The former varies with rainfall regime, state of weediness etc., but can often exceed yield increments of over 30 percent or more. Improvements in quality of the coffee "beans" (seed) are related to a number of factors, including an increase in the proportion of larger beans, indicating an improved plant water status during the critical seed-swelling period (Cannell 1974 - see Figs. 11 and 12).

Improvement in rainfall infiltration rate and soil structure were reported by Jones (1950) with an increase in the depth of rainfall penetration (Pereira and Jones, 1954). Topsoils remained wetter for longer under mulch as compared with unmulched soils (Blore, 1964).

These results have been paralleled by similar studies elsewhere in the world. For example in Nigeria, Lal (1974) recorded about 4 cm of extra water retained in the top 20cm of soil under mulch (Table 8), i.e. in the crop rooting zone. In sunny weather this might extend the period during which the crop remained relatively free from water stress by some 6 or 8 days. Important, of course, but perhaps of equal consideration is the likely beneficial effect on plants of enhanced nutrient uptake during this period (e.g. Table 9).

Table 7:

Effects of mulch and nitrogen fertilizer on the yield of arabica coffee. (Mean of 1959-1980)

	-N		+N	Mean
a) Yield of beans ($kgha^{-1}$)				
- Mulch	916		1258	1087
		± 69		± 49
- Mulch	1262		1473	1367
b. Grade 'A' beans(%)				
- Mulch	59.2		55.5	57.4
		±1.6		±1.2
+ Mulch	64.1		62.3	63.2

L.S.D's (P=0.05) shown as appropriate.

- from "Results of Field Experiments -1980/81, CRS, Ruiru, by E. Mwakna and J.M. Kiara. 1982

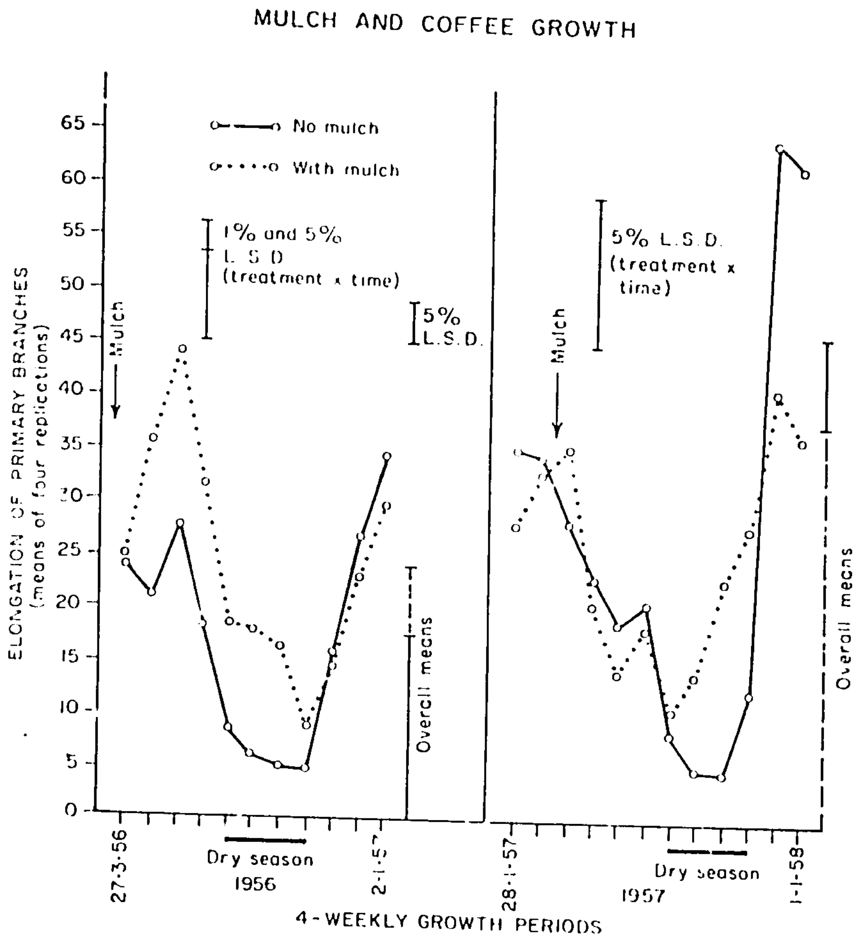


Fig. 11: The influence of mulch on the growth (elongation) of arabica coffee primary shoots.

Reproduced by permission from :

Robinson, J.B.D. and P.H. Hosegood, 1965. Effects of organic mulch on fertility of a latosolic coffee soil in Kenya. Expl. Agric. 1, 67-80. Cambridge University Press.

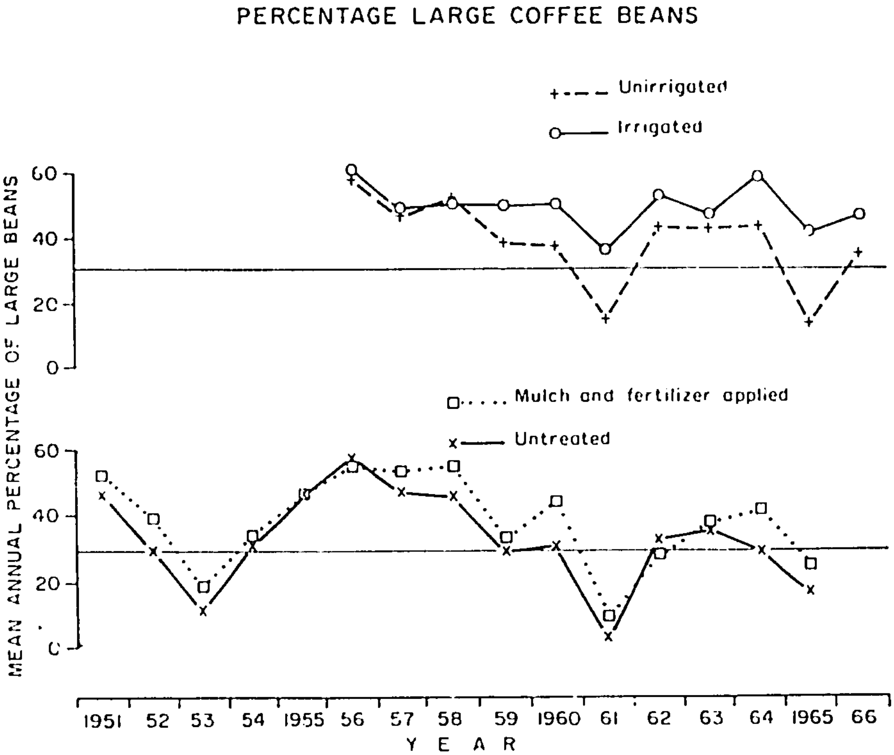


Fig. 12: Yearly variation in the proportion of "Grade A" arabica coffee beans at Ruiru, Kenya, as affected by irrigation (above) and mulch (below).

- From Cannell, M.G.R., 1974. "Factors affecting Arabic Coffee bean size", J. Hort-Sci. 49, 65-76.

Table 8:

Increase in soil moisture of mulched over unmulched plots

Depth (cm)	cm of water		
	1st Season 1971	1st Season 1972	2nd Season 1972
0-10	2.26	3.24	1.12
10-20	2.11	1.22	0.70
Total	4.37	4.46	1.82

Reproduced by permission from:

Lal, R. 1974. Soil temperature, soil moisture and maize yields from mulched and unmulched tropical soils. Plant and soil, 40, 129-143.

Table 9:

Mean root length and rates of nutrient uptake per plant (umol day^{-1}) Pearl millet.

Days after sowing	Mean root length (m)	Nitrogen		Phosphorus		Potassium	
		Dry	Irrigated	Dry	Irrigated	Dry	Irrigated
0-13	0.2	49		1.4		8.2	
13-26	27	475		19.9		152	
26-33	84	651	1033	24.2	43.5	150	371
33-40	125	507	798	0.7	23.7	117	353
40-47	134	121	374	-7.7	4.3	-63	180
47-54	129	187	169	1.0	17.0	116	64
54-61	125	-169	10	8.7	22.7	-69	9.8
61-68	121	2	-94	3.8	10.0	81	79
68-75	117	-53	-54	-0.5	2.1	6.4	21
75-82	113	-272	-46	-3.9	-7.6	-32	-2.9

Reproduced by permission from:
Gregory P.J., 1979. Uptake of N,P and K by irrigated and unirrigated pearl millet (*Pennisetum typhoides*) Expl. Agric. 15: 217-223. Cambridge University Press.

In an experiment using 32P as a tracer to study seasonal changes in Arabica coffee root activity at different levels in the soil (Huxley, et al, 1974), very high concentrations of labelled P were found in ovules and young developing fruits. Cannell and Kimeu (1971) also found that flower buds took 39 percent of the P increment during one flowering period in the hot, dry season. This represented only quantitively small amounts, but a critical need for readily-available P at this time of rapid cell division can be postulated as a pre-requisite for adequate fruit set. There are likely to be numerous other critical demand periods for specific nutrients (or combinations of nutrients) for particular sinks in the plant which will be more likely to be satisfied by the enhancement of soil water status (and topsoil temperatures) which mulching affords. The kinetics (Cooke, 1966) of P supply under mulch certainly need much more attention.

If mulch tends to prolong a satisfactory topsoil water status, the mineralization of nitrogen which occurs when many tropical soils are wetted after a period of being dry (e.g. Birch, 1960) will be reduced. However, the additional quantities of nitrogen being added by the mulch itself probably more than make up for this.

The results of 11 years of mulch application on soil characteristics, as well as a summary of the work of H.C. Pereira and others, is given in Robinson and Hosegood's paper (1965). On a Kikuyu red loam soil regular annual applications of Pennisetum purpureum mulch resulted in very significant increases in total pore space, free draining pore space, rainfall acceptance and the quantity of stored water held in the topsoil. The greatest effects of mulch on soil chemical differences was to decrease soil acidity and greatly increase the level of exchangeable K and P. Exchangeable Ca and Mn were actually leached in these long term trials, and exchangeable Mg increased in the topsoil but decreased deeper in the profile due, perhaps, to increased leaching and/or mobilization. Nitrogen and organic carbon were greatly increased. But some earlier studies (Robinson, 1961a & b) showed that topsoil nutrients levels after fertilizer application were much lower under mulch than in bare soil and, if mulch was present, a split N-fertilizer application was more efficient than a single one.

The application of mulch can markedly affect the level of different elements in various parts of the coffee tree. Leaf nitrogen, for example, was higher over an entire season, especially during drought periods, and leaf P and K levels were also substantially higher in mulched coffee. Leaf Mg and Ca were actually decreased, but the reduction in Mg in this case was probably due to the unbalanced K/Mg ratios brought about by the excessive amounts of K in Pennisetum purpureum (some 2 to 4 times that normally found in leaves). Mulch had a considerable effect in increasing K and P levels on both soil and plant.

There is a much more extensive and active root system in topsoil where coffee is mulched (Bull, 1963); and see Medcalf, 1956, above). Also using soil cores Thomas (1939, reported in Medcalf, 1956) measured the amount of Robusta coffee roots in the topsoil (3 inches depth) and found, similarly, three and half times more under mulch than in bare soil. Such improvements in root density have been reported for many other crops, and they can result in, for example, enhanced uptake of

P (e.g. for tea, Willson, 1974). Again, the data in Cannell and Kimeu (1971) indicate the importance of active fine root growth for efficient P uptake. They investigated the uptake and distribution of macro-nutrients in Arabica coffee, from growth analysis studies on whole trees, which showed that root absorbtion efficiency for P, and actual P uptake, were related to the period when fine roots were growing most vigorously, rather than to growth of the aerial parts, as other nutrients were.

The work of Robinson and Hosegood with Arabica coffee was accompanied by micro-plot trials using tomato seedlings as an index plant, which clearly showed the long-term improvement in soil fertility. And by measurements of primary shoot elogation which, especially during the course of the dry season, re-emphasizes the short-term benefits conferred by mulch (see also Fig. 11). What may be equally important is that the kind of roots (including their ability to extract water and nutrients) will change (e.g. see Sharma and Ghildyal, 1977, for example).

In general, and as expected, all the work on mulching coffee has shown that results are greatest when it is applied to poorer, more eroded soils, where rainfall is lower or more erratic, and where a weed-suppressing function is needed. Mulching, generally, counteracts the adverse effects of continuous tillage required to obtain control of weeds (Blore, 1965).

In Tanzania, Robinson and Mitchell (1964) have also reported the results of mulching Arabica coffee annually with the equivalent of 10 tons per hectare of banana trash over an 18 year period. This is for a relatively fertile, high rainfall (1500mm) area. And yet mulching was still highly favourable. The effects of mulch on the root system in this experiment were reported by Bull (1963).

The general coffee culture trial at the Coffee Research Station, Ruiru, Kenya, was started in 1957. This was a 2 x 5 factorial investigating the effects of N-fertilizer, weeding, irrigation, pruning and mulch on both yield and quality. Weeding and irrigation were suspended in 1976 but the other treatments have continued. The greatest response has been to mulch (alternate inter-row application of Pennisetum purpureum each year) and N. fertilizer. The results are given in Table 7. Although mulching increased the proportion of large (Grade "A") beans, N-fertilizer had an adverse effect on bean size.

Where woody plants are grown for fruits/seeds there can be complex interactions between, for example, P nutrition and changes in soil (and hence plant) water status as brought about by mulching, and this makes the effects of the latter more difficult to evaluate. For example, in an experiment with Arabica coffee treated for 10 years at Ruiru, Kenya, with either ground-applied P (as single superphosphate at 0,196,392 and 785 kg P ha^{-1}), foliar applied P as bi-monthly sprays of 0.28% Phosphoric acid) and Napier grass mulch (Michori, 1982; Michori and Kanyanja, 1985), mulch treatments consistently improved yields and leaf P, effectively raised soil reaction, but increased the amount of soil absorbed P only slightly (indicating that this treatment had not increased soil P effectively). Soil absorption of P was lowest in mulched treatments, suggesting that decomposition of the mulch had reduced or blocked soil absorption sites for P but mulch + ground-applied P did not have an additive effect on soil P desorbtion/absorption, nor did ground applied P and mulch show any statistically positive interaction for yield. Topsoil treatments had little or no effect on subsoil P availability. The best treatments (in terms of yield and leaf P) were obtained by P applied both to the ground and to the leaves in the presence of mulch.

Finally, we should remember that flowering plants have not one but several forms of symbiotic association with micro-organisms and these can be encouraged by mulching. Daft et al., (1985) have recently summarized what is known about these associations. At least four tri-partite associations have been recognised with higher plants; endomycorrhizas + Rhizobia; endomycorrhizas and actinorrhizas, (important, for example, with Casuarina spp); ectomycorrhizas + actinorrhizas, and endo-ectomycorrhizas + actinorhizas. Nitrogen can be accumulated in a system by asymbiotic processes, of course, but the re-cycling of P so that it is more efficiently used in the system by flowering plants can be greatly enchanced by some form of mycorrhizal and/or actinorrhizal association. Endomycorrhizal + Rhizobial associations have been found to increase plant growth more efficiently than Rhizobial associations alone, and this could have important practical applications with regard to the beneficial effects of mulch.

Litterfall from coffee and cocoa plantings

Beer (1985) has recently summarized the relative importance of organic matter inputs, nutrient inputs and litterfall for shaded plantations of coffee and cocoa in Costa Rica. Erythrina poeppigiana pruned two or three times a year can return to the litter layer more nutrients than the highest recommended annual rates of inorganic fertilizers; that is some 400kg N; 30kg P, and 100kg K (and see also Russo and Budowski's (1986) results in Tables 10a, b and c.). This is close to the level of these nutrients stored in the above-ground biomass. Cordia alliodora (a timber/shade tree which is removed, ultimately) returns 30% of the N, 18% of the P, and only 12% of the K (Fassbender et al. in Beer, 1985). Pruning of E. poeppigiana provides at least 50% of the total crop and tree litterfall in these coffee plantations; and release of P and K from decomposing litter is said to be faster than the release of N (quoted by Nye & Greenland, 1960).

Beer emphasises the value of large amounts of litter from shade trees, which provide a range of nutrient elements, and suggests that the research emphasis on N-cycling may be exaggerated. A high biomass productivity under intensive pruning may be a more important characteristic. To this might be added a more critical appreciation of the importance of litter on soil physical conditions for any particular site/crop associations, and the selection of tree species with high leaf levels of the nutrients that are required (e.g. high Ca in Gmelina arborea etc.) If we just remember the outcome of much agricultural research on various cropping systems (e.g. Sanchez, 1984)

Table 10a

Nutrient content (%) of pollarded biomass of *Erythrina poeppigiana* by pollarding frequency in Turrialba, Costa Rica

Pollarding frequency	Branch part	N	P	K	Ca	Mg
4 months	Leaves	2.82	0.20	1.25	1.47	0.35
	Branches	1.16	0.14	1.18	0.70	0.33
	Ratio	3.3:1	1.3:1	1:1	2.1:1	1:1
6 months	Leaves	3.60	0.18	1.22	0.94	0.35
	Branches	1.08	0.13	1.15	0.60	0.32
	Ratio	3.3:1	1.4:1	1:1	1.6:1	1.1:1
12 months	Leaves	3.35	0.18	1.16	1.52	0.46
	Branches	0.84	0.13	0.60	1.15	0.27
	Ratio	4:1	1.4:1	1.9:1	1.3:1	1.7:1

- from Russo and Budowski, 1986.

Table 10b

Estimation of total nutrients recycled from pollarded biomass and fallen leaves from *Erythrina poeppigiana* trees, planted at a density of 280 trees/ha corresponding to a spacing of 6m x 6m, with three pollarding frequencies, in Turrialba, Costa Rica.

Component	Pollarded biomass (kg/ha/yr)			Fallen leaves (kg/ha/yr)			Total recycled (kg/ha/yr)		
	1 poll.	2 poll.	3 poll.	1 poll.	2 poll	3 poll	1 poll.	2 poll.	3 poll.
Dry matter	18,470	11,800	7,850	4,280	1,914	-----	22,750	13,714	7,850
Nitrogen	237.2	227.6	173.0	93.3	41.7	-----	330.5	269.3	173.0
Phosphorus	26.0	17.9	13.6	6.4	2.9		32.4	20.8	13.6
Potassium (K)	130.0	138.4	118.9	25.4	11.5	-----	155.7	149.9	118.9
Calcium (Ca)	224.7	84.0	88.4	94.2	42.1	-----	318.9	126.1	94.2
Magnesium (Mg)	56.1	38.0	26.7	30.0	13.4	-----	86.1	51.4	26.7

- from Russo and Budowski, 1986

Table 10c

Biomass and nutrient content (kg/ha/yr) of pollarded biomass of *Erythrina poeppigiana*

	Total Biomass	N	P	K	Ca	Mg
			(kg/ha/year)			
1 pollarding per year						
Leaflets	2.260	94.9	4.1	26.2	34.4	10.4
Petioles	1.010	14.9	1.8	11.7	15.4	4.7
Branchwood	13.370	80.2	16.0	80.3	153.8	36.1
Bark	1.830	47.2	2.2	11.8	21.1	4.9
Total	18.470	237.2	24.1	130.0	224.7	56.1
2 pollardings per year						
Leaflets	2.710	121.3	5.3	33.1	25.5	8.9
Petioles	1.190	18.3	2.2	14.5	11.2	3.9
Branchwood	6.790	52.9	8.9	78.1	40.7	21.6
Bark	1.110	35.1	1.5	12.7	6.6	3.6
Total	11.800	227.6	17.9	138.4	84.0	38.0
3 pollardings per year						
Leaflets	3.045	116.3	6.1	61.2	44.8	10.6
Petioles	1.295	15.0	2.6	16.2	19.0	4.5
Branchwood	2.990	25.1	4.2	35.5	20.9	9.9
Total	7.850	173.4	13.6	118.9	88.4	26.7

- from Russo and Budowski, 1986.

the importance of plant residue for improving the physical conditions of the soil under long term cropping needs no emphasis. Litter is of more particular importance in mixed, multi-storey agroforestry systems than in alley cropping but, if the top canopy can be regulated (by choosing appropriate species and by spacing) so as to allow enough light to come through, there might well be a place for having alley-cropping below a litter forming stratum of tall trees in high rainfall/high insolation areas?

Litter in the Miombo and elsewhere, and what about residues from roots?

A contrasting situation is to be found in miombo woodland in Southern Africa where - *Brachystegia* spp, *Julbernardia* spp. and other slow-growing Ceasalpineaceae are to be found over extensive areas on acid soils under one wet and one dry season per year.

Malaisse et al.(1975) found that, for their sites, the herb strata produced, on average, 3.2 t ha^{-1} yr of litter (largely burnt) and the trees/shrubs 2.9 t ha^{-1} leaves, 0.5 t ha^{-1}, fruit and about 4.5 t ha^{-1} of wood. Microflora/microfauna, termites and fire were major factors in litter decomposition with considerable differences shown by the litter from different tree species. Termites and fire (the former spatially heterogeneous and relatively non-active in the warm dry season) jointly accelerated litter decomposition by a factor of two.

In fact, termites can make up to more than 80% of the total soil animal biomass - in miombo about 22kg dry weight of termites per hectare. Under mulch the mass of soil animals and microflora/fauna will greatly increase. Estimates of around 2000kg ha^{-1} d.m. have been quoted for earthworms alone. Some biomass extracts from soil fauna are given in Table 11. This represents a considerable store of nutrients in the system but, more important, mostly around or close to the fine roots, as anyone observing roots in situ will know. For example, in the study made by Huxley and Turk, (1975) numerous fungal eating collembolla were seen round root-tips, as well as all kinds of other insects and insect larvae moving along and near to roots.

It is very difficult to find other than fragmentary records of the actual dry weight of soil fauna and/or microbial biomass in the soil. Most reports deal with kinds and numbers. Chemical composition is also omitted from agricultural and applied soil management literature (for example, see Swift et al (1979). That arable agriculture leads to an impoverishment of soil fauna compared with other type of systems such as grassland, forest etc. is well proven. (e.g. Russell, 1973, Swift, 1980, Ryszkowski et al, 1985; Karg, 1985, and other papers in Cooley (Ed), 1985). Even detailed work on termites (Lee and Wood, 1971; Roy-Noel, 1979) provide only scanty evidence on these aspects, and more specific summaries (e.g. Collins, 1983 on the utilization of nitrogen resources by termites) serve mainly to indicate the need to direct soil zoologists and ecologists to gather up what is already known and join forces to obtain a greater understanding of what is happening in applied agroforestry situations. Perhaps, in the first instance, we need to be less concerned with the enormous complexities of the population ecology/decomposition biochemistry aspects and

Table 11:

Some biomass estimations for soil fauna
(quoted in Lee and Wood, 1971 (*) and Russell, 1973)

Country	Type of soil fauna	Biomass Estimates (kg/ha^{-1})	References
Holland	large herbivores large decomposers small decomposers Predators	92 660 38 9 } 799	Macfadyen (1963)/ Drift (1951)*
Congo (miombo)	termites (subterranian and mound building)	110	Maldague (1964)*
Australia (Eucalypt.)	termites (mound building and others)	60	Lee and Wood (1963)*
Nigeria/ Cote D'Ivoire	termites	50-500	Sands (1965)* and Bodot (1967)
Nigeria	Earthworms	100	Madge (1965)
Uganda (various habitats)	Earthworms	0.6-455	Block and Banage (1968)
Denmark (various sites)	a) Earthworms b) All other animals	550-2000 (forest) 40-190	Bornebusch

concentrate on obtaining some simpler data on dry weights, chemical composition and the rates of change of these in relation to clearly stated field conditions?

As we know well, root growth can be greatly enhanced, where the activity of soil animals of one kind or another, has increased the number of soil passages (shown very elegantly by Edwards and Lofty, 1978). And this becomes particularly important in zero or minimum tillage systems.

Of the many papers on litter few present the situation to be found under single, well-spaced trees. The work of Kellman (1979) has been mentioned above as one example. A cautionary feature is the "evolutionary" scale with which such effects may take place. Furthermore, the assumption that all trees are effective at "pumping" nutrients from lower layers is probably a myth. For example, in wet highly acid subsoils (the Amazon region) we have little information about the rooting depth of particular woody species, even whether on some sites they are rooting in the deeper soil layers at all.

Certainly woody species vary a great deal in the ability to exploit the lower soil stratum. For example, as Kerfoot (1962) has shown in Kenya, tea (Camellia simensis) roots to a much greater depth than its associated woody shade species (e.g. Grevillea robusta), which is outstripped by a local grass (Pennisetum clandestinum). Furthermore, the normal tap-rooted characteristic of some woody species may be highly modified if this structure is removed in the nursery and/or plants are propagated from cuttings.

Finally, both rainfall and leaching of nutrients through the plant canopy provide important additions to the level of nutrients brought to the soil in forest (i.e. closed canopy) systems. A study of two types of rainforest in the Ivory Coast clearly shows the important part played in this process by canopy leaching (Benhard-Reversat, 1975 see Table 12). In wide-spaced zonal agroforestry systems that are regularly loped this effect will be greatly diminished, of course.

Some Conclusions

I would like to draw a few conclusions from this somewhat cursory glimse at the large amount of data on mulch and litter that is available. What of all this is particularly relevant to hedgerow intercropping? I suggest the following:

- There is absolutely no doubt about the effectiveness, in a vary wide range of soil type /climate combinations, of mulch used at quite substantial rates of applications (e.g. 10-20 t ha^{-1} air-dried material). This will actually improve a whole range of soil characteristics over time, even on a basically fertile soil (e.g. Kikuyu Red Loam). However, there is a clear indication that, with consistent crop removal (or removal of parts of the hedgerow biomass for fuel and/or fodder?) supplementary fertilization will be needed in most, if not all high output systems.

Table 12

Annual Amounts of nutrients brought to the soil and percentage of different parts

Site		N	P	K	Ca	Mg
Plateau	Total kg/ha/yr	258	9.8	85	97	91
	Rainfall %	9	14	6	22	4
	Leaching %	25	4	61	15	40
	Litter %	66	82	33	63	56
Valley	Total kg/ha/yr	246	24	264	135	90
	Rainfall %	10	6	2	16	4
	Leaching %	26	38	67	21	56
	Litter %	64	56	31	63	40

- from Bernhard - Reversat, 1975

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In the Banco Forest (Cote D'Ivoire); at two sites, plateau and valley; rainfall 1400 and 1800 mm. p.a. during study period (2 rainy seasons).

- Smaller amounts of mulch than this may still have some effect on physically poor and/or nutrient-depleted soils. And the same applies potentially to low as compared with high rainfall areas, but limits to hedgerow biomass production may then provide insufficient amounts of mulch to achieve any significant long-term results. This certainly needs testing in a wider range of environments then has been done so far.

- Although the short-term benefits of mulch have been clearly recognized they may, and especially where only small amounts of plant residues are available, and/or in increasingly drier areas, become the over-riding benefit to continuous-cropping schemes. There is plenty of evidence, when we look, to indicate a range of immediate plant responses to the effects of mulching (improved topsoil water release curves, reduced topsoil temperatures, more rooting in the topsoil, plant nutrients in more available forms as well as in larger quantities, greatly increased soil fauna etc. etc.). And these are clearly reflected in the kinds of plant responses that indicate benefits of this nature.

- Probably far too much emphasis on nitrogen has been made rather than on the balance of plant nutrients required for any particular soil/cropping scheme combination. In this respect, too much emphasis just on "nitrogen-fixing trees" may, in the long term, be counter-productive. Indeed, an appropriate "mix" of woody and other mulch materials is likely to be best, depending on the soil characteristics of the site.

- The nutrient additions in plant residues can vary very greatly according to the species mixture we are using. This provides both opportunities (i.e. to seek out and use woody species that "accumulate" the elements required), and limitations (we can 'unbalance' the soil nutrient status by continuing to apply a single type of plant residue which has an incorrect ratio of nutrients for the soil/crop combination for which it is being used).

- Although mulch (and especially the hedgerows themselves) will increase rainfall infiltration significally, "balance sheets" for water use in a system with hedgerows are needed. An increase in soil water storage because of improved infiltration could be more than offset by greater water use because of an increase in canopy coverage and/or duration (mainly because of the hedgerow). This can be mitigated during the critical crop-growing season, of course, by cutting back the hedge, but the hedge plants have to be allowed to grow some time (and hence use water) if appropriate amounts of biomass are to produced and/or they are not to be so severely restricted that they decline and die out.

- We need to know a great deal more than we already do about the decomposition of plant residues from the practical standpoint of how best to manage residues so as to benefit from them in agroforestry systems to the greatest advantage.

Much of the existing experimental work is of great practical importance (e.g. Swift et al. 1979; Swift, 1984), although there are two large "compartments" of organic carbon and plant nutrients, represented by the soil fauna and by the fine roots (+ root excretions?) of woody plants, that now seem as if they might be much more significant in the system's "budget".

o We need first to "model" this situation so as to be able to compare the potentials for agroforestry land use systems against what is already known for agricultural and forestry (see Young et al, 1986 for soil carbon), before embarking on large, costly field experiments. In particular, the rates and times at which water and various nutrients become available in relation to plant needs and rooting activity in mixed woody/non-woody systems must be better explored. Much of this work can be done with micro-plots.

o Finally, there have been no reports so far of benefits to hedgerows (in terms of yields of loppings) from their own residues being incorporated in the between-row soils, as compared with them being removed. This suggests that frequent lopping diminishes the differences from any other kinds of treatments (see the section on lopping, below).

C. SHELTER

This is another important subject, but space restricts what can be said here.

Shelter effects per se

There is a large and scattered literature on the whole subject of shelter, including "wind-breaks" and other forms of barriers that bring about a reduction of air movement, an increase in humidity and changes in ambient soil and air temperatures. All of these can have a range of possible primary and secondary effects on plant growth and development, from germination through to maturity. And they operate through a large number of complex factors affecting physiological processes e.g. leaf differentiation, water loss, photosynthesis, pollination/fertilization, and so on.

Various reviews (e.g. Sturrock , 1983) have indicated the very large benefits to be gained from shelter with various fruit, vegetable and agricultural crop species under particular sets of circumstances, with yield responses up to an order of magnitude being not uncommon.

Rather few data are available for the tropics, and what there is is often anecdotal. For example, Carr, 1972 (for tea), summarises reports on the benefit of increased humidity and of wind protection. And the detailed studies on the effects of shade and shelter on tea in

East Africa (McCulloch at al. 1974; Ripley, 1967) provide an excellent example of what is required to disaggregate the various factors involved.

"Shelter" effects may, therefore, be a much more important issue in hedgerow intercropping then we have assumed, and there is a need to continue to evaluate the effects of hedgerow orientation, and to devise some rapid assessments of the relevance of "shelter" to particular site situations.

Windbreaks

Windbreaks are being reviewed by ICRAF in terms of their usefulness as a potential agroforestry intervention (Darnhofer, pers. comm.) and will, therefore, not be further considered here, other then to raise one issue. The effectiveness or otherwise of windbreaks or shelterbelts is practically always evaluated in terms of the changes brought about on the yield of adjacent crops. An equally important factor, particularly for arid and semi-arid regions where their beneficial effects are likely to be greatest, is the change in water use at the site that will occur when woody perennials are established as windbreaks. Especially if these are rooting into a water table. Few accounts or reviews of windbreaks have, in the past, taken this into account, perhaps none?.

Environmental coupling and other matters

What is environmental coupling?

This subject applies more to the extent of any mutual sheltering effects of plants grown as associations, communities or separated to some degree. That is the ways in which their geometry affects the physical processes of transfer of mass (i.e. entities such as gases) or energy between the "crop" and the environment in which it is situated. "Coupling" describes, then, the degree to which two systems (e.g. a leaf and the surrounding air, or a plant canopy and the atmosphere above it) can exchange, for example, carbon dioxide or water through an appropriate set of physical conditions.The subject, despite its apparently esoteric nature, is relevant to our understanding of how to evaluate what is happening environmentally in hedgerow situations, so a brief discussion is in order. The physical concepts of how plants are "coupled" to their environment have been discussed by Montieth (1981) and have recently have been further explored by Jarvis (1985).

A crop is said to be "well-coupled" with the atmosphere above or around it if the boundary layer resistances to the transfer, for example, of energy (heat) or mass (carbon dioxide and water molecules) are small. This comes about if the canopy is aerodynamically "rough" i.e. tall, irregular, mobile when exposed to wind etc. On the other hand an extensive close-planted agricultural crop will be "badly coupled" with the atmosphere above it; this is because canopy resistances are much higher.

In practice this means, as Jarvis points out, that the main environmental driving variables (e.g. net radiation) and effective plant controls (e.g. stomatal resistance) to, say, either water loss from a canopy or canopy photosynthesis, will vary according to the degree of environmental coupling. Thus, water loss from a free-standing, single plant (herbaceous or woody), which is extremely-well coupled with its environment, will be imposed not mainly by net-radiation income (the "equilibrium rate") as it is in a close-planted, uniform crops (poorly-coupled), but by a combination of net-radiation and modifications set by saturation deficit and stomatal conductance, i.e. the free-standing plant has effective stomatal control (an "imposed" rate).

With small, uniform plots the centre of a plot is likely to be less-well coupled than the edges and this will affect the interpretation of the factors affecting transpiration and assimilation depending on where the plant is that is being studied. At a tree/crop interface of plots of woody and non-woody plants of different statures a higher degree of coupling might be expected than in the centre of the plots.

Jarvis points out some other interesting problems. Selecting a new crop species and growing it in a crop community when it has previously evolved in small clumps, or as isolated plants, may result in some of the adaptations it has acquired being of little use. For example, a sensitive closure response of stomata to increasing saturation deficits will be of less value than it was.

Again, in a strongly de-coupled close-planted canopy of mixed species the transpiration rate will be mainly imposed by the level of net radiation, so that if one component suffers competitive water stress, and its water loss is reduced through a degree of stomatal closure, the transpiration rate of other plant components will increase and the canopy as a whole will continue to lose water as before. This will not be the case, according to Jarvis, in the mixtures of species that present a strongly coupled canopy (e.g. a community of trees with a high dgree of canopy "roughness"), and an overall reduction in water loss may result. In multi-storied mixtures the upper emergent layer will be strongly coupled, to the atmosphere, and water loss will be at the imposed rate; whereas the understorey may be almost completely de-coupled, and water loss will be at some equilibrium rate. Increasing the amount of upper canopy will increase water loss for this strongly-coupled layer, but the additional shading lower down will diminish, to some extent, the equilibrium rate of water loss there. Exactly how this is balanced out in multistrata systems still requires further investigation. Jarvis concludes that the addition of a tree component to a crop system will not necessarily add an additional drain on the water resources of the site.

Water loss from hedgerows

From the point of view of water loss from hedgerow-intercropping the system, overall, is likely to be fairly closely-coupled to the environment. Mature hedges of one form or another will usually be exposed above a young crop, but they may be level or even, if it is a tall cereal, submerged below its upper surface at crop maturity (less well-coupled and more dependent directly on net radiation receipt at that canopy level). In addition orientation is likely to affect the degree of coupling in different parts of the system, although it may all be fairly well coupled. It will certainly modify the effective wind speed, slowing it down across hedges, or speeding it up between the rows, so especially, influencing water loss from well-coupled vegetation. Orientation may, therefore, be rather more important for hedgerow intercropping than in less well-coupled situations.

As well as water use aspects we need also to consider the factors affecting water input where hedgerows are grown. The soil water status and water balance in a hedgerow intercropping site will be different from that of one occupied by an agricultural crop or crop mixture. In the first place, and especially depending on the slope, aspect and characterisitics of the rainfall, the soil beneath the strips themselves should readily collect runoff. Infiltration rates under hedges can be as much as five times greater than in adjacent cropped soil on a vertisol in India (Charandrasakariah, pers comm.). How much runoff is available to be collected will clearly also depend on the type and soil management, as well as the distance between the hedges.

Being able to store water that might otherwise have run on down-slope is clearly beneficial. If the hedgerow is cut back at crop-sewing time some of it may even become available to the immediately adjacent crop rows, and so help to diminish any adverse tree/crop interface effects.

Accumulating more water is likely to prolong the growth of the hedgerow plants and, as this will be to a large extent effectively under stomatal control, it will, in some circumstances, lead to greater water use. However, there are close similarities when considering well- or poorly-coupled vegetation with regard to assimilation. In close-coupled tree canopies the atmospheric carbon dioxide concentration is effectively controlled by canopy conductance and by changes in stomatal resistance. In poorly-coupled agricultural crop canopies assimilation, like transpiration, is strongly dependent on radiation. Thus, well-coupled alley-cropping systems that make better use of available water than sole agricultural crops are likely to benefit from this through improved and/or extended assimilation.

Unlike the situation with agricultural crops (except in their early growth stages) both water use and assimilation in hedgerow intercropping are likely to depend very closely on the amount of leaf area present and the way in which this is managed in relation to seasonal climatic opportunities (an outcome that might seem more obvious to the farmer than to a crop physiologist! PAH).

D. TWO ASPECTS RELEVANT TO HEDGEROW MANAGEMENT

There are many aspects of mananging woody/plants that are relevant to hedgerow intercropping but, for this paper, I would like to concentrate on what happens when we remove parts, and on some effects of fruiting.

Lopping and subsequent growth in general

As Maggs showed for apple many years ago (Maggs, 1964), removing parts of a woody perennial, as in any lopping or pruning operation, will have the effect of decreasing the next season's dry matter increment. The extent to which this happens will depend on: (a) the amount removed in relation to the total living "capital" the plant possesses: (b) the effects that any removal of aerial parts has over changing the geometry of the canopy (or the renewed canopy) vis-a-vis improving the illumination of leaves; as well as (c) changing the proportion of photosynthetically-active to less-active leaves (i.e. the proportion of young versus old foliage); and (d) whether non-living parts (lignified secondary material dead or senescent leaves etc. are removed as distinct from living ones.

The effect of plant part removal on decreasing the following level of biomass increment is shown in some of the accompanying tables.

Tables 13 to 15 illustrate the situation with tea (*Camellia sinensis*). Magambo (1983) has provided data that show very clearly the detrimental effect of plucking on total biomass production of container grown young tea plants in Kenya (table [illegible]

Table 13:

Dry matter production (g/plant) after 12 months (Aug. 1978 to July 1979) in plucked and unplucked young plants of 3 TRFK tea clones growing in nursery beds

	Dry matter g/plant					
	31/8		6/8		7/14	
Plant part	Pl.	Unpl.	Pl	Unpl.	Pl.	Unpl.
Leaves	49.4^{jk*}	171.8^{fg}	47.5^{jk}	165.1^{fg}	17.1^{k}	182.9^{efg}
Frame	98.2^{hij}	267.8^{bcd}	99.8^{hij}	281.4^{abc}	57.8^{jk}	337.3^{a}
Roots	69.0^{ijk}	217.5^{cdef}	129.6^{ghi}	314.0^{ab}	39.4^{jk}	242.6^{cde}
TOTAL	216.7$^{e'}$	657,1$^{b'}$	276.9$^{d'}$	761.1$^{a'}$	114.3$^{f'}$	762.8$^{a'}$

* = Mean seperation by Duncan's multiple range test, at 5% level. - from Magambo, 1983.

the field were similarly affected after an initial 6 months from the time plucking started (Table 14, which also shows th effects on the distribution of dry matter). Table 15 shows the effect of keeping young tea bushes to a range of different plucking heights (70cm down to 10cm). Shortening the plants greatly reduced the surface area for plucking and, hence, the yield of leaves per bush but, as yields per unit plucking area per bush were increased, a projected re-adjustment of spacing indicated a possibility for increased leaf yields under a complete field cover.

The data from Russo and Budowski (1985) on pollarding of *Erythrina poeppigiana* in Costa Rica, again, illustrates exactly what one would expect (Table 16 and 17) i.e. fewer pollardings resulted in a greater total biomass production (although more leaves).

The time at which parts are removed may also be important as, depending on the phenological stage the tree is in, it can be "entrained" so that shoot growth, flowering and fruiting takes place in a more or less favourable part of the season (Huxley, 1983).

In non-woody perennials (e.g. many grasses) there may be a real improvement in subsequent yields when these are first cut over, or burned, due to the removal of "ageing" parts of the canopy. With trees, even "fast-growing" ones, the decline in growth due to various restrictions to transfer of organic (and possibly inorganic) materials, because of an increasing complexity and distance of transfer pathways (e.g. Wareing, 1964), is likely to take a number of years. In general, trees age slowly and these effects can be mitigated, or even eliminated by "renewal" pruning at appropriate periods.

Table 14:

Mean accumulative dry matter production (tonnes/ha) from July 1977 to June 1978, according to sub-divisions of plant parts of plucked and unplucked tea bushes of clone 6/8 in the field.

	1977			
	September		December	
Plant part	Pl.	Unpl.	Pl.	Unpl.
Pluckings-leaves	0.25	-	0.65	-
Pluckings-stems	0.05	-	0.16	-
Leaves - young	-0.03	-1.09	-1.26	-0.84
Leaves - Old (including-fallen)	0.96	1.10	1.53	3.12
Frame - Young	1.33	1.08	2.10	2.66
Frame - Old	1.18	0.15	1.38	1.17
Roots - Thick	0.64	1.30	-0.05	0.59
Roots - Thin	2.76	1.53	0.50	0.34
TOTAL	6.14	4.07	5.01	7.04

	1978			
	March		June	
Plant part	Pl.	Unpl.	Pl.	Unpl.
Pluckings-leaves	0.99	-	1.11	-
Pluckings-stems	0.28	-	0.32	-
Leaves - Young	-1.31	-0.20	-1.70	-1.22
Leaves - Old (including-fallen)	2.33	4.46	5.59	8.43
Frame - Young	1.26	1.97	2.75	1.69
Frame - old	1.12	3.63	4.62	11.73
Roots - Thick	-1.06	1.95	3.01	3.77
Roots - Thin	1.64	1.19	1.22	1.85
TOTAL	5.25	13.00	16.90	26.25*

* = Significant differences between plucked (Pl.) and unplucked (Unpl.) plants means at p≤0.05. - from Magambo 1983

Table 15:

Plucking surface area and yields (Feb -Dec 1981) of tea bushes pruned and maintained at different heights.

Bush height	Plucking Surface area. (m^2)	Yields. (kg/plot)	Yields/area (kg/m^2)	Yields Assuming complete cover at that kg/ha	Actual Yields 1.22m x 1.22m (kg/ha)
70 cm	54.0[a*]	15.4[a]	0.28[c]	2847[c]	2847[a]
40 cm	39.5[b]	13.5[b]	0.34[b]	3409[b]	2504[b]
25 cm	25.9[c]	9.8[c]	0.37[b]	3746[b]	1814[c]
10 cm	8.8[d]	3.9[d]	0.44[a]	4425[a]	723[d]

* = Mean separation within columns by Duncan's multiple range test, 5% level.

- from Magambo, 1983.

Table 16 :

Biomass production (Kg/ha/year) for leaves and branches of *Erythrina poeppigiana* trees.

Treatment	Leaves	Branches (kg/ha/year)	Poll. Total Biomass
2 pollardings/ year, branches left on the ground	3,839 a 1/	7,992 a	11,829 a
2 pollardings/ year, branches removed from the plot	4,041 a	7,803 a	11,844 a
1 pollarding/ year, branches left on the ground.	3,270 b	15,200 b	18,470 b

1/ Means with the same letter in the same column are not statistically different ($P<0.05$) -from Russo and Budowski, 1986

Table 17:

Annual biomass production (dry weight) from Erythrina poeppigiana pollarded once, twice and three times a year in Turrialba, Costa Rica (280 trees/ha, corresponding to a spacing of 6 x 6m)

Pollarding frequency per year	Leaf Biomass	Branch biomass	Pollarded Total Biomass
1 (12 month interval	kg/tree 11.70+3.39 kg/ha 3,270	54.28 + 13.82 15,200	65.98 + 17.17 1/ 18.470
2 (6 month interval)	kg/tree 13.93 + 3.99 kg/ha 3,900	28.20 + 8.11 7,900	42.13 + 12.67 2/ 11,800
3 (4 month interval)	kg/tree 15.50 + 4.95 kg/ha 4,340	12.52 + 4.85 3,510	28.02 + 9.80 3/ 7,850

1/ Data from 24 trees, on pollarding

2/ Data from 48 trees, sum of two pollardings

3/ Data from 12 trees, sum of three pollardings

- from Russo and Budowski, 1985.

Allometric relationships

When it comes to considering the changes in relative amounts of different parts as affected by pruning and lopping we need to remember that the relative rate of growth of different organs can be described by a particular set of allometric relationships which describe the change in the ratio between parts of an organism with time. These relationships obtain in any one plant/environment situation i.e. they depend primarily on the genotype as modified by a resource "rich" or "poor" aerial or soil environment (or both). The stage of plant development will also alter the allometry, because new "sinks" will arise with changes in growth and plant development (e.g. secondary stem formation following early seedling growth, and flowering and fruiting). Allometric relationships are often described by plotting the changing dry weights of the parts being considered eg. root:shoot, stem:leaf etc. on log/log scales (and then the slope of the line indicates the relevant relative growth rates).

As Cannell (1983) points out, the important issues to realise are that:

- Shoot or root pruning does not permanently alter the shoot-cambial-root allometric relationships. Shoot pruning temporarily checks root growth, and root pruning temporarily checks shoot growth. Both in proportion to the amount removed, and until the original allometry is restored. Thus root pruning temporarily diverts a greater amount of available, current assimilates (and, possibly, some mobilized stored materials) to the roots, and a shoot pruning similarly to the shoots.

- Where the production of stem wood is an objective we must remember that the stem cambium represents one of the plant's several "sinks" which is continuous throughout the trunk (bole) and larger and smaller branches. Thus, depending on how the tree is trained or maintained (i.e. with more or less trunk), then a greater or smaller amount of the stemwood dry matter allocation will be used to produce a bole as distinct from smaller branches (as foresters well know).

- Similarly, and where we are mainly interested in leaf or young leafy shoots (without secondary thickening), pruning away these will divert current assimilates and/or mobilized reserves to replace these organs, but there will be less total assimilates available than if they had not been removed.

Lopping hedgerows

The above facts have been well-known to crop physiologists for many years, but we need to re-examine their implications in the light of hedgerow intercropping.

Tables 18 to 20 give some hedgerow production data - mainly on *Leucanena leucocephala*. The major factors affecting biomass production from hedegrows will be species, climate and soil; lopping regime and in-row spacing; and competition from between-row cropping. Whether the hedgerow loppings are left on a site or removed will probably be important in the long term, but it appears to have little immediate effect (see Tables 16 and 18).

Table 18a: Some examples of biomass production from Leucaena leucocephala hedgerows

Spacing	Country	Authority	Biomass Production ($t\ ha^{-1}\ yr^{-1}$ d.m.)	Comments
2 x 2m	Indonesia	Soekotyo (1982)	3.6 (cv Cunningham)	Sun-dried
rows [illegible] 4m	Queensland Australia	Raymond and Bray (1982)	1.5 to 12.5 (cv Peru)	various cultivas 0 sites
1 x 1m	Ambarnath India	Sudhir et al (1982)	20.6 (extrapalated)	cv K8 (")
various	various Tropics	Torres (1984)	6.1 to 17.6	summarized yield data from 7 authors
0.25 x 4.0m	Nigeria	Kang et al (1985)	5.77 to 7.04 (prunings removed) 5.43 to 6.32 (prunings retained) with woody stems means≈11.5 (removed) ≈10.40 (retained)	Addition N (40 & 80kg N ha^{-1} raised biomass production 1 yr ou of 3 only - not including woody stems

Table 18b

Leucaena hedge biomass and crop yields.

Treatments	1979	Treatments	1980	1981	1982	1983	Comments
No Nitrogen	a. 6.4	nitrogen & pruning removed	a. 5.1	6.30	7.04	5.77	Approx. 8-10 t aerial biomass yr^{-1}
	b. 3.8		b. -	1.50	2.23	10.52	
	c. -		c. 1.9	0.48	0.61	0.26	Maize grain yields drop under continued cropping with no leucaena residues.
			d. -	-	0.45	0.27	
			e. -	2.56	0.59	0.57	Cowpea is little affected by tillage treatment
			f. -	1.81	0.58	0.49	
		No nitrogen and pruning retained	a. 5.1	6.32	5.43	5.79	Retaining prunings does not seem to affect the leucaena itself.
			b. -	1.59	2.40	9.94	
			c. 3.5	1.21	2.10	1.92	Mulch improves maize grain yields whether soil is tilled or not
			d. -	-	1.57	2.17	
			e -	2.95	0.61	0.45	Cowpea is little affected in the short term whether leucaena residues are left or not.
			f -	2.54	0.53	0.50	

a) Dry matter yield of Leucaena prunings ($t\ ha^{-1}\ yr^{-1}$) b) Woody stem prunings c) Maize grain yields tilled

d) Maize grain yields - zero tilled e) Cowpea grain yields (tilled) f) Cowpea grain yields - zero tilled

- from Kang et al. [illegible]

Table 19:

Dry weight of prunings from species alley cropped with maize and cowpeas, IITA, 1983

Spacing/ Fertilizer*	Gliri- cidia	Leucaena	Alchornea	Acioa	Mean
		t/ha/yr			
2m/F1..........	6.30	9.06	3.83	2.62	5.46
4m/F1..........	5.03	8.16	3.28	1.50	4.19
2m/F2..........	5.40	9.23	4.49	2.62	5.43
4m/F2..........	3.99	8.10	3.47	1.51	4.26
Mean	5.18	8.64	3.77	2.07	

LSD(5%)	
Species means	1.52
Spacing and fertilizer treatment means	0.60
Spacing and fert. trtmt. means for same species	1.30
Spacing and fert. trtmt. means for diff. species	1.83

* Spacing between hedge rows. F1=45-20-20 and F2 = 90-40-40 kg N-P-K/ha applied to the maize crop. - from IITA, 1984.

Table 20:

Shoot biomass production of four species at IITA, sites A20 and W1

	Shoot		Dry Weight	
	A20	W1	A20	W1
	-----g/tree ---		------ kg/ha -------	
Leucaena	229	806	716	2519
Gliricidia	121	162	378	506
Flemingia	358	357	1119	1116
Cassia	177	867	553	2709
CV (%)	44.5	44.6		
[illegible]	[illegible]	[illegible]		

Table 18 summarizes some of the available data and gives the IITA results from 1979 - 1983. Also from IITA are the results from a species x spacing x fertilizer trial in which it is clear that Leucaena leucocephala will outyield the other three species tested (Gliricidia, Alchornea and Acioa - see Table 19) Further investigations (Hall, 1985) have given a preliminary indication that Flemingia congesta and Cassia siamea might also do well in this region (Table 20), and further data are given in the recent papers of Yamaoh et al., 1986a and 1986b).

There may be even more promising species for alley-cropping in humid regions than Leucaena leucocephala. For example, Yamoah et al. (1986a and 1986b) have looked at Cassia Siamea, Gliricidia sepium and Flemingia congesta and assessed both the biomass yields and contributions of N.P.K. made over 1 year (2 maize growing seasons) starting 2 years from planting out. Cassia provided the most biomass (nearly 17 t ha^{-1}) in the whole period, however outputs were very different, both totally and with time. Litter fall during this period differed by a factor of nearly 8 (1.26 t ha^{-1} for Gliricidia as against 10.1 t ha^{-1} for Cassia). Available plant residues for mulch at the first cut varied some 5 times (1.96 t ha^{-1} for Flemingia as against 10.7 t ha^{-1} for Cassia), and subsequent yields of prunings varied by a factor of 3.6 (4.1 t ha^{-1} for Cassia and 15.0 t ha^{-1} for Flemingia). These figures can be compared with those of Leucaena in Table 18 (and see Hall, 1983 for other comparisons) between Leucaena and other species). Cassia also produced nearly 30 t ha^{-1} of fuelwood, as against only 6.8 t ha^{-1} for Flemingia.

There are clearly very large differences between the performance of different species, and a great need for more information of this kind. Particularly, for the long-term performance under different hedgerow management systems. Also, it is interesting to note that despite the large amounts of plant residues produced initially by Cassia in this experiment estimates of the nitrogen made available to the maize still showed a shortfall of that required.

In a drier region at Morogero, Tanzania, Lulandala (1985) obtained hedgerow fodder yields of around only 3 tonnes ha^{-1} per year for the first 22 months of growth (Table 21).

Although more data are needed it would seem that, in wetter regions (rainfall, 1200-1500mm p.a.), and on appropriate sites, a fast-growing species such as leucaena will produce some 8 to 10 tonnes ha^{-1} or per annum cut over several times a year, and in drier regions 3 to 4 tonnes ha^{-1} per year, similarly.

The probable effects over time of in-row hedgerow spacing are shown in Fig.13b

Relatively few studies give information about the actual proportion of subsequent dry matter increment that goes to the roots after lopping but we can suppose, in principle, that lopping would probably restrict this to some extent. However, some recent reviews (Bowen, 1985; Cannell, 1985) have indicated that data are now available to show that

Table 21:

Leucaena hedgerow fodder yields (Morogoro, Tanzania) - $t\ ha^{-1}$ d.m.

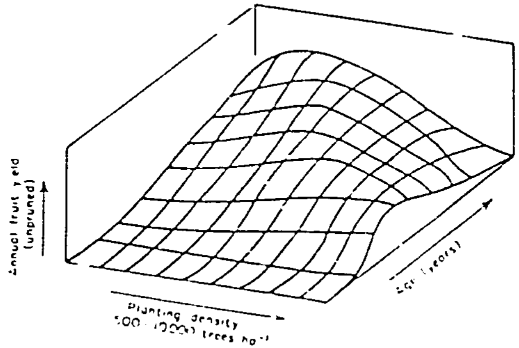
- from Lulandala, 1985

	Age (months)								
Treatment	14	23	26	28	32	35	38	41	Total (& Ann. Mean)
Clean-weeded	2.48	0.58	1.70*	0.52	0.64	1.06	2.14	0.40	9.52 (2.86)
Bean intercrop	2.59	0.65	2.24*	0.97	0.72	1.08	2.78	0.50	11.53 (3.45)
Maize intercrop	2.03	0.56	1.48*	0.88	0.90	1.01	2.12	0.49	9.47 (2.84)

* sig.diff. (p=0.05) - all other treatment diffs. N.S. Hedgerow was first harvested at 1m height at 23 months, thereafter at back to 1m high/1m wide.

Ann. Means for spacing: 1x3m ($3333ha^{-1}$)=3.29; 1x4(2500)=3.03; 1x5(2000)=3.05; 1x6(1667)=2.82.

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.



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.

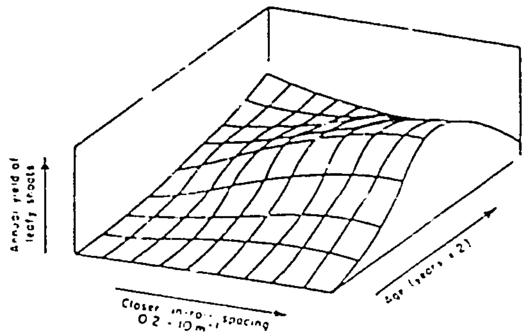


FIG.13

much larger proportions altogether of the plants' total fixed carbon can be allocated to fine roots than was originally thought from studies of recovered fine root dry matter in intermittent destructive harvests (see Table 22). It is clear that there is some seasonal "turnover" of fine roots (e.g. Head, 1973; Bowen, 1985) and, where they occur, of root nodules and mycorrhizas - the latter having especially high respiration rates. Indeed, Bowen (1984) calculated that fine roots + mycorrhizas can contribute 2-4 times more N, 6-10 times more P and K and 2-3 times more Ca to soil than above-ground litter fall.

Methods of calculating fine root production are discussed in Fairley and Alexander (1985) but, unfortunately, we still know very little about how much, when and what happens to the fine roots from different tree species on different sites, and we may have to be careful not to generalize too widely from just a few data. For example, visual observations for coffee roots in a root observation laboratory certainly did not suggest such high rates of fine root death (Huxley and Turk, 1975). Indeed, they noted that many of the finer roots of Arabica coffee remain white and unsuberised for at least up to two years. The old, but thorough review by Lyr and Hoffman (1967) mentioned cases where fine roots were observed to survive for periods of from 2 to 10 years. A recent investigation (Gholz, et al, (1986) of the organic matter dynamics of fine roots in plantations of slash pine (*Pinus elliottii*) in North Florida, gives an excellent example of the kind of research that needs to be adapted to alley cropping studies.

Certainly, we understand the general way in which soils and different kinds of plant management can affect the growth and activity of woody perennial root

Table 22:

Some recent high estimates of root biomass increment (extracted from Cannell, 1985)

Species	Country	Net Production ($t\ ha^{-1}\ yr^{-1}$) Stemwood/ stembark	Branches	Fruits etc.	Foliage	Root estimate	Comments
1. *Picea sitchensis*	UK	16.43	4.30	-	6.01	5.28 (fine) + 3.15 (thick)	
2. Natural decid. forest: *Liriodendron tulipifera* with *Quercus* spp.		1.11	0.57	0.20	3.09	2.55	Root subseqently re-estimated at 9.0 $t\ ha^{-1} yr^{-1}$
Pinus echinata	USA	0.39 (woody litter)	0.46				
Carya tomentosa		0.59 (under-storey)	0.02	0.50	0.37		
		0.52	0.04	0.02	0.10		
3. Second generation forest: *Pseudotsuga menziesii*, *Castanea chrysophylla*, *Alnus rubra*	USA	1.37	0.27	-	2.41	9.16	With estimated turnover of mycorrhizal roots
4. Experimental forest *Pseudotsuga menziesii*	USA	4.3				8.5 to 10.2	
Tsuga heterophylla, *Thuja plicata* + Understorey shrubs		0.6 (under-storey)	0.4 (losses)				

systems, and the balance between roots and aerial parts; clearly, root residue contributions to soil nutrients cannot be overlooked.

In the light of new information, and the possibility that, in some circumstances, much greater amounts of root residues (or excretions to soil organic carbon) may be being deposited in the site, there is a need to investigate the management of hedgerows in relation to the effects on below-ground dry matter increments. Lopping may seriously diminish these, although the immediate effect, especially if root die-back occurs, may be a surge of available easily decomposable sub-surface materials (including nodules from leguminous species). If lopping brings about fine root death it may open up possibilities of increased attack by root pathogens such as *Phytophthora* and *Fusarium* spp. (recent report on die-back of *Leucaena leucocephala* at Mtwapa, Kenya pers. comm. B. Jama).

We might also expect a detrimental effect on nodule numbers and nitrogen fixation activity when part of the canopy is removed, if the rate of carbon assimilation is thereby reduced (Sprent, 1986) Similarly, the assimilation "cost" of mycorrhizas has to be met if they are to remain or, at least, remain effective.

Matching above-ground plant management practices (e.g. pruning) to entrain the trees so that root activity and enhanced ion uptake occur at times when nutrient release under mulch/litter are greatest (e.g. Huxley, et al., 1974) may seem, at this stage, to promote a policy of perfection. But developing a greater understanding of plant-environment interactions in alley-cropping should eventually lead to this.

Finally, both rainfall and leaching of nutrients through the plant canopy provide important additions to the level of nutrients brought to the soil. For, example, Table 12 (above), from a study of two types of rainforest in the Ivory Coast, shows clearly, that the amounts and kinds of nutrients can vary with vegetation type and that they are not inconsiderable (Benhard-Reversat, 1975). However, in wide spaced zonal agroforestry systems that are regularly lopped this contribution will, of course, be greatly diminished.

Fruiting Hedgerows

Hedgerow intercropping is less-often proposed for edible fruit production than for mulch fodder, fuelwood etc. There are, however, many species of tropical fruits that will grow and fruit well as hedges (e.g. guava and Indian mulberry being two examples of widely-adapted species).

The challenge for such a system is to establish the appropriate compromise between maintaining growth of branches which form the fruiting sites without imposing too high a level of competition on the adjacent agricultural crop. That is, we cannot just "cut-back" the hedgerow at the beginning of the cropping season - or it is unlikely that this will be satisfactory treatment to promote fruit production.

However, there are many forms of restrictive pruning that can still maintain, with regard to the ground area occupied, a high level of fruit production. For example, guava can be trained in hedges to produce prolific fruiting on "short shoots" and so occupy only a very limited space most productively.

The reader is referred to some summaries on intensive fruit growing practices that might be applicable (Huxley, 1974; Mohammed and Wilson, 1984; and to Nair (1985) for some comments on and lists of fruit trees for tropical agroforestry systems.

If we have to deal with the "fruiting" tree the implications concerning dry matter distribution which were briefly mentioned under "lopping" require some further modification. A number of woody species have been examined in detail with regard to the effects of fruiting or growth and dry matter distribution, but a good example to take here is that of the work done on Coffea Arabica by Cannell, (1971) and Cannell and Kimeu (1971).

This work showed that fruiting coffee trees had at least a 10-20% higher net assimilation rate than de-blossomed ones. Indicating that the addition of a fruit "sink" enhanced assimilation. It also increased the rate of uptake of nutrients as Table 23 shows. The

Table 23:

Rate of uptake of nutrients by the heavily fruiting trees as a percentage of that of deblossomed trees (coffee)

	19.xii. 67 to 10.iii. 68, Hot, dry season		10.iii.68 to 5.vi.68 Long Rains	
Rate of growth (gwk^{-1}) of all roots 1mm diameter (% of deblossomed) ...	91 (N.S)		13***	
Rate of nutrient uptake (% of deblossomed)	g $tree^{-1}$	mg g^{-1} dry matter of roots 1 mm diameter	g $tree^{-1}$	mg g^{-1} dry matter of roots 1 mm diameter
N÷	146***	165***	84***	101(N.S)
P	310***	500***	80*	86(N.S.)
K	180***	216***	134***	162***
Ca	156*	176(N.S.)	71***	86(N.S.)
Mg	136(N.S.)	150 (N.S.)	93(N.S.)	110 (N.S.)

*** P = 0.01, **P = 0.05, *P = 0.10 ÷ Mainly organic-N

- from Cannell and Kimeu, 1971.

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extent to which these nutrients moved into fruits, even at the expense of other parts of the tree, is shown in Table 24, and Table 25 provides information on the "turnover" of nutrients returned to the soil in prunings and fallen leaves as compared with that removed in harvested fruits (similar amounts, in this case). Careful studies of this nature are needed, at least for selected sites, species and management procedures, if we are fully to understand the physiological basis of the management of hedgerows.

Figure 13a shows the way planting density is likely to effect fruit yield with time in unpruned trees. Various forms of intensive pruning can markedly enhance the yield from close or very closely planted woody fruits, but this will need to be tested experimentally for species which are not usually grown in this way.

Table 24:

Percentage distribution of nutrient increment in the heavily fruiting trees (Coffee)

Element	19.xii.67 to 10.iii.68, Hot, dry season			10.iii.68 to 5.vi.68 long Rains		
	Fruits	Leaves	Rest of tree	Fruits	Leaves	Rest of tree
N*	58	37	5	98	5	-3
P	71	22	7	99	10	-9
K	45	41	14	95	1	4
Ca	32	54	14	39	57	4
Mg	52	41	7	89	13	-2

* Mainly organic-N

- from Cannell and Kimeu, 1971.

Table 25:

Estimated mean annual nutrient uptake of a single-stem tree of Arabica coffee in Kenya, the amount returned to the soil by pruning and leaf fall, and removed in an average crop of fruits (g $tree^{-1}$).

- from Cannell and Kimeu, 1971

Element	Uptake (1)	Returned to the soil in prunings and fallen leaves: Young 5-year-Old tree (2)	Returned to the soil in prunings and fallen leaves: Trees over about 10 years of age (3)	whole fruits (4)
N	98*	26	65	23*
P	6.1	1.5	3.5	1.7
K	101	18	50	29
Ca	36	10	29	2.7
Mg	10.3	2.6	7.2	2.0
S†	8.1	1.2	3.9	2.3
Dry matter	6000	1070	3225	1500

(1) Estimated from the mean rate of uptake from September 1967 to June 1968 by fruiting and deblossomed trees.

(2) Estimated from the rate of leaf fall from September 1967 to June 1968, plus twice the amount off in December 1967.

(3) Estimated from the rate of increase in branches and leaves from September 1967 to June 1968, and assuming that the weight of leaves and bearing wood on mature trees is maintained approximately constant from year to year by pruning and leaf fall.

(4) Equivalent to a yield of about 1100 kg ha^{-1} (9cwt $acre^{-1}$) of clean sun-dried beans from 1500 trees ha^{-1}, the average for commercial estates in the Ruiru area.

* Probably underestimates

† Estimated using percentage composition data from Malavolta et al' (1962) Muller (1966) and Arzolla et al (1965)'

E. SOME USEFUL ECOLOGICAL CONCEPTS

Stress-tolerance, competition, disturbance

In this section, I would like just to introduce some ecological concepts, discussed and developed by Grime (1977), concerning the evolution of 3 major "strategies" for vascular plants. And to emphasize how important an understanding of these could be to our approach to the selection of species and types of management for agroforestry systems in general, including hedgerow intercropping systems.

Our understanding of "disturbance" and some of the factors that affect the competitive ability of plants is a useful place to start before going on to consider stress tolerance and its relevance to choice of species in agroforestry.

Grime (1977) in his most thoughtful and perceptive paper defines "Disturbance" as any mechanism which limits plant biomass by causing its destruction. This can be selective (litter decomposition) or non-selective (fire), and with or without removal from the habitat. Competitive and stress-tolerant types have evolved in sites that do not have a high level of disturbance (Table 26). Plants adapted to disturbed sites ("ruderals") have certain other common features (Table 27). They tend to have attributes which assist generally in the ability to "capture" a site. Grime has interpreted a mass of physiological/ecological evidence to suggest that the abilities to

Table 26:

Suggested basis for the evolution of three strategies in vascular plants

- from Grime, 1977

Intensity of disturbance	Intensity of Stress	
	Low	High
Low	Competitive strategy	Stress-tolerant strategy
High	Ruderal strategy	(No viable strategy)

Table 27:

Some characteristics of ruderal plants

	Ruderal
Morphology of shoot	Small stature, limited lateral spread.
Leaf form	Various, often mesomorphic
Litter	Sparce, not usually persistent
Maximum potential relative growth rate	Rapid
Life forms	Annual herbs
Longevity of leaves	Short
Phenology of leaf production	Short period of leave production in periods of high potential productivity
Phenology of flowering	Flowers produced at the end of temporarily favorable period
Proportion of annual production devoted to seeds	Large

- from Grime, 1977

compete for light, water, mineral nutrients (and space) are interdependent. For example (and greatly summarized), adaptations to arid habitants have resulted in rather obvious changes in stature and in leaf sclerophylly. In shaded habitats (plant-induced) it is the species that show the greatest capacity to maximise dry matter production in low light conditions, by exhibiting large phenotypic responses(e.g.by increasing leaf area, changing root/shoot ratio), that are most competitive (Table 28) - but these have evolved in unshaded or lightly-shaded habitants where, for example, leaves are organs of aggression. The truely shade-tolerant species are, in fact, slow - growing and can survive under lengthy periods of low light intensity.

In nutrient-deficient habitants, both truely impoverished and/or where the nutrients are sequestered in the biomass, we find that well-adapted species have a small stature, a tendency to a sclerophyllous leaf form and slow growth rates. They have, therefore, low rates of demand on soil nutrients and, presumably, a good ability to store nutrients in times of excess; as well as a loss of any well-defined seasonal pattern of growth and a slow replacement of leaves (again a nutrient-conserving feature which may be associated with a high degree of unpalatability). All these are features to conserve absorbed mineral nutrients rather than to maximise the quantity captured. As Grime points out, many of the features of stress-tolerance (Table 29) are to some extent common to all types of stress environment.

Thus we can distinguish some major groups arising as an outcome of "competitive" "stress-tolerant" and "ruderal" trends which exhibit

Table 28:

Some characteristics of competitive plants.

	Competitive
Morphology of shoot	High dense canopy of leaves; extensive lateral spread above and below ground
Leaf form	Robust, often mesomorphic
Litter	Copious, often persistent
Maximum potential relative growth rate	Rapid
Life forms	Perennial herbs, shrub, and trees
Longevity of leaves	Relatively short
Phenology of leaf production	Well-defined peaks of leaf production coinciding with period(s) of maximum potential productivity
Phenology of flowering	Flowers produced after (or, more rarely, before) periods of maximum potential productivity
Proportion of annual production devoted to seeds	Small

- from Grime, 1977

Table 29:

.Some characteristics of stress-tolerant plants

	Stress-tolerant
Morphology of shoot	Extremely wide range of growth forms
Leaf form	Often small or leathery, or needle-like.
Litter	Sparce, sometimes persistent
Maximum potential relative growth rate	Slow
Life forms	Lichens, perennial herbs, shrubs, and trees (often very long lived)
Longevity of leaves	Long
Phenology of leaf production	Evergreens with various patterns of leaf production
Phenology of flowering	No general relationship between time of flowering and season.
Proportion of annual production devoted to seeds	Small

- from Grime, 1977

particular plant characteristics and confer certain attributes. Of course, there is a continuous spectrum of evolutionary types that overlap these definitive classes.

Plants may have evolved some common strategies of form and function so as to overcome environmental stresses of different kinds, as Grime asserts. But the imposition of stress at different stages in the growth of an individual plant species can still result in a quite different outcome depending on what stress factor was applied and when (e.g. Table 30, for cowpea). Probably, because, on this more detailed time-scale, particular stages of plant growth and development are more susceptible to one form of stress than another (water, light, nutrients) according to the sensitivity of the processes in train at that particular point in time.

The reader is referred to the paper by Connor (1983) for a discussion of how to view the development of differential stress between the woody and non-woody components of an agroforestry system so as to achieve the greatest complementarity of resource-sharing opportunities. Without such an understanding the management of agroforestry systems reverts to a process of trial and error.

Fortunately, some information is coming forward on some of these aspects. For example, Hesla et al.,(1985) have studied the leaf conductance and leaf water potential of two savanna ecosystems in East Africa and found that grasses and shrubs appear to have different water use strategies. Shrub leaves showed small or no differences between the wet and dry seasons, implying that their access to a

Table 30:

Some effects of environmental stress* on yield of cowpea cv "Prima"

- from Huxley, Summerfield, Dart and Hughes, 1974.

Stress factor	Response
A. Nitrogen	Lack of applied N from seedling emergence to first flower was without effect - plants "caught up" later (cf. water stress, below). Only severe N-deficiency from the onset of flowering and during seed formation (i.e. for non-nodulated plants with no applied N) markedly reduced seed yield.
B. Water	Severe decrease in seed yield caused by allowing plants to wilt during pre-flowering phase. Nodule development and nitrogenase activity drastically reduced at flowering time onwards.
C. Shading	Least effect on seed yield. Shading throughout somewhat diminished growth and yield

* The stress treatments were applied, individually, to containerised plants grown under controlled conditions (air-inflated greenhouse) at specific growth stages - Nitrogen, elimination of N from nutrient solution; water, repeated wilting cycles; shade, 40-50% of normal illumination.

suitable water supply was not strongly affected by seasonal precipitation patterns. There was consistent diurnal closure of shrub stomata reducing midday transpiration during all months. The grass species, however, tended to maintain a constant stomatal conductance and allowed water loss to be controlled by saturation deficit. Hence, the grasses used what water they could before the near-surface supply was depleted. The shrubs curbed their water use (and thus competed less with themselves and associated species), and so they extended their growth into the dry season. Such information has considerable practical implications for they management of agroforestry systems, including alley-cropping.

Lessons for agroforesters

What are some of the lessons for agroforestry from these and other ecological/physiological approaches?

- In continuously fertile habitats competitive species will do best, although in single-crop situations we need also to chose resource-sharing "crop" ideotypes. In mixtures "association" ideotypes are likely to exploit the available environmental resources better (Huxley, 1985).

- In continuously unproductive habitats competitive types are likely to exhaust resources of water and/or nutrients quickly. Stress-tolerant types will conserve the utilization of water and nutrients, although dry matter production rates will be low and, where foliage is to be continuously removed (e.g hedgerow intercropping), "stress-tolerant" types are unlikely to have rapid re-growth characteristics.

o Plants with adaptations for disturbed habitants ("ruderals") will generally have rapid growth rates, high seed production (which may or may not be required in woody perennials, used for agroforestry), short leaf-longevity cycles (good for nutrient recycling), and with flowers produced at the end of temporarily favourable period (not the best situation if this is followed by a long dry season on an impoverished site when the plant is committed to using stored and/or current assimilates for fruit development).

In fact, at least an elementary appreciation of the range of plant strategies to be encountered, including factors affecting and affected by flowering and fruiting, is of some considerable importance to agroforesters, both with regard to choice of woody species and their management options (Huxley 1983; 1985).

Quite simply we can summarise these rather theoretical but far-reaching issues by reminding ourselves that there are "no free lunches"! The selection of species for high biomass turnover in, for example, hedgerow intercropping systems, implies that certain site characteristics have to be met. The selection of stress-tolerant types of woody species for other agroforestry situations carries with it some in-built constraints to continuous harvesting. The age-old evolutionary conflicts between "survival" and "competition" are still very real considerations in understanding the practical choices we have to make for agroforestry today.

Exploiting heterogeneity (from Huxley, 1980a)

Whichever type of agroforestry system is chosen there is a chance to take advantage of environmental heterogeneity. Much of temperate agriculture and forestry has been aimed at specialisation (homogeneity), which utilises the benefits in output that can accrue through the relative ease with which various inputs can be added, and management processes manipulated, so as to maximise output from such systems. However, environmental heterogeneity, or variability, is a fundamental feature of our surroundings. From among all this apparent "disorder" we have development highly skilled ways of handling sample data in order to try to contain variability in order, as scientists, to be able to understand the main features of it. Nevertheless, users of land in the tropics invariably exploit heterogeneity, both in space and time. For example, a small farmer will often arrange his crops to take advantage of the varied pattern of soil fertility across his plot. Also he may use sequential plantings to obtain the best growth opportunities, or to avoid pest infestations, as far as possible.

The farmer adopting hedgerow intercropping is, in fact, creating heterogeneity in order to exploit its possibilities. As hedgerows grow they increase the potential for exploiting the site vertically even if, for environmental resource sharing reasons, their aerial growth is restricted. Deeper soil layers may be occupied by nutrient-acquiring roots, and the soil water profiles will be spatially modified. Accumulated biomass is moved laterally and there are induced micro-climatic changes.

Agroforestry systems of landuse, by incorporating plant species of very diverse economic life span and phenology, and with different spatial requirements, provide a better than usual choice of combinations which can share the environmental riches available. Hedgerow intercropping in an appropriate climatic zone, and involving the right choice of species and management, may exploit environmental potentials in a more satisfactory way than many sole cropping systems. But until we understand more fully exactly how it achieves this we will not be in any position to develop the system fully.

F. SOME FURTHER CONSIDERATIONS ABOUT RESEARCH.

Introduction

There are a number of previous ICRAF publications, and others in the press, that relate to agroforestry research methodology, or the background to such research. Most of these are appropriate to hedgerow intercropping investigations. It would be unnecessarily repetitive to reproduce all the relevant materials here, but a list is produced in Appendix I which the reader may wish to refer to for additional information.

Simplifying experimental agroforestry

Hedgerow intercropping is just one form of "zonal" agroforestry and it may be useful to consider the place of hedgerow intercropping research in relation to the whole scope of possible agroforestry investigations.

At first sight the number and types of experiments required to investigate particular agroforestry problems and potential interventions might seem unlimited and confusingly intricate. For example, there are not only hundreds of different agroforestry land use systems but there are literally thousands of different components species to deal with. And particularly for the woody species, very little is known about how best to arrange and manage them so as to optimize the mix of multiple products available, or how to use them to elicit maximum soil sustainability effects.

This situation is apparently even worse with regard to tree/crop mixtures, some of which can be very complex. So, will this welter of potential investigations chasing possible solutions lead to an unlimited proliferation of experiments? Or is there any way of rationalizing what has to be done?

The situation may not be as bad as it seems. First of all, a good way to simplify the kinds of systems we are dealing with, and one which takes into account the set of initial experimental needs required for each, is to lump them all into just three categories: "zonal" or "mixtures" (which are both based on spatial arrangements) or "rotational" (which is alternating landuse with time).

Zonal, mixtures and rotational plots

Zonal agroforestry systems are those in which "trees" (including any kind of perennial woody species) are geometrically arranged in strips or plots interspersed with agricultural crops (including grasses). That is where the intimacy between these two components, or sets of components, is restricted. Mixtures are where these associations are arranged in a way that more frequently brings them together (but not necessarily more closely); that is, where initimacy is encouraged. Hedgerow intercropping is an example of the first and multi-strata home gardens an example of the second kind. Rotational plantings are found where the land unit is used, first of all to produce either the "tree" component/s or the agricultural crop/s, but is then changed to the other. Bush fallow systems and fuelwood and/or browse/fodder plots using bushes are examples of these kinds of systems. This does not, of course, cover the detailed ways of classifying agroforestry land use, but it may well be adequate, and enable research workers to start thinking about what general types of experimental approaches are needed, initially, at least.

Two more!

Before these approaches can be considered, there are two other areas of investigations that need, necessarily, to be included in a comprehensive programme, if this is what is required. Research workers know enough, at present, about at least some of the agricultural plant components, but for many of the so-called "multipurpose trees", with the exception of a few genera (Leucaena, some acacias, Glyricidia, Calliandra, etc.), it may well be that very little is known about such things as propagation or tree management (for example responses to changes in spacing or lopping or pruning, etc.). Thus, almost certainly, a set of species introduction and selection and establishment trials will be required as will, in due course, some management investigations, for at least some of the "trees". In addition to this there could, and most probably will, be specific areas of technology that need to be addressed. For example, the potentials for nitrogen fixation, or for soil improvement in general or palatability and feed value, as forage, etc. These kinds of investigations will almost certainly use existing well tried and tested experimental methodologies and they will not be considered further here.

Trials needed to select and test multipurpose "trees" will involve a set of assessments that are somewhat different from and more complex than those usually carried out for, say, sole purpose timber trees. This arises from the fact that selection might well be required for a range of outputs, such as gums or medicinal extracts, honey production and such "service" factors as soil fertility improvement, soil water conservation, shelter etc.

The implications for assessment methodology and data analysis when investigating trees in this way are numerous, and some of them are considered in the set of "Source Materials and Guidelines for Research Methodology for the Exploration and Assessment of Multipurpose Trees", available from ICRAF. Table 31 is an overall summary classifying the basic "sets" of investigations to be undertaken initially so as to cover a full programme of investigation.

Common elements

In fact, although we have reduced the kinds of experimental approaches to five sets, there are some common elements in 2,3 and 4 that make it even simpler. For both zonal and mixed agroforestry the first type of information required, after choosing potential species, is about their interactions. This is best done by investigating the "tree/crop interfaces". In fact, the initial choice of "zonal" or "mixed" arrangements, as well as their subsequent management cannot logically be made unless the interactive effects of the woody and agricultural crop components on one another are known, or can be predicted.

Table 31 The five basic approaches to agroforestry experimentation* (from Huxley, 1986b).

Categories	Sets of experiments required
1. Species selection and testing (for all types of agroforestry	- Multipurpose tree introduction, establishment and assessment trials;assessment methodologies and data analysis need careful review and, in some cases, have to be developed. Tree establishment will offen need to be studied.
2. Investigations concerned with promotion of mixed agroforestry systems	- Tree/crop interface effects; simple phenology studies aimed at providing information about tree management; investigations into ways of optimizing environmental resource sharing; land sustainability.
3. Investigations concerned with the promotion of Zonal agroforestry systems	- Tree/crop interface effects; simple management trials (lopping, spacing); land sustainability.
4. Investigations concerned with the promotion of rotational agroforestry systems	- Tree-planting density; early management; harvest removals in relation to the "trade-offs" to be decided with reference to quantity of outputs removed versus land sustainability.
5. Special subject areas (according to problems associated with particular kinds of agroforestry systems)	- For example, nitrogen fixation; honey or gum production; fodder value; timber or fuelwood quality, etc. These will mainly use well-tried research methodologies

* Note: 1 is likely to be common to all programmes; 2,3 and 4 will be selected according to the type or types of agrofrestry systems for which the research is to be undertaken, and 5 may be necessary only in particular cases.

Similarly, all agroforestry systems are supposed to address the problem of land sustainability more effectively than many agricultural cropping schemes; so that investigations aimed at promoting zonal, mixed and rotational agroforestry will all need to evaluate, from the start, the effects of the plant components, either singly or in mixtures, on soil characteristics. Thus there is another set of common, priority investigational techniques that should be included in any experimental programme.

Crop production or soil improvement: the dilemma

Figs. 14 and 15 show, diagrammatically, examples each type of system: "zonal" (permanent "alley cropping");" mixed" (permanent, mixed high tree/high crop); and "rotational plots". The accompanying notes indicate what the principle objectives (outcome) of adopting each of these is likely to be. Taungya leading to plantation forestry (or perhaps, to a tree "fallow") is also included.

The systems' constraints which lead to chosing hedgerow intercropping (permanent alley cropping) are likely to be related to achieving sustained crop yields. However, from what has been said earlier on in this Working Paper, there may well be sites where long-term beneficial soil changes are unlikely to be simultaneously achieved, or at least not until many years have passed (e.g. in semi-arid zones). Similarly, rotational plots may be chosen in order, mainly, to bring about beneficial changes in the soil. But there are a number of economic and social factors that may well preclude their use, as it means taking the site out of crop production for a number of years.

In fact, a compromise approach between the "zonal" and "rotational plot" approaches may well hold the most promise. The scheme for this is shown in Fig. 16. Basically it means planting a suitable woody species for initial hedgerow intercropping, but then allowing it to grow into a complete cover as a temporary "rotational plot" (see ILCA's current trial, using the "rotational plot" period for animal browsing (and see Raintree and Warner (1986) for a discussion of trends of intensification in agroforestry systems). This is a highly

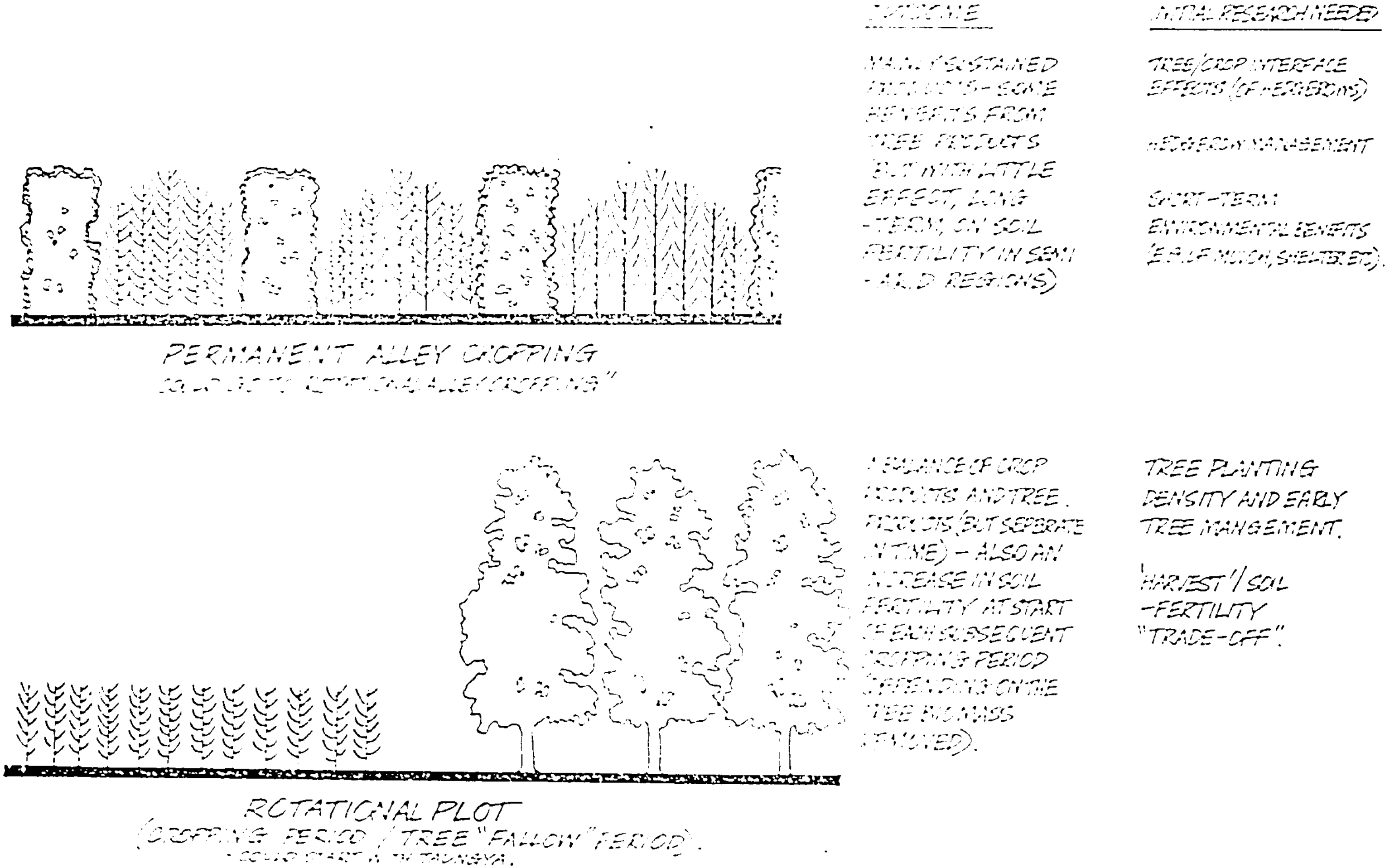


Fig. 14: Diagrammatic representation of some "basic" agroforestry planting arrangements - "permanent alley-cropping" and a "rotational plot".

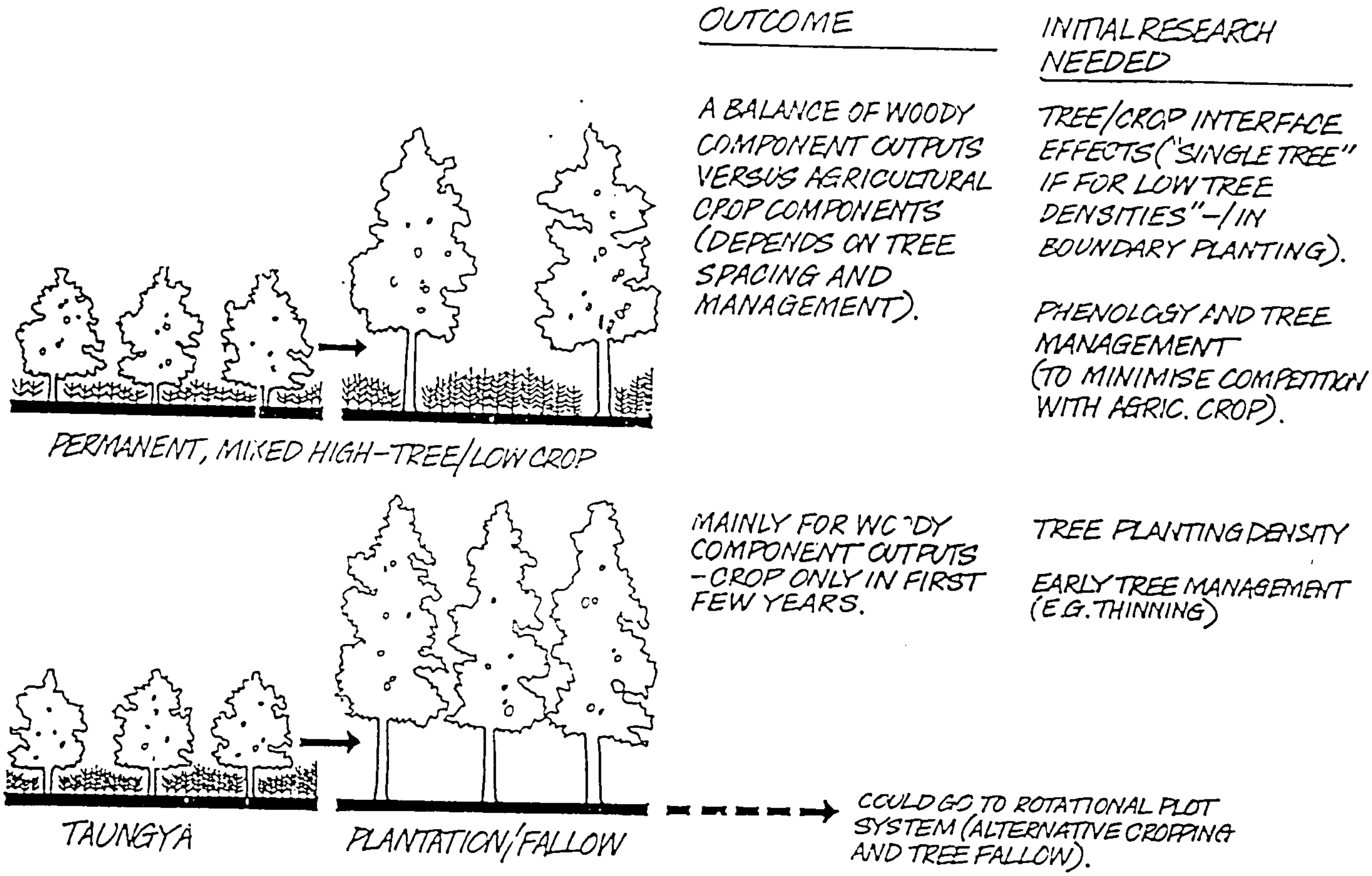


Fig. 15: Diagramatic representation of some basic agroforestry planting arrangements - "permanent, mixed high tree/low crops" and "Taungya".

flexible approach which will enable the farmer to adjust the crop output/soil fertility improvement aspects to suit his own circumstances. The "trade-off" between removing plant biomass (in harvests) and leaving it for soil improvement is critical, of course, and implies a period of adaptive research with these schemes in order to optimize the ratio of time under alley-cropping as compared with "rotational plot".

There is considerable scope for systems research ("prototype-research)" on such an schemes which, once again, emphasizes the need to consider "hedgerow intercropping" as just one form of agroforestry. This is especially the case if it were to be elaborated as just part of multistorical system, should the environment offer this possibility. It illustrates, also, how the basic "sets" of experiments listed in Table 31 can be envisaged as each underpinning a wide range of potential agroforestry land use systems.

Focus

Large or small?

Field experiments which establish large plots with various kinds of hedgerow systems on them can provide an invaluable initial insight into the dimensions of the problems involved. They can also, undoubtedly, clarify what kind of effects are important (e.g. the overall outcome of using plant residues, the influence of shelter,

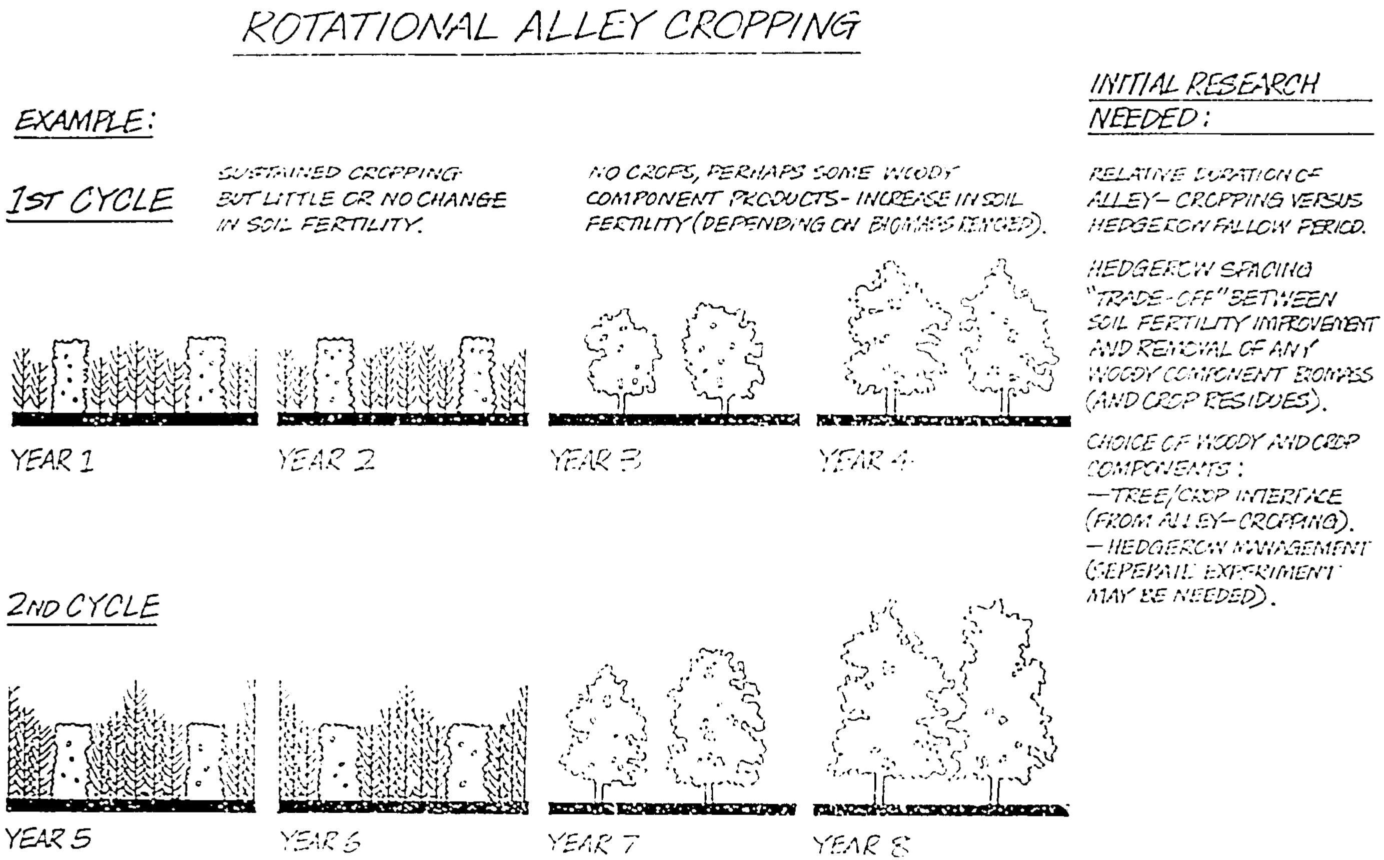


Fig.16: Diagramatic representation of a "rotation alley-cropping" scheme showing two cycles.

hedgerow management etc.), and what their magnitude is, as well as giving an indication of what are the most important experimental variables influencing these effects. But then what is needed is a more critical assessment, using experimental situations where the most important variables can be carefully examined, over a suitable range of environmental conditions, and without them being confounded. In addition, some speedy, cost-effective adaptive research approaches are also needed for those who, necessarily, have to try "best-bet" options now.

For agroforestry the ways to test the variables quickly but critically, is through carefully designed single tree or small plot trials in which they are isolated and tested in relatively simple combinations. By doing this we lose a measure of experimental efficiency that would come from studying the interactions of variables in, say, factorial combinations. However, block sizes must be kept small if unwanted locational variability is not to swamp the experiment. Moreover, we may be so unfamiliar with the experimental plants (MPTs) and possible management practices that we just have to start very simply.

The form and efficiency of adaptive trials depends on what we know (or think we know) about the relative importance of the variables involved, but these can target in on site-species-management optimization.

Considering the arrangements and behaviour of MPT species

As with all other forms of agroforestry research (Huxley, 1984) that for hedgerow intercropping will involve:-

- o selecting the appropriate species
- o selecting appropriate management practices
- o designing an appropriate geometry for a system.

In fact, a complete analysis of the problem requires a careful review of the most relevant topics for any particular set of research objects from the matrix shown in Table 32 below:

Table 32 Factors to be taken into account when considering the selection, management and evaluation of multipurpose trees (see Huxley, 1985 for a full explanation and examples).

	What species?	How many, and How arranged?	What management
The single tree	X	X	X
The tree as a crop	X	X	X
The tree grown in a mixture	0	0	0

The bottom line clearly refers also to such systems as hedgerow intercropping but, as more fully discussed in the original Working Paper (IWP No. 25, 1984 published in shortened form as Huxley, 1985), and in previous sections on ecology/physiology in this one, a knowledge of what to expect with regard to the origins and behaviour of the tree, overall, is also likely to be needed.

Experimental approaches

Breaking the system down

In order to focus the research more precisely a division of any hedgerow-intercropping scheme into 3 seperate parts is proposed. These are: (a) the cropped area, (b) the hedgerow itself and (c) the "tree/crop interface" (see Fig. 17). Enough might well already be known about how to manage the agricultural crop, so that research can be concentrated on (b) and (c). As stated above, these might well be best tested separately, unless some information on how to manage them is already available.

Tree/crop interface investigations (see also Huxley, 1986d)*

Tree/crop interface experiments will normally be undertaken with one of two objectives in view:

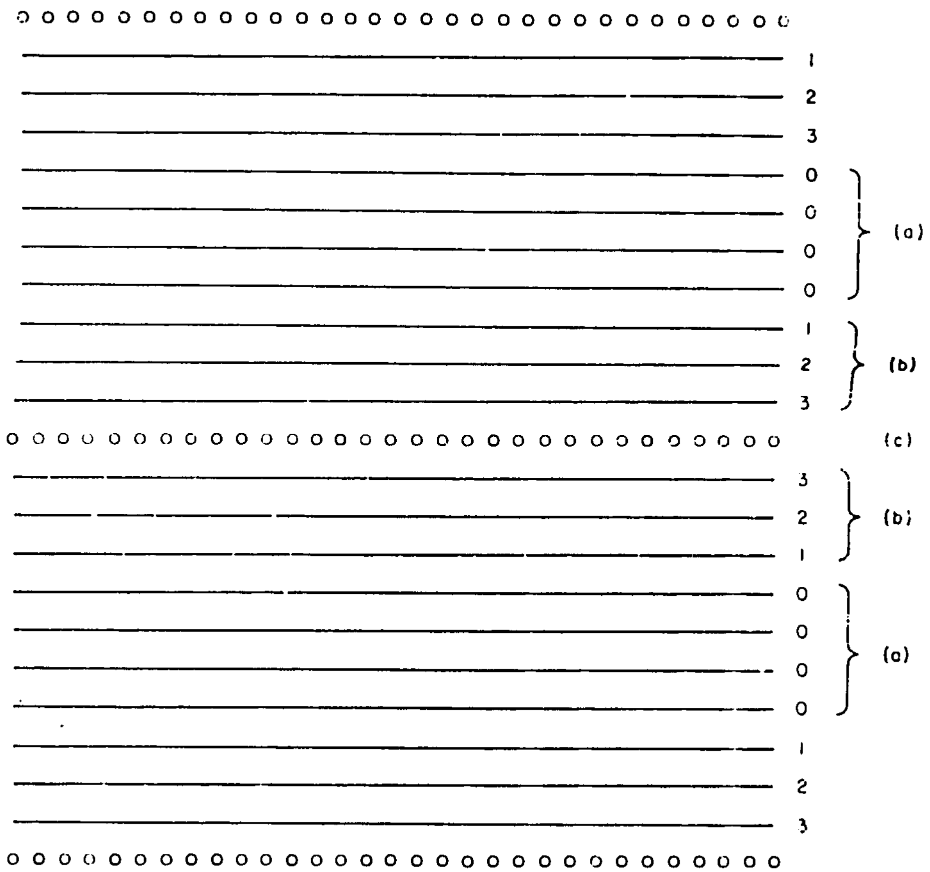


Fig. 17: The basic "parts" of any alley-cropping scheme (a) the cropped area (b) the "tree/crop interface" and (c) the hedgerow itself.

- from Huxley, 1986c

- o To test pairs of plant components (woody and non-woody) and/or management practices (time and degree of lopping the hedgerow) in order to obtain a relative ranking of the outcome.

  - these most be done under a set of standardized conditions rather like a "biological assay", which will tend to maximise the interface effects (see Table 33) whilst still retaining a feasible level of growth/production of the crop and (say) hedge plants.

- o To simulate a practical situation

  - alternative advantageous management conditions compared with the "standards" (above) might be imposed, but some of these may obviate competitive effects between the woody and non woody plant components and so reduce interactions. Indeed, the objectives may well be to see exactly what combination of management treatments and species results in a minimum amount of competition between the woody and non woody components.

Table 33: Management factors and their relative effects on tree/crop interactions indicated as beneficial (+) or detrimental (-) trends*

	Effect on crop growth	Effect on woody plant (hedge) growth
Tillage	+	-
Fertilizer/irrigation (overall)	+	+
Hedgerow lopping	+	-
Retention of hedge loppings on site	+	?
Presence of crop	+	-
Late sowing of crop	-	+
Reduced planting density of crop	-	+

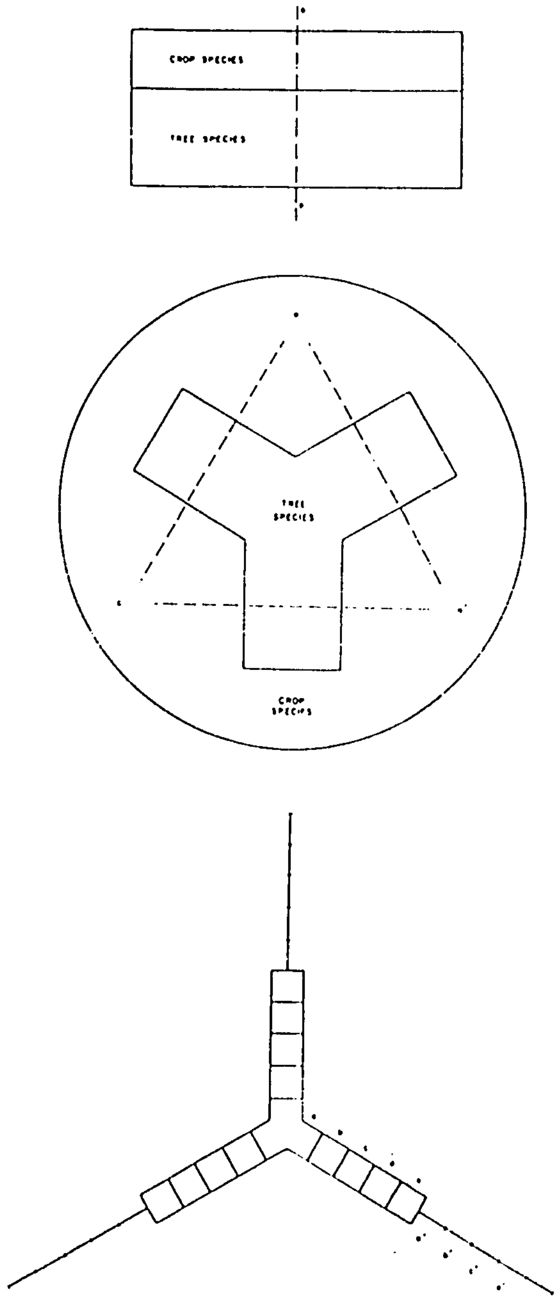
*An increased degree of any treatment is likely to have an enhanced effect of the same kind, and omission of a treatment will tend to reverse the trend for the woody and non-woody plant components, respectively.

A "Programme of Work for 1986" and the first "Interim Report" of the ICRAF/GTZ Project on "Development of Research Methodology Aimed at Simplifying the Study of Potential Tree/Crop Mixtures" is available on request.

Geometric designs

Fig. 18 shows the "geometric" and "geometric/systematic" field layouts that have been proposed, and which are under test. These designs can and should be replicated, but they are not amenable to "between-treatment" statistical analysis. However, it is our experience so far, that they produce a considerable amount of valuable observational/measurement data that can provide a useful insight into the way various pairs of woody and non-woody plant associates can interact under any particular set of management conditions. If they can be instrumented so as to discover the reasons for the plant behavioural and growth responses found (i.e. in terms of environmental interactions), then the results become much more meaningful and can be used to interpret what would happen under different environmental/ management situations. At all events, they help to focus on the most important experimental variables, which can then be examined more critically in conventional, statistically-analysable field experiments.

Early on in hedgerow intercropping experimentation it is necessary to decide whether orientation is a factor to be considered or not. There are a number of reasons why it should be (sun-angles and shading, wind profiles etc.). It may be of less importance in the humid tropics/less chance of soil water stress, although slowly conditions make any shading more detrimental), than in semi-arid regions where hedgerow interference with rainfall distribution could be critical. If orientation is to be included as a factor in design, then the geometry of the layout will involve selecting particular angular relationships.



(a)

(b)

(c)

Fig. 18: 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, 1986c)

The "geometric" designs tested by ICRAF so far represent the first examples of a whole set of possibilities. The existing designs (120° "Y" designs) were chosen as affording the least number of arms that could be used and still allow some estimation of the effects that would occur in any other orientations. To be able to predict these it is assumed that any "response" will follow a sine curve. However, one then needs to know the orientations at which the maximum and minimum responses will occur. For a climatic variable such as shade, which is dependent on the sun's declination and the latitude, this is easy to calculate. The direction of prevailing winds, which will affect the crop plant's responses both to shelter effects and to rainfall redistribution by hedgerows, will be also known, or it can be measured. However, the effects of sun and wind may not co-incide angularly, and so some confounding of effects will occur.

It remains to be seen from the practical field tests what actual difficulties there may be in interpretation. However, to avoid this - although at greater cost - it is easy to establish a geometric layout with a greater angular discrimination - i.e. more arms. For example, at ICRISAT an 8-pointed "star" design has been laid down with gaps at the centre (M.R.Rao, pers. comm.). Figs. 19 and 20 show the most recent layouts being tested at ICRAF's Field Station, Machakos, Kenya.

Thus the first decision is about what angular discrimination is required (a common multiple of 180° - as arms on all reciprocal orientation angles are just replicates). Then the units (arms) representing each angle can be spaced out as required in order to

TREE/CROP INTERFACE: 45° ANGLE LAYOUT, SPACED OUT (2 REPLICATIONS)

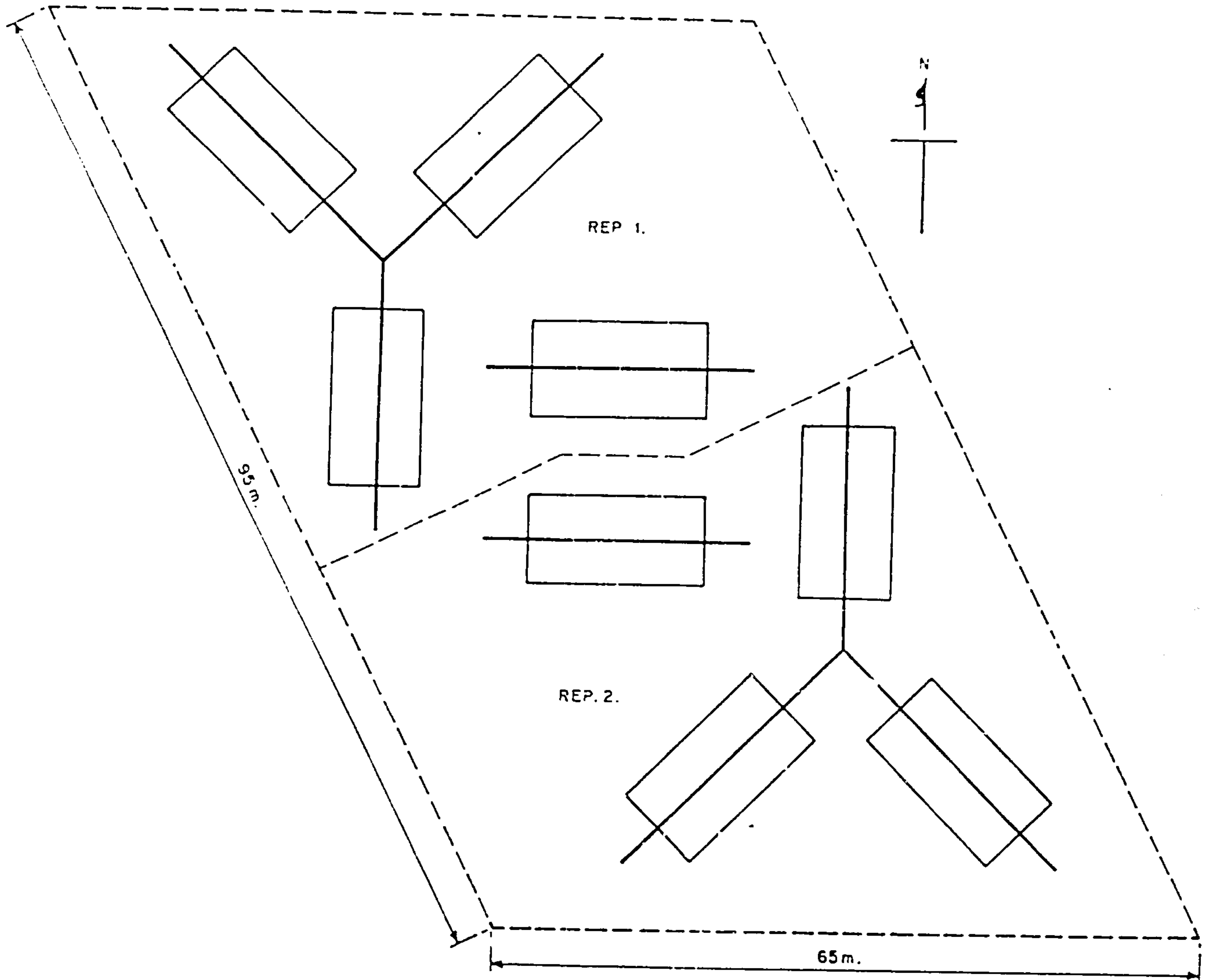


Fig. 19: A reasonably compact way of arranging the "set" of arms from Figs.19 and 20 which still reduces mutual interference to some extent. Two replicates shown.

TREE/CROP INTERFACE: SINGLE PLOT, SHOWING A SET OF POSSIBLE TREATMENTS

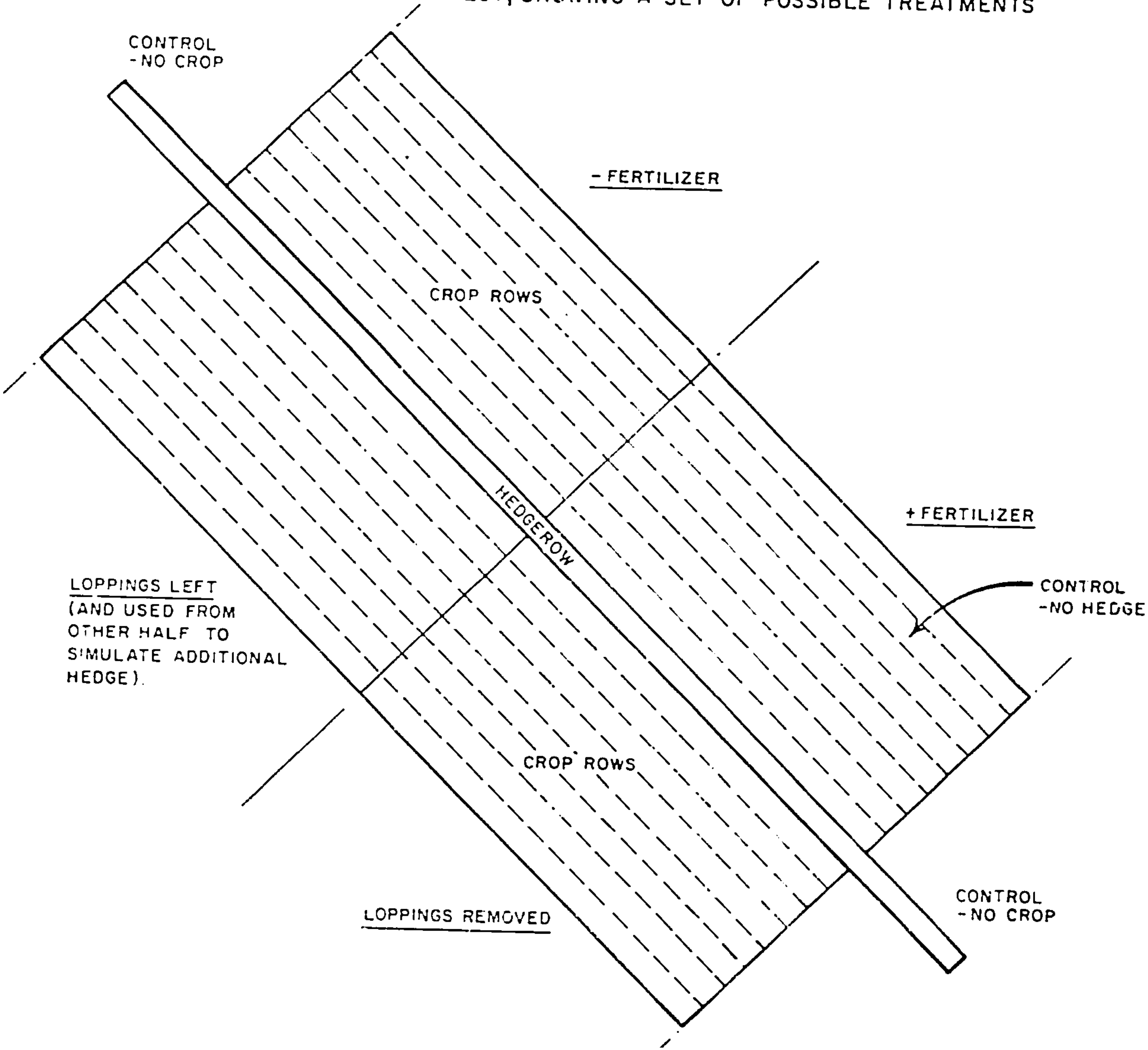


Fig. 20: A single plot ("arm") of the designs shown in Fig. 19-21 with some suggested treatments.

avoid mutual interference, depending on the extent of the homogeneous, flat area available. To arrange them, seperated, in a strip may take up rather a lot of space - but they can be fitted together as in Fig. 19.

Problems of small plots

There are two aspects of using geometric designs for tree/crop interface studies that need careful consideration; or, at least, an awareness of the problems involved. They are common to all small plot trials, in fact, but their effects are of especial concern if the results of an experiment measuring plant growth and development are to be related to climatic factors in a quantitative manner in order, for example, to tests a physical theory (e.g. to establish a precise measure of plant response to evaporative demand caused by changes in specific climatic variables). These are the "fetch" of the site and the degree of "environmental coupling" that is exhibited by the crop (or vegetation (as discussed in Section C, above).

Fetch

Fetch is defined as "a line of continuous extent". In the sense it is used in plant studies it can mean the linear distance of ground crop or vegetation surface needed to eliminate boundary turbulence or perturbation effects (for example in crop water use studies); or the distance required to achieve an equilibrium flow rate of air, or an equilibrium set of humidity condition etc.

Small plots may suffer bias effects and an increase in the error variance caused by unwanted plant responses to anomalous micro-climatic variations. This is due either to an "island" effect or some external impedence to the smooth flow of air, water or heat energy across them.

Because a tree/crop interface will only consist of a relatively short transect, and be under study in a plant arrangement of some particular shape (e.g. angled hedgerows), there will almost inevitably be problems of fetch. However, if external obstructions are avoided any conditions of, for example, irregular patterns of turbulence at the interface will, at least realistically simulate a natural condition, complex as it may be.

Environmental coupling

This was considered in Section C. As a reminder, briefly, vegetation with a rough canopy is "closely coupled" to the atmosphere and the individual plants have effective stomatal control over their rates of transpiration and assimilation. Dense, "smooth" agricultural crop canopies are "poorly coupled", and their rates of transpiration and assimilation are more closely set by radiation.

in terms of experimental design for tree/crop interface experiments, it is as well to remember that hedgerows are likely to well-coupled, but those that involve plots of a woody plant the outside edge of these will be better-coupled than the middle, and this might influence the "driving" variables controlling water loss and photosynthesis to some extent. However, "canopy" structure in an experimental tree/crop interface plot is likely to be similar to the agroforestry field situations to which it might be extrapolated. So that there is probably little to be concerned about with regard to the practical validity of any comparisons, in relative terms, but the interpretation of more detailed investigation of absolute values of biophysical increments (e.g. assimilation and/or evapotranspiration) need more cautions interpretation.

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Appendix 1 List of ICRAF publications of value to hedgerow intercropping research

Source Materials and Gudelines for Research Methodology for the Exploration and Assessment of Multipurpose Trees species (Ed. P.A. Huxley) 1984.

In particular

Parts

1B Introduction and general considerations

3A General considerations of the evaluation of MPTs

3C The scope and design of field trials

4A Introduction to MPT mixed cropping trials

4E Considerations when experimenting with changes in plant spacing.

4J Some considerations and suggestions for research on hedgerow intercropping.

2. Mongi, H.O.and Huxley, P.A. 1979. Soils Research in Agroforestry (Proceedings of an Expert Consultation)

3. Huxley, P.A. (Ed) 1983. Plant Research and Agroforestry (Proceedings of a Consultative Meeting).

4. Burley, J. and von Carlowitz, P.G.(Ed) 1984. Multipurpose Tree Germplasm (Proceedings of a Planning Workshop)

5. Nair, P.K.R. 1984. Soil Productivity Aspects of Agroforestry, ICRAF's "Science and Practice series" No.1.

6. Torres F, Potential contribution of Leucaena hedgerows intercropped with maize to the production of organic nitrogen and fuelwood in the lowland tropics. Agroforestry Systems. 1,323-333.

7. Nair, P.K.R., Fernandes E.C.M. and Wambugu, P.W. Multipurpose leguminous trees and shrubs for agroforestry. Agroforestry Systems 2, 145-163.

8. von Carlowitz P.G. 1984. Multipurpose trees and shrubs: opportunities and limitations. ICRAF Working Paper No. 17.

9. Hoekstra, D.A. 1985. Choosing the discount rate for analysing agroforestry systems/techniques from a private economic viewpoint. For. Ecol. & Management. 10, 177-183.

10. Huxley, P.A. 1984. The basis for selection, management and evaluation of multipurpose trees: an overview, ICRAF, Working Paper No. 25.

11. Hoekstra, D.A. 1985. The use of economics in diagnosis and designing of agroforestry systems. ICRAF, Working Paper, No. 29.

12. Young, A. 1985. The potential of agroforestry as a practical means of sustaining soil fertility. ICRAF, Working Paper. No. 34.

13 Huxley, P.A. 1985. Systematic designs for field experimental with multipurpose trees. Agroforestry Systems. 3, 197-207.

14 Huxley, P.A. 1986. The "Tree/crop interface" - or simplifying the biological/environmental study of mixed cropping agroforestry systems. Agroforestry Systems 3, 251-256.

15 Huxley, P.A. Hedgerow intercropping: some ecological/plant physiological issues. - chapter in the Proceedings of the IITA/ILCA Alley-Farming Workshop. March 10-14 1986.

16 Huxley, P.A. Experimental Agroforestry Chapter in "Agroforestry: Classification and Management (Ed K.G.MacDickens and N.T. Vergara) J. Wiley -in the press.

17 Huxley, P.A. and P.Muraya. The sustainability of agroforestry systems

contribution to Florida State University, Dept. of Forestry Agroforestry Seminar Series

- to be published in "Agroforestry Systems" - in preparation.

18 Young, A. Review: the role of agroforestry in soil and water conservation. ICRAF/SIDA - in preparation