CHAPTER V

LAND USE PRACTICES FOR AMELIORATION OF SOILS BY TREES.

It is clear that there is little point investigating soil ameliorative properties of trees without considering the implementation of these processes into practical management systems.

Which land use systems are most suited to incorporation of trees to improve soil productivity?

P Robinson in Section 1, leaves us with little choice. His review of the trends in supply and demand of crop, livestock and wood products shows that demand for each of these resources will soon outstrip supply. The expansion required in production of each of these resources must be at the expense of reduction in others due to the further deterioration of suitable land. He shows that these resource production systems are interrelated. This suggests that agroforestry, a land use system which can combine production of all three, is a suitable land use system for implementation of soil amelioration by trees.

The potential of agroforestry as a practical management method for sustaining soil fertility is examined in more detail by A Young in Section 2.

Case studies of two agroforestry systems are described by Handawela and Jama et al. The potential of maize cropping with Gliricidia maculata or with Leucaena leucocephala is examined for improvement of soil fertility and increased maize yields. The practical value of integration of trees with crops with respect to sustainable production is shown.

In Section 4, it is emphasised by M Douglas, that although it is clear that incorporation of trees into agricultural systems has potential for the improvement of soil productivity, such improved land use practices must be designed within the context of the people they are intended for. Lack of consideration of socio-economic constraints will probably result in failure of farmers to adopt such new and improved management methods.

THE DEPENDENCE OF CROP PRODUCTION ON TREES AND FOREST LAND

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SUMMARY

A number of studies have shown that in some situations cropland fertility and crop yields can be maintained by alley cropping systems which include mulch production by tree species. However, the great majority of crop production systems which are not sustained by application of artificial fertilizers continue to rely upon the import of nutrients (fodder, animal bedding, compost) from forest and other non-cultivated land. Trees on crop land also provide animal fodder, animal bedding and composting material.

Data from published sources are given to illustrate the importance of trees and forest land in supporting crop and animal production. The available data are often difficult to intepret and a plea is made for greater clarity in the presentation of data. The forest management and policy implications of the dependence of cropping systems on forest material are briefly discussed.

INTRODUCTION

Evidence from many parts of the world indicates that it is becoming harder and/or more expensive to maintain cropland soil fertility; in several countries crop yields are dropping, largely as a result of lowered soil fertility. Yet, with an expanding human population, the demands for crop, livestock and forestry products are increasing each year. High input (eg. artificial fertilizers) means of improving or maintaining soil fertility have often been inappropriate, particularly in the more marginal areas (eg. steep terrain, semi-arid lands) and for farming communities of low economic status. In the last decade the search for more appropriate means of sustaining soil productive capacity has intensified, and promising methods (both traditional and more recently developed) have been identified.

This review is restricted to those systems where trees and shrubs (from here onwards referred to collectively as trees) and forest land can play an important role in sustaining soil fertility and crop production. A critical evaluation of the evidence available on these systems should indicate the extent to which trees can contribute to improved sustainability, priorities for research, and ways in which Government policies may encourage promising systems of land husbandry.

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TRENDS IN SUPPLY AND DEMAND OF CROP, LIVESTOCK AND WOOD PRODUCE

There is considerable interdependence between crop and livestock production (ILCA 1981, Bernsten et al 1983, FAO 1983 b, Robinson 1983) and these often rely susbtantially on resources from trees and forest land. A brief review of the world's trends in the supply and demand for crop, livestock and forest products helps to highlight the magnitude of the problems which a substantial proportion of the world's population is increasingly going to face in the future.

Forestry and Wood Products

The Centre for Agricultural Strategy (CAS 1980), based on various figures published by FAO and The World Bank, suggested that by the year 2000 there is likely to be an annual deficit of about 8% of the total world wood demand, and by the year 2025, a 32% deficit. A number of assumptions were made to arrive at such predictions, including a doubling of yields from existing forests, and the cessation of destruction of natural forest. However, a doubling of yield may be difficult to achieve; further, the natural forest area was estimated to be declining by up to 16 million ha a year, an area much greater than that of new plantations being created annually (part of this loss of forest area is caused by the demand for new agricultural land, see below).

The demand for industrial wood products may be lower than predicted by the Centre for Agricultural Strategy, due to the general down turn in the World economy since the mid-seventies. However, the projections of fuel-wood and charcoal demand are likely to be realistic, since such demand is believed to be very inelastic. Fuelwood and charcoal demand are expected to make up about 40% of the projected demand for roundwood in the year 2000.

More recent studies, again largely based on FAO and UN figures, suggest that fuelwood deficits in the tropics will have more than doubled between 1980 and 2000, requiring a plantation area of over 100 million ha to meet the predicted deficit (Burley 1984). Yet the current annual rate of afforestation is only 1 million ha in the tropics.

Hence, in order to satisfy the need for wood products, the indications are that there should be a) No further reduction of forest and tree cover (and therefore no transfer to agricultural production); b) Increases in yield, which would necessitate improvements in forest management (including the management of livestock use of the forest) and c) Actual increases in the area planted to trees.

Crop Trends

The absence of reliable data on overall cropland and crop production trends has handicapped efforts to assess the impact of mounting pressures on the world's croplands. Nevertheless, data exist from 1950 onwards for lands on which cereals are grown; cereals occupy 70% of the world's croplands and are the dietary staple of most societies (Brown 1978). Table 1 shows that the area capita^{-1} under cereal crops has dropped since 1950 even with an increase of 26% in the area cropped; while with an estimated 10% increase in cropped area by the year 2000, the cropped area capita^{-1} will be close to half that of 1950.

World cereal yields increased by 2.2% $year^{-1}$ from 1950 to 1970 and only by 1.5% $year^{-1}$ from 1970 to 1980 (Brown 1981). Not only has food production failed to keep up with population growth in more than half of the developing countries, but yields in a number of countries are believed to be dropping, (eg. for Nepal, Bajracharya 1983, FAO 1983a). The reasons for the slow down in yield improvements and even for yield decreases are due to a combination of factors. These include; the addition of marginal land to the world's cropland base, the loss of fertile land to urban and engineering developments, higher energy prices, a reduction in fallow in dry-land grain growing regions, a shortening of the fallow cycle in areas of shifting cultivation and the cumulative loss of top soil and fertility in major food producing regions. Brown (1978) reported that one fifth of the world's cropland was degrading at a rate which was intolerable in the long run. In the arid and semi-arid zones, 10% of the irrigated croplands are subject to waterlogging and 8% to salinization with considerable reductions in yields (UN 1977); the annual rate of desertification of cropland in tropical areas alone is believed to be 2.5 million ha (Burley 1984).

TABLE 1: Average cropland area $capita^{-1}$ under grain in 1950 and 1980 and predicted area $capita^{-1}$ in 2000; actual increase in cropped area between 1950 to 1980 and predicted increase 1980 to 2000 (from Brown 1978, Brown 1981).

	ha $capita^{-1}$	**% increase in cropped area**
1950	0.24	
		26
1980	0.17	
		10
2000	0.13	

FAO (1980) suggested that the developing countries could double food production by the end of the century and meet increasing demand by improving production by 4% $year^{-1}$ during the 1980's, and 3.7% $year^{-1}$ during the 1990's. However, for this to happen the annual increases in yield ha^{-1} would have to be considerably greater than those achieved between 1950 and 1970, a very unlikely development given the evidence presented above. Hence increased pressure on marginal lands, including encroachment onto more forest land, to provide food for a growing population is likely to lead to an increase in soil deterioration in cropping areas.

Livestock Trends

The discussion is restricted to developing countries since in developed countries there have been difficulties in adjusting production to stagnating or shrinking domestic markets.

The growth in consumption of animal food products has exceeded that of production in the past two decades (FAO 1983 b). The less optimistic of two scenarios investigated up to the year 2000 (FAO 1981) suggested an 80% increase in animal production (cattle, sheep and goats) with an increase in livestock numbers of 15%. Yet, with few exceptions, any increase in animal production in the last 50 years in developing countries has been due to greater livestock numbers and not to improved productivity (ILCA 1981, Mahadevan 1982).

Livestock perform a number of essential functions in farming and cropping systems apart from direct food production (eg. draught power, dung production). FAO (1983b) suggested that if the value of draught power and utilized manure (estimated on the basis of the values of mechanical power and chemical fertilizers which can be replaced by livestock) are included, the total value of livestock production increases by almost 50% in developing countries. It can be argued however, that their value could be in fact even greater if one takes into account:

a) Production foregone due to manure utilization for other purposes (eg. fuel)
and
b) Inability to utilize the full ploughing potential of livestock due to feed shortages resulting in weak stock (eg. Hoekstra 1984 for Kenya).

Draught power is at present inadequate (Mahadevan 1982), and the demand for animal power is expected to increase. FAO (1983b) has calculated that to enable food production in developing countries to double by the year 2000, power input to agriculture would have to increase by 2.3% $year^{-1}$. If this involves only a 15% increase in the number of draught animals (see above), tractor numbers would have to increase by 400%. Since this is unlikely, a greater increase than 15% in the number of draught animals will be necessary as well as an improvement in their working performance in order for FAO's projections to be accomplished.

Small farmers sometimes derive a considerably greater proportion of their income from sales of livestock and livestock products than larger farmers within the same area and farming system, or derive more of their food from livestock than larger farmers (eg. for Nepal Conlin and Falk 1979, Gautam 1983). Livestock can provide food and income to the rural landless (Bernsten et al 1983). Hence it would seem to be important to maintain and develop fodder resources to which poorer sectors of society can have access.

The low productivity of livestock is due mainly to shortages of forage and of grazing areas and to the low quality of fodder; both of these have a seasonal dimension whereby, except in the wet tropics, livestock live on a sub-maintenance diet for considerable periods of the year (Crowder and Chheda 1982, Robinson 1985). To reverse this situation in order to improve productivity as suggested by FAO (1983b) would require substantial improvements in fodder availability and quality. However it has been suggested that all 3600 million ha of rangelands in arid and semi-arid lands are deteriorating (UN 1977). Further, there is no disagreement about the loss of grazing land to cropland (Mahadevan 1982, FAO 1983b, Sandford 1983). This is particularly significant since these areas are usually potentially the best grazing lands and particularly the best dry or cold season grazing lands. Hence increases in grazing areas or even their maintenance at present levels would be largely at the expense of further loss of forest or tree cover (much forest land is heavily grazed resulting in its gradual degradation).

In conclusion, it seems clear that crop, animal and wood products are likely to be in short supply in the future, at least on a regional and local basis. There are strong indications that the sectorial approach to likely supply and demand of natural resource products (livestock, agricultural crops and forestry) fails to appreciate the interrelated nature of these resource production systems. For instance, the expansion of cropland is at the expense of resources (forest, grazing land) upon which its own production is dependent. It is hard to see how, as suggested independently by various studies (largely based on FAO data), expansion can occur in the use of land for any one of these production systems without consequent reduction in at least one another.

SUSTAINABLE CROP PRODUCTION THROUGH AGROFORESTRY DEVELOPMENT?

It is within the context of the degradation of many land husbandry systems and of the increase in demand for products from frequently competing forms of land use (crops, livestock, forestry) that interest has grown in the capacity of agroforestry systems and technologies to reverse this trend. Agroforestry is a collective name for land use systems and practices where woody perennials (trees, shrubs, palms, bamboos etc) are deliberately used on the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components (Lundgren and Nair 1985).

One important objective of agroforestry is to obtain a more sustainable production from available resources. A key characteristic of such systems, which is often mentioned in agroforestry definitions, is that of the deliberate promotion of the woody perennial component (Anon 1982). Because agroforestry has considerable appeal, a large number of projects which include the introduction of agroforestry technologies have been initiated. However the belief that agroforestry technologies can increase production in a sustainable way is too often based on uncritical evaluation of the evidence.

Trees Within Cropland

Some of the potentially most attractive agroforestry systems are those in which the cropland fertility is improved or maintained by woody perennials growing within the cropland (as scattered trees or as closely planted hedgerows). Such systems rely on the fertility generating capacity of the cropland itself and therefore may avoid dependence on a shift of nutrients from land outside the cropland. Crop yields may be improved to such an extent that sustainability is achieved with crop production being maintained or even improved per unit area of "agroforestry combination" (rather than per unit area planted solely to the crop) thereby not requiring a larger area of agroforestry combination to produce the same quantity of crop. This is particularly important since land holding size is usually limited. The evidence which is often quoted to support the capacity of such technologies to solve soil fertility problems comes from areas ranging in climate from humid to semi-arid.

Torres (1983) hypothesized that maize production could be increased intercropped ha^{-1} on a sustainable basis through intercropping with a Leucaena leucocephala hedgerow which is managed to produce green manure. The hypothesis was based on available data on nutrient removal following the harvest of varying maize yields, and on the production of leaf prunings and foliar N from intensively managed Leucaena leucocephala hedgerows. The best response was expected to be in areas of low soil fertility and with closely spaced (1.5 m interrow spacing) Leucaena rows (i.e. greater production of Leucaena intercropped ha^{-1}).

More recently, Kang et al (1985) have reported the results of a 6 year old alley cropping trial with Leucaena leucocephala (Cultivar K-28) in the humid area of South Western Nigeria. The Leucaena interrow spacing was 4 m and the plants were harvested at a height of 0.75 m fives times a year. The mulch production of the plants from which successive prunings were not removed and onto which no N fertilizer was added produced a mean of 5.9 tonnes (dw) ha^{-1} year^{-1} and 173 kg N ha^{-1} year^{-1}. The maize grain yields could be sustained (over 5 years) at about 2.0 tonnes intercropped ha^{-1} with Leucaena prunings. Without application of Leucaena prunings, maize yields dropped from 1.0 tonnes ha^{-1} year^{-1} to less than 0.3 tonnes ha^{-1} year^{-1} over 4 years. However all the plots in this trial (including the control) received some additional P, K and Zn.

Two farming systems in which trees have traditionally been grown scattered in the cropland are currently frequently being quoted as systems in which scattered trees sustain productivity of associated crops (through improvements in soil fertility): Acacia albida - peanut and millet associations in the Sahel (eg. Felker 1978, Nair 1984, Lundgren and Nair 1985, Young, this volume); Prosopis cineraria and pearl millet associations in the semi-arid and arid zones of India (Mann and Saxena 1980, Nair 1984, Lundgren and Nair 1985).

The case for the Acacia albida agroforestry system is convincing. Table 2 shows the quantities of dry leaf matter and N added year^{-1} for fields with 10 to 40 trees ha^{-1} (the range in density found on farmers' fields), and for the areas beneath the tree canopies alone or for the whole cropped area. The study showed substantially and significantly higher soil fertility status under tree canopies.

Summarising some data on these systems in Senegal, Poulain (undated) stated that average millet yields were 460 kg ha^{-1} equivalent in the open between trees and 930 kg ha^{-1} equivalent in the understorey of Acacia albida.

TABLE 2: Foliage (d.w.) and N added year^{-1} by 10 and 40 Acacia albida trees ha^{-1} of cropland; additions ha^{-1} of understorey and total ha^{-1} (derived from Charreau and Vidal 1965).

Trees ha^{-1}	**Leaf Litter (tonnes d.w.)**		**N (Kg)**	
	ha^{-1} of tree understorey	**total ha^{-1}**	**ha^{-1} of tree understorey**	**total ha^{-1}**
10	5.12	0.64	90.4	11.3
40	5.12	2.56	90.4	45.2

However there is still a question concerning the full reasons for differences in soil fertility under the trees. The experiments were conducted under well established trees on a research station. While Charreau and Vidal (1965) stated that livestock had been excluded from the research site for a number of years prior to the start of the study, it is known that dung concentrations can influence the fertility of sites for many years. This could be particularly relevant on those study sites which have deep soils. The residual effects of dung accumulation may be substantial at depths out of reach of annual crops but within the large volume of soil tapped by the deep acacia roots. Chareau and Nicou (1971) did state that the traditional management of this agroforestry system involved fallow periods (both within the year and between years) when livestock return dung from areas outside the cropped area and distribute it in greater quantities under the trees where they seek shelter.

The situation with the Prosopis cineraria agroforestry system is far less clear. Foliar yield estimates range from 10 kg (d.w.) year $^{-1}$ (Paroda and Muthana 1981) to 72 kg (d.w.) year^{-1} (Acharya 1980) for mature P.cinerania for the same area of Rajasthan. Yet actual measurements on trees in the DBH size range of 24-30 cm give annual foliar yields ranging from 3.3 kg (d.w.) (Bhimaya et al 1964) to 27 kg (d.w.) (Mann and Saxena 1983). Tree densities on private cropland vary from 20-40 trees ha^{-1} (Mann and Saxena 1980) to 40 - 400 trees ha $^{-1}$ (Purohit 1981). Uncritical use of such figures could lead one to state that total annual foliar production of P. cinerania could be 66 kg (d.w.) ha^{-1} (3.3 kg tree^{-1} x 20 trees) or 28.8 tonnes (d.w.) ha^{-1} (72 kg tree^{-1} x 400 trees). The published information is insufficient to realistically evaluate the nutrient contribution of P.cinerania to cropland (Robinson in press). While a number of publications (Singh and Lal 1969, Saxena 1981, Shankararayan 1981) suggest that crop yields, and in particular those of pearl millet, are improved by P. cinerania, there appear to be no published research results to substantiate the statements (Robinson in press). Purahit and Khan (1980) quoted villagers' reasons for better crop growth under the trees as being due to fertility improvements by falling leaves, accumulation of bird droppings and dung concentration from cattle sheltering under the trees in summer, and to microclimate improvements. However this tree is usually lopped for fodder prior to leaf fall so leaf matter addition is not seen as a realistic explanation per se of the soil fertility and crop yield improvements which have been noted under the trees. Cattle and other livestock graze and browze extensively in areas outside cropland resulting in a shift of nutrients onto the croplands.

There is a shortage of critical information both on the quantitative contribution of trees to improved soil fertility and to increased crop yields which have in some situations been observed in the vicinity of trees. The mechanisms by which these improvements are achieved are also seldom understood. Soil fertility and crop yields can be improved when foliage is added to the soil as mulch, compost or via manure (from ingested material).

In order to select promising tree species for inclusion in trials to evaluate different species as soil fertility and crop yield improvers, data on the yield and nutrient composition of foliage of various species in different environments would be particularly valuable. However figures for foliar yields in non temperate areas are scarce.

A survey of worldwide literature on dry zone fodder trees (Robinson 1985, Robinson in press) showed that information on foliar yields is available for less than 20 species and for most of these there are difficulties in the interpretation of the data: eg. nature of leaves (freshweight of dry weight) not stated; size of tree or management history of the tree (such as canopy manipulation) not provided; sampling strategy not described.

It is possible that the maintenance or improvement of soil fertility and of crop yields on a sustained basis intercropped ha^{-1} may be achieved by only a very few tree species in selected environments. Leucaena leucocephala is a species which can continue to produce large quantities of leaf material under frequent harvesting regimes. The range of other species which are known to be promising for similar purposes is still limited (eg. Gliricidia sepium, Cassia siamea). It is more likely that the development of such managed systems of trees on cropland will help to reduce the dependence of crop production on the import of nutrients from forest and other non-cultivated land, or even on the import of artificial fertilizers.

Agrosilvipastoral Systems

Agrosilvipastoral systems are management systems in which a mixed agricultural system (i.e. including both a livestock and a crop production component) is in some way integrated with, or dependent on tree or forest production. For the purpose of this review, at least some of the area under trees or forest in agrosilvipastoral systems is spatially distinct from the area under crops. A number of studies have attempted to quantify the contribution which livestock make to crop production (demand for draught power and for manure) and the contribution which nutrients from forestland and other non-cultivated land make to crop production. This substantial dependence on foliage from trees and grass for nutrients can be through its direct utilization as compost or ashes following burning, or indirectly as animal feed or animal bedding.

Table 3 provides data from a small area in Western Nepal (altitude 500 m to 2000 m; precipitation, 1000 mm to 2000 mm yr^{-1}) on the ratio of land area under trees and grass (both government /communal and private) to cropland area, as well as the contribution which each area is estimated to make to the total calculated fodder demand for the livestock population of the area. Fonzen and Oberholzer (1984) suggested that the system is likely to break down because of the decline in soil fertility and crop production. The fodder supply is not sufficient to satisfy the demand (it does not add up to 100% of the estimated demand) and while there is some reliance on fodder from outside the area, animals are underfed during the dry season. It is interesting to note that the private land is nearly 7 times more productive in terms of fodder than land under government or common ownership. While a combination of both differences in inherent site conditions and in the management of the vegetation are likely to be responsible, the relative contribution of each factor to the differences in fodder production is unknown. The area from which these data were obtained is unusually well managed compared to the average farming community in the hills of Nepal.

TABLE 3: Ratio of land area under different uses and ownership categories and percentage of the estimated fodder demand supplied by each land category: Palpa District, Western Nepal (derived from Fonzen and Oberholzer 1984).

	Land Category		
	Cropland	**Trees/Grass Private ownership**	**Trees/Grass Government/ communal owner**
Area ratio	1	0.32	1.17
Fodder supply (% of demand)	10.5	51.5	27.5

Because of the difficulties in obtaining accurate average figures concerning a number of components of the farming systems of Western Nepal, only approximate figures could be given by Wyatt-Smith (1982) on the ratio of forest land required to sustain the fodder needs of the present farming systems. He suggested that his ratio of 2.8 ha of forest/shrub land ha^{-1} of private agricultural land was conservative; indeed using other figures from his paper on average private holding size for the hills of Nepal, 7 ha of accessible unmanaged forest land are required ha^{-1} of private agricultural land. Yet some of the areas which he mentions only have one ha of forest and grazing land ha^{-1} of terraced agricultural land.

Using figures for Nepal as a whole, Panday (1982) suggested that the percentage of the fodder supply contributed by various components of the land production system is as follows: cropland 14%; grassland 27%; forest grass 15% forest trees 39%; private trees 5%.

The hilly area of Nepal covered by the Nepal-Australia Forestry Project has been better studied than other areas in terms of quantitative assessments of the complex linkages between the forest, the agricultural system and the human population. Yet, even for the same project area, estimates vary significantly. Shepherd (1985) calculated that the area of forest required to "sustain one ha of cultivated" land was 3.16 ha. The calculation assumed a proportion of annual foliage production which could be harvested for fodder and litter without impairing the future productivity of "fully productive" (protected), "average" (in species composition) forest; the assumptions concerning the demand for foliage were based on household surveys to determine the number of head loads obtained from the forest for various purposes (litter for manuring, animal bedding material, fodder) and the total fodder demand for livestock; conversion rates were used to convert head loads to oven dry biomass and various livestock types to standard livestock units. However not all the steps in the calculations were provided.

Byrne (1985), for the same area, calculated that 6.38 ha of forest land was required to sustain one ha of "agricultural" land. His calculations were based on the same harvestable amount of consumable foliage from the forest as used by Shepherd (1985) and on household surveys to determine the area under crops, the number of livestock, the fodder demand and the proportion of total fodder supplied by the forest (some conversion factors were not the same as those used by Shepherd). Again not all the steps in the calculations or all the conversion rates were provided.

The estimates of the amount of forest leaf material harvested for animal bedding and composting range from 24% to 44% of the total amount of foliage harvested from the forest (Byrne 1985, Shepherd and Griffin 1983, Shepherd 1985). It has generally been assumed that the same area of forest land which supplies fodder can also supply foliage for litter and bedding.

Byrne (1985) however estimated that, in his area of study, the present land use system consisted of only 1.1 ha of forest, scrub and grazing land for each ha of "agricultural" land.

Other statistics for Sindupalchock district (the district which is better endowed with forest out of the two districts of the project area) give ratios ranging from 1.54 ha of forest and grazing land for each ha of "agricultural" land to 8.75 ha of "non-cultivated" land available for harvesting fodder and litter ha^{-1} of "cultivated" land (Gilmour and Applegate 1985, Griffin et al 1985, Shepherd and Griffin 1983, Shepherd 1985).

It is not always explicitly stated what the various areas include: total areas of forest/scrubland grazing land for the district, or that which is accessible from the villages and therefore utilized; sometimes "cultivated" land is interchangeably used with "agricultural" land when a considerable proportion of "agricultural" land is in fact not "cultivated" (74% according to one estimate for Sindupalchok district, Shepherd 1985); the latter therefore contributes at least some nutrients to the land which is actually cultivated. Nevertheless all the publications agreed, even in the case of the highest estimate for the ratio of uncultivated to cultivated land, that the current supply of nutrients to the cultivated land is insufficient to maintain its productivity. The various estimates for the ratios have led to conclusions ranging from: i) the ratio is insufficient to sustain cultivated land even if the forest/grazing land was fully productive; to ii) the ratio of non-cultivated to cultivated land is sufficient provided that the former were reasonably productive (and it is stated that this condition is not met).

It has frequently been argued that the large population of largely "unproductive" livestock in the hills of Nepal should be reduced. Data provided by Karki (1984) suggests that, for a hilly area of Western Nepal, the manure production of the livestock population provides only 28% of the recommended fertilizer requirement of the cereal and vegetable crops of the area; further, some of this potential manure is lost during free range grazing away from cropland and during transhumance.

A similar pattern of heavy dependence of the crop production and farming systems on forest land emerges from the Kumaon mountain areas of India. Pandey and Singh (1984) calculated, on the basis of annual herb and leaf litter production from forest close to their study village, that 9.3 ha of forest land were required "to support one ha of the agricultural system" of the village. The anlysis relied on energy values, derived from other sources, for the various inputs to and outputs from the system. Another study in the same region suggests that 18 ha of forest land are required to supply the fodder necessary to sustain each ha of "cultivated" land (Singh et al 1984) (assuming 10% of fodder needs being met by grasses on denuded slopes and 30% from the forest tree leaves). Yet the actual ratio was 1.33 to 1.0 and only 0.84 ha of good forest for each ha of "agricultural" land. Yet another study in the same region suggests an actual ratio of 1.58 ha of forest for each ha of "agricultural" land (Upreti et al 1985). In Kerala State (India), biomass from 40 ha of mixed forest is said to be required to sustain the productivity of each ha of Arecanut plantation (Chaturvedi, 1986).

DISCUSSION AND CONCLUSIONS

It is quite likely that some of the assumptions behind the calculations of supply of fodder and litter from various land use categories and of the demand for these products are unrealistic. This would help explain at least part of the wide discrepancies found between various estimates of the area of uncultivated land required to sustain production from cultivated land and the actual ratios which are found in various areas. More studies are required to validate locally or even regionally some of the assumptions which have been derived in some cases from very different situations (eg. conversion rates for various inputs and outputs; fodder requirement of a livestock unit under village stall-fed conditions or in free grazing situations; foliage production of forest harvested at different levels of intensity).

Some of the discrepancies are also clearly due to differences in definition of various land use categories (eg. agricultural land which includes only cultivated land or all private land including both cultivated and uncultivated land); and in the definition of various inputs and outputs (eg. fodder actually consumed by livestock or potential fodder consumption). The lack of clarity and precision in the presentation of data in many publications often precludes the drawing of realistic conclusions.

The efficiency of transfer of nutrients from non-cultivated land to cultivated land by livestock converting fodder to manure is also highly variable. The area of non-cultivated land required to sustain the productivity of cropland through conversion of fodder to manure will be considerably smaller where livestock are stall-fed than in areas where livestock spend most of the day or perhaps several months of the year grazing and browsing on non cultivated land.

Nevertheless, the weight of evidence, however imperfect, indicates that the crop-producing lands of the Himalayan region are degenerating because of insufficient nutrient inputs. (Bajracharya 1983, FAO 1983a, Karki 1984). The evidence also indicates that the pressure of foliar biomass and nutrient harvesting on non-cultivated lands is such that their productivity is also likely to be declining. Evidence from some other parts of the world suggests similar trends (Raintree, 1983 for Kenya; Robinson in press, for Western Rajasthan).

While the potential for improving soil fertility and crop production by introducing appropriate tree species within cropland is recognised, it is suggested that the main hope for reversing the present trend of overall decline in productivity in many environments in developing countries is to improve:

i) the production of harvestable nutrients from non-cultivated lands (including forests);

ii) the efficiency of transfer of nutrients from non-cultivated to cultivated lands;

iii) the efficiency of utilization by the crops of the nutrients imported from non-cultivated land.

It is only possible to discuss briefly a few of the ways in which improvements of these three parameters can be achieved. Selected examples are used to illustrate some of the technical, managerial and policy factors which could have a significant impact on these parameters.

i. The proportion of private land which is not cultivated is considerable in a number of farming systems. There is much scope for increasing the overall foliage production from such areas by planting selected species of trees at densities which still allow grass production. In many farming systems, farmers are prepared to protect trees on such land and to manage them for optimum production (eg. Fonzen and Oberholzer, 1984). However extension facilities for private seedling distribution are seldom sufficient to cover the areas where planting needs to be carried out. Farmers are not prepared to walk far to collect seedlings when the tree planting season usually coincides with the time of year when labour is at a premium for other farm work. A considerable increase in and decentralisation of extension facilities is required in many countries. If private land is likely to be better managed than communal or government land, there may be advantages in the equitable privatisation of at least some such land. Any suggestion for such changes in the ownership of land is likely to face strong resistance from government forestry departments. The need for any privatisation to be equitable would be essential; small farmers often rely more on land other than their own for fodder and other foliage, compared to wealthier farmers.

On government and communal land, the choice of tree species must coincide with the requirements of local people and with their site requirements. In many cases, government institutions have chosen species (eg. pines and eucalypts for timber, paper and fuelwood) which are not the most appropriate to satisfy the various products required by the community. Preferences for forest products often differ between men and women and between wealthier and poorer sectors of the same communities. The question has to be faced as to how much forest land has to be kept for fodder and other foliage production. Is foliage production compatible with the management of forest for other products, even if their management is separated over time, or should different areas of forest be managed separately for various products, perhaps aimed at different users? In many areas, for instance in the Himalayan region, the most important forest product is foliage.

The criteria for the selection of species aimed at foliage production on both private and government or communal land should take a number of factors into account. In all cases foliar yields and nutrient content of the leaves are important; species which have the ability to effectively add nutrients to the system (eg. by fixing nitrogen, facilitating the availability of nutrients from soil sources where they are otherwise unavailable), rather than purely recycle nutrients returned to the soil following decomposition, are also advantageous. In situations where trees are to be lopped, time in leaf in relation to foliage demand, and resilience to harvesting are important, as is foliage digestibility in the case of fodder foliage.

There are different ways of managing trees for foliage production. Oak forest in the Himalayan region is usually managed by frequent stem pruning of the tall trees. However it is possible that the pollarding of denser stands of trees which are kept smaller may provide more foliage per unit area of forest. Further, the labour requirement necessary to harvest a unit amount of foliage would be reduced, thereby enabling a larger area of forest to be harvested for the same labour input. Such a system could spread the harvesting pressure and reduce the trend of "peripheral degradation" (degeneration at the margin) of the forest described by Moench and Bandyopadhyay (1986) and which occurs in most of the Himalayan region; foliage production could therefore be increased. The easier harvesting of smaller trees could be carried out by children (tall trees are generally lopped by adults, and particularly by women, eg. Fox 1983, Singh et al 1984) thereby reducing the labour requirement of adult women which could itself result in improved management in other sectors of the farming system. A greater sustainable foliage production per unit area would release land for more conventional forms of forest production.

ii. The main way in which the efficiency of nutrient transfer from forest to crop land can be achieved, where foliage is fed to livestock, is by increasing the proportion of stall-fed animals; this would increase the amount of dung available for application to cropland from each unit area of fodder harvested from trees and forest land. While dung can be collected from land which is freely grazed by livestock, the labour requirement for this activity is high. The nutrient loss should also be lower from dung (and urine) accumulated with leaf litter in a stall fed situation compared to dung left lying in grazing land. Again there are a number of technical and socio-economic factors impinging on uncultivated land management, which determine the extent to which a change from free range grazing to stall-feeding is feasible. Some of these, including those of labour in foliage harvesting, are discussed above. Fox (1983) has argued that substituting stall-feeding for grazing might be more difficult than is generally believed. This is because fodder collecting (in his study area) requires the labour of healthy adult women which is already the most overworked labour sector, whereas grazing makes use of the labour of children and the elderly. The extent to which children attend school is also likely to affect the feasibility or desirability of stall feeding.

    Technical factors concerned with compost and dung management also influence the efficiency of the transfer of nutrients to cultivated land. Rural communities manage compost and dung in different ways, and some practices are more conservative of nutrients than others. Research should identify the most appropriate means of reducing nutrient loss in different climatic areas and given local cropping patterns.

iii. In different cropping systems, the timing of the demand by crops for nutrients varies. The release of nutrients from applied dung and compost/mulch should be matched with the crops' demands. Nutrient release rates vary with temperature (altitude and latitude) and rainfall regime. Mulch made of small leaves (eg. Leucaena leucocephala) may decompose too fast in some situations (eg. Philippines) and the nutrients may be leached out of the rooting zone of crops before the crop has been able to take up the nutrients. Larger leaves, with slower decomposition rates, would be more appropriate in such cases. Conversely, at higher altitudes or in low rainfall areas, faster decomposing mulch or compost may be desirable.

In many parts of the world, crop production is dependent on the shift of nutrients from forest and other non-cultivated land to cropland. The shrinking forest areas and competing demands on forests for different products make it imperative that their production potential be improved. While trees located within cropland can improve the nutrient status of cropland soils, the indications are that the main source of nutrients for maintaining cropland fertility originates and will continue to originate from forest land and other non-cultivated lands. It is necessary that forest departments take into account the dependence of farming systems on foliage harvesting from forest land in their overall forest policy and in their management prescriptions. Research can help identify ways in which tree and forest production can be increased and made more appropriate to the need of nutrient exports. The proportion of research funds for renewable natural resources which is allocated by central governments and international organizations to forestry should reflect this dependence of agricultural production on forestry. A number of changes in attitudes to the management of government and communal level, both at community and at government level, are necessary to optimise the production of agricultural and forest products.

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2. THE POTENTIAL OF AGROFORESTRY AS A PRACTICAL MEANS OF SUSTAINING SOIL FERTILITY*

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SUMMARY

The maintenance of fertility through soil biological processes requires management practices which control the quantity, quality and timing of decomposition of plant residues. Agroforestry is one of the major practical management methods which has the potential to bring this about. It is widely applicable, through many different kinds of practice, has substantial effects on the soil, and is relatively free from supply constraints. Trees restore soil fertility through their potential to increase the supply of organic materials and nutrients, to reduce nutrient losses and to control the quality and timing of inputs. A first approximation to a plant/soil organic matter cycle under agroforestry is presented, showing that if the assumptions on which it is based can be verified, agroforestry has the potential for the design of land use systems that combine production of annual crops with maintenance of soil fertility. The significance of work on different fractions of organic matter, and on root residues, is discussed; these studies suggest benefits from mixtures of woody and herbaceous litter. Results of work on soil rest period (fallow) requirements are summarized; it has yet to be shown whether spatially based agroforestry systems can be more efficient, in terms of land requirements, than crop/fallow rotations. Current research in agroforestry suffers from over-emphasis on pragmatic approach at the expense of an understanding of basic processes. Research is needed on the decomposition of woody and herbaceous residues, singly and in combination, and their effects on soil properties.

* This is a shortened version of a publication which first appeared as ICRAF Working Paper 34, Nairobi. 1985, 28 pp

INTRODUCTION AND OBJECTIVES

The Tropical Soil Biological and Fertility Programme (TSBF) is a collaborative programme of research, the objective of which is "to determine" the management options for improving tropical soil fertility through soil biological processes" (Swift, 1984). This objective can be achieved through two stages:

i to develop a predictive understanding of the functioning of biological processes in tropical soils, and their role in contributing to fertility;

ii to apply such an understanding to the development of practical management measures to sustain and improve fertility.

The present account originated from two papers presented to meetings of the TSBF (see Acknowledgements). This coincided with and ICRAF review of the role of agroforestry in soil conservation, taken in its broader sense to mean conservation of fertility as well as prevention of erosion. An account of soil productivity and management under agroforestry systems have been given by Nair (1984).

The objectives of the present paper are:

i To outline some of the hypotheses of the TSBF that are of particular significance to agroforestry.

ii To show the potential of agroforestry as one of the major practical management alternatives for maintenance of tropical soil fertility through biological processes.

iii Based on present knowledge of plant/soil organic matter processes, to give a preliminary outline of a possible organic matter cycle under agroforestry.

iv To discuss the significance for agroforestry of recent advances in knowledge of soil organic matter processes.

v To outline needs for research.

It should be emphasized that this is an interim statment of work in progress, and still at a relatively early stage. Much of it consists of hypotheses not yet fully supported by experimental evidence; these hypothoses, however, have substantial and favourable consequences if they can be verified.

Lastly, it should be emphasized that as a working paper, this is intended as a means to invite criticism and comment on the ideas presented.

BIOLOGICAL PROCESSES AND SOIL FERTILITY

Fertility is the capacity to support plant growth, and as such arises jointly from climate and soil. However, it is frequently desirable to isolate the element of soil fertility, which can be taken as the capacity of the soil to support plant growth, given satisfactory climatic and other environmental conditions.

The main soil conditions contributing to fertility are favourable physical properties, an adequate supply of nutrients, and absence of toxicities. None of these conditions are biological. The indifference of plant growth to soil organic matter as such is shown by the high crop yields that can be obtained, with fertilizer, on sandy soils with well under one percent organic matter, and by the not especially high fertility of peats.

It is widely recognised, however, that soil organic matter greatly influences fertility, through its effects on both physical conditions and nutrients supply (see, e.g. Young, 1976, p. 300; Swift and Sanchez, 1984, p. 7). Formerly, the emphasis was simply on maintaining the quantity of organic matter. This remains the priority, since if the soil humus can be kept above some critical level, which varies with environment, then most other favourable consequences will follow. Recent work, brough into focus by TSBF, has drawn attention to two other aspects: the quality of organic matter and the timing of its decomposition.

'Quality' is a loosely-defined term which refers to various aspects of physical and chemical composition. The term may be applied to both plant residues (litter and roots) and to soil humus. In the case of plant residues, it refers primarily to the relative proportions of sugars, nutrient elements, lignin and other polyphenols (Swift et al., 1978). This aspect is discussed further below.

The timing of mineralization of soil organic matter controls the release of nutrients; and since nutrients are also subject to leaching, fixation and other losses, it is advantageous if this release can be effected at the same time as the major requirements for uptake by plant roots. The main control over timing of release is the period when plant residues are applied to the soil; other controls are the quality of such residues, how they are applied (e.g. to the surface or buried), physical and chemical soil properties, especially moisture, and the soil fauna.

There are two basic hypotheses underlying the TSBF, concerning synchrony in nutrient release and uptake, and soil organic matter, the SYNCH and SOM hyptheses respectively.

The SYNCH hypothesis is that the release of nutrients from plants, and their subsequent transformation via litter, humus and mineralisation, can be synchronised with plant growth requirements, by means of management measures.

The SOM hypotheses is that the amounts and types of soil organic matter, and thus its effects on soil properties and fertility, can be regulated by the types of litter and root residues.

Thus, seeking to improve soil fertility through biological means, the factors that it is possible to manipulate are:

i the quantity of plant residues;
ii the types of residues, and thus their quality;
iii the timing and manner of their addition;
iv the soil conditions that affect their decomposition.

PRACTICAL MANAGEMENT OPTIONS

These soil changes have to be brought about through practical management options, measures that the farmer with limited capital and technical resources can carry out on a field scale (as distinct from horticultural). In the first report of the TSBF programme there is a list of 21 soil biological processes or effects, with management practices by which they can be manipulated. Table 1 is a transformation of that list, in which the management practices are given in the first column, followed by their soil biological effects. Thus, fertilization (inclusive of liming and sulphur addition) can affect root turnover, rate of organic mater decomposition, solubilization of rock phosphate and denitrification.

Two columns have been added, "non-biological reasons" and "supply constraints". The former refers to practices that are usually carried out with objectives in mind that are not primarily control of soil biology. Thus fertilizers are added to increase the nutrient supply directly, crop rotation to achieve balance in the nutrient demands, intercropping for a variety of reasons, ecological and economic. This applies also to management of burning, drainage, application of pesticides, and grazing control. All these practices have soil biological effects, but these are not the main reasons why they are carried out.

Thus, pesticides are applied to kill insects; the fact that they may also reduce the detritivore population is a side effect.

This situation also applied to agroforestry practices. The most common reason for them is probably to obtain firewood from the farm. Others are to produce fodder for livestock, fruit (for food or cash sale), or for food conservation. In other cases, agroforestry is practised with the perceived objective of soil fertility improvement. Examples are the practice of laying Erythrina poeppigiana prunings on the soil in coffee cultivation, found widely in Central and South America, and the use of Leucaena leucocephala as a managed rotation in parts of the Philippines.

The fourth column in Table 1, supply constraints, indicates where the application of a management practice is often prevented or restricted by problems of supply. This is obviously so in the case of fertilizers. For grass mulching, composting or application of farmyard manure, there is frequently not the quantity of material available for application to the main area of field crops. From the 1950s onwards it was shown that 5-10 t/ha per year of manure is very beneficial to the soil; but in most farming systems, the supply is not likely to exceed 1-2 t/ha per year, and this alone does not maintain soil organic matter level. In herbaceous legume fallows the constraint is one of land; green manuring, solely for the purpose of ploughing in the residues, is not viable. With regard to incorporation of crop residues, nothing so well combines practicability, even at a low level of technology, with clear beneficial effects on the soil; but the poorer farmers frequently have more pressing uses for crop residues, as livestock feed (especially in the Indian subcontinent) or construction materials for compounds (e.g. northern Nigeria). The possible supply constraint to tillage management is in the supply of herbicides where required for minimum tillage.

Summarizing this position, the practical management measures that are listed can be put into the following groups:

i Practices carried out primarily for reasons other than their effects on soil biology: fertilization, crop rotation and intercropping, management of burning, drainage, pesticides and grazing.

ii Practices in which soil biological effects are a substantial and perceived purpose, but which for poorer farmers are often subject to supply constraints: green manuring, mulching, composting and manuring, incorporation of crop residues, and tillage management.

iii Direct biological manipulation; the case listed in the table is mycorrhizal inoculation but there are others, e.g. fumigation to destroy nematodes.

iv Agroforestry, which: (a) can be practised for economic reasons, with side-effects on soil biology and fertility, or with such effects as a perceived benefit; and (b) is often practicable for the poorer farmer, or can be made so by a modest level of governmental assistance (e.g. tree nurseries).

TABLE 1: Management Practices which influence soil biology and fertility. Derived from Swift (1984, Table 1).

Management practice	Soil biological effects, see below	Non-biological reasons	Supply constraints
Fertilization, liming	1, 10, 12, 14	x	
Crop rotation, intercropping	2, 21	x	
Legume fallow (herbaceous)	3		
Mulching, compost, manure	7, 8, 19		
Crop residue management	7, 8, 15, 17		(x)
Tillage management	6, 20		(x)
Agroforestry practices	2, 3, 4, 7, 15, 19	(x)	
Control of burning	11	x	
Drainage	13	x	
Pesticide management	5, 9, 20	x	
Grazing control	18	x	
Mycorrhizal inoculation	16		

x Normally or frequently (x) Sometimes

Soil biological effects:

1. Increase root production
2. Cause variation in root exudates
3. Cause N fixation
4. Cause upward movement of nutrients
5. Reduce detritivore populations
6. Increase biological oxidation
7. Low quality residues promote synthesis of organic colloids
8. Low quality residues lead to nutrient immobilization
9. Insecticides increase microbial immobilization
10. Liming increases rate of soil organic matter decomposition
11. Burning increases mobilization
12. Addition of S increases solubilization of rock P
13. Drainage increases nitrification
14. Nitrate fertilization increases denitrification
15. Nutrient-rich residues increase reduction of S, F, Mn
16. Mycorrhizal inoculation increases nutrient uptake
17. Crop residues increase soil particle aggregation
18. Heavy grazing increases soil surface capping
19. Organic residues maintain macrofauna and thus soil pores
20. Termites reverse clay illuviation, tillage or pesticides destroy termites
21. Crop rotation reduces toxification of soil

In summary, there are three management practices which are practicable, applicable in a wide variety of circumstances, and which have substantial effects on soil biological properties:

- crop residue management
- tillage management
- agroforestry

The first two of these are linked in techniques of minimum tillage. There are also possibilities of combining (herbaceous) crop residue management and/or tillage management with agroforestry.

There is a wide range of agroforestry practices, and many thousands of local agroforestry systems. Some are traditional indigenous land use systems, other more recently developed. A list of the main practices is given in Table 2.

TABLE 2: Agroforestry practices. (Adapted from the ICRAF agroforestry systems inventory)

Improved shifting cultivation
Planted tree fallow
Taungya
Alley cropping
Boundary planting
Live fences

- mainly barrier function
- multipurpose

Multipurpose trees on:

- cropland
- rangeland or improved pastures

Woodlots (with multipurpose management)
Protein banks
Trees as shelter for:

- crops (windbreaks, shelterbelts)
- animals
- homesteads

Trees for soil conservation:

- on bunds, terraces
- strips
- hedges

Trees in water management
Home gardens
Plantation crop combinations:

- with lower-storey tree/shrub crops
- with herbaceous crops
- with upper storey trees (shade of multipurpose)
- with pastures and livestock

Livestock under trees
Dune fixation
Aquaforestry (including mangrove)
Apiculture with forestry

THE BASIS OF PLANT/SOIL INTERACTIONS UNDER AGROFORESTRY

The foundation for assuming that agroforestry systems can lead to a steady state of the soil lies in the observation that tree fallows build up soil fertility, as demonstrated by systems of shifting cultivation. This counteracts the decline in fertility under continuous cultivation of of annual crops.

There are three agroforestry practices based on a time rotation of trees with crops: improved forms of shifting cultivation, planted tree fallows, and taungya. Improved shifting cultivation started with the corridor system developed at Yangambi on the former Belgian Congo; there are versions, including a livestock component, more recently devised for the Amazon (Bishop, 1982). In planted tree fallows, a fast-growing, nitrogen-fixing tree is planted in blocks, rotated around the agricultural land; the larger woody parts may be harvested for firewood, the remainder is returned to the soil. In taungya systems, the major objective is the harvest of the tree, annual crops being interplanted for 1 - 3 years; this is successfully practised in forest villages of Thailand and the shamba systems of Kenya, less effectively in some other instances.

More flexibility in design comes from substituting spatial arrangements of trees and herbaceous plants for rotations in time. The trees may be spaced more or less randomly, as in home gardens and some types of sylvopastoralism; regularly, in grazing beneath coconuts, rubber or timber trees; in single rows, as in boundary planting and some forms of alley cropping; or in strips several trees wide, also possible in alley cropping designs. In practices dependent upon spatial arrangements, a large range of interactions come into existence at the tree/crop interface. Important as these are, they will not be considered in the present discussions (cf. Huxley, 1983).

Essentially, therefore, an agroforestry system is made up of trees and herbaceous plants, each occupying a certain proportion of space and/or time. One way of looking at this situation is as a continuum between 100% crops and 100% trees, the former degrading the soil, the latter restoring fertility, but with the crops normally giving the higher economic return. Agroforestry systems lie somewhere between these extremes, and seek to find a mixture of components that will combine sustainability with an acceptable economic return. Such three-dimensional models are outlined by Huxley (1984, 1985). Soil-related aspects of a range of different agroforestry practices have been outlined by Nair (1984).

The basis for the role of agroforestry in sustainable land use systems is the same, whether there is a rotation of components in time or an arrangement in space: namely, that a net loss of soil fertility under the cropping component is balanced by a net gain under the tree component. Trees achieve favourable effects on the soil through range of processes, listed in "Effects of trees on soils", Chapter II.

THE PLANT/SOIL ORGANIC MATTER CYCLE

Conceptual basis and the cycle under vegetation and cropping

The starting point for discussion of organic matter cycling is the model of the carbon balance under shifting cultivation constructed by Nye and Greenland (1960). There are two components to this model: the stores and flows of organic carbon under natural fallows (forest or savanna), and the basic assumption of a decomposition constant in the oxidation loss of soil organic carbon.

Although there has been much subsequent quantitative work on organic matter cycling under natural vegetation, the orders of magnitude for stores and flows of carbon established by Nye and Greenland have proved to be correct. Table 3 gives representative values for these stores and flows for three climatic environments: lowland rain forest, moist savannas (annual rainfall 900-1200 mm) and dry savannas (annual rainfall 600-900 mm). The savanna data are subdivided according to whether it is burnt (with assumed loss of above-ground vegetation) or unburnt).

The losses of carbon from the soil humus, through bacterial oxidation, are based on the concept of a decomposition constant. That is the amount of carbon lost in unit time through oxidation is assumed to be proportional to the amount of carbon initially present. This proportion is the decomposition constant, usually expressed as a percentage. The rationale for this assumption is that the oxidizing activity is proportional to the soil fauna present, the population of which is dependent on the substrate which supports it. In this paper, the decomposition constant under forest. kf, is taken as 3% (0.03) and the decomposition constant under cultivation, kc, as 4%. The assumption of a decomposition constant provides a homeostatic mechanism whereby soil organic matter will tend towards an equilibrium value under constant inputs, however large or small these may be.

This model takes no account of the existence of varying qualities of soil organic matter, with differing rates of breakdown, the implications of which are discussed later.

Figure 1 gives the models for the rainforest and moist savanna conditions, showing the position under equilibrium conditions. Gains to soil humus equal losses, at 190 g/m^2 per year in the forest environment and 120 g/m^2 per year under savanna. The soil humus contents of 6330 and 5700 g/m^2 carbon respectively are equivalent (making a number of assumptions) to topsoil organic matter levels of 4.24 under forest and 3.8% under savanna.

As a basis for discussing carbon flows under agriculture, one of these environments only is selected, that of rainforest. A cereal crop is assumed (typically maize), with two levels of grain yield: 1000 kg/ha, typical of low-input or 'traditional' agriculture in developing countries; and 3000 kg/ha representative of intermediate inputs, i.e. improved farming, with some use of fertilizers, but lower than in high-capital high-technology agriculture. For each yield level, two alternatives considered are that the crop residues are or are not returned to the soil.

Figure 1
The carbon cycle under natural vegetation. Cf Table 3. Source: Young (1976, p111), based mainly on data in Nye and Greenland (1960).

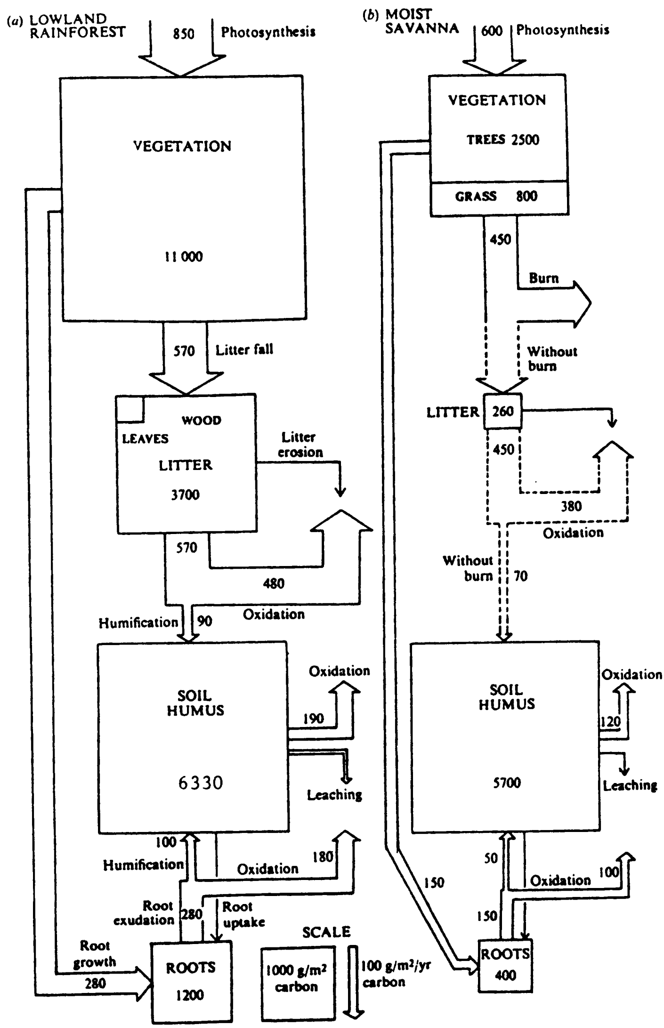


TABLE 3: Estimates of typical values of parameters in the carbon cycle under natural vegetation. Based on data in Nye and Greenland (1960), with some modifications. All values refer to organic carbon, which is assumed by Nye and Greenland to constitute approximately half of organic matter.

A. Stores of carbon (Values in g/m^2)

		Lowland rainforest	Moist savannas	Dry savannas
Living vegetation:	trees	11000	2500	2400
	grasses	0	800	400
	roots	1200	400	200
Dead vegetation:	leaf litter	100	60	30
	wood	3600	200	200
Total living vegetation		12200	3700	2800
Total dead vegetation		3700	260	230
Soil humus		6330	5700	1700
Total in plant-soil system		22230	9660	4730

B. flows of carbon (Values in $g/m^2/yr$)

	Lowland rainforest	Moist savannas		Dry savannas	
		Unburnt	Burnt	Unburnt	Burnt
Net intake from atmosphere	850	600		170	
Loss in burning	0	0	450	0	120
Root growth	280	150		50	
Litter and timber fall	570	450	0	120	0
Humification of litter	90	70	0	20	0
Oxidation loss in above	480	380	0	100	0
Root exudation	280	150		50	
Humification of roots	100	50		20	
Oxidation loss in above	180	100		30	
Total additions to soil humus	190	120	50	40	20

Table 4 gives stores and flows of carbon for four conditions: low and moderate yields, each with removal or retention of residues. It is assumed that cultivation has already lowered soil humus to half of its level under forest, 3500 g/m^2 carbon. The harvest index (grain as percent of above groun biomass) is taken as 33%, and biomass of roots as 33% of the above-ground biomass. The same assumptions are made as in Table 3, namely that the split between humification and oxidation loss is 15% : 85% for crop residues (litter in Table 3), and 33% : 67% for roots.

There is net loss of carbon from soil humus under all four sets of assumptions. Its level is lowered annually by about 1% of its initial level under the most favourable conditions and 3% under the least favourable. If such cropping were continued (avoiding erosion), the soil humus would reach equilibrium at levels shown in Part C of the table. On grounds of soil structure maintenance, erosion resistance, and retaining a nutrient source and retention medium, these levels are certainly unacceptably low for the first three cases, and even in the most favourable case represent only one third of the level under natural forest.

The situation for moderate yields with residues removed is shown diagrammatically in Figure 2. As compared with the model under forest (figure 1) the feature is the high proportion of total carbon in plant-soil system that is contained in the soil store. Losses are shown by shaded boxes, the dotted area for 5 years of cereal cultivation with removal of residues.

The soil organic matter balance under agroforestry

If assumptions made in the preceding section are justifiable, it is possible to construct a first approximation of cycling of organic matter (represented by carbon) under a schematic agroforestry system. It should be re-stated that this simplified model takes no account of the existence of fractions of organic matter with differing rates of decomposition.

The model is based on the following assumptions:

- A humid tropical (rain forest) environment;
- The planting of trees which have a rate of growth, and thus litter production, equal to that of a natural forest fallow.
- An agroforestry practice in which trees and crops each occupy 50% of land in space or time.
- The assumptions, from Table 4, of a 'moderate' crop yield (3000 kg/ha grain) with crop residues removed.
- The assumptions on processes set out in the above section.

The effects are virtually the same for a rotation of trees and crops as for a spatial mixture of equal proportions, except for a toothed pattern to the curve of soil carbon with time in the former case compared with a smooth curve in the latter.

The assumptions are perhaps unduly favourable (for soil organic matter) in that only one cereal crop per year is taken, whereas two crops are common in humid tropics; but errs on the cautious side in assuming that the trees planted in the agroforestry system have only the same rate of growth as natural vegetation.

In Figure 3, the upper diagram shows what happens when the forest is first cleared. Under forest conditions, inputs and outputs of soil carbon are equal, at 190 g/m^2 per year. Under the crop they are very unequal, leading to a rapid fall in soil humus level. The half-and-half agroforestry system still leads to a combined loss of 100 g/m2 carbon per year.

The lower diagram shows the situation when soil carbon has reached 3450 g/m^2. Inputs from tree and crop components are unchanged, but the assumption of the decomposition constant leads to approximate halving of the oxidation losses. Under the crop alone there is still a net annual loss of 86 g/m^2 carbon, but this is balanced by an equal net gain under the tree component. The agroforestry system as a whole — soil, soil organisms, tree, crop and environment — is stable, This equilibrium is reached with soil organic matter at slightly over half its natural level, a proportion generally taken to be acceptable in agriculture.

This result is exciting in the prospects which it opens up. It amounts to an hypothesis that, provided the assumptions can be verified, agroforestry systems can be designed that are productive in terms of crops, and at the same time lead to a steady state of soil organic matter. The features that require verification are that the processes operate in the manner stated, and that the general magnitudes of plant growth assumed are correct.

This result is currently being followed up, through the construction of models of the cycling both of organic matter and nutrients, the former taking into account the different organic matter fractions. There is a substantial body of source data, both studies of cycles as a whole and individual components (eg. litter fall, nitrogen fixation). This exists for:

- natural vegetation; there is an imbalance towards studies of forest, but with some data on savanna and semi-arid ecosystems.
- agricultural systems;
- forest plantations; these studies arise from the concern of foresters about the long-term effects on soils of fast-growing forest plantations;
- agroforestry systems; there are a substantial number of records of individual components, particularly tree growth rates and litter production, and a few studies of total cycles.

Computerized models are being developed, of greater complexity but with similar basis to those of Figures 1-3.

TABLE 4: Estimates of the carbon cycle under cereal crops of low yields (1000 kg/ha) and moderate yield (3000 hg/ha). Values in g/m^2 carbon.

	Low yield		Moderate yield	
Crop Residues:	**Removed**	**Retained**	**Removed**	**Retained**
A. Stores				
Crop: grain	50	50	150	150
vegetative	100	100	300	300
roots	50	50	150	150
Soil humus (OM = 2.33%)	3500	3500	3500	3500
Plant soil system	3700	3700	4100	4100
B. Flows				
From atmosphere	200	200	600	600
Root growth	50	50	150	150
Harvest	50	50	150	150
Crop residues, removed	100	0	300	0
" " retained	0	100	0	300
Humification of residues	0	15	0	45
Oxidation loss in above	0	85	0	255
Root exudation	50	50	150	150
Humification of roots	17	17	52	52
Oxidation loss in above	33	33	98	98
Total additions to soil humus	17	32	52	97
Loss from soil humus (k_c=4%)	140	140	140	140
Net changed in soil humus	-123	-108	-88	-43
C. Equilibrium level of soil humus				
Carbon, g m^{-2}	425	800	1300	2425
Equivalent topsoil OM%	0.28	0.53	0.87	1.62

Figure 2
The carbon cycle under a moderate-yielding cereal crop in the lowland rainforest zone. Shaded areas show net losses of soil humus as follows: 1 yr ret. = loss in 1 year, crop residues retained; 1 yr rem. = loss in 1 year, crop residues removed; 5 yr rem. = loss in 5 years, crop residues removed.

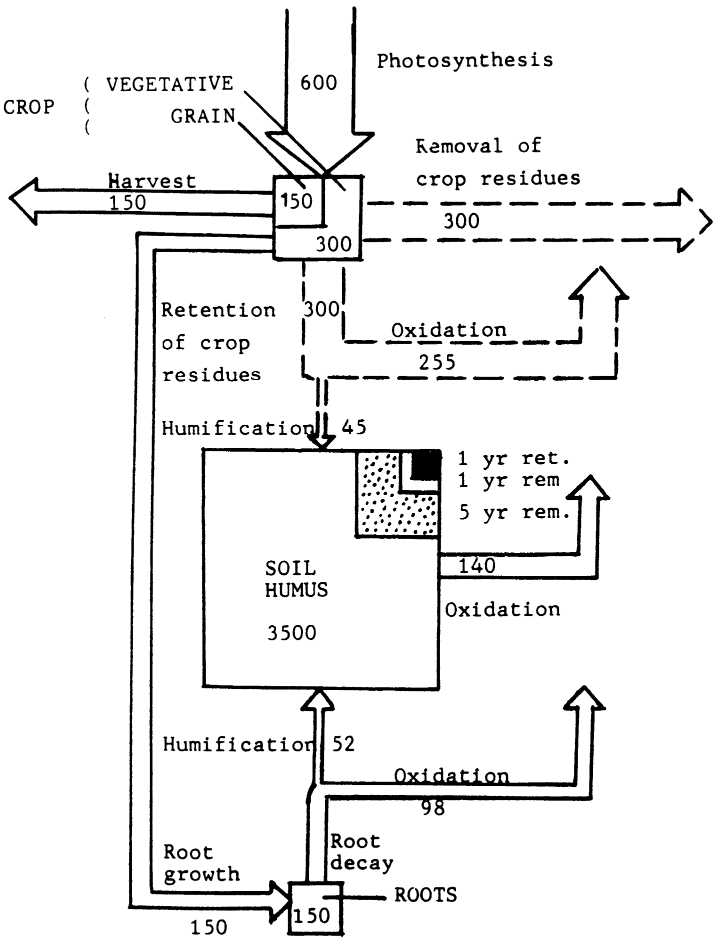
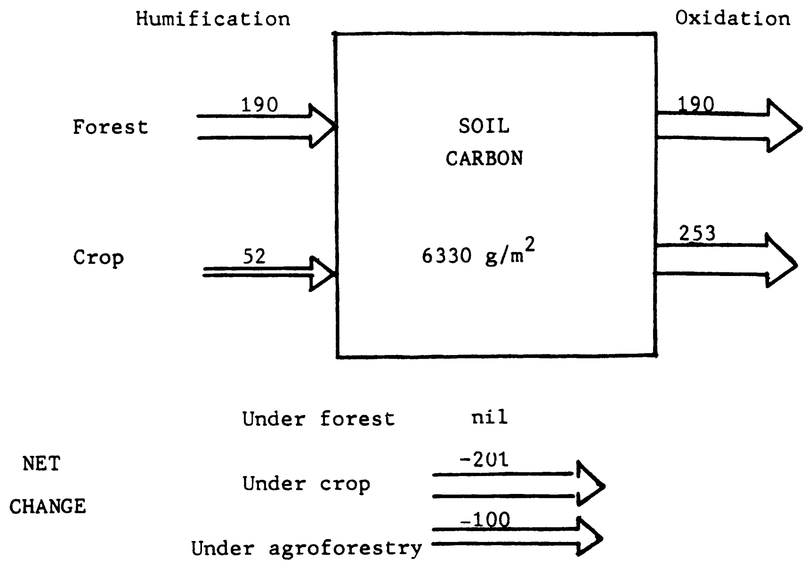
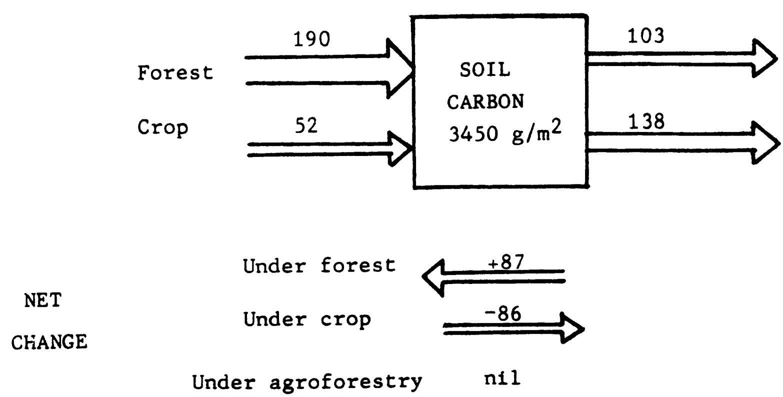


Figure 3
Changes in soil carbon, g/m², under forest, a cereal crop and agroforestry, at two levels of soil humus carbon. Assumptions are: (i) cereal crop, moderate yield, residues removed; (ii) decomposition constants, for forest, k_f = 3%, for cultivation, k_c = 4%.





SPECIFIC ASPECTS OF SOIL ORGANIC MATTER

Two advances in knowledge about soil organic matter are of much potential significance to agroforestry. These are the distinction betwen fractions with differing rates of loss, and the role of root exudation and decay.

Fractions of organic matter

The former assumption (employed in the above model) was of a single decomposition constant for soil organic matter, a fixed proportion of the current store that was lost by bacterial oxidation each year. Reasoning from observed equilibrium levels led to the supposition of constants of some 3% under natural vegetation, rising to 4% under agriculture. It was soon suspected that the losses during the initial decomposition of plant residues, for the first six months to a year, were very much faster (Young, 1979 pp. 114-5). The position has been transformed by carbon isotope studies, which enable the progress of labelled plant material to be followed through the system (Jenkinson, 1971, 1977; Jenkinson and Ayanaba, 1977; Sauerbeck and Gonzalez, 1977; Paul and van Veen, 1978; Gonzalez and Sauerbeck, 1982.

The addition of carbon-14 labelled residues to a soil enables the loss of this specific material to be followed over time. Studies both in temperate and tropical soils have a decay curve of the same form; a very rapid loss over the first 3-6 months, changing fairly abruptly into a slower rate of exponential decay. For studies in the UK and Nigeria, using the same plant material, the two curves could be superimposed almost exactly if the time scale for Nigeria was divided by four. This led to the assumption that these correspond to two different fractions of organic matter.

The fast-decay fraction is lost rapidly, such that in tropical soils, some 65% of the labelled plant material is lost within the first 6 months or less. It seems likely that this corresponds to the loss in 'conversion' from litter to humus in the Nye Greenland model, which takes values of 75-90% loss for above-ground litter and 50-80% for roots.

The next organic matter fraction is lost in an exponential decay manner, with a half-life of between 3 and 6 years. These are the only two fractions directly monitored by carbon-14 labelling.

The equation underlying the Nye-Greenland model is of the form:

$$C_1 = C_o - kC_o$$

or

$$C_1 = C_o (1-k)$$

where C_o = initial carbon, C_1 = carbon after 1 year, and k is the decomposition constant expressed as a fraction.

This simplified equation takes no account of the effect of decrease in the course of the year on the quantity of carbon remaining. For short periods of time, the relation is more precisely expressed by an equation of exponential form:

$$C_t = C_o.e^{-rt}$$

where C_t = carbon after time t (years), e is the exponential constant, and r is a parameter. For slow rates of decay (k and $r < 0.1$) the equations are nearly equivalent and r   k. For a single organic matter fraction the half-life $T_{1/2}$ is given by:

$$T_{1/2} = \ln(2)/r$$

With two fractions, the equation becomes:

$$C_t = C_1.e^{-rt} + C_2.e^{-r_2 t}$$

where C_1 and C_2 are the fast and slow-decay fractions respectively, and r_1 and r_2 the corresponding values of r. In Gonzalez and Sauerbeck's (1982) results for Costa Rica soils, C_1 ranged from 52-72% of total carbon and C_2 correspondingly from 28-48%. Values of r_1 were mainly in the range 3.4-7/4, those of r_2 in the range 0.12-0.23. Jenkinson and Ayanba's (1977) values for Nigeria are similar.

Three lines of evidence suggest the existence of a third organic matter fraction, with a considerably slower rate of decay. First, it is possible to calculate the equilibrium value of soil carbon, based on the existence only of the first two fractions. The theoretical equilibrium calculated in this way is found to be about 1.5-3.0 times the annual addition of plant material. Observed soil carbon percentages, however, are very much higher, such as to imply a totally unrealistic value of annual plant fractions. This leads to the presumption of a third fraction, with substantially slower decay.

The second piece of evidence comes from the decay of non-labelled carbon in the same experiments as those described above, that is, carbon already present in the soil at the start of the experiment. This is lost very much more slowly than the labelled carbon; typical values appear to be some 3% per year, a similar value to the formerly - assumed decomposition constant. This unlabelled soil carbon may be taken to comprise a mixture of relatively recently-added plant carbon and older material, and thus the loss rate of the latter is likely to be less than that of the total carbon.

Thirdly, there has for long been the apparent anomaly that carbon dating of soil organic matter has sometimes yielded values of hundreds of years. This could refer to the third, very stable fraction.

Thus there appear to be three organic matter fractions:

- a fast-decay fraction with a half-life in tropical soils of less than 6 months; this may alternatively be treated in modelling as loss during humification;

- an intermediate-decay or labile fraction with a half-life in tropical soils of about 3 years.

- a slow-decay or stable fraction, capable of remaining in the soil for periods in excess of 50 years.

The first two fractions are clearly likely to be the main contributors to nutrient release. It has been speculated that the third fraction contributes particularly to maintenance of favourable physical conditions in the soil, but there is no evidence for or against this.

Does the stable fraction originate mainly from decay of lignin, and is it thus favoured by woody litter? If so, there is an obvious significance for agroforestry. There is also a management implication, namely that twigs and fine branches should be left to rot with leaf litter, and not removed for convenience of agricultural operations.

Whatever the detailed mechanisms, it is plausible to suppose that litter of differing quality affects soil biology in varying ways, one of the basic hypotheses of the TSBF (Section 2). If this is so, then there is clearly a potential value in the capacity of agroforestry to yield a mixture of herbaceous and woody residues.

The role of roots

The second advance in knowledge, also found by C labelling, is that root exudation and root death during the growth of a plant, taken together, can substantially exceed the mass of roots found by digging up the plant and weighing what remains (Sauerbeck and Johnen, 1977; Bowen, 1984). That is, more labelled carbon remains in the soil over a period that can be accounted for by the roots present at the end of that period. This may help to explain why the soil organic matter situation under agriculture is not even worse that it might be!

We do not know if tree roots are more active or less than those of herbaceous plants in this respect. There is a potential significance, likely enough to be worthy of investigation, in the fact that trees produce a mixture of different types of roots, which could be beneficial in a similar way to that of a mixture of different types of above-ground litter.

RELATED TOPICS

Interactions in time and space: the relevance of soil rest period requirements

The situation in which a period of annual crops is alternated with a fallow or other means of restoring fertility has been reviewed in terms of soil rest periods (Ahn, 1979; Young and Wright, 1980). A rest period is defined as natural fallow, grass ley or managed woody fallow. The rest period requirement is the proportion of rest time needed to maintain the soil in a steady and productive state, when used for cultivation of annual crops. The requirement is expressed in terms of the cultivation factor, R, the number of years under cropping expressed as a percentage of the total cropping/non-cropping cycle.

A review of available information on rest period requirements was conducted as part of the FAO study of crop production potential of agro-ecological zones. Data were obtained both from published information and a questionnaire. Rest period requirements were obtained according to climate, soil type and level of agricultural inputs (Young and Wright, 1980). Low inputs refer to traditional farming methods without use of fertilizers, intermediate inputs to improved farming but with moderate technical and capital resources, high inputs to advanced technology. A summary of the results is given as Table 5.

This review was conducted in terms of rotations in time. It is important for agroforestry to know whether the results would remain the same if transplanted into spatial terms. For example, for ferralsols in the rain forest zone under low inputs, the R value is given as 15%, a requirement of 6.67 years of fallow to every one of annual crops. Translated into spatial terms, this implies that to maintain soil fertility, the tree strips would have to cover 85% of the land, leaving only 15% for crops. This is acceptable under a taungya system, but certainly not for alley cropping. For luvisols in the savanna zone at intermediate input levels, the rest period requirement is 50%, equivalent in the alley cropping system to equal widths of crop and tree rows.

These results deserve careful notice, particularly in the planning of alley cropping. If it appears, whether by reference to logical experience or from Table 5, that the rest period needed to maintain fertility in a cultivation fallow rotation is X percent of time, then the initial assumption must be that to achieve the same result in a spatially-based system, X percent of the land must be occupied by trees. If it could be shown that a given percentage of tree cover grown at the same time as crops had a more beneficial effect on fertility than an equal percentage of time in fallow, then this would be of great significance and potential benefit. Unless and until such evidence is forthcoming, however, the null hypothesis must be that the tree cover required to maintain fertility is proportional to the fallow period found to be necessary.

The use of tree litter for purposes other than fertilization

Throughout the discussion, it has been assumed that all parts of the tree are returned as litter to the soil. In agroforestry systems this frequently will not be the case. The larger branches and, on felling, the stem will commonly be harvested as fuelwood, the leaf litter and reproductive parts (e.g. legume pods) may be fed to livestock. Many agroforestry systems are designed and practised precisely with the objective of helping with these supply problems. If fuelwood or fodder are in short supply, and labour sufficient, most farmers will choose to harvest these tree products. The above-ground woody and/or herbaceous residues are not then available to maintain soil fertility.

In the case of fuelwood, there could be a partial return of nutrients if the ash is returned to the soil, but a permanent loss of carbon. In the case of cut-and-carry fodder, the cycle is closed if the kraal dung is returned to the fields. Since livestock are a source of farm income it may well prove to be more beneficial combining economic with ecological aspects, to pass litter through the digestive systems of livestock than to apply it directly to the soil. Many farmers will do so anyway, without the need for analysis of benefits by linear programming!

Erosion control

Although data from the tropics are still sparse, there is clear evidence of a link between soil erosion and fertility decline (Stocking, 1984). Material lost by sheet erosion contains a disproportionately high content of nutrients, compared with the topsoil as a whole. There is also loss of soil organic matter, the highest content being at the surface, as well as the washing away of litter prior to its decomposition. The quantitative relations between erosion rates and fertility loss are poorly known but need to be taken into consideration in models of nutrient cycling and maintenance of fertility.

Table 5: Rest period requirements of tropical soils. All values refer to the cultivation factor, R, expressed as a percentage. Source: Young and Wright (1980).

	LOW INPUTS			INTERMEDIATE INPUTS			HIGH INPUTS		
Soil type (FAO / Growing period (days)	Rain Forest Zone 270-365	Savanna Zone 120-269	Semi-arid Zone 75-119	Rain forest Zone 270-365	Savanna Zone 120-269	Semi-arid Zone 75-119	Rain forest Zone 270-365	Savanna Zone 120-269	Semi-arid Zone 75-119
R, Q Regosols and Arenosols	10	15	20	30	35	45	50	65	50
F Ferralsols	15	15	20	35	35	40	70	70	75
Fa acric	5			10			60		
A Acrisols	15	15	20	40	35	60	65	65	75
Luvisols	25	30	35	50	50	55	70	75	75
B Cambisols	35	50	40	65	60	60	85	85	80
N Nitosols									
Nd dystric	25	30	40	55	80	70	90	90	90
Ne eutric	40	55	75						
V Vertisols	40	55	45	70	75	75	90	90	90
J, G Fluvisols and	60	70	90	80	80	90	90	90	90

The main agroforestry techniques for soil conversion are as follows:

- planting trees on the risers of terraces (for both stabilization and production);
- planting trees on contour bunds or strips (mainly to make productive use of this land, but also to ensure that these remain in fixed positions);
- using closely spaced hedges as conservation barriers.

The third of these in particular can be combined with fertility improvement, since the hedges are kept low by repeated pruning. Prunings from the other two techniques can also be thrown onto the soil between rows of trees, thus combining fertility maintenance with physical soil conservation, and the necessity of pruning the trees to prevent excessive shading.

REQUIREMENTS FOR RESEARCH

It has not yet been demonstrated that the desirable situation shown in Figure 3, the combination of crop production with maintenance of soil fertility in a steady state, can be brought about; nor is there proof of the other possible beneficial effects of trees upon the soil that have been discussed. The purpose of this paper is to put forward hypotheses which have highly attractive consequences if they can be verified. These hypotheses need to be tested by research.

There is now a substantial amount of ongoing research in agroforestry, and a growing body of completed results. Comments on this research are first, the existence of a bias towards alley cropping, and secondly too much emphasis on a pragmatic approach at the expense of a basic understanding of processes.

The bias towards alley cropping is explicable in the light of scientists' preference for controlled conditions and the opportunity to change variables (e.g. spacing) in a regular manner. There has been relatively little work on boundary planting — and whoever heard of research on the highly productive, practicable and extremely sustainable system of home gardens? This bias is understandable and perhaps excusable, except that alley cropping must not be regarded as a panacea.

More serious is the emphasis on pragmatic research, on the approach of 'try it and see if it works'. The reason for this is the desire quickly to produce a technology that can be put into practice. This in turn stems first, from the worthy idea that research is for the benefit of farmers, and secondly, from pressure by aid agencies to go ahead with development as soon as possible.

The outcome is that too much current research leads to uncoordinated ad hoc results, rather than a basic understanding of the processes involved. This is illustrated by alley cropping experiments, on species and spacing designs, in which the results are evaluated solely in terms of crop yields, without monitoring changes in soil. This black box approach — and the soil ecosystem is inside the box — leads to results that cannot be extrapolated or manipulated. They show that certain combinations of species, spacing and plant management will work well in a particular environment; but through omitting to demonstrate why these function well, and why other combinations do not, this fails to supply the means for scientific design of other combinations for different circumstances.

This comment applies to many aspects of agroforestry research including soil biology and fertility. The basic understanding that is needed in this field is the mechanisms by which trees improve the soil. The field design of such experimental work should be based on experimental plots with:

- trees only;
- crops only;
- mixtures of trees with crops.

Plant growth, litter production and decomposition, and soil changes are monitored under each of these. Only the mixtures are in themselves agroforestry; but frequently, advances in knowledge needed for agroforestry design are obtained from research based on monocultures.

For the monitoring observations under such a design, the 'minimum package' devised by the TSBF programme forms an excellent basis. Because of high micro-variability of soil properties, a statistical design based on composite sampling is necessary. The significance of results can be calculated in advance on the basis of coefficients of variation of individual soil properties from single samples of some 30 - 70%. The soil monitoring programme at the ICRAF Machakos Field Station employs such a sampling design, although as it is a station for demonstration and training, it is currently monitoring mixtures only, without monoculture controls (Young, 1984).

Another way of expressing the position is to say that an understanding of how agroforestry techniques can best be applied to raise soil fertility will come from two sets of research; first, the broad range of soil biological research, leading to an understanding of basic processes; and secondly, studies of the specific effects of mixtures of woody and herbaceous litter, of different types of roots, and thus of trees and herbaceous plants.

At present, much pragmatic research is inefficient, partly because a high proportion of the species/spacing/management combinations tried are unsuccessful, but mostly because they do not lead to an understanding of the mechanisms involved. If a basic understanding of processes can be built up, then 'try-it-and-see' work, which is also necessary as a final predevelopment stage, can start from a much more advanced position, with a good prediction of what can be expected to succeed.

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3. EFFECT OF TREES ON UPLAND ANNUAL AGRICULTURE IN THE LOW COUNTRY DRY ZONE OF SRI LANKA

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SUMMARY

(1) As an alternative to shifting cultivation on eluvial land, cropping of a degraded upland under simulated forest conditions was attempted.

(2) Annual crop performance, soil properties and weed flora and density were compared with and without simulated forest of Gliricidia maculata.

(3) Simulated forest plots had the following advantages over the plots without simulated forest:

- (i) Better crop plant growth and higher crop yield at low N levels;
- (ii) Better infiltration and less surface ponding following rain;
- (iii) Lower soil hardness in surface layers enabling easy tillage;
- (iv) Lower proportion of problem weed species.

INTRODUCTION

Soil in the low country dry zone of Sri Lanka consists mainly of a catenary association of upland Ustalfs and lowland Aqualfs. Aqualfs, being accumulative are essentially rich and hence are ideally suited to lowland paddy cultivation.

Ustalfs suffer leaching in wet weather and fast decomposition of less stable material specially when the insulating forest layer is removed. Therefore, in this ecosystem, biomass plays a key role as an available nutrient reserve. In shifting cultivation, forest is felled to harvest this reserve for use in crop cultivation. Following felling and burning of forest, reserves of available P, available S, Ca, Mg, K and N added to soil become depleted with every advancing cropping season.

Along with this chemical impoverishment, soil tilth deteriorates, and weeds become more competitive. These factors collectively compel the shifting cultivator to abandon unproductive fields.

In this investigation, a new method that aims at solving or circumventing the cause of low productivity of eluvial lands is attempted. It, as in shifting cultivation, accepts the usefulness of live biomass as an ecological stabilizer. Trees are grown to simulate forest conditions as best as possible and to perform the same functions of the forest fallow in shifting cultivation. For this reason the proposed method is called "Agriculture under Simulated Forest".

Under this new system, soil in the eluvial part of the catena is treated more as a mechanical support for crops rather than as a source of nutrients. Nutrients are held by live biomass and are applied to crops at a time calculated to meet the latter's peak nutrient requirements. As soil is not trusted as nutrient store even for short periods, tree loppings (through which the nutrients stored in tree biomass are transferred to soil for use by crop plants) are given just enough time to decompose and release the nutrients locked therein before the crop plants reach their time of peak nutrient requirement.

MATERIALS

A block of eluvial land on a valley side slope that drains to Maha Illuppallama tank was selected for this study. It belongs to the Agriculture Research Station at Maha Illuppallama and presumably had been cleared from forest at least 50 years ago. It probably had been subjected to many unsuccessful attempts with upland agriculture. The land composed of eluvial soil, had been graded in 1968 to terraces and by 1976 it was in an abandoned state under unmanaged Brachiaria brizantha grass.

METHODS

Preliminary Preparations

In 1977, the leguminous tree species, Glyricidia maculata, was planted in a square design at a spacing of 5m by 5m. This design was altered in April 1980 to a row design with a higher tree density, rows spaced 5m apart and trees spaced 1m apart within each row. Planting material used was 2.5m long cuttings.

First year of field experimentation

The first experiment with a field crop was established in October 1980 using the loppings from the trees planted in 1977. It was a simple experiment on a randomised block design with one limitation, control plots with no trees had to be on one end of the replicates, for all the replicates. Each plot was 25m by 20m and 4 treatments were tested (Table 1). There were 4 replicates.

The field was hoe-weeded in September 1980. The canopy of the trees planted in 1977 was about 1m in radius and it offered some shelter to the operators from the mid day heat of September, during weeding. Maize was planted in October after a few rains had provided enough moisture to wet the soil profile. The whole land area was planted as in monocrop cultivation and no special space was spared for the trees. Thus planting density and plant population per hectare of the crop were the same as in monocrop maize cultivation.

About 10 days from germination of maize seed, trees were lopped at a height of 2m from ground level and loppings were placed between the maize rows. For fertilizer plots, basal fertilizer was added with this operation. Any new branches that developed after this pruning were regularly removed and added as mulch to the ground surface. Top dressing of fertilizer that is usually due in 45 days from planting was accordingly applied to the fertilizer plots.

Growth of maize was watched and when it reached a stage at which it no longer required sun light, moisture or nutrients, pruning of trees was suspended and the trees were allowed to grow while the maize crop was still in the field. Height and colour of maize plants was recorded using the standard procedures.

TABLE 1: Effect of fertilizer and simulated forest conditions on crop performance and soil properties in eluvial land during the first year of experimentation

Treatment	Plant height cm @	Dry matter yield kg/ha***		Loppings added kg/ha^{-1}	Soil chemical properties (surface soil)			
		Straw	Grain		pH	E.C. mmhos/cm	Organic matter %	Total nitrogen %
1. Control, no simulated forest, no fertilizer	174	1145	1163	-	5.92	0.025	1.29	0.076
2. Simulated forest, no fertilizer	185	1334	1373	561	5.92	0.031	1.43	0.104
3. Simulated forest, P_2O_5 60 kg/ha, K_2O 60 kg/ha	216	1493	1841*	663	6.13	0.040	1.59	0.105
4. Simulated forest, N 60 kg/ha, P_2O_5 60 kg/ha, K_2O 60 kg/ha	225	2035	3002**	579	5.94	0.040	1.57	0.089
Average	200	1502	1845					
C.V.%			18.74					
L.S.D. at 5% probability			553					
L.S.D. at 1% probability			794					

@ at cob maturation, *** at 14% moisture, + $70^{\circ}C$ dry, * significant at 5%, ** significant at 1%

At harvesting only the maize cobs were removed from the field and straw and stubble were left on the soil surface. The trees were allowed to grow uninterrupted.

Second year of field experimentation

In order to eliminate any interplot differences that may arise from fertilizer added to some plots during the first year, gingelly (Sesamum indicum) was sown throughout the land with rains in March/April, 1981. No fertilizer was added to this crop. Tree growth from early January 1981 was pruned and the loppings were added to gingelly crop in the tree plots. The trees were maintained in a pruned state as long as gingelly needed sunlight, soil moisture and nutrients for growth.

Making use of the tree growth from May 1981 the experiment proper was commenced in September/October 1981. By this time there was a bigger biomass in tree plots than in the year before because the trees planted in 1980 too had grown to some size. Two separate experiments were conducted, one under simulated forest and the other on bare land. Both were of randomised complete block design with 4 treatments (Table 2) and 4 replicates. The individual plots in the experiment under simulated forest conditions were 15m by 15m and the bare plots were smaller, 15m long and 5m wide. Both experiments were located on the same contour adjacent to each other to guarantee comparability of soil between the two.

After weeding with the hoe in September and early October, maize seed was planted in mid October. As in the previous year, 10 days from planting of crop, basal fertilizer was applied to fertilizer plots and the trees were pruned and loppings mulched in the tree plots. Top dressing of fertilizer due on 45 days from planting was given to fertilizer plots.

Plant height and plant colour were recorded at appropriate times. The trees were maintained in a pruned state to allow the maize crop to grow without any competition for sunlight, moisture and nutrients by the trees. When the maize crop had reached a stage at which it no longer required the above supplies, the trees were allowed to regrow.

Cobs were harvested from the mature maize crop. Straw and stubble were left in the field to mulch the ground.

Growth rate of Gliricidia trees after pruning

In order to determine the optimum pruning interval of Gliricidia trees, the length attained by growing new shoots was recorded. Seventy two trees were randomly selected and in each the length of 3 shoots was monitored over a period of 3 months after pruning.

TABLE 2: Crop performance in eluvial land with and without simulated forest during the second year of experimentation

Treatment	Loppings added kg ha^{-1}+	Crop dry matter yield kg ha^{-1}++ Straw	Grain	Plant height cm@	Soil strength kg/cm^2
With simulated forest					
1. No fertilizer	2811	3190	1561	127	1.06
2. N 60 kg ha^{-1}	3129	3134	1921 ns	133	0.87
3. N 60 kg ha^{-1}, P_2O_5 60 kg ha^{-1}	2986	3470	2476 ns	146	1.00
4. N 60 kg ha^{-1}, P_2O_5 60 kg ha^{-1}, K_2O 60 kg ha^{-1}	2963	3190	2728 ns	152	1.06
Average	2972	3246	2172	139	1.00
Without simulated forest					
1. No fertilizer	-	2126	680	94	1.69
2. N 60 kg ha^{-1}	-	2238	1385**	99	1.87
3. N 60 kg ha^{-1}, P_2O_5 60 kg ha^{-1}	-	2070	1251**	92	1.56
4. N 60 kg ha^{-1}, P_2O_5 60 kg ha^{-1}, K_2O 60 kg ha^{-1}	-	2726	1354**	100	1.81
Average	-	2290	1168	96	1.73
L.S.D. 1%			542		

+ at 70°C, ++ at 14% moisture, @ 50 day old plants,
ns not significant, ** significant at 1% probability

Soil chemical properties

Although it is still too early to look for differences in soil chemical properties, soil pH (1:2.5 water), electrical conductivity (1:5 water), soil organic matter and total nitrogen were determined in late April 1981, about 6 months after initiating the first field experiment with crops.

Soil tilth

In addition to the ameliorating effects provided by trees during weeding prior to crop planting, the soil in tree plots was found to be offering less resistance to tools. In order to check this, soil in tree plots and in bare plots was tested for unconfined compressive strength in March 1982. The instrument used for measuring this soil property offered a plane surface of 0.25 square inches. The force at which the soil surface gave way when this plane was pressed against soil was recorded as the unconfined compressive strength of surface soil.

RESULTS AND DISCUSSION

Initial condition of the land

The degraded condition of the land before commencement of the experiment is clear from the following soil characteristics.
soil pH (1:2.5 water) 5.98, electrical conductivity of soil (1:5 water)
0.035 mmho/cm, soil organic matter 1.47% and total nitrogen 0.08%.

First year of experimentation with field crops

The results of the first year of experimentation clearly show response to fertilizer, particularly nitrogen, and insignificant response to biomass added from trees (Table 1). This confirms the eluvial nature of the land and the fact that the small amount of biomass averaging to about 600 kg/ha added is not enough to have any impact on the productivity of degraded land. Also the period during which the land had been under this small biomass cover may have been too short for there to have been any cumulative protection to the soil. Therefore this experiment can be interpreted as illustrating the inadequacy of insulation and of the amount of biomass that is produced by few young trees to compensate for the degradation that had been going on in this land for many years.

Second year of experimentation with field crops

Results of the two experiments, with and without a perennial tree component are presented in Table 2.

In the experiment under simulated forest conditions, the observed yield increase in response to added fertilizer is not high enough to be statistically significant. This is because even the treatment without fertilizer has a satisfactory yield that results from the effect of the trees and their loppings. This shows that when a crop is grown in eluvial land under simulated forest conditions as in this experiment there is no particular need for application of fertilizer.

The results of the experiment in bare land that was not afforded with the protective role of simulated forest clearly show that bare soil is a poorer source of nutrients and when fertilizer is added to such a soil the crop yield can be improved.

Therefore what emerges from the two experiments is that the soil in eluvial land is a poor supplier of nutrients and that for it to produce good yields it needs nutrient supplies either through organic recycling or through fertilizer application.

Although comparison of two different experiments is not sound statistical practice, it may not be unreasonable to compare the above two experiments for identical treatments were tested in both, and both were managed in the same manner and located adjacent to each other on the same contour. Higher average grain yield, higher straw yield and taller crop plants in the experiment under simulated forest may be taken as indicative of the supremacy of agriculture under simulated forest over agriculture on bare land.

Pruning cycle of perennial trees in plots under simulated forest

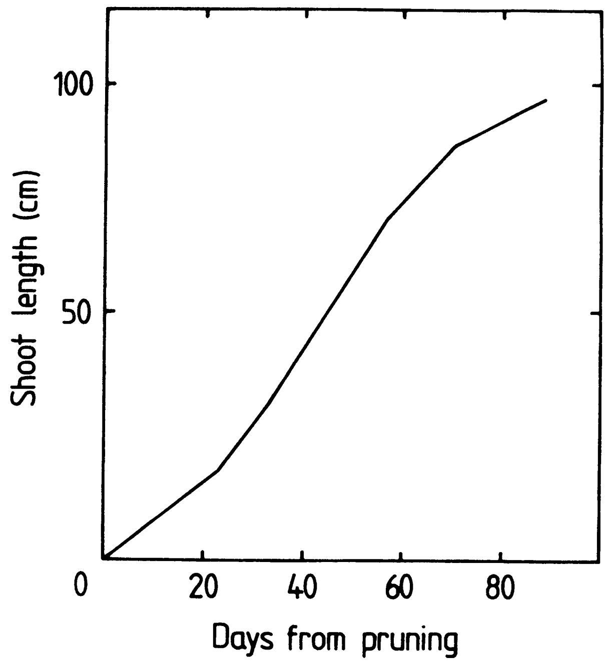
The length of growing Gliricidia shoots when plotted against time makes a sigmoid curve (Figure 1). Within the first 3 weeks of shoot elongation after pruning they grow at a rate of about 0.83 cm a day. This is followed by a period of rapid elongation at a rate of about 1.54 cm/day for almost 6 weeks. Over the next 3 weeks the rate of growth slackens down to 0.57 cm/day. Beyond this stage, the growth rate tends to level off. Therefore for highest dry matter production from these trees, the best pruning interval appears to be about 10-12 weeks. Coupling this finding with other considerations such as rainfall pattern, crop needs for nutrients and insulation offered by tree canopy to both soil and field operators, tree pruning for the October cropping season is best done after planting the crop. One important consideration is not to prune too early before the crop plants are ready to take up the nutrients released from decomposing loppings.

After this initial pruning the trees are maintained in a pruned state in order to maintain the best of conditions for crop plant growth without any tree induced competition for soil moisture, nutrients and sunlight. When the crop has reached physiological maturity there is no fear of the tree competing with the crop for inputs, and from this point onwards the tree component can be allowed to grow. In the cropping pattern of the eluvial land in the dry zone region, the crop plants reach physiological maturity by early January, and after this time it is possible to let the trees regrow. The objective of this regrowth is to afford the soil cover after the crop is harvested and to establish a medium for locking up nutrients that are released for decomposing crop residue.

The branches that begin regrowth in January are generally ready for lopping in March. It would, however, be beneficial to keep the branches on until after the April crop is sown so that the tree canopy can protect the soil from rain till the crop is ready to assume a protective role. The trees are pruned after the crop plants have established themselves, and thereafter top priority is given to the needs of the crop. Trees take over when the April grown annual crop is physiologically mature and continue to perform the soil protecting and nutrient conserving functions till the next rainy season in October.

Thus the pruning procedure of trees is aimed at maintaining a continuous cycle or relay between the physiologically active tree and the physiologically active crop (Figure 2). The purpose of this relay is not only to harbour soluble nutrients in the biomass but also to afford insulation and protection to soil and man from the harsh tropical climate.

Figure 1
Pattern of Gliricidia shoot regrowth after pruning



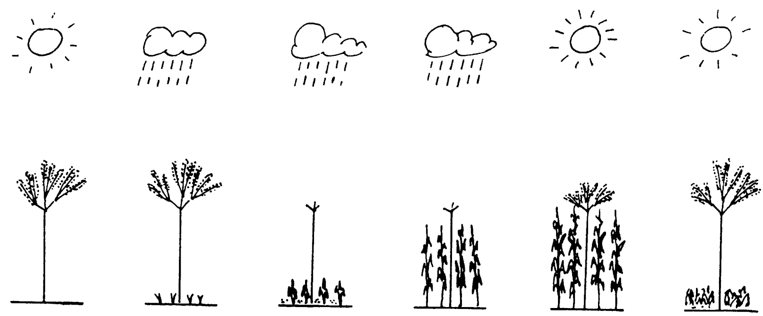
Soil chemical properties

Even at this early stage of experimentation with limited amounts of tree biomass, the surface soil of tree plots shows some improvement over the bare plots. The former soil has slightly more organic matter and total nitrogen and a slightly higher electrical conductivity (Table 1).

Soil tilth

Unconfined compressive strength of surface soil is reported in Table 2. The soil strength figures show that surface soil in tree plots has a better tilth than in the bare plots. This is perhaps due to better protection received by the soil in tree plots from tropical sun and rain and higher activity of soil fauna in tree plots. During rainy weather there were more earthworm casts in the tree plots than in the bare plots.

Figure 2: Diagrammatic presentation of relationship between simulated forest and annual crop in relation to change in weather over a cropping season.



TREE	With canopy	With canopy	Pruned	Pruned	Growing	Growing
CROP	Absent	Planted	Growing	Growing	Mature	Harvested
MULCH			Tree loppings			Crop residue

Nature and management of simulated forest

The two main roles played by the trees that make up the simulated forest could be conservation of the plant nutrients available in the ecosystem within the tree biomass and protection of soil from harsh tropical climate. The former arrests leaching of nutrients that are released to the soil by rock weathering and decomposition of organic matter. The latter helps the soil to acquire a good tilth and arrests erosion. It also helps to smother weeds. If the trees include leguminous species they could also fix atmospheric nitrogen and store more nitrogen in the biomass.

Trees can yield other benefits such as fruits and timber of economic value. For the purpose of this study which is exclusively for growing annual agricultural crops in eluvial land there is no need to be concerned with such aspects. For the same reason, considerations such as perpetuation of species and variety and heterogeneity of natural forest flora are not of direct relevance to this study.

This canopy of the simulated forest must be dense enough to lock up enough nutrients for circulation into the succeeding crop and to provide sufficient insulation to soil. It must also be light enough to allow easy handling.

In the first year of this investigation, 600 kg ha^{-1} of dry matter added was too little to be of any help for crop cultivation. In the second year of operation the dry matter added via loppings in October 1981 amounted to almost 3000 kg ha^{-1} (Table 2). Analysis of the loppings for nitrogen gave an average value of 3.63% on a 70°C dry basis (range 2.83%-4.11%). On this basis 3000 kg of loppings contain about 108 kg nitrogen. From Table 2 it is clear that the tree plots that got additional nitrogen fertilizer produced higher yields than the tree plot that got no fertilizer even though the increase in yield is not statistically significant. From this we can see that 3000 kg of dry matter per hectare is still too little. During the operation of this experiment many of the trees were still too small. Therefore it is too early to say whether the stand of 1 tree/5m^2 is too low a density. Increasing tree density is easy but before doing so it must be assessed whether increased tree density would interfere with farm operations.

According to Nagarajah and Amarasiri (1977) Gliricidia maculata leaves on an oven dry basis have 4.15% N, 0.27% P and 1.30% K. On this basis 3000 kg of loppings add close to 8 kg/ha and 39 kg/ha of P and K respectively. The low figure of P does not imply any adverse effects because over the years the soil at Maha Iluppallama has become saturated with phosphorus from annually added fertilizer. In common with other government managed farms, the soil at Maha Iluppallama does not show response to fertilizer phosphorus. Other lands of course show phosphorus deficiency but it can be easily and safely corrected because of the relative safety of phosphorus from leaching and relative scarcity of sesquioxides that can fix it.

Pruning height of trees was fixed at 2 meters from ground level for two reasons. If branches emerge at a height below 2 meters they can interfere with field operations. If pruning is attempted above 2 meters, the pruning operation would be a difficult one. Also if the tree stump is shorter than 2 meters (as it can be if pruned at a lower level), it has little use if and when it is removed from the field. Gliricidia stems that are mature and are at least 2 meters long have a demand as fence posts.

It is important to explain why the little documented Gliricidia maculata was used instead of the much publicised Leucaena leucocephala (National Academy Sciences 1977). Gliricidia maculata needs less introduction to the local farmer. Its leaves have more nitrogen that Leucaena. It also does not contain the toxic amino acid, mimosine, which Leucaena is noted for. The straight branches of Gliricidia are more amenable to handling than the bent and twisted branches of Leucaena. Most of all, the Gliricidia tree population can never proliferate into menacing dimensions because the little seed it produces does not germinate that well. In fact, the accepted method of its propagation is by cuttings. Leucaena on the other hand is a prolific producer of viable seed and hence it harbours the threat of becoming a weed if ever its population is to go out of control.

If properly managed the simulated forest can set in motion a desirable cycle. The greater the biomass added to soil by it the better would be the growth of the succeeding crop. The larger the crop straw volume and the nutrients contained therein the more advantageous would it be for the simulated forest to regrow.

4. LEUCAENA ALLEY CROPPING FOR THE KENYAN COAST

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SUMMARY

Leucaena leucocephala alley cropping was found to contribute to increased maize yields on sandy coastal soils. This was due to (i) the addition of the high Nitrogen-containing green leaf manure to the soil; (ii) other improvements in soil fertility, including increased carbon; and (iii) a significant decrease in weed populations.

Higher inter-row and intra-row densities of Leucaena were significant in both higher production of green leaf manure and greater increase of maize yields.

INTRODUCTION

Average yields of 900-1000 kg/ha of maize at the Kenya coast are low, despite good annual rainfall (1260mm). The major reasons for poor maize yields are poor soil fertility and weed infestation (Muturi, 1981, Anon. 1984). Weeds alone are thought to cause over 40% crop loss (Michieka, 1982). Soils at the coast are variable but are generally sandy loams, deficient in the major soil nutrients (N, P, and K), and have high rates of leaching.

Fertilizer application and/or use of animal manure is therefore recommended in order to realize good crop yields. However, both chemical fertilizer and animal manure are expensive and often not easily accessible. The recommended rate of animal manure application, 1.2 tons/ha/year (Grimes and Clarke, 1962) is high and typically not feasible for the small scale farmer.

It was against this background that alley cropping of maize with Leucaena leucocephala (hereafter referred to simply as leucaena) was initiated in May, 1982 at Mtwapa, and at Matuga the following year. Leucaena is a small leguminous multipurpose tree used for soil fertility improvement, fodder production, weed control and for woodfuel and poles. Alley cropping is a substitute for natural bush fallow and shifting cultivation which allows the land to be continuously and highly productive with a minimum of external inputs. There are many different alley cropping practices, one of the most promising of which is to establish permanent hedgerows of fast growing typically leguminous, shrub species in the crop fields. These hedgerows can be cut back during the cropping season. This practice can improve crop yields by improving land productivity through N fixation, leaf litter production, soil and water conservation, and weed control.

SITE AND METHODS

Leucaena leucocephala, variety K28, was planted in a parallel systematic design (Bleasdale, 1967) at Mtwapa in May 1982. Variable inter- (2, 4, and 8m) and intra- (0.5, 1, 2 and 3m) row spacings formed the major and the minor treatments respectively. This arrangement gives a split-plot design with 5 replicates each of 12 different planting arrangements (modules) as illustrated in Figure 1.

Cassava (Manihot esculenta) was used as the initial crop in the establishment of the leucaena. Both seedling survival and growth rates were high, possibly because the cassava provided an improved microclimate through its canopy which decreased water loss and discouraged weeds.

Maize (Coast Composite) was intercropped during the April 1983 long rains at a spacing of 90 x 30cm (one plant/hole), after the 1982/83 cassava crop was harvested. Green gram was then planted in the short rains (September-November) of that year. This maize/green gram rotation has been repeated each year since then and extensive data on their performance have been recorded each season. A control plot (without trees) is being maintained for comparison to these data. Recommended maize and green gram husbandry practices for the coast (eg weeding, fertiliser application and disease and pest control) are being followed, thus keeping the agricultural system constant and introducing the tree element as the only variable.

For the first 2½ years the leucaena trees were allowed to grow unmanaged and extensive mensurations were taken on their growth rates and associated crop yields for baseline data. These data are being used in assessing various leucaena management techniques presently being investigated.

Some of these data are presented below.

Each season soil samples are taken from each of the modules. These are analysed at the National Agricultural Labs for all major soil chemical properties. These data are then compared from season to season for changes in soil properties over time.

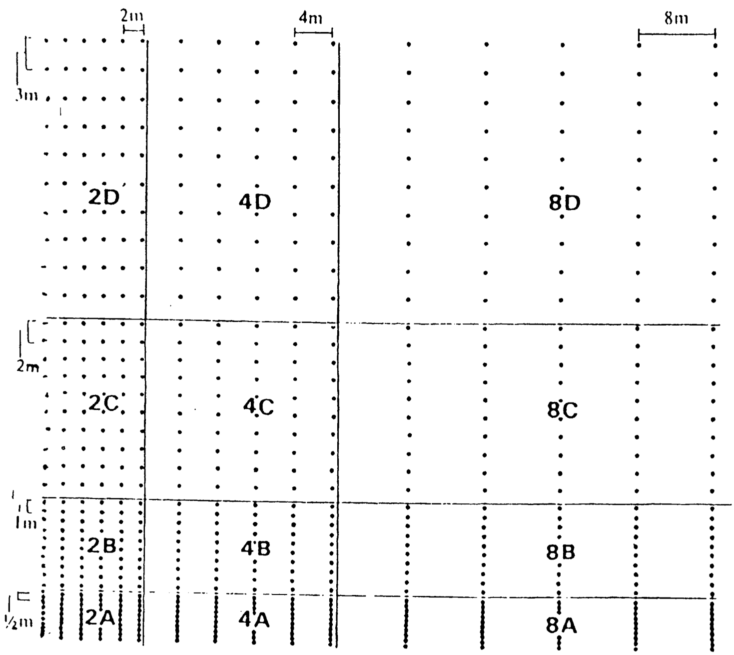
Weed control through leucaena is being investigated by estimating standing weed biomass in each of the modules. This is being done by taking the mean fresh weights (g/m^2) of several randomly placed one-meter square quadrats in each of the modules. These measurements are taken before crop harvest.

The first management of leucaena was tried with the 1984 green gram crop. The trees were all pollarded through the complete removal of all side branches. However, though the associated crop was much improved over that with no tree management, yields were still depressed as compared to the control due to very vigorous regrowth and canopy closure. As pollarding was very labor intensive, a new management practice was experimented with in 1985.

This practice is similar to a system of coppicing that has been studied at the International Institute of Tropical Agriculture at Ibadan, Nigeria. In this practice, the leucaena were coppiced at 0.5m above the ground two weeks before the 1985 maize crop was planted. Leaves and twigs (under 5mm diameter) were incorporated into the soil of the maize plots, while the woody parts were removed for charcoal. The leucaena hedgerows grew back vigorously and thus had to be cut back at intervals of approximately one month during the development of the maize crop. Thus, the leucaena was coppiced again twice during the maize growing season. The green manure produced was incorporated into the soil on each occasion.

Figure 1: Layout of the Research/Demonstration Plots

Each '.' represents a tree. In each row there are 10 trees spaced ½ meter apart, 10 spaced 1 meter, 10 spaced 2 meters and 20 spaced 3 metres apart. After the first row, there are 5 rows that are 2 meters apart, 5 that are 4 meters apart and 5 that are 8 meters apart. This gives the 12 different planting arrangements, from very dense to very dispersed. The crops are planted based on the recommendation of the Ministry of Agriculture and Livestock Development regardless of the tree.



RESULTS

Maize Yields

Yields of the 1983 and 1984 maize and green gram crops before tree management was initiated were depressed. This was especially apparent in the 2 and 4m blocks. This is interpreted as being largely due to shade.

Coppicing trials in 1985 have, however, given much more promising results. The 1985 maize yields (kg ha^{-1}) are shown in Table 1.

TABLE 1: Maize yields (kg ha^{-1}) in leucaena plots, August, 1985, Mtwapa, Kenya.

Leucaena Inter-row Spacing (m)	Leucaena Intra-row spacing (m) 0.5	1.0	2.0	3.0	Mean
2.0	4,000.0	3,600.0	3,600.0	2,500.0	3,425.0
4.0	3,400.0	2,675.0	2,363.0	2,683.0	2,780.0
8.0	3,100.0	2,475.0	3,100.0	2,033.0	2,677.0
					Overall:
Mean	3,500.0	2,917.0	3,021.0	2,406.0	2,961.0
Control Plot Mean					2,526.0

C.V. (%) of Inter- row mean = 12
C.V. (%) of Intra- row mean = 28

The data in Table 1 indicate that this coppicing system shows much promise, as maize yields in the leucaena plots were generally higher than the control plot. Significant interaction (at 5% level) was found between the inter- and intra- row leucaena treatments on maize yields. In general, decrease in both inter- and intra- row spacing led to an increase in maize yields. These high maize yields are attributed to N-fixation by the leucaena (whose roots showed heavy nodulation) and therefore to the cumulative Green Leaf Manure (GLM) added and incorporated into the soil.

The contribution of below ground litter (roots) to soil fertility (and therefore to maize yields) has not yet been investigated.

Leucaena Green Leaf Manure (GLM) Yields

Table 2 shows the cumulative leucaena fresh GLM yield (t/ha) for the 3 cuttings during the 1985 maize growing season.

TABLE 2: Cumulative leucaena fresh GLM (t ha^{-1}) incorporated into soil, March-May 1985.

Inter-row Spacing (m)	Intra-row spacing (m) 0.5	1.0	2.0	3.0	Mean
2.0	28.3	17.4	13.9	11.3	17.7
4.0	18.3	8.6	6.5	8.2	10.4
8.0	12.1	6.2	4.6	4.8	6.9
Mean	19.5	10.7	8.3	8.2	

C.V. (%) of Inter-row mean = 17.3
C.V. (%) of Intra-row mean = 27.0

Significant interaction between inter- and intra- row spacings was noticed. The higher leucaena densities yielded more than the wider spacings.

This GLM yield represents leucaena growth of 5 months. Half of this period was during the dry season (December 1984 through March 1985). This growth was harvested on March 15th, before the maize was planted (wood biomass yields are presented in Appendix 2). Vigorous coppicing by the leucaena required it to be cut again 30 days later on the 16th April, and again 35 days later on 21st of May. On each occasion all leaves and twigs less than 0.5cm diameter were incorporated in the soil. As the corn crop had by then reached a substantial height (no longer in danger from light competition from the leucaena) the leucaena was not cut again during this cropping season.

This leucaena was allowed to grow till the beginning of preparations for the short rains crop in September 1985. Between May and September (4 months), the leucaena grew vigorously, producing not only large amounts of GLM, but also considerable fuelwood (see Appendix 2). Complete canopy closure of the leucaena occurred in both the 2m and 4m modules during this period resulting in weed control, and general soil improvement.

The GLM (leaves and twigs) being incorporated was analysed for nutrient composition to determine the potential nutrient contribution on a dry weight basis. Table 3 shows the nutrient composition of the GLM, while Table 4 shows the potential nitrogen contribution (kg ha^{-1}) from this GLM to the intercropped plots.

TABLE 3: Mean nutrient composition of Leucaena GLM, March 1985, Mtwapa - Kenya*

		Percent Dry Matter						PPM	
N	P	K	Ca	Mg	S	Cu	Zu	Mn	Fe
4.4	0.3	2.2	2.2	0.2	0.3	11.9	21.0	51.0	216.0

* Note that leucaena GLM can decompose into humus in only 2 weeks when incorporated (Kang, et al, 1981), thus releasing most of these essential nutrients.

TABLE 4: Potential Nitrogen Contribution (Kg ha^{-1}) from Leucaena GLM (dry weight** basis) April-August 1985 Mtwapa, Kenya

Inter-row Spacing (m)	Intra-row spacing (m) 0.5	1.0	2.0	3.0	Mean
2.0	284	174	140	114	178
4.0	183	86	65	82	104
8.0	122	63	47	48	70
Mean	196	108	84	81	

** 1 kg dry weight - 4.4 kg fresh weight GLM

These high N-contributions from GLM were probably a major reason for the high maize yields from the trials. There was also substantial weed reduction and probable improved soil moisture (not measured in this experiment) due to the tree canopy during the dry season that contributed to the differential maize yields.

WEED CONTROL

Significant weed reduction was achieved through the canopies developed between cropping seasons. As an example, the fresh weights (g/m^2) of weeds harvested in August of 1985 are shown in Table 5.

TABLE 5: Mean effect of Leucaena treatments on weed fresh weight (g/m^2), August 1985.

Inter-row Spacing (m)	Intra-row spacing (m) 0.5	1.0	2.0	3.0	Mean
2.0	68	38	30	54	47
4.0	70	60	170	130	107
8.0	230	133	163	147	168
					Overall:
Mean	123	77	121	110	108
Control Plot Mean					650

Weed populations in the plots were significantly lower than the control plot despite the absence of the tree shade during the cropping season (trees only form a canopy between crop seasons whereas during the crop seasons the trees are kept pruned). This weed reduction undoubtedly contributed significantly to the increased crop yields discussed in earlier sections of this report. As well, this effect would reduce the labour needs for weeding thus offsetting the extra labour required for leucaena management.

Soil Fertility

Results of soil analysis from 1984 and 1985 are presented in Table 6. In general, there was a trend for increase in potassium, calcium, phosphorus and carbon over time and compared to the control. The pH values showed no definite trends, while the magnesium values showed a decrease over time, but an overall increase as compared to the controls. On the other hand, when comparing the modules to each other, no definite trends were apparent between treatments. That is, there were no apparent differences in the extent of soil improvement between the different tree densities. This was unexpected and these data will continue to be monitored in the future in order to better understand the impacts of the trees on soil fertility. However, as it is, the increased levels of soil nutrients indicated to date have undoubtedly contributed to the improvement of soil fertility and therefore to increased maize yields realised in August of 1985.

TABLE 6: Soil Analysis (Top soil) from the Leucaena Plots

Modules	Sample Dates	pH	K m.e.%	Ca m.e.%	Mg m.e.%	P p.p.m.	C %
	April '84	6.1	0.16	2.0		24.0	0.29
2M	Aug '84	6.08	0.24	2.58	1.55	18.0	0.45
	Jan '85	5.80	0.26	3.60	0.48	66.75	0.97
	April '84	5.9	0.14	1.6		22.0	0.26
4M	Aug '84	6.30	0.22	2.20	1.38	22.0	0.24
	Jan '85	5.98	0.24	3.40	0.80	31.75	0.87
	April '84	6.1	0.12	2.4		37.0	0.35
8M	Aug '84	6.32	0.24	2.78	1.80	29.0	0.40
	Jan '85	5.78	0.25	3.70	0.73	30.25	0.94
	April '84	-	-	-	-	-	-
Control	Aug '84	5.79	0.17	1.92	0.83	16.6	0.38
	Jan '85	5.83	0.23	3.10	0.40	32.25	0.49

DISCUSSION

Many scientists have investigated the use of leucaena hedgerows/alley cropping as a soil improvement system in which crop yields can be sustained at relatively high levels without the addition of high amounts of chemical fertilisers (Torres, 1984). Such a system is self sustainable in terms of soil fertility maintenance, and also contributes to reduction of soil erosion, weed infestation, and tillage requirements.

Other studies have shown that the production potential of leucaena appears to be higher when associated with agricultural crops than when planted alone (Gill, 1982). This is probably due to the leucaena benefiting from crop management practices. (However, this may not be true for perennial grasses such as sugar-cane and napier grass which have depressed leucaena yields, especially if simultaneous establishment is attempted instead of giving Leucaena a head start). Kang et al (1981 and 1985) investigated the effectiveness of leucaena GLM as N-source for maize in Nigeria and reported a 40% increase in yields as compared to the control plot (maize alone) with the application of 10 tons fresh GLM or a combination of 5 tons GLM and N at 50 kg/ha. The GLM as an N fertilizer source appeared most effective when incorporated than when applied as surface mulch. In our trials, an increase in maize yield of up to 58% was realised depending on the leucaena inter- and intra-row spacing (Table 1). This was felt to be due in part to the incorporated GLM which contributed as much as 284 Kg/ha of potential nitrogen from three cuttings during the maize cropping season in 1985.

Besides GLM, biological nitrogen-fixation is another important attribute of leucaena. Under favourable year round conditions, nitrogen fixation rates as high as 500-600 kg/ha/year have been measured (Guevarra, 1976). In our experiments, maize plants (rows) close to the leucaena row were consistently taller, on the average, than those farthest away. Those height differences were reflected in higher crop residue (stover) yields in the leucaena blocks (Appendix 4).

Considerable weed reduction was realised in the leucaena plots. Thus, leucaena alley cropping, particularly at narrower inter- and intra-row spacings (eg 2 x 0.5m or 4 x 0.5m) could contribute to increased maize yields at the sandy coastal strip of Kenya through GLM, nitrogen-fixation and biological weed control.

These trials need to be continued in order to confirm and clarify these results. As well, other species and leucaena cultivars need to be tried in these experiments. The results presented here show the potential that agroforestry has in maintaining soil fertility and improving crop yields for farmers at the coast, thus indicating the importance of continuing these trials and presenting their results to the public.

RECOMMENDATIONS

Leucaena establishment, that is, its initial rate of growth is slow. It also initially tends to be a poor competitor to weeds, and young leucaena are highly browsed and thus need protection. The following guidelines and recommendations should be followed if leucaena is being established in alley cropping at the coast:

1. Leucaena can be established by either direct seeding (pretreated seeds) or from seedlings along with an agricultural crop such as maize. The leucaena should be planted directly in the row of crop so that it will not be weeded out when the crops are weeded. This system provides leucaena with weed-free conditions, protection from grazing/browsing animals and benefits from the applied fertilizers, especially phosphorus.

2. It is necessary to allow the leucaena to become well established before initiating tree management. This will result in a strong and effective leucaena hedgerow that can withstand frequent cuttings with good biomass yields. In our trials the trees were allowed to grow over 24 months before being harvested, however, tree management could be started as little as 12 months after planting if the trees have grown well. It is recommended that first tree cutting not be started until the tree is at least 4m tall.

3. The cutting height of the leucaena practised in our trials was 0.5m above ground level, and this has worked well and thus can be recommended. However, other cutting heights could provide decreased labour by making management of the tree canopies easier.

4. For best results, GLM from each cutting should be incorporated into the soil and not as surface green mulch. However, if the GLM is allowed to sit on the surface for 24 hours before incorporation, better nitrogen utilization can be realised.

5. Leucaena should be allowed to form a good canopy between growing seasons in order to effect better soil moisture retention, good weed control, as well as enhanced minimum tillage.

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5. SOME LAND USE CONSIDERATIONS IN THE AMELIORATION OF SOILS BY TREES

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SUMMARY

Whereas the integration of trees into the farming system has considerable potential for ameliorating adverse soil conditions under smallholder conditions, the following points need to be borne in mind.

1. Improved land use practices need to be designed within the context of the people they are intended for and are therefore area specific.

2. Traditional practices frequently have a sound basis and can offer guidelines to the direction in which improvements should be made.

3. Farmers' own perceptions on the benefits and use of trees may be different to the land use planners' and need to be understood and respected before appropriate recommendations can be made.

4. Soil conservation and fertility maintenance should be an integral part of any agroforestry practice but will frequently be achieved as the by product of a practice recommended to meet a more specific need of the farmer.

Improved land use practices for the amelioration of soils by trees for the smallholder should ideally be :

a) Simple - so they can readily understood and adopted by farmers;

b) Low cost - within the financial reach of farmers;

c) Labour efficient - produce the maximum benefits for the labour expended;

d) Productive - increase the total productivity of the system and maintain and increase food crop yields;

e) Sustainable - maintain productivity over the long term.

INTRODUCTION

In the process of developing ways in which trees can be used to ameliorate adverse soil conditions there is a need for much fundamental and basic research and many of the papers in this volume deal with aspects of this. The purpose of this paper is to try and promote an understanding and consideration of the socio-economic environment in which the results of that work will ultimately be applied. It is important that those engaged in fundamental research should retain an awareness of the context in which their findings and recommmendations will be implemented as ultimately the benefits of such research will be measured by whether or not they are taken up and used. There are many examples of research leading to technically sound recommendations which fail to be be adopted by farmers because the socio-economic constraints on their adoption have been overlooked.

For the purposes of this paper I wish to concentrate on the situation of the small rural farmer. Those of us concerned with land use planning for small holders are seeking for ways in which we can help them to make the best use of their own land so as to satisfy as many of their needs as possible by advising on ecologically sound, sustainable, economically viable and socially acceptable farming practices. Therefore what we recommend must be suited to the environmental conditions of the area, ie. suited to the soils, slopes, climate etc. It must be sustainable in that it must be possible to use the land in the recommended way over the years without it becoming degraded. The recommended practices must be ones which if followed will result in greater returns for the resources of, for instance, labour, cash expended eg. increased income from cash crops, greater self-sufficiency of food and fuel-wood. A farmer is very unlikely to follow advice which in the short term reduces his/her income or food production even if in the long term it maintains soil fertility nor will he/she do something which has a high labour demand for what are seen as relatively limited returns. Whatever a farmer is asked to do must match with what he/she regard as acceptable, for instance it's unrealistic to recommend something that requires considerably more labour per day than is the normal practice, nor should extra labour be called for at a time of year that is traditionally set aside for social non-agricultural activities (Douglas 1984).

CONSIDERATION OF EXISTING FARMING SYSTEMS

As well as these basic principles, it's important to develop an understanding of the existing farming systems to recognise that the small farmer operates under specific constraints and has particular problems and needs. The farmer may well approach things from a totally different perspective to that of a Western orientated professional adviser or researcher, and whereas at first sight what he/she does may appear irrational, careful study will reveal a complex rationality behind a particular practice. Where traditional farming systems have been developed over many years, close examination will usually show that farmers have an intimate knowledge of their local ecological conditions and have developed farming practices and cropping strategies designed to exploit these within the limits of their own technology while minimising the risk to themselves. (See Richards 1985). Above all, traditional farming practices have evolved first and foremost to ensure that as far as possible the needs of the household's food supply will be met. Therefore greater importance will be attached to farming practices which will ensure some food production even in the poorest cropping season than those that would produce higher yields in a good year but could produce nothing in a bad year. This is one reason why farmers appear to stubbornly stick to low yielding traditional varieties in preference to the new higher yielding varieties available. They are fully aware of the limitations of their own varieties but cannot afford to risk all on the new ones.

The land use planner who attempts to change and improve the system without first seeking to understand the existing farming systems and the land use perceptions of the farmers is asking for failure. Improved land use practices therefore have to be designed within the context of the people they will affect and be capable of incorporation into and adaptation of the existing farming system (Stocking 1985).

INCORPORATION OF TREES INTO EXISTING FARMING SYSTEMS

The above holds true for the incorporation of trees into smallholder farming systems where there exists considerable potential to use trees to improve soil conditions in the pursuit of increasing and sustaining agricultural production. The potential for using trees to ameliorate adverse soil conditions is highest where natural soil fertility is low and dependent on the soil organic matter fraction; where there is a high risk of erosion; and where the soil surface is prone to desiccation. On such marginal lands, the deliberate use of woody perennials, if properly integrated into the farming system, can enhance both land productivity and sustainability (Lundgren and Nair 1985) and has great potential as a land use practice for small farmer with limited access to purchased farm inputs such as chemical fertilizers.

A careful look at most traditional smallholder farming systems will show that trees are an integral component of them. In traditional shifting cultivation and bush fallow systems, the fallow period, when the natural woody vegettion reestablishes itself and thereby restores the soil fertility, is a deliberate and important part of the farming system, interacting both ecologically and economically with the crops grown in the cultivation phase (Lundgren, Nair 1985). In some such systems, farmers will select the areas to be cleared on the basis of the presence of particular tree species, believing crops will grow better where this species occurs. This may be because the tree is only found on the more fertile soils or itself directly affects the fertility status. Farmers may also deliberately impose a basic degree of management into the woody component of the bush fallow by ensuring that when clearing the land for cultivation:

i. the tree stumps are left high enough to withstand the effect of burning the woody trash;

ii. the side branches on the remaining trunks are lopped to allow light through to the soil and crops and

iii. the tree roots are left intact so that rapid regeneration of the vegetation from the stumps is permitted, thereby reducing the time needed to restore fertility before the area can be used again (Wijewardene and Waidyanatha 1984).

In areas of low population density with acid soils of low inherent fertility such as the "miombo" woodland areas of parts of Zambia and Tanzania, bush fallowing is an ecologically sound, sustainable, economically viable and socially acceptable farming practice where trees ae deliberately used as a means of ameliorating adverse soil conditions, ie low fertility. The challenge to the land use planner is to try and improve on this by selective introduction of faster growing, particularly leguminous species that will both improve the fertility status and reduce the length of fallow period required. This is important where population pressure has led to a reduction in the fallow period due to shortage of available land and where appropriate land use practices for permanent cultivation have yet to be developed or adopted by the farmers.

In settled areas with permanent cultivation, smallholder farmers will have generally retained a number of trees when the land was cleared for cultivation. This has not been done in a haphazard way. On the contrary they can be clearly observed to have selectively left trees that they believe do not compete seriously with neighbouring crops. Indeed these trees may even enhance the growth of crops. The farmers can be observed to manage those trees by, for instance, pruning the side branches to reduce any shading effect. At the same time, preference will be given to species that yield produce that the farmer values, such as wood for fuel or construction, fibres, medicines, fruit etc. Where a farmer deliberately retains a tree that has an adverse effect on neighbouring crops you can be sure that this is because the particular species produces something of sufficient value to the user of the land that it will compensate for the loss of crop yield. The decision to leave trees in the farmland is a deliberate choice by the farmer even though he/she may not be able to fully explain the reason or benefits. It is interesting to note, from a rapid survey undertaken in Malawi, that of the indigenous trees deliberately retained by smallholders in their farmland, most were leguminous species and therefore likely to be compatible with and beneficial to crop farming (Poulsen 1981).

Some traditional farming systems, such as the home gardens characteristic of many wet tropical regions, show a sophisticated use of woody perennials. These home gardens are characterised by the intensive integration of numberous multipurpose trees and shrubs with food crops and animals, simultaneously on the same unit of land. A study of one such system, the Chagga homegardens of Mt Kilimangaro, North Tanzania, showed that as the native forest was settled, trees that provided fodder, fuel and fruits were retained while the less useful species were eliminated and replaced with new tree and crop species. The Chagga are skilled farmers with an intimate knowledge of the different crop and plant species in the home gardens and have evolved appropriate management techniques. These take into consideration their particular requirements for the various components of the system so as to optimise the total production. The large species diversity provides both subsistence and cash crops and enables the farmer to keep his/her management options open while providing an insurance against drought, pest and economic risks. Although the soils are generally inherently fertile, cultivation of the steep slopes would lead to sever erosion and declining fertility were it not for the woody component of the system. (Fernandes, Oktingati and Maghembe 1984).

The above examples illustrate how trees are nothing new to the small farmer, and the land use planner should therefore start by trying to develop an understanding of how the small farmer perceives the benefits of the trees to the system as a whole and how the existing trees are managed and used. For instance, is there a conscious awareness of the tree benefiting neighbouring crop production, does the farmer manage the tree to reduce its effect on crops and what products does the tree yield? These will act as the starting points for introducing more trees into the system. For instance, where the soil improving qualities of an indigenous tree, such as Acacia albida, are known to the farmer to increase crop yields this can be used to illustrate to them the princicple of using trees for improved soil fertility. It may then be possible to develop in discussion with the farmers an improved land use package whereby the known indigenous tree is deliberately planted in the farmer's field along with a faster growing exotic species that has been introduced to the farmers as having similar benefits to the known tree. Such a practice is being recommended to farmers in Malawi where they are encouraged to plant Acacia albida at 10-15m intervals along the contour marker ridges that run through the fields and to plant Leucaena leucocephala in between (see Douglas 1984 and Casey 1983). One word of caution on recommending the planting of indigineous trees, as it's been found that in areas where local foresters are zealous in protecting indigenous species, farmers may be reluctant to plant them for fear that the forestry department will claim them as theirs once they've grown.

MANAGEMENT OF TREES

Trees deliberately planted in and grown with crops will require some form of management to obtain many of the benefits and to avoid adverse effects on neighbouring crops. Seeing how farmers presently manage trees will indicate the types of management practices they are already familiar with and therefore already accept as worthwhile use of their labour. New management practices should therefore, if possible, be introduced as a development of the existing practices rather than something totally new.

MULTIPLE USES OF TREES

Of particular interest are the present uses to which the trees in the farmer's land are being put. This will show which particular needs he/she is tyring to meet from the tree component of the farming system. Initially the farmer is more likely to be willing to plant new tree species that have the same uses and will enable those same needs to be better met. In many cases the land use planner may see a need that the farmer has yet to perceive, for instance the need to conserve soil on a sloping field. It may prove difficult to persuade the farmer to plant a contour strip of trees for the sake of a conservation barrier but if the farmer has livestock and is experiencing a shortage of feed it is possible to recommend the growing of a tree or shrub with edible leaves and to suggest that this is grown on contour strips through the crops. In this way the farmer can not only meet the fodder need as he/she sees it but help conserve the soil. The soil conservation benefit being the by product of a land use practice recommended to meet the farmers perceived need.

POSSIBLE CONSTRAINTS TO THE USE OF TREES

An objection raised by many farmers to planting trees is that they don't have enough land to grow both food crops and trees. The agroforestry answer is to grow both together but many agroforestry practices do require that parts of the farm are taken out of crop production and put under trees. For instance strips of trees running through farm land in the practice known as alley cropping will occupy a significant portion of the total farm holding. For the farmer to accept that as a worthwhile use of his/her land, either the value of the products from the tree strips has to outweigh the lost crop production from those strips or the strips have to result in increased crop production on the rest of the farm eg. through the use of the leaves as green manure, so that the total yield from the field is the same or preferably higher.

A major constraint affecting many smallholder farming systems is that of shortage of labour, particularly at key times during the cropping season. Many agroforestry practices are labour intensive and this may work against their adoption unless the periods of labour demand can be fitted into the periods of low labour demand from the other farm activities or unless the benefits of the agroforestry practices are seen by the farmer to justify the extra labour. The small farmer will first and foremost direct his/her labour to the cultivation of the good crops. It is therefore important for the land use planner and research worker to remember that to the farmer the most important component of any tree/crop system is the food crop. This must be borne in mind when designing the management practices and their labour requirements. Applying to the soil as a mulch, the prunings from hedgerows grown for the purpose of supplying green manure, is labour intensive but the initial application can be done just prior to the start of the cropping season when there may be a lull in the labour demand before the peak of planting time. Subsequent applications can be done during other labour lows. A good mulch should also reduce the labour required for weeding. In a number of countries the rise in the cost of chemical fertilizers has resulted in it now being cheaper for the farmer to employ labour to make compost and cut green manure and apply them to crops than to buy the equivalent nutrients as fertilizer (eg. Douglas 1984).

WHICH TREES?

Finally a few thoughts on the trees themselves. Ideally what the land use planner wants from the research worker is a selection of tree and shrub species with as wide a range of potential uses as possible and with detailed information on the range of environmental conditions under which these will grow. The trees should be simple to grow, the simplest is if they can be direct seeded or grown from cuttings and preferably not requiring careful raising in nurseries. They should be able to survive poor management and goats, grow quickly and start to show benefits in the first couple of years. Trees that require careful nurturing to maturity, grow slowly and give no returns to the farmer for many years will not be readily adopted even if in the long run they offer many benefits. Furthermore, examples of the recommended trees should already be growing in the area so that farmers can see what they look like, how to manage them and most importantly what they can be used for.

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