ORGANIC MATTER CYCLING BY TROPICAL AGROFORESTRY SYSTEMS: A REVIEW

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SCHROEDER, P. 1995. Organic matter cycling by tropical agroforestry systems: a review. The trend in shifting tropical agriculture to shorter fallow periods and ultimately to attempts at continuous cultivation usually leads to land degradation and reduced productivity. This often results in the clearing of more forest land. Although the effects of these practices are most apparent at local scales, large releases of carbon dioxide and other greenhouse gases from forest clearing and land use change also have implications for the global environment. Agroforestry appears to be a promising technique to achieve sustainable land use by conserving soil organic matter. This paper compares the organic matter dynamics of agroforestry systems to successful long fallow agricultural systems. For the studies surveyed, agroforestry systems on average returned 7.4 t ha^{-1} y^{-1} (± 0.8) of organic matter to the soil surface in the form of prunings. This is within the range of litter production observed for long fallow systems. There is also evidence that the sustainability of agroforestry systems may be constrained by soil properties. On infertile soils, a limited potential for increasing nutrient inputs results in reduced plant growth, litterfall, and nutrient cycling. Implementation of agroforestry systems as an alternative to continuous cropping, however, should slow the loss of soil organic carbon and extend the cropping period.

Key words: Tropical agriculture - degradation - land - environment - agroforestry - organic matter dynamics - sustainability

SCHROEDER, P., 1995. Kitaran jisim organik oleh sistem perhutanan tani: satu kajian semula. Trend dalam pertanian pindah tropika kepada tanah rang yang mempunyai jangkamasa lebih pendek dan akhirnya kepada cubaan untuk penanaman berterusan biasanya menyebabkan degradasi tanih dan pengurangan produktiviti. Hal ini selalunya mengakibatkan lebih banyak tanah hutan dilegakan. Walaupun kesan-kesan amalan ini adalah lebih ketara setempat, pengeluaran karbon dioksida yang banyak dan gas rumah kaca yang lain dari kelegaan hutan dan kegunaan tanah yang berubah juga mempunyai implikasi terhadap persekitaran sejagat. Perhutanan tani merupakan teknik yang mempunyai harapan untuk mencapai kegunaan tanah yang berkekalan dengan memulihara jirim organik tanih. Kertas kerja ini membandingkan dinamik jirim organik sistem perhutanan tani dengan sistem pertanian rang yang berjaya dan lama tempohnya. Untuk kajian-kajian yang ditinjau, sistem perhutanan tani pada puratanya memulangkan 7.4t ha^{-1} y^{-1} (± 0.8) jirim organik kepada permukaan tanih dalam bentuk pemangkasan. Jumlah ini adalah dalam julat pengeluaran sarap yang diperhatikan untuk sistem rang yang panjang. Terdapat juga bukti bahawa pengekalan sistem perhutanan tani mungkin dikekang oleh sifat-sifat tanih. Pada tanih yang tidak subur, potensi terhad untuk meningkatkan input nutrien mengakibatkan pertumbuhan pokok yang berkurangan, kejatuhan sarap dan kitaran nutrien. Bagaimanapun implementasi sistem-sistem perhutanan tani sebagai alternatif kepada penanaman berterusan akan melambatkan kehilangan karbon organik tanih dan melanjutkan tempoh penanaman.

Introduction

The trend in shifting tropical agriculture is toward shorter fallow periods and ultimately to attempts at continuous cultivation. This trend, driven largely by an increasing landless rural population, usually leads to land degradation, reduced productivity, and clearing of more forest land (Allen & Barnes 1985, Sanchez *et al.* 1990). Effects of environmental degradation are most obvious at local scales, but large releases of carbon dioxide and other greenhouse gases from forest clearing also have implications for the global environment. Current estimates are that 1.1-2.2 GT (GT=gigaton=10^9 tons) of carbon are released to the atmosphere annually due to deforestation (Brown *et al.* 1993). In the humid tropics, as many as 300 million people are dependent on some form of shifting cultivation that accounts for about 60% of all deforestation (Myers 1991).

Agricultural practices that conserve soil resources and prevent degradation should also lessen the need to clear additional forest land. Agroforestry appears to be a promising technique to achieve sustainable land use. Broadly defined, agroforestry is "a land use that involves deliberate retention, introduction, or mixture of trees or other woody perennials in crop/animal production fields to benefit from the resultant ecological and economic interactions" (MacDicken & Vergara 1990). Examples of agroforestry systems include alley cropping, multi-layer tree gardens, interplanting of trees on pasture or crop land, live hedges, and shelterbelts. A successful agroforestry system allows synergistic interactions between woody and non-woody components to increase, sustain and diversify total land output (Swaminathan 1987). Important interactions are improved nutrient cycling and retention, moderation of microclimate and diversification of product outputs.

One of the reasons for interest in agroforestry practices is that many of them cycle organic matter in the form of tree prunings returned to the soil surface. Organic matter is particularly important in humid tropical soils because many of them have inherently low cation exchange capacity (Lal 1986, Pritchett & Fisher 1987, MacDicken & Vergara 1990). Soil organic matter provides additional exchange surfaces that are critical for nutrient retention (Nye & Greenland 1960, Ahn 1979, Cerri *et al.* 1991). If fallow periods on these soils are too short, plant nutrients and organic matter cannot fully recover and degradation occurs (Sabhasri 1978, Ruthenberg 1980). Not only does the microclimate of short fallow systems enhance organic matter decomposition, but additions of new organic matter to the soil are also limited (Nye & Greenland 1960, 1964, Cunningham 1963, Ahn 1979). Conservation or improvement of fertility and sustainability, therefore, is dependent on conservation and addition of organic matter (Lal 1986).

The purpose of this paper is to survey the current state of knowledge regarding the organic matter dynamics of agroforestry systems, and to draw comparisons to successful rotational agricultural systems as well as to natural systems. The paper begins by first discussing the effects of forest clearing and cultivation on soil organic matter in the humid and sub-humid tropics. It then goes on to describe the characteristics of long fallow systems that allow them to successfully restore organic matter after a period of cultivation. The paper next presents data from the technical literature on the production of pruning material by agroforestry systems. Finally, a discussion compares agroforestry litter and pruning production to fallow systems, mature forest systems and secondary forest systems.

Organic matter depletion by forest clearing

There is a large body of knowledge on the effects of clearing and cultivating tropical forest soils. This section is not intended to present a comprehensive review of all of the pertinent literature, but to briefly summarize the effects of clearing on soil organic matter and carbon.

Cultivated tropical soils in general contain lower levels of carbon than forest soils (Ayanaba *et al.* 1976, Allen 1985). The extent of organic matter loss caused by cultivation depends on the intensity of cultivation (Nye & Greenland 1960), but depletion can be rapid. Sanchez *et al.* (1983) observed a 25% loss of soil organic carbon during the first year of cultivation. A similar 20% loss was reported by Nye and Greenland (1960) after one year of cultivation. Martins *et al.* (1991) showed a 22% loss of soil organic matter after five years of cultivation. Forest soils converted to pasture also undergo rapid initial loss of soil carbon. Eden *et al.* (1991) reported a 23% drop in soil carbon during the first year of pasture establishment, and Cerri *et al.* (1991) showed a 25% decrease in organic matter over two years. Beyond their implications for soil fertility, these carbon losses represent a flux of CO_2 to the atmosphere that is in addition to emissions directly caused by clearing and burning the forest biomass.

Several studies have shown that burning is usually not responsible for site degradation or soil carbon depletion, and that coarse woody debris, charcoal, and soil carbon, may actually briefly increase as a result of incomplete combustion (Nye & Greenland 1960, Ewel *et al.* 1981, Cerri *et al.* 1991). Under cultivation, however, organic carbon declines in part because the amount of plant organic materials returned to the soil decreases dramatically (Ramakrishnan & Toky 1981, Dalal & Mayer 1986). At the same time, decomposition rates increase sharply due to removal of canopy shading which causes increased soil temperature (Cunningham 1963, Martins *et al.* 1991). The combination of decreased organic inputs and accelerated decomposition leads to the observed sharp soil carbon declines (Ahn 1979). These declines can actually continue for years into the fallow period until organic inputs reach sufficiently high levels to offset decomposition losses (Ramakrishnan & Toky 1981).

The commonly observed crop yield decline under continuous cultivation has been attributed to plant nutrient depletion, deterioration of soil physical properties, and pests (Lal 1986). The first two of these factors are directly linked to loss of organic matter. Maintaining adequate levels of organic matter, therefore, would address some of the major factors that lead to the need to clear additional land. Examining traditional forms of long fallow shifting agriculture that successfully replenish stocks of organic matter should provide some clues to achieving sustainability.

Traditional agriculture

Many traditional agricultural systems in the tropics have been based on rotational or forest fallow methods. Clearing and burning release plant nutrients which are exploited during a one to two-year cultivation cycle. The period of cultivation is followed by a relatively longer fallow period of 10 or more years during which both organic matter and nutrients are restored. Soil regeneration is due to addition of organic matter and nutrients in litter, and to root activity (Sabhasri 1978).

Soil carbon increases with an increasing length of the fallow period. In Brazil, for example, three years of fallow after five years of cultivation returned soil carbon to 80% of that in a well drained soil under natural forest (Martins *et al.* 1991). A long 30 - 50 year fallow in Puerto Rico restored 90 - 100% of the soil carbon of a mature forest (Lugo & Sanchez 1986). Zinke *et al.* (1978) also observed restoration of soil fertility after about 10 years in the humid tropics of northern Thailand. Even in semi-arid regions, organic matter losses from cultivation can be recovered after about 10 years of fallow due to continuous inputs from litterfall and root turnover (Tiessen *et al.* 1992).

The rate of litter production varies with a number of factors, most notably age of the fallow. In India, litterfall increased from 1.2 t ha^{-1} y^{-1} for a one-year fallow to 9.7 t ha^{-1} y^{-1} at 20 years (Toky & Ramakrishnan 1983). At high elevation in India, litterfall was 0.8 t ha^{-1} y^{-1} at one year and 6.1 t ha^{-1} y^{-1} at 15 years (Mishra and Ramakrishnan 1983). Litterfall in the Philippines has been observed at as high as 12 t ha^{-1} y^{-1} in a six-year-old fallow (Kellman 1969).

The fallow period reverses the trends seen during the cropping period. The return of organic matter to the soil is the key to the functioning of these systems. Effects of increasing levels of organic matter on soil physical properties during the fallow, along with the protective action of the fallow vegetation, may be as important as the chemical nutrient increases (Ahn 1979). Increased organic matter improves soil structure which leads to lower bulk density and to better aeration, permeability, and rainfall infiltration (Ahn 1979). Available water holding capacity is also improved (Ahn 1979). If it is necessary to replace traditional shifting cultivation with forms of continuous cropping, as has been suggested in numerous studies and within the development community, systems will have to be developed that not only maintain nutrient levels, but also restore soil structure and soil water relationships. A system of continuous supply of organic matter to the soil surface is essential to meet this requirement and, therefore, may be a viable alternative in areas where long fallow periods are no longer feasible (Lal 1986, Tiessen *et al.* 1992).

Agroforestry

The many diverse contributions of the tree components are the key to the ecological benefits of agroforestry systems (Kang & Wilson 1987, Young 1989, Ingram 1990). An important structural attribute of agroforestry is multiple vertical strata that occupy space efficiently and provide a range of growing conditions. The tree canopy provides shade and reduces evaporation from the soil. This shading effect also reduces temperature and provides a more moderate microclimate for crop growth. The tree canopy also provides shelter from wind and low-statured canopies protect the soil from the impacts of heavy rain and help to reduce soil erosion. Leaf litterfall acts as a mulch and reduces both evaporation and surface runoff and erosion. Incorporation of leaves into soil adds organic matter and improves soil quality. Below ground, tree roots penetrate to deeper soil layers than crop roots and bring nutrients to the surface via leaf fall. Nitrogen fixing agroforestry tree species capture that key nutrient from the atmosphere and make it available to crop plants. The economic benefits of agroforestry are derived from diversification of outputs, spreading risk, and, in many cases, actually increasing physical output (MacDicken & Vergara 1990). These characteristics may also make agroforestry systems more resistant to climate change than monocropping systems.

Agroforestry systems can also have some disadvantages that must be considered. Trees occupy space that would otherwise be available for crop plants, and they compete for water, light, and nutrients. The altered microclimate of agroforestry systems tends to be more humid than monocrop situations and, therefore, may be more conducive to fungal diseases. Operationally, agroforestry systems may require more manual labor than other systems (MacDicken & Vergara 1990). Optimizing these advantages and disadvantages can be a complex task which is itself a disadvantage where there is a scarcity of trained personnel and extension workers to provide information and advice to farmers.

Pruning operations are conducted in agroforestry systems for a variety of reasons. One is intentionally to incorporate organic matter in the soil. This is the case in alley cropping systems where the rows of trees are cut back several times per year and the pruned material distributed on the soil surface between the rows. Pruning is also undertaken to control the growth of trees planted to shade plantation crops like coffee or cacao. These prunings may also be added to the soil. Pruning is also a method for harvesting products for off-site use. Some agroforestry systems are designed to produce fodder for livestock. Nearly all agroforestry systems produce some amount of fuelwood. For the studies discussed here, most of which were experimental plantings, it was assumed that all production of prunings would be returned to the soil. This was an effort to assess the total potential of these systems to cycle organic matter to the soil. Any material harvested for off-site use would, of course, reduce the amount available to maintain soil organic carbon.

To assess potential inputs of organic matter in agroforestry systems from returning pruning material to the soil, the technical literature was searched for as many examples as possible, regardless of tree species, spacing, or location. The search resulted in 29 observations of pruning production from 11 separate studies (Table 1). Pruning production and recycling ranged from less than 1 t ha^{-1} y^{-1} for a lightly stocked system in semi-arid Senegal to over 18 t ha^{-1} y^{1} for a mature intercropping system in humid Costa Rica. The mean for all examples was 7.4 t ha^{-1} y^{-1} (± 0.8). This is within the range of litter production cited above for traditional systems, although near the lower end of that range. In general, the pruning production values in Table 1 overlap the litter production values for traditional systems that are discussed in the preceding section. Most of these agroforestry systems returned as much organic matter to the soil as successful traditional systems.

Pruning and litter production of 7.4 t ha^{-1} y^{-1} is also comparable to the 8 t ha^{-1} y^{-1} dry matter input that Young (1989) modeled would be required to maintain soil organic matter levels in the humid tropics. He also estimated corresponding values of 4 and 2 t ha^{-1} y^{1} for the sub-humid and semi-arid zones. Very few data were available for these zones, but ecozone is listed for each of the observations in Table 1.

Table 1. Annual production of pruning material by agroforestry systems

Tree species	Ecozone	Age (y)	Pruning production (t ha^{-1} y^{-1})	Source
Leucaena leucocephala	Subhumid	4	6.0	Atta-Krah 1990
L. leucocephala	Humid	2	12.0	Duguma *et al.* 1988
Theobroma cacao	"	10	3.3	Fassbender *et al.* 1991
T. cacao/Erythrina poeppigiana	"	10	13.6	"
Coffee arabica/ E. poeppigiana	"	13	13.5	Glover & Beer 1986
L. leucocephala	"	7	5.9	Kang *et al.* 1985
Acio barterii	"	3	1.5	Kang *et al.* 1990
Alchornea cordifolia	"	3	3.4	"
Gliricidia sepium	"	3	4.5	"
L. leucocephala	"	3	8.1	"
A. barterii	"	3	2.6	"
A. cordifolia	"	3	4.2	"
G. sepium	"	3	5.8	"
L. leucocephala	"	3	9.1	"
L. leucocephala	Semiarid	3	3.0	Rao *et al.* 1991
"	"	3	4.0	"
Acacia albida	"	N.A.	0.6	Robinson 1986
"	"	N.A.	2.6	"
Calliandra calothyrsus	Humid	4	7.6	Rosecrance *et al.* 1992
G. sepium	"	4	6.5	"
C. calothyrsus	"	4	9.1	"
G. sepium	"	4	8.7	"
G. sepium	"	4	10.7	"
C. calothyrsus	"	4	12.1	"
E. poeppigiana	"	10	11.8	Russo & Budowski 1986
"	"	10	18.5	"
Flemingia spp.	Subhumid	2	4.1	Yamoah *et al.* 1986
Gliricidia spp.	"	2	7.7	"
Cassia spp.	"	2	15.0	"

N.A. = information not available.

In addition to the pruning material manually applied to the soil, agroforestry systems also produce natural litterfall. Litterfall data, however, are extremely limited. Perhaps the most comprehensive analysis of agroforestry organic matter and nutrient dynamics is presented by Fassbender *et al.* (1991). They reported that intercropping of mature *Theobroma cacao* and *Erythrina poeppigiana* produced 8 - 9 t ha^{-1} y^{1} of litterfall in addition to prunings of up to 13 t ha^{-1} y^{1}. In an *Erythrina* and coffee intercropping system, Glover and Beer (1986) reported that litterfall was 3.7 t ha^{-1} y^{-1} in addition to over 13 t ha^{-1} y^{1} of prunings. These examples indicate that for some types of agroforestry systems, litterfall can be an important component of organic matter dynamics. No examples of litter production by alley cropping systems were located in the literature. We can speculate, however, that in the many applications where hedgerows are frequently pruned to keep them short, additional natural litter production may be limited.

Root production and turnover in agroforestry systems is even less known. Fassbender *et al.* (1991) estimated that fine root turnover was 1.8 and 4.4 t ha^{-1} y^{1} for two intercropping systems. Szott *et al.* (1991) discussed the potential importance of root turnover in maintaining soil organic matter, but could not reach any conclusions because of lack of information. They did, however, point out that root turnover can be large in natural systems in the tropics, and can be responsible for large nutrient fluxes. They also indicated that agroforestry systems appear to have slightly larger fine root biomass than annual crops, but much less than tropical forests. Root turnover is likely to be an important additional source of organic matter in agroforestry systems.

A few of the studies in Table 1 also assessed effect of pruning additions on soil carbon content itself. Fassbender *et al.* (1991) observed that soil carbon increased 10 t ha^{-1} (9%) and 22 t ha^{-1} (21%) under cacao and cacao/*Erythrina* respectively over a 10-year period. Atta-Krah (1990) reported that an alley cropping system maintained soil organic carbon levels over four years while a monocropped control showed a decrease. In a study by Kang *et al.* (1985), soil carbon content was 1.07% when prunings were returned to the soil, but only 0.65% when they were removed from the field. Rosecrance *et al.* (1992), however, found no difference in soil carbon content between alley cropped plots and monocropped controls at the end of a four-year experiment. Soil was not analyzed prior to installation of the experiment so we do not know what changes may have occurred during the course of the study. The authors reported, however, that the soil type on which the study was conducted was initially high in organic carbon. This could have made small incremental changes difficult to detect. Lal (1989a) reported that soil organic carbon decreased during a six-year alley cropping experiment, but that the alley cropping treatment had significantly higher soil organic carbon than either of the plow-till or no-till treatments. He attributed superior carbon status to the addition of prunings to the soil in the alley cropping treatment as well as to greater root biomass.

Litter and pruning production by both traditional agricultural and agroforestry systems are comparable to litter production in secondary and mature forests in the tropics. A number of articles in the literature present many examples of litterfall in forests throughout the tropics (e.g. Toky & Ramakrishnan 1983, Lal 1986, Luizao 1989). Table 2 presents a sample of some of these published estimates rather than a comprehensive listing. The table shows a range of litterfall values from as low as 5.5 to as high as over 12 t ha^{-1} y^{-1}. Higher or lower values may appear elsewhere in the literature, but there is considerable overlap between Tables 1 and 2. If agroforestry systems cycle organic matter at levels comparable to forests, this lends support to the idea that agroforestry might be a sustainable technology.

Table 2. Annual litterfall for selected mature mixed species in tropical and sub-tropical forests

Source	Litter Production (t ha^{-1} y^{-1})	Location
Pandey & Singh 1981	5.5	India
Tanner 1980	6.4	Jamaica
Luizao 1989	8.2	Brazil
Proctor *et al.* 1983	8.8	Malaysia
Toky & Ramakrishnan 1983	9.7	India
Cuevas & Medina 1986	10.2	Venezuela
Greenland & Kowal 1960	12.5	Ghana

Discussion

Implementation of agroforestry systems would likely result in an increase in organic matter cycling relative to systems currently in use (i.e. short fallow systems). An earlier section of this paper discussed litter production by traditional agricultural systems and noted that it increases with age of the fallow. Young or short fallows, therefore, have the lowest levels of litter production. Following repeated cropping cycles and more intensive use, therefore, litter production would be expected to be further reduced (Uhl *et al.* 1988). In India, fields subjected to three and five-year fallow cycles produced litter at rates of only 2.1 and 4.8 t ha^{-1} y^{-1} respectively (Mishra & Ramakrishnan 1983, Toky & Ramakrishnan 1983). Many agroforestry systems with permanent tree components surpass these rates.

However, there is also evidence that the sustainability of agroforestry systems may be constrained by soil properties. In an extensive review of the literature, Szott *et al.* (1991) concluded that successful agroforestry systems are almost always practiced on soils that are inherently fertile. On infertile soils, a limited potential for increasing nutrient inputs results in reduced plant growth, litterfall, and nutrient recycling. Apparently, there must already be adequate nutrients on site to recycle if recycling is to be an advantage (Lal 1989b). Alternatively, commercial fertilizers could be used to improve the nutrient status of infertile soils. In many agroforestry applications, however, it is desirable or necessary to limit the use of external inputs. Szott *et al.* (1991) suggest that in low fertility situations the best solution may be agroforestry technologies that are more similar to shifting cultivation with long fallow rotations. Fallows could also be economically or biologically enriched by planting and cultivating desirable plant species.

To be successful, agroforestry systems must not only conserve soil resources, but also produce adequate crop yields. There are many examples where, at least in experimental applications, agroforestry practices have been shown to be more productive than monocropping. For example, in Nigeria, intercropping with *Leucaena* trees increased maize yield by 68% (Ngambeki 1985). Pasture grass in Australia was more productive when grown in conjunction with trees (Wilson *et al.* 1990). Tea yields in China were 30% higher under trees than without trees (Yu *et al.* 1991). MacDicken and Vergara(1990) reviewed 11 examples of crop yield improvements of 14 - 367% under coconut, with a mean increase of 89%. They also cited five examples of crop yield increases under *Acacia albida* that average 78%. These yield improvements presumably occurred because of microenvironmental improvements caused by the trees (MacDicken & Vergara 1990). For example, shading and lower temperature may have reduced evapotranspiration and conserved moisture in the upper soil layers.

Other results, however, suggest that agroforestry practices may be less effective than monocropping in some circumstances. Competition between trees and crop plants may be most intense where light, water, and soil nutrient supplies are most limiting. For example, Kang *et al.* (1990) found that the agroforestry practice of alley cropping is not as promising in semi-arid as humid zones because of greater competition for moisture between crops and trees. Rao *et al.* (1991) also blamed competition for moisture for crop yield reductions of 40 - 50% in a *Leucaena* alley cropping trial. The space occupied by trees in itself can reduce crop yield per hectare. This was the cause attributed to a 25% crop reduction in the narrowest hedgerow spacing treatment by Rosecrance *et al.* (1992). Nair (1990) also cites nine examples from India, Nigeria and Kenya where crop yields were lower for agroforestry than for monocropping.

Although crop production is critical, the overall success of an agroforestry system often also depends on other factors such as greater tenure stability or risk reduction. In some cases declines in crop production could be compensated by food and fuel production from trees, as well as increases in long term agricultural stability versus short term crop yield. The goal is to substantially improve the present land use and enhance the overall resulting system.

Before concluding, we should acknowledge the potential complexities of implementing agroforestry systems. Whether agroforestry systems will be sustainable depends on more than organic matter cycling, crop production, or other biophysical factors. There is a distinction between developing the agroforestry technology itself and actually implementing that technology (Wiersum 1990). Implementation of agroforestry systems occurs within a social and economic context that usually involves rural change. It is not only a change in land use practices, but may also involve changes in attitudes toward land tenure and labor productivity. For example, communal arrangements may become private or subsistence systems may become commercial. Implementation, therefore, is more than a process of technology transfer. Attention should also be given to the development of proper tools for effectively implementing the technology, including support measures and organizational structures (Wiersum 1990).

Conclusion

Agroforestry systems have been observed to cycle substantial amounts of organic matter in a variety of situations where prunings are returned to the soil. Rates of cycling can be comparable to those of traditional long fallow systems, as well as forest systems. This is a positive indication that agroforestry systems have the potential to conserve soil carbon, retard degradation, and promote sustainability. In such situations, agroforestry could slow emissions of CO_2 to the atmosphere by replacing short fallow shifting agriculture and reducing the need to clear forest land.

On the other hand, the results and experiences with agroforestry systems have been mixed. There have been some cases where soil organic matter was not conserved and continued to be depleted despite application of prunings (Lal 1989a). Agricultural yields can be reduced to unsatisfactory levels by competition from trees for space and other resources. It seems clear now that agroforestry technology is not universally applicable; it may be best suited for sites that are initially relatively fertile and humid. This emphasizes the need to individually evaluate specific situations before implementing a technology. Broad generalizations and recommendations may have disappointing outcomes. Implementation of agroforestry as an alternative to continuous cropping, however, should slow the loss of soil organic carbon and extend the cropping period. There is a continuing need to develop sustainable agricultural technologies for as many site and soil situations as possible.

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