Chapter 8
Agroforestry

The information presented thus far on culture and management has been concerned almost entirely with trees, assuming that production of trees is the primary land-management objective. Such singular emphasis is attractive because of its simplicity. Concrete results and high timber yields are possible, because this type of management makes the most of available and appropriately forested sites in the region. In most tropical countries, it is only by such concentrated production that the foreseeable national requirements for wood products can be met without increasingly costly imports.

However convincing or obvious the arguments for such focused production may seem, no tropical country is dedicating enough land exclusively to forests to meet its needs. The lead time that is necessary before management produces wood yields may cause serious local deficiencies in timber supplies in most tropical countries.

The reasons for this anomaly are many. Not the least is the sharp divergence between the views of proponents of intensified forest production and those who live on or near the land involved. Implementation of long-term forest management affects the land in ways that may be new, unexplained, and constraining to an affected rural community. The fact that employment opportunities may result does not, in the eyes of tropical people, necessarily compensate for perceived restrictions imposed on them by forest regulations.

These and other factors restrain government forestry investment in what should seem to all as both a social and an economic good. Private investments in plantations are likewise frustrated by a lack of popularity and public support. The crux of the matter is that benefits are seen to accrue to someone else, somewhere else, some time in the future; in short, the benefits are not for the immediate "public." This feeling of remoteness is most acute among rural populations far from the decision-makers whose choices affect local welfare.

Therefore, the integration of forestry and agriculture in the Tropics is commonly seen as an underexploited opportunity to bring forestry "to the people." In its broadest sense, this concept includes upstream trees that protect downstream farmlands. It includes trees on farms that protect food or forage crops growing beside or beneath them. Also included is the practice of intercropping to control weeds in tree plantations.

The combination of forests and other crops may not be an equal partnership. Usually, the coexisting crops are unequal in their respective economic yields, and the trees generally produce the lowest. Therefore, the introduction of trees into crop mixtures must generally be done at little cost to the yields of the other, more appreciated crops. Thus, the task of integrating forestry and agriculture involves not only forestry technology but also agronomy, knowledge of rural social traditions, and skill in human relations. These disciplines are still slighted in forestry curricula.

This chapter is devoted primarily to what is known in the Tropics about agriculture that can be considered pertinent to forestry. The practice of shifting cultivation that is so prevalent in and adjacent to tropical forest areas is reviewed. Its adaptation for tree-plantation establishment through the taungya system is also described. Then, experiences with the additional practices defined as agroforestry are explored.

Shifting Cultivation

Shifting cultivation (rotation of tree and agricultural crops), possibly the oldest of agricultural systems, is a source of livelihood for more than one-quarter of a billion people throughout the Tropics. Application varies from place to place, but several shifting-cultivation practices are nearly universal (Blaut 1960). Among them are rotation of fields, clearing by fire, exclusion of draft animals and manuring, exclusive use of hand labor, planting by means of dibbles, and short periods of crop production alternating with long periods of fallow. The system developed under conditions of low population density, subsistence orientation, the presence of forests, and the concurrent production of many crops with different times of harvest. Fertility is restored by the long fallow, and little if any weeding is necessary in the first planting season.

Custom and Precedent. In what is now Zambia, shifting cultivation has been intimately interwoven with the lives and customs of the native people. For instance, trees have been cut and burned only on certain days (Endean 1960), and after 4 to 6 years of cultivation, land lay fallow for 20 to 30 years. Managed in this way, as many as 50 to 80 ha of land have been needed to sustain one family. Rural people in the Philippines are also sentimentally and psychologically bound to the forest (Maturan 1976). Their attitudes, motivations, and aspirations are deeply involved in their use of virgin forests, secondary forests, and logged areas for shifting cultivation.

It has only been a few millennia since settlers came as hunters and fishermen to the Amazon (Sioli 1973). They collected wild food plants and adapted farming practices, planting only enough to satisfy home needs. As their numbers were small, they did not significantly influence the structure and dynamics of the forests as a whole. Later, European colonists discovered that cultivation was practical for only 2 successive years; if the fallow was recut at 10 years, only one more harvest was possible. The terra firme soils lacked the colloids needed to fix minerals; even adding minerals from outside sources did no good (Sioli 1973). Only where annual flooding replenished these minerals was continuing cultivation possible.

Primary forests offer the most fertile areas for shifting cultivation, but secondary forests have proved easier to clear and more productive per unit of labor. The optimum forests, then, are in some stage of secondary succession. To compensate for the lower nutrient base of these secondary forests the farmer has simply used more land.

The fallow forests differ markedly from the original forests but seem to adequately restore the sites (Blaut 1960). The forests need not return to their primary condition. Even a permanent deflection toward fewer species, more fire-resistant species, or fewer stories should not substantially affect the crop yields after subsequent burning. Nor is soil structure worse or nutrient supply much lower under a secondary forest than under a primary forest. To a point, yields overall may increase by shortening the fallow.

Environmental changes can diminish or eliminate shifting cultivation. For example, increased population density, access to outside commerce, or the introduction of more intensive technology all tend to shorten the fallow period and thus reduce the forest proportionately. As the fallow period shortens, more labor is required for tillage and weeding, and yields decline. There is also a tendency toward fewer, hardier, and more salable crops and the fixing of property boundaries. All these factors work against the duration of the forest fallow.

As the process breaks down, new crops and drastic changes in techniques may be required. New crops must not compete for labor during periods when other activities peak. The soils may deteriorate under more intensive use as crop marketability becomes more of an objective.

The problems arising from progressive land shortages are not solved simply by intensifying cultivation (Blaut 1960). Erosion control and fertilizers may be required. Tree crops may provide more permanent income but less income per unit of area than ground crops. Converting an area of shifting agriculture to purely commercial forest or pastureland is no solution unless an alternate means can be found to support the people forced out by the reduced employment.

In dealing with the problems of shifting agriculture, Blaut (1960) points to certain fallacies that in the past have led to misunderstanding and misdirected efforts. These are as follows:

- Shifting agriculture is the only system suited for the Tropics.
- Shifting cultivation cannot sustain an equilibrium.
- Villages must eventually move because of land impoverishment inherent in shifting agriculture.

Traditional Practices. The shifting cultivation systems of the Amerindians in the Orinoco Basin of Venezuela evolved into complex polycultures of manioc, yams, gourds, cotton, and tobacco (Harris 1971). Such mixtures utilize both vertical and lateral light. The Waikas cultivated these mixtures for 5 to 6 years, until reclearing and weeding became difficult; then, a gradual transition to fallow permitted continued harvesting of fruits. Their monocultures, in contrast, could be farmed for only 2 to 4 years and were abandoned abruptly because of fertility loss rather than weediness. The fallow started with pioneer shrubs and trees such as *Aegiphila, Cecropia, Clidemia, Miconia, Palicourea, Psychotria,* and *Trema.*

Carib polycultures in the Amazon region involved fields of 2 to 3 ha where 12 species of food plants were mixed (Smith 1978). This approach provided a ground layer, middle layer, and top layer, the latter usually composed of small trees such as *Bixa.* Individual fields were 2 to 3 km apart, a distance that reduced the danger of pest buildup. Simultaneous cultivation for 2 to 5 years permitted a sequence of crop maturation.

In Papua New Guinea, the reuse of organic wastes has been a striking feature of shifting agriculture (Kingston

1960). One result is that in the uplands, as little as 0.04 to 0.09 ha of garden per capita has been required. Pits were used to store organic matter while it decomposes. *Casuarina equisetifolia,* a nitrogen (N)-fixing species, may be planted a year or two before farm cropping ceases. It is easier to clear away than natural regrowth and provides timber and firewood. The branches can be used as stakes for erosion control, and the leaves are either composted or burned.

Native forests were converted to what appears to be permanent cultures of coffee more than a century ago in Mysore, India, on steep slopes with rainfall up to 380 cm/yr (Mayne 1947). The basis for the system was the introduction of an economic crop, coffee, within the existing plant association, evergreen forests. The natural regrowth was cut and allowed to decay, usually without burning. The coffee was planted close, never at more than a 1.8- by 1.8-m spacing, to produce a quick cover like that of the former undergrowth. Canopy density was maintained well below the optimum for maximum cropping, ensuring maintenance of the mulch and protecting the soil from the impact of the heavy rains. Managing the shade proved one of the planter's most exacting tasks.

This successful technique was generally ignored in the eagerness to expand coffee culture in south India and what is now Sri Lanka after 1860. The forests were felled and burned, and coffee was subsequently planted in the open. All that remains of this early practice is poor secondary forests and thickets of *Lantana*. On the other hand, where there was partial clearing and light burning, shade was provided, using both leguminous and nonleguminous species. The use of genera such as *Erythrina* and *Grevillea* deviated widely from the native forest composition. The success of this venture suggests that other species may also serve as a permanent culture.

In what was formerly Zaire, shifting cultivation developed to a complex degree, extending the period of cultivation on good soils up to a total of 9 years (table 8–1; Henry 1952). The difference in the lengths of the cultivation cycle reflects soil quality.

A study of the Bantu cultivation systems in what was formerly Zaire led to a number of conclusions (Coene 1956). In high-forest areas, burning alone was sufficient site preparation. Clearing of stumps and roots was not necessary for bananas, cassava, and yams. On the forest edge, however, the crops were mainly maize, sorghum, and millet, which require more complete cultivation. As a result, fields were worn out; they were cultivated until repeated burning turned them into savannas.

The growth of urban communities in tropical areas and the consequent introduction of economic crops such as cotton, rice, and peanuts encouraged farmers to lengthen the cultivation period or return to field crops too soon. Inadequate restoration during the fallow progressively deteriorated the soil. The intensified search for fresh soils often meant a nomadic way of life, declining income, and a search for work in the towns.

Several characteristics of shifting cultivation have hindered its practice. Polyculture is one; mixed plantings are incompatible with high yields of the most profitable crops, but clearing of bush fallow for monocultures is difficult to mechanize. Deep plowing and leguminous fallow have produced deplorable results. Heavy mulching and composting favor productivity but are not feasible for the average cultivator. The prevalence of the tse-tse fly in west Africa has meant no dung or draft animals.

Shifting cultivation systems, those requiring fallows and including tree crops, may survive where permanent agriculture cannot, but they yield so little per unit of land area that they may not support such community services as roads and schools (Holdridge 1959).

The length and shape of the clearing for cultivation in the forest are of paramount importance. The long axis should be east-west for maximum light. The optimum breadth is about 100 m. Under these conditions, loss of yield along the borders amounts to 10 percent in heavy forests but only 3 percent in secondary forests (Coene 1956).

Two weeded crops with short cycles may generally be grown in the same field in the same year. Annual weeded crops, such as maize, peanuts, soya, and cotton, are very sensitive to competitors; therefore, before they are planted, the soil should be exposed to the sun and rain. When planted immediately after removing the heavy forest, these crops do not usually yield well. Cutting the fallow a year before cultivation for annual crops increases yields greatly. Complete clearing, however, eliminates tree stumps as a source of sprouts for the subsequent fallow. Perennial crops such as bananas and

Table 8–1.—Past shifting cultivation regimes in what was formerly Zaire

Sequence (yr)	Location: Bambesa	Gandajika	Yangambi
1	Deforest, maize, rice	Deforest	Deforest, maize
2	Cotton	Cotton	Maize, rice, manioc, bananas
3	Manioc, bananas	Maize, root crops	Bananas, manioc
4	Manioc, bananas	Maize, peanuts, root crops	Bananas, manioc
6	Fallow	Maize, manioc	Bananas, manioc
7	Fallow	Manioc	Legumes
8	Fallow	Manioc	Legumes
9	Fallow	Manioc	12-year fallow
10	Fallow	Fallow	6-year fallow

Source: Henry 1952.

cassava ordinarily do not require this treatment. They protect the soil better and have little effect on residual fertility.

Perennial crops are well suited to newly cleared areas and are an excellent precursor for annual crops. They increase the pH of the soil and favor decomposition and mineralization of organic residues from land clearing. The pigeon pea *(Cajanus indicus)* has proved to be a good crop to sow before a farm is abandoned (Page 1948), and its stems are large enough to use as fuel.

In the Philippines, shifting agriculture (referred to as "swidden") can produce rice yields double the national average (Conklin 1957). The system uses 2 ha of cultivable land per person on a 12-year cycle. The intensity of management varies. At one extreme, the vegetation is cleared each year; at the other, plentiful tree crops are established with little or no clearing of the climax forest.

During its first (and most active) year, an average swidden may have up to 40 different basic crops and 85 to 150 crop types at the same time (Conklin 1957). By the beginning of the second year, there was a shift toward tree crops, including bananas, fruits, and bamboo. When all cultivated crops were exhausted, a forest fallow may already be well advanced. The fallow period is two-thirds to three-fourths of the total swidden cycle.

The swidden system is land extensive and labor intensive (Harris 1972). It involves 500 to 1,000 hours of labor per family per year; however, no concerted action by large groups is generally required. Although the system is inefficient in terms of the amount of land cultivated, the yield per unit of labor expended can equal or even surpass some types of permanent field agriculture. It is the fallow, not the productivity, that restricts the capacity of swidden cultivation to support concentrated populations. The number of people living in swidden areas seldom exceeds 60 per square kilometer and is usually less than 40.

Shifting cultivation in Venezuela has been practiced on all humid lowlands (Watters 1968c). Above 1,600 m, decomposition is slower, and agriculture tends to be more continuous. Shifting cultivation is not the most productive system on poor soils, but it is the best available to people without implements or fertilizer. The first two crops may equal those of better land without fertilizer but are much less than what could be achieved with fertilizer.

Because shifting cultivators move to new areas when yields drop 50 percent, the practice is a principal cause of deforestation (Watters 1968c). Although primary forest areas permit a shorter cycle, cultivators will normally select secondary forests if they are more accessible. The system is hard to beat in terms of yield per unit of work. The labor input ranges from 32 to 86 d/ha.

In central Brazil, a village of 145 people that has been stable for 90 years cultivates a gross area of 5,500 ha, or nearly 40 ha per capita (Watters 1974). But at any one time, the area in use is less than 3 ha per capita. Half the food produced is sold. Only 3-1/2 hours each day are spent on subsistence, and of these, only 2 involve agriculture. The system has been a reasoned approach in that it has made lavish use of the resource that was available (land) while economizing on capital that was in short supply.

Shifting cultivation in what is now Sri Lanka has depended greatly on the products of burning for its nutrients and was therefore not necessarily a heavy drain on the soil during short cultivation periods (Joachim and Kandiah 1948). Intrinsic soil composition is restored in 5 to 10 years.

An unusual dry-climate variant of shifting agriculture has been described in the Sudan (Jackson and Shawki 1950). Here, the scrubby native vegetation was cleared from sand dunes, and sorghum was cultivated for 4 to 10 years, during which time the soil becomes exhausted. Natural revegetation with *Acacia senegal* and *A. seyal* followed, and after 8 years, the trees were ready to be tapped for gum arabic. Tapping continued for 6 to 10 years, during which time the trees wear out and die. The area was then burned and cultivated again.

Shifting cultivators are usually at least partially concerned with subsistence; therefore, their cultivated patches are normally a complex mixture of plants. The mixture is apparently chosen to satisfy the diverse needs of the family table and to give the farmer the relative security that comes from crop diversity. However, as would be expected, mixtures give lower yields per unit area for each crop than pure cultures (table 8–2).

The diversity of natural vegetation in the Tropics, a product of long evolution and succession, has suggested other reasons for the use of crop mixtures by farmers, and much research has been undertaken on this subject. Some hold that interspecific interactions not only protect mixtures from pests and diseases more than they do pure cultures but also can make mixtures equally (or even more) productive. However, studies have shown that most crop-mixture yields are intermediate between those of each component as a monoculture (Trenbath 1974). The yield totals tend to be nearly equal. Trangressive yields (above the limits of any component alone) are few and seldom significant or repeated. Such yields occur only in mixtures of similar components and, thus, are not to be expected with wide differences within subsistence cropping mixtures.

Table 8–2.—Comparative yields from shifting cultivation in what was formerly Zaire (t/ha)

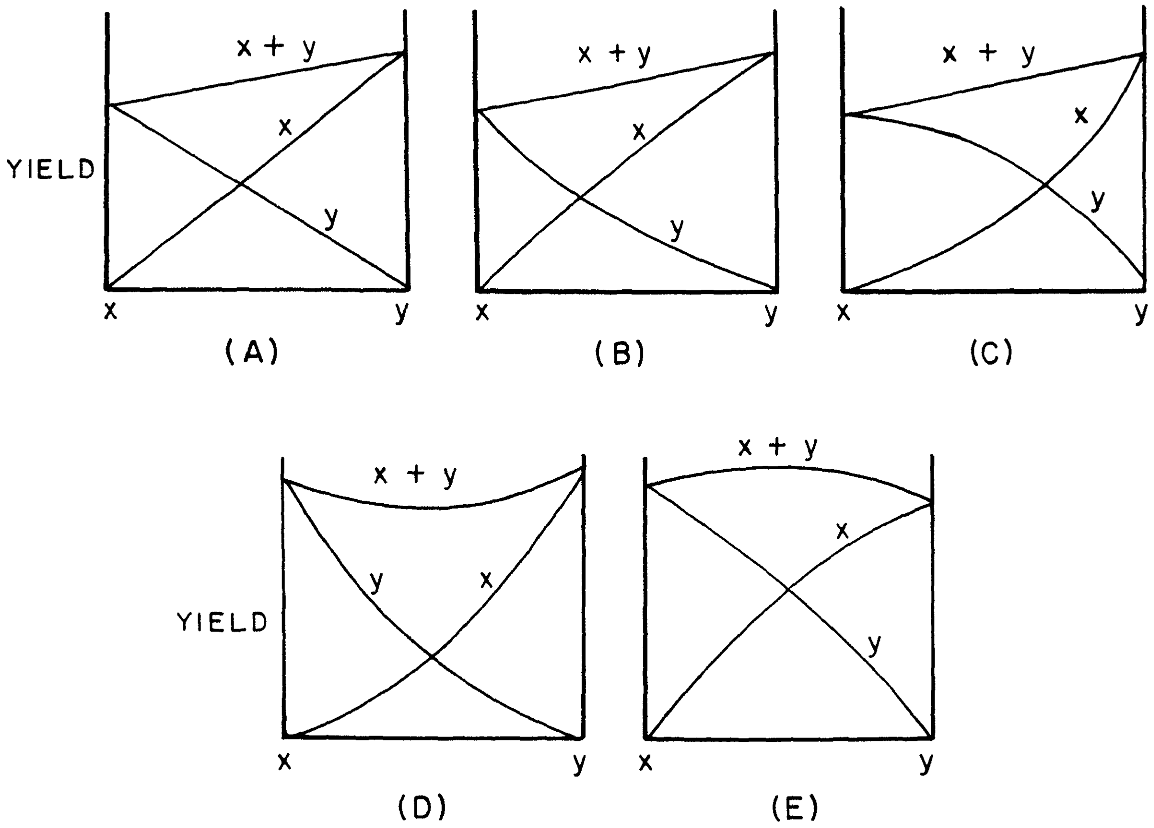
Crop	Mixed yield	Pure yield
Rice	1.5	2.5
Manioc	15.0	25.0
Bananas	4.0	15.0

Source: Henry 1952.

Mixed cropping systems have dominated northern Nigeria (Baker 1975) and are justified by their dependable return per unit of land or per June-July hour of work, which is higher than for pure crops. To obtain gains from mixtures over pure crops, the constituents must have complementary growth cycles. Intercrop competition must be less than intracrop competition. The arrangement and relative numbers of the different plants in mixtures will influence the degree of competition. Factors that may produce a gain from mixed cropping are differences in light interception (because of different canopy heights and structures) and differences in water utilization. These factors themselves change over time because of different growth periods for the mixture's constituents.

The theoretical significance of mixtures has been explored by Harper (1977) (fig. 8–1). In case "a," species "x" and species "y" compete with more or less equal effect on each other; so, yields are directly proportional to their relative representation. In case "b," species "x" is more aggressive than species "y"; so, mixtures of the two lead to greater than proportional yields from "x" at the expense of "y." For case "c," the opposite is true; the yield of species "y" is greater than its proportional representation in the crop. When, as in case "d," each crop is recessive relative to its level of intraspecific competition, mixtures yield less of each than their proportional representation and total yield is less than each species could produce alone. In case "e," both are more aggressive against each other than they are intraspecifically. Thus, each permits greater yields of the other species than their proportional representation would suggest, and their overall yield in a mixture is greater than the sum of their respective yields alone. Only in this instance is transgressive yield to be expected.

However, it is generally not true as alleged that yield capacity is correlated with aggressiveness, that mixtures always outyield pure stands, that mixtures have the mean yields of pure stands, that competitive capacities are additive, or that competition is more intensive between members of the same species (Harper 1977). Each of these statements can be true in specific cases, but can be clearly untrue in others.



Mixture	Mixture, x & y	
	crop x	crop y
(A)	equal	equal
(B)	aggressive	recessive
(C)	recessive	aggressive
(D)	recessive	recessive
(E)	aggressive	aggressive

Figure 8–1.—*Prospective yield effects of crop mixtures (Harper 1977).*

A study of 572 crop mixtures showed that two-thirds had total yields close to the sum of their separate yields (Trenbath 1974). Another 20 percent exceeded that sum by as much as 70 percent. About 14 percent produced less in mixtures than as pure crops.

Nine mixed cropping systems outproduced a monoculture of yams in Jamaica (Schroder and Warnken 1981). They required more labor and more capital, including fertilizer, but produced a 50-percent increase in farm income, three to four times what is typical for hill agriculture. Apparently, fertilizer helped, but most of the benefit seemed to arise from multiple cropping.

The following advantages and disadvantages of multiple cropping have been described (Gleissman 1981b):

Advantages

- Better use of time and vertical space, capture of solar energy and nutrients, crop overlapping
- Pumping of nutrients from deep in the soil
- Less vulnerability to climatic extremes and wind
- Less vulnerability to pests and diseases
- More flexible distribution of labor through the year.

Disadvantages

- Competitive constraints on short crops
- Limitations from species incompatibilities
- Damage from partial harvesting
- Inconsistency with a fixed fallow period
- Limited volume of each crop
- Unsuitability to mechanization and crop uniformity for marketing
- Greater complexity, making it little understood agronomically and biologically
- Incompatibility with prevalent social, economic, and political systems.

Although shifting cultivation has been an ingenious use of labor and resources in the Tropics to sustain primitive cultures, its limited capacity to support expanding populations has resulted in extensive land destruction. By 1952, shifting cultivation in west Africa was presenting a tragic picture. In the Sudan, all attempts to prevent widespread annual fires had failed. The lack of fuelwood had led to the plundering of the forests, and shifting cultivation with a shortened fallow was destroying the soil (Faure 1952). In Niger, the fallow stages had already become too short to restore the land between cultivation periods, and the entire territory was burned every year (Jorvanceau 1952). In Chad, the soil "discipline" formerly enforced had disappeared (Anon. 1952j). As a result, some 150,000 ha of forests were being cleared annually, fires were everywhere, and shifting cultivation was wearing out the soil.

In what is now Burkina Faso, forest exploitation for fuel and charcoal and the impossibility of protecting the country from fires led to a proposal to give the forest reserves to the people to farm (Civette 1953). In Ivory Coast, native farming practices were formerly kept in balance with the woodlands, but this balance was upset by overpopulation, emphasis on industrial development, changes in diet, and migration (Piolant 1952).

In Sierra Leone and The Gambia, the balance between cultivation and fallow had been upset by 1952, and the fallow was shortened to less than 7 years (Anon. 1952m). All unreserved forests were being released for more agriculture. In Togo, firebreaks to protect forests were thought to be too expensive, and the government was considering releasing the forests to farmers (Chollet 1952). In what is now Ghana, inadequate patrol of unreserved forests had led to trespass and illegal exploitation. All such forests were soon to be transferred to agricultural use (Anon. 1952i).

Soil destruction caused by shifting cultivation has been documented in the Western Ghats of India (Satyanarayan 1960). Soil depth ranged from 150 cm under teak *(Tectona grandis)* forest to 15 cm under poor grass. The pH of the latter decreased 0.8, the sand content doubled, and organic matter dropped to one-third, N to one-sixth, exchange capacity to one-third, and calcium (Ca) to one-fifth.

Studies in what is now Malaysia have shown that shifting cultivation persisting after 18 months wipes out all tree sprouts from the former forest (Wyatt-Smith 1958c). A shift there from millet to hill rice extended cultivation into the second year, wiping out most forest sprouts (Carey 1960). Even the isolated relics left as possible seed bearers were soon gone (Wyatt-Smith 1960d). Soil degradation continued because the people were unwilling to return to millet for a year; the soils were considered too poor to warrant the expense of their conservation and the area too remote for fertilizer or cash crops (Carey 1960).

The destruction of forests by shifting cultivators in Thailand has been spectacular. By 1958, two-thirds of the forests above 1,000 m were gone (Loetsch 1958). The waste was obvious because the timber was burned, yet there was reportedly little sympathy for forestry in the Parliament.

Burning, almost universally associated with shifting cultivation, causes some nutrients to be lost to the atmosphere or released in ashes lying loosely on the surface exposed to runoff water. Yet, studies in Ghana showed that after forest clearing and burning, almost all the potassium (K), Ca, and magnesium (Mg) in the first 30 cm of soil was retained (Nye and Greenland 1964). There was a marked rise in the pH. An increase in the soil N and carbon (C) was due to a mixture of parts of the vegetation with the soil. There was no net loss of humus in the soil as a result of burning. During the subsequent year, organic matter was lost as a result of oxidation of unhumidified material; however, the rate of loss was much lower the second year. In general, there was a rapid loss of nutrients through leaching and erosion during the first year. Burning accentuates these losses, particularly when repeated, after which grasses may take over and preclude further cropping (Frissel 1977).

Further light was shed on the results of burning in a study on yellow Latosols in Amazonia (Brinkman and Nascimento 1973). After burning, the pH, Ca, Mg, and K had increased in the top 20 cm of the soil (table 8–3). Thereafter, K, which is relatively mobile, declined.

In 1957, the Food and Agriculture Organization (FAO) detailed the shortcomings of shifting cultivation (Anon. 1957b) as follows:

- The fallow is not subject to control; therefore, site improvement is impossible.

- Fire and erosion are destroying the soils.

- Nomadic life offers no inducement to intensify management or make long-term improvements.

- Shifting cultivators accumulate no material wealth as a reward for good practices.

- When population exceeds the sustainable limit, all of the soil becomes degraded, and famines disperse the population.

- No prospect for specialization or progressive change is possible.

- The trend toward cash crops destroys the soil.

The causes of low efficiency in subsistence farming were listed by Phillips (1961). Among them, the following still seem especially important: poor land use; poor soil husbandry; poor seeds; insufficient tools and implements; and inadequate weed, pest, and disease control.

These factors differ in importance, and some are debatable. There is little question that the subsistence farmer, when not subject to outside influences, has made good use of the land, available crop plants, labor, and ingenuity in spacing and timing crops. There is also no doubt that the practices of the subsistence farmer are as durable as those of modern agriculture in the absence of fertilizer. The difficulty comes with the desire to produce more than is needed for subsistence purposes. This goal requires larger crop yields and usually a departure from mixed cropping and the multistoried cover. It also demands competitive production, involving fertilizers or a high return on hand labor. Efficiency, then, must be judged not solely by unit production costs but also by how well the yield serves the needs of the rural community that produces it.

One of the most common criticisms of shifting cultivation is that it seems to support only 8 to 12 persons per square kilometer (Nye and Greenland 1964). However restrictive this may sound, the system could thus support a village of 630 to 950 people using land within a 5-km radius. The fact that shifting cultivation does not necessarily dictate low population densities or a lack of social development is indicated by actual cases (Rebugio 1976). In Campeche, Mexico, more than 20 people have been supported per square kilometer. The Uaxactum culture has supported up to 40. In Indonesia, as many as 50 people have been supported. In parts of Africa, the

Table 8–3.—Burning effects on soil properties in Amazonia

Soil property	Before felling	Days after burning 14	148	290
pH	3.70–4.10	4.30–4.80	3.50–3.80	4.10–4.50
Calcium and magnesium (meq%[a])	0.30–0.50	1.00–1.60	0.50–1.00	1.00–1.40
Potassium (meq%)	.06–.09	.17–.31	.08–.12	.15–.09
Phosphorus (meq%)	.46–.67	.69	.69	.69
Aluminum (meq%)	1.20–2.10	.50–.90	1.10–1.80	.40–1.10

Source: Brinkman and Nascimento 1973.
[a]meq% = milliquivalents per 100 g.

number is 90 or higher, and in highland New Guinea, nearly 200 persons are supported per square kilometer.

The culture of the Xingu in Brazil, involving 3-year shifting cultivation of 0.3 ha per person and a 25-year fallow, has sustained a village of 145 people on 385 ha (Carneiro 1961b). A village of 2,000 could be supported at this intensity on 5,400 ha, all within walking distance.

Although under certain circumstances these shifting-cultivation systems can support dense populations, no convincing evidence appears to confirm that they can sustain a complex, stratified society concentrated in large villages or towns. In fact, some suggest that the shifting cultivation that led to the Mayan civilization was also the cause of its downfall (Rebugio 1976). People in small, dispersed settlements face a difficult transition to dependency on remote, centralized-market control. Support of large populations may be facilitated by concentrating cultivation on vegetables and root crops that remove only a small fraction of existing nutrients in their harvests. These and other crops, such as the peach palm *(Guilielma gasipaes)* and *Brosimum alicastrum*, may have supported the Mayan civilization (Harris 1972).

The Fallow: Nutrient Conservation. Cropping can deplete plant nutrients, which may seriously threaten productivity, even under shifting-cultivation systems. A significant portion of available plant nutrients may be stored within the fallow vegetation. Destruction of the fallow predisposes these nutrients to loss during decomposition through runoff and leaching. The rapidity of this loss is seen in the results of a study in Ghana where nutrient levels 3 years after forest treatment were compared (Cunningham 1963). In an area reduced to half the forest density, the decline in the top 5 cm of soil was 47 percent of N, 44 percent of phosphorus (P), and 48 percent of organic C. Where the forest was cleared, the corresponding percentages of loss were 53, 50, and 57.

In the Venezuelan Amazon, a decline in the cassava crop from 4.3 t/ha in the first year to 2.8 t/ha in the second was attributed to loss of soil fertility (Uhl and Murphy 1981). During the first year after cutting and burning the fallow, the cassava crop produced nearly five times as much dry matter as the secondary forest. In the second year, however, the productivity of the secondary forest (the fallow) rose to 2.7 times that of the cassava crop.

Runoff and erosion increase dramatically after conversion from primary forests to cleared cultivation (table 8–4). But a secondary fallow at 6 years is almost as effective as a primary forest. These data from Mindanao, Philippines, were collected on slopes of about 25 percent and for a period of 227 days (Kellman 1969).

Table 8–4.—Runoff and sediment losses with clearing of forests in Mindanao, Philippines

Forest type	Rainfall runoff (%)	Mean daily loss (kg/ha)	Annual organic matter loss (kg/ha)
Primary forest	26	200	45
6-year secondary forest	26	290	65
10-year abaca	64	590	133

Source: Kellman 1969.

Fallow systems do not markedly accelerate liberation of nutrients from primary sources in the soil, but the capacity of fallows to capture and immobilize released nutrients is unique. The following two factors help enhance soil productivity during the fallow (Bartholomew and others 1953):

- Accumulation of plant nutrients in organic combinations and prevention of nutrient losses by plant immobilization
- Improvement of soil structure by both biological activity and rest from cultivation.

Total dry-weight biomass accumulation in fallows was shown by early studies at Yangambi (table 8–5; Bartholomew and others 1953). The chemical composition of this biomass further indicates the immobilization rate of nutrients by the fallow (table 8–6). Immobilization of nutrients by 3-year-old grass cover in the same area produced a total biomass averaging 86.1 t/ha dry weight, 418 kg/ha of N, 46 kg/ha of P, 348 kg/ha of K, and 201 kg/ha of Ca and Mg (Bartholomew and others 1953). Obviously, grasses may initially immobilize more nutrients than does the forest fallow, but the latter eventually immobilizes far more.

Tree and shrub crops that keep the soil covered, such as rubber, oil palms, coconuts, and tea, produce significant leaffall and may support a cover crop beneath them that can be managed to sustain the level of organic matter (Young 1976). However, for the culture of annuals, there appears to be no practical means of maintaining organic matter in humid areas other than by extended fallows or supplementary soil treatments.

Table 8–5.—Dry-weight biomass accumulation in forest fallows in Yangambi, in what was formerly Zaire (t/ha)

Tree component	Dry weight of fallow		
	2 yr.	8 yr.	17–18 yr.
Leaves	5.6	5.3	6.4
Wood	5.4	116.3	114.6
Roots	6.9	22.7	31.2
Litter	1.9	8.0	22.8
Total	**19.8**	**152.3**	**175.0**

Source: Bartholomew and others 1953.

A benefit from fallows not generally recognized is their relative resistance to burning. Even where fallows are frequently subject to fire, all organic matter is rarely consumed, and their residual root systems and capacity to sprout favor prompt immobilization of a maximum of the released nutrients.

There is evidence that the pioneer tree species that naturally come up after clearing are superior to others in their capacity to immobilize nutrients (Kellman 1969). Most of the soil recovery takes place during the life of these pioneers, be it 5, 10, or 15 years. During this period, soil-surface conditions are restored, and runoff and erosion are reduced to levels similar to those of older forests.

The length of the fallow period that is necessary to restore forest sites for further food crop production has become a problem where population density or increases in demand have pressed for expanded agriculture. Many estimates of this time period have been made from general observations. Early estimates suggested a fallow of 15 years in North Borneo (Coene 1956, Lee 1961) and 5 to 10 years in what is now Sri Lanka (Rosayro 1961). In Trinidad, the fallow period required after clearing, burning, and 1 year of cultivation is directly related to steepness and wetness because of the great propensity to erosion and leaching (Cornforth 1970b). Increases in K, Ca, and Mg and decreases in N resulting from burning disappeared in about 4 years. Nitrogen reached its original level in about 10 years. Phosphorus decreased for 7 years and never regained its original level, remaining about 25 percent lower. In Sarawak, estimates of site recovery time range from 7 to 12 years (Cramb 1978, Hatch 1980).

Studies in Central America further detail the effect of fallow length on-site recovery (Ewel 1976, Ewel and Conde 1978). Litterfall in secondary forests in Guatemala equals that of the mature forests by the 14th year. Equality of cycling for some nutrients was reached earlier. Litterfall may be even greater in secondary than in primary forests because of more deciduousness and the successional changes in species.

In eastern Guatemala, with 200 cm of annual rainfall, organic matter accumulation after clearing was found to reach half that of the undisturbed forest in less than 1 year of fallowing and to equal that rate in 3 to 5 years (Ewel and Conde 1978). Litter production peaked at 21 years and declined to the natural level at 30 to

Table 8–6.—The chemical composition of forest fallows in Yangambi, in what was formerly Zaire (kg/ha)

Tree component	Nutrient	Nutrient content 2 yr.	8 yr.	17–18 yr.
Leaves	Nitrogen	80.0	120.0	143.0
	Phosphorus	10.7	6.6	7.5
	Potassium	80.0	79.0	80.0
	Calcium, magnesium	63.0	87.0	76.0
Wood	Nitrogen	18.0	206.0	301.0
	Phosphorus	6.2	15.3	62.2
	Potassium	37.0	579.0	305.0
	Calcium, magnesium	34.0	344.0	378.0
Roots	Nitrogen	76.0	152.0	146.0
	Phosphorus	4.9	9.1	34.0
	Potassium	65.0	100.0	200.0
	Calcium, magnesium	42.0	127.0	266.0
Litter	Nitrogen	15.0	101.0	11.0
	Phosphorus	0.4	13.2	4.1
	Potassium	4.0	81.0	16.0
	Calcium, magnesium	21.0	110.0	102.0
Total	Nitrogen	**189.0**	**579.0**	**701.0**
	Phosphorus	**22.2**	**44.2**	**108.0**
	Potassium	**186.0**	**839.0**	**601.0**
	Calcium, magnesium	**160.0**	**668.0**	**822.0**

Source: Bartholomew and others 1953.

35 years. Organic matter decomposed more slowly in cleared areas than in areas covered by vegetation.

Nitrogen, probably more than any other element studied, reflects the benefits of fallowing. Inputs of N are age dependent and are never higher in secondary than in primary forests (Ewel and Conde 1978). Phosphorus in a secondary forest dropped to one-half the former level in 5 weeks and to one-fourth in 6 months. Returns of P were closely related to litter production and probably reached a peak at about 20 years. Potassium declined 5 percent in 3 weeks or less and 10 percent in 6 weeks. Ensuing losses were slower. Subsequent K levels did not correlate well with forest age nor did those of Ca and Mg, both of which were relatively stable.

Where long fallows cannot be allowed, it is generally agreed that some fertilizer, especially N, P, and K, will be necessary (Kanehiro 1978).

The difficulty of procuring fertilizers in many tropical areas has led to the use of leguminous plants to fix N. Nitrogen in the atmosphere is stable and inert and cannot be used directly. Fixation involves splitting dinitrogen into two N atoms that react with hydrogen (H) to form first ammonia and then a range of compounds (Halliday 1981). Rhizobia bacteria penetrate the roots of some legumes and other plants and give rise to highly specialized organs referred to as root nodules, which are capable of fixing N. Some tropical legumes associate with only a few bacteria, others with many. They may fix up to 100 kilograms per hectare per year of N; *Leucaena* has the highest rate of N fixation, up to 350 kg/ha/yr.

Although some legumes can *in some circumstances* contribute N to the soil (Halliday 1981), many cannot (Kellogg 1963). Of 68 native and exotic leguminous species studied in Peninsular Malaysia and Singapore, 37 (more than half) did not have root nodules (Lim 1977). For the

Caesalpinioideae, only 4 of 27 had nodules; for Mimosoideae, only 5 of 13; and for Papilionoideae, 22 of 27. An absence of nodules in a natural habitat, however, does not prove a lack of nodulating capability. But there is no convincing evidence that even nodulated legumes excrete significant amounts of N from their roots or nodules. A crop fixing 100 kg of N per year excretes only about 0.5 kg to the soil (Halliday 1981). Even on poor soils, only a part of the N accumulated by legumes comes from biological fixation. The main N benefit to associated plants is considered to be indirect, through the loss and decay of shoot, root, and nodule tissue. But even then, 5 t of green matter add only 40 kg/ha of N to the soil, of which only about half would mineralize to the benefit of the other vegetation.

These findings contradict many widely made claims about the capabilities of N-fixing plants. Nevertheless, such plants clearly have a place on poor soils where other N is limiting; and, in association with other plants, those that fix N presumably compete less for N than do other species.

Ameliorating Shifting-Cultivation Effects

Shifting cultivation has been so widely criticized, particularly from distant sources, that many have concluded it should be eliminated. Under some conditions, shifting cultivation undeniably creates many serious problems. However, elimination of the practice is, in most of the Tropics, neither feasible nor necessarily desirable. Rather, the practice of shifting cultivation must be adapted to the productive capacity of the environment. This calls for an understanding of both the human needs involved and the techniques that might alleviate the problems.

Because of the need to support growing populations in the Tropics, Gourou (1956) believed forest production should be relegated to slopes and plateaus. Concentrating agriculture on the lowest, richest, and wettest areas would increase output per hectare of land, output per hour of labor, and the total mass of food produced. This trend, however, would not necessarily mean abandoning shifting cultivation, because in the absence of manure, it yields more per day of work than paddy rice.

In contrast, Watters (1968a) observed that increases in production per unit of work seldom result in corresponding increases in investment in further production. Rather, such increases result in more leisure. Nevertheless, he recommended solving the problems of shifting cultivation by increasing output per unit area in densely populated places and per hour of work in sparsely settled areas (Watters 1971). He further concluded that while many technical problems remain, most are relatively simple to solve. The real difficulty lies in implementing the solutions, that is, inducing rural people to accept them. Development should be not so much *for* the people as *by* the people. Governments must recognize that what is ultimately involved is the conservation of people; their very lives and cultures are at stake (Watters 1974). These historic and rightful owners of the land have every right to participate in the decision making that will affect their future lives and the future use of the forest. Unfortunately, their needs and desires are not often considered. For example, policymakers in North Borneo recommended controlling shifting cultivation by limiting population density to 10 families (57 people) per 4 km^2 (Lee 1961). Such proposals suggest a wide gulf between decision making and those affected by decisions.

Shifting cultivators are wary of attempts to change their practices. Thus, in what is now Malaysia, although technicians agreed that the only real "remedy" for shifting cultivation was more permanent methods of husbandry that involved cooperative production and that permitted fencing of animals, the cultivators did not accept the change until it could be proved to their benefit (Arnot and Smith 1937).

Among the Bantu in what was formerly Zaire, the value of shifting cultivation was seen, partly, to be its guarantee of economic stability (Tondeur 1955). The system operates on family labor, providing the families with food and protecting them from the economic troubles caused by fluctuations in the produce and labor markets. Any more elaborate system of agriculture could be much more vulnerable.

It is commonly said that the prospect for protecting and managing forests in the Tropics depends on intensifying farming and stock-raising elsewhere, thus relieving forests of the pressures of extensive farming (Fontaine 1976). This approach undoubtedly has merit, but intensive farming will generally not employ all those previously dedicated to extensive farming. Also, because intensive farming requires more specialization and skills, the people it does employ may not be the shifting cultivators.

Replacing primitive agricultural systems with more intensive techniques must be examined in the light of economics. Shifting cultivators start with nothing, and changing their methods could mean an enormous investment in land improvement, irrigation, drainage, implements, sheds, roadways, machines, vehicles, cattle and draft animals, and pest control. Because native agriculture cannot bear even a slight increase in costs, intensification would be advisable only if the net crop return were clearly greater as a result. The economy not only must be capable of absorbing the investment, but the cultivator, who has no capital, must have a source of credit (Tondeur 1955).

The scientific principles on which agricultural practice is based may be universal, but individual practices must be tested locally (Greenland 1975). It cannot be assumed that new methods of agriculture developed by the industrial countries are unconditionally superior to local methods (Egger 1981). Industrial and developing countries have different goals and different resources. In the Tropics, emphasis has been on subsistence rather than production for the market, on security and stability rather than maximum yield, and on great diversity in husbandry rather than mechanized and chemical aids. One approach to changing that emphasis might be to adopt advanced methods in use in neighboring regions. Another might be to adopt carefully selected modern methods capable of increasing the efficiency of traditional systems without endangering their basic structure (Egger 1981). The best strategy would be to balance population factors with the technological potential of shifting cultivation rather than eliminating or rigidly controlling the practice (Rebugio 1976).

Promoting changes in shifting agriculture requires rare combinations of tact and expertise. Raghavan (1960a) concluded that in India, those who attempt it should be not only scientists but also practical sociologists with missionary zeal. Even for those with experience in practical economics and organization, the task requires time, patience, and persistence (Jurion and Henry 1967). Conventional schools are not providing the type of education needed to change the practice of shifting agriculture (Raghavan 1960b). To help meld the rural population with the forest environment, forestry curricula must stress the importance of forests for a host of allied farming opportunities, such as poultry raising, pasture management, production of dairy products, woodcarving, basketmaking, and carpentry.

In Thailand, stabilization of shifting cultivators has been attempted through broad rural development (Samapuddhi 1974). The forest is divided into large tracts for each village, as much as 96,000 ha for 100 families. The community leaders are provided with educational material that emphasizes ways the organized village may help the people. Village improvements (water, electricity, and education) may be supplied. Forestry tasks are a source of part-time employment. A taungya system is organized to produce significant income to the community.

Improved Local Planning. Agricultural settlement schemes commonly have goals that assume the cessation of nomadic agriculture. As an example, in what was formerly Zaire, two systems were applied (Coene 1956). In one, families were initially assigned a tract within which they worked in a small area at one time. In another, farmers were assigned strips of land in sequence. In both systems, the land remained communal property. The first alternative resulted in better care of the soil because the farmer always worked the same land.

Where pure subsistence farming has given way to cash-crop farming, any previously harmonious relation with the environment has usually become strained. It is generally neither desirable nor possible to re-create the old relations (Watters 1960). The task is rather to establish new relations that do not violate the "design of nature" and yet are consistent with modern needs.

Where tree crops, such as rubber, oil palm, nuts, and fruits, are appropriate on rainy slopes and marginal soils, both the initial investment required and the delay in returns make the proposition unattractive for private landowners (Santiago 1961). Public participation may be needed in the form of at least temporary, direct administration or continuing governmental incentives.

Government participation calls for recognizing a dual role in forest production. Assistance to rural communities and particularly to farmers who can benefit from better practices on land requiring special conservation measures may appear to be the primary public goal. However, the government must also stimulate production of enough industrial timber to satisfy national requirements. To ensure both objectives, public planning must identify permanent forests as well as those forests whose primary function is as fallows to sustain the production of other crops.

An example of local planning is seen in Madras, India (Venkataramany 1960c). The community consisted of 100 families (500 people) and 400 cattle. Annual domestic fuelwood consumption was 1/6 t per capita, or a total of 83 t. On a 30-year rotation, this called for about 100 ha of forest. In addition, the cattle needed 80 ha of pasture, for a combined total of 180 ha. This is equivalent to 0.36 ha per person, more than triple the land generally available at that time throughout India. Recommendations to remedy this deficiency included reducing the number of cattle and shifting from manure to chemical fertilizers, dedicating fallows to intensive production of fuelwood and fodder, and dedicating part of the nearby forest reserves to fuel and fodder.

In a 1960's survey, tropical land managers agreed that combined tree and food crops could prosper on land not capable of supporting continuous cultivation (King 1968a). Fallows of either secondary forest or planted trees were seen as a key to success. As a result, village projects were proposed in which land use would be closely controlled and production supplemented by sustained taungya crops within reserved forest land. The attraction was the advantages over alternative systems such as frequent moving, expensive monocultures, and tree planting with paid crews (King 1968a).

Land Use. A wide array of techniques, some proven but largely unused, offers hope for improving and stabilizing land use where shifting cultivation precludes sustained productivity. Some of the current practices are no more pleasing to the cultivators than they are protective. It was pointed out in India (Sagreiya 1946a) that peasants use cow dung for fuel only as a last resort. The recommended alternative was the establishment of "fuel cum fodder" plantations, using rapidly growing, hardy tree species, such as *Acacia* spp., *Dalbergia sissoo, Melia* spp., *Prosopis* spp., and *Senna siamea,* thinned to 5 by 5 after 2 to 3 years and interplanted with fodder grasses.

The corridor system developed in what was formerly Zaire was designed to stabilize the boundaries between each cultivator (Kellogg 1963). The entire area was managed on a rotation based on the number of years cropped plus the number of years of fallow. Appropriate amounts of land were planted and fallowed each year. Supplemental permanent crops were planted nearby. Wood ashes, manures, and composts were used. Tall crops not requiring clean cultivation, such as cassava and bananas, were used during the last year before fallowing to give the trees a better start. Each cultivator worked strips 100 m wide along the contour, and a protected strip was left in between (Nath 1968).

"Alley cropping" is a practice developed by agriculturists in which food crops are grown in alleys between hedgerows of trees or shrubs. Food cropping may be only periodic, with the hedgerows pruned only during food-cropping periods. Hedgerow species must be easy to establish, grow rapidly, develop deep roots, produce heavy foliage, and coppice well. Hedgerows are spaced 2 to 4 m apart, with trees or shrubs spaced 25 to 100 cm apart in the rows. During cropping periods, the trees are pruned every 5 to 6 weeks to a height of 2.5 to 7.5 m. Five prunings of *Leucaena* per year on mildly acid soils yielded 160 kg of P, 100 kg of K, 40 kg of Ca, and 15 kg of Mg per hectare. Over 4 years, the application of these prunings to maize tripled the yields.

Changes in the shifting cultivation system considered in India include longer fallows (taungya) with tree crops, such as *Alnus, Gmelina, Leucaena,* or *Sesbania,* and shifting to better land for continuous cultivation with fertilizer, crop rotation, or bench terracing where necessary (Nath 1968).

Where shifting cultivation is wearing out the soil, intensifying treatment has been widely recommended. This includes fertilizer use, plowing as soon as stumps decay, more efficient use of forage and tree crops, and the use of fungicides and pesticides (Watters 1974). These, however, are departures from subsistence farming and the dual economy. Such intensification has not generally helped the peasant farmers as much as it has enslaved them to one or a few crops at the expense of their subsistence needs. Unless the government can compensate with community-development benefits, small farmers on marginal land generally lose out to competition from production on better land.

Whatever the apparent obstacles to betterment of shifting cultivation, the natural primary productivity of the humid Tropics remains among the highest in the world (Lieth 1976). Although this productivity may be reduced substantially by conversion from natural ecosystems to cultivated crops and although fertilizers may be needed for sustained production, there remain many areas of great promise and a vast number of untried native crop species that should prove widely adaptable.

In both natural and agricultural systems, high biological activity is almost always achieved with the aid of energy subsidies from outside the system (Odum 1972). However, attempting to force too much productivity from the land could lead to pollution from heavy chemical use, unstable one-crop systems, and increased vulnerability of plants to disease if their protective mechanisms are genetically suppressed in favor of yield. Young ecosystems are high in production, growth rate, and quantity of yield. Mature ecosystems have high protective values, stability, and quality. Some of these traits from both systems need to be conserved.

For any agricultural system to be stable, the physical condition of the soil must remain suitable. Maintaining arability involves control of erosion, acidity, and toxicity. The soil must be protected against the direct force of falling rain; therefore, a continuous or intermittent cover crop is required. The nutrients removed by cropping must be replenished, and there must be no weed or pest buildup (Greenland 1975). Under shifting cultivation, these conditions can be met only with a fallow that may be 1 to 20 times as long as the cropping period. Reducing the fallow and lengthening the period of cultivation induce site deterioration.

A cultivation system potentially beneficial to the small farmer could include zero tillage, mulching, use of mixed crops of high-yielding varieties that are pest and disease resistant, application of P and possibly other fertilizers, addition of legumes, and control of acidity by ash and mulch. To be practical, alternatives to shifting agriculture should require minimal capital investment. This combination should reduce or eliminate the fallow and increase productivity at least fourfold (Greenland 1975). However, the possibility always exists that intensive cropping may exacerbate soil degradation. Therefore, organic matter levels and structure should be monitored to foretell any need for corrective measures (Young 1976).

Traditional farming can often be improved by adopting methods used in neighboring regions (Egger 1981). Examples of such methods include the use of tree crops, cover crops, weed management, mixtures, and staggered rotations. These practices tend to lead from subsistence agriculture toward marketable crops, something best done gradually.

Improved Fallows. A great potential for increasing agricultural production lies in the intensification of fallow systems (Greenland 1974a). This could lead to a shorter fallow or a longer cultivation period. Fertilizing during cropping will always be necessary and should significantly stimulate production. Ammonium fertilizers tend to acidify, eventually calling for costly liming; fallowing followed by burning adds nutrients largely in the form of carbonates and, thus, economically counteracts acidification (Greenland 1974b). Nevertheless, protection from burning may be critical, otherwise the fallows may not accumulate enough nutrients to support subsequent crops. This problem, which is widespread, arose years ago in what was formerly Zaire and led to the practice of leaving strips of native forest throughout agricultural regions as fuelbreaks (Collin 1952b). Protecting the fallow from fire by itself can greatly increase its effectiveness.

Woody fallows on savannas store far more K, Ca, and Mg than do grass fallows (Nye 1958). Even pigeon peas are greatly superior to native grasslands as fallows.

Different tree species may be equally valuable as fallows, yet vary widely in usefulness for other purposes. *Acioa barteri,* a shrubby tree of the Chrysobalanaceae family native to west Africa, was tested because it coppices well (Nye and Hutton 1957). After 4 years, it had stored less N, P, and K than the natural regrowth but had produced nearly double the aboveground phytomass (table 8–7). Thus, in the long run, it may be as beneficial as the natural fallow.

Another alternative for fallows is rapidly growing tree species (Young 1976). Promptly introduced at the end of the cropping period, they may be as effective as natural fallows in restoring soil humus. A 6-year-old fallow of

Table 8–7.—Four-year nutrient storage of an *Acioa barteri* fallow in west Africa (kg/ha)

Nutrient	4-yr. storage in stems, leaves, and litter	
	Natural fallow	*A. barteri* fallow
Total dry matter	24,800	46,700
Nitrogen	382	310
Phosphorus	52	27
Potassium	367	174
Calcium	168	230
Magnesium	104	147

Source: Nye and Halton 1957.

such trees on a 25-percent slope in Mindanao, Philippines, kept sediment and organic matter losses to only 45 percent above those of a primary forest and rainfall runoff to only 2 percent above that of a primary forest (table 8–8; Kellman 1969). Short-cropping and skillful utilization of fast-growing softwood fallows might keep the rate of site deterioration below what is common to traditional, periodic logging of forests and at the same time provide optimum fallow benefit to the cultivation cycle (Kellman 1969).

Improved Cropping Practices. There seems to be a fund of local knowledge in the Tropics suggesting that increasing the use of food crops could prolong the cropping period. For prolonged cropping, two cropping sequences were recommended for what was formerly Zaire, considering the compatibilities of different crops (Coene 1956):

Heavy forest areas:

1st year:	bananas and rice, then cassava after rice harvest
2nd year:	bananas with cassava, harvest beginning near the end of the year
3rd year:	bananas and cassava harvested
4th year:	maize, pumpkins, and beans, followed by cotton
5th year:	peanuts, followed by cotton
6th to 19th year:	bush fallow.

After bush fallow:

1st year:	rice on 20 percent of the land; maize, beans, and pumpkins, followed by cotton on the other 80 percent
2nd year:	peanuts on 100 percent of the tract, followed immediately by cotton on 50 percent; 2 months later, cassava interplanted with the cotton
3rd year:	bananas and cassava not weeded
4th and 5th years:	bananas and cassava harvested
5th to 17th years:	bush fallow.

The balance between subsistence and cash crops is critical but varies widely from place to place. As communication and transportation improve, the shift toward market crops and a money economy for rural populations is increasing. This trend accentuates a need for recognizing and developing superior varieties of the crop plants. Of course, many improved varieties depend on fertilizers for highest yields. However, often overlooked but gaining recognition are those crops that are most efficient when fertilizers are used sparingly.

A shift to more permanent crops, such as forage and trees, has been recommended as one way to increase the stability of shifting cultivators. Certain tree crops, carefully husbanded, have sustained their productivity for decades.

Table 8–8.—*Soil effects of cropping in Mindanao, Philippines*

Index	Primary forest	Cleared, abandoned for 7 yr.	Cleared, in abaca for 12 yr., abandoned for 7 yr.
Nitrogen (percent)	1.1	0.6	0.4
Phosphorus (ppm P_2O_5)		8.0	24.0
Potassium (meq%)[a]	0.4	0.4	0.4
Calcium (meq%)	2.6	3.3	3.9
Magnesium (meq%)	1.0	0.8	1.0
Carbon (percent)	8.5	9.0	4.0
Sodium (meq%)	0.1	0.04	0.1
pH	4.7	5.2	5.5
Cation exchange capacity	76.7	46.5	43.3

Source: Kellman 1969.
[a]meq% = milliquivalents per 100 g.

Crop improvement might well include better use of legumes. Although legumes differ widely in their ability to fix N (Halliday 1981), this capacity can be improved significantly by inoculating with selected strains of Rhizobia. The result can be not only less drain on soil N but better use of the N. Nitrogen-fixing legumes take up less soil N than do nonlegumes. If the nonleguminous species outlive the legumes, they benefit by the release of N from the legume decomposition. In addition, 60 to 90 percent of the N in leguminous grains can be harvested for human food, a contribution far more important than the benefit to neighboring crops (Halliday 1981).

Nitrogen fixation by legumes is largely a complement to N fertilizer rather than a substitute (Halliday 1981). Any suggestion of replacing N fertilization of cereal and root crops by biologically fixed N is unrealistic because these crops need much more N than could be supplied through N fixation by legumes.

The future of legume usage, however, may well be bright. Legumes are not yet widely produced because of low volume yields (Halliday 1981); cereal grains yield four times as much. Legumes, however, may yield five times as much protein as cereals, and thus, techniques that increase legume yields deserve investigation. A list of tree species appropriate for agroforestry appears in appendix L.

Fertilizer Use. The shift from subsistence farming to market crops has brought to the forefront the need to compete with farm produce from other areas where fertilizers are used. There seems little doubt that more fertilizer application will eventually prove both productive and profitable for small farmers despite currently perceived financial and balance-of-payment limitations. Use of small quantities of fertilizers and chemicals can greatly increase growth. There is no logic in foregoing fertilizers for the sake of tradition. If the fertilizers are justifiable economically and applied properly, there should be no ecological reservations against using them or other chemicals (Egger 1981).

In the Campo Cerrado of Brazil, where felling and burning have reduced the former moist evergreen forest to scrubgrass savanna, shifting cultivation cannot succeed without fertilizers, including P, Ca, sulphur (S), and minor elements (Hardy 1962a).

Government subsidies have been proposed to encourage the use of cash crops and fertilizers in tropical America as a remedy for the ills of shifting agriculture (Watters 1971). The supposition is that only through such financial assistance can the small farmer benefit fully from participation in national economies.

Intensification of small farming in the Tropics must count on the use of fertilizers, both to lengthen cropping periods and to increase yields to competitive levels (Greenland 1974b). Improved cultivars of crops (including the so-called high-yielding varieties) require more nutrients than lower yielding varieties (Young 1976). The potential nutrient deficiencies are not remedied solely by fertilizers; other good soil management practices are required. The key to providing plants with adequate N is to maintain reasonable levels of organic matter by applying fertilizers supplemented with compost.

The objective of fertilizer use should be to maximize the output-to-input ratio rather than to maximize yield alone (Liebhardt 1981). Small amounts of fertilizer may greatly increase production. On the high-base soils that cover 18 percent of the Tropics, small amounts of N, P, and micronutrients should be sufficient. On low-base soils, which cover 51 percent of the Tropics, high acidity, aluminum (Al) toxicity, and P deficiencies may have to be corrected by adding lime, P, and possibly S. Fertilizer requirements may be reduced by using crops that tolerate adverse conditions, such as upland rice, cassava, sweet potatoes, cowpeas, some grass species, and legumes (Liebhardt 1981).

Taungya Systems

Taungya systems involve using farm crops to render the land suitable for starting a forest plantation. The word, meaning literally "field on the hill" in Burmese, became "kumri" in India, where the system migrated from what is now Myanmar in 1870 (Clarke-Butler-Coke 1943, Raghavan 1960b).

In Java, the taungya system had been used to plant 40,000 ha of teak *(Tectona grandis)* by 1891 (Becking 1951). The total had risen to 190,000 ha by 1920 and to 312,000 ha by 1952 (figs. 8–2, 8–3; Wepf 1954). There were 40,000 ha of teak and mixed plantings under the taungya system in what is now Myanmar by 1962 (Hundley 1962). In 1977 alone, 132,000 ha of teak were planted in Java using the system (Atmosoedarjo and Banyard 1978). The taungya system spread throughout much of India after 1914, including the dry fuel forests planted throughout the 1920's. It reached west Africa by the late 1920's (Brookman-Amissah 1976). By 1935, the

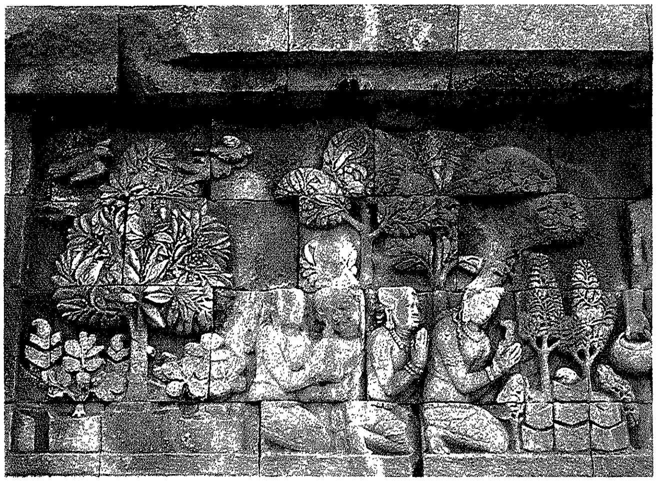


Figure 8–2.—*An indication that agroforestry may not be so new after all is depicted on the wall of the 8th-century Boburadur Temple in Java.*

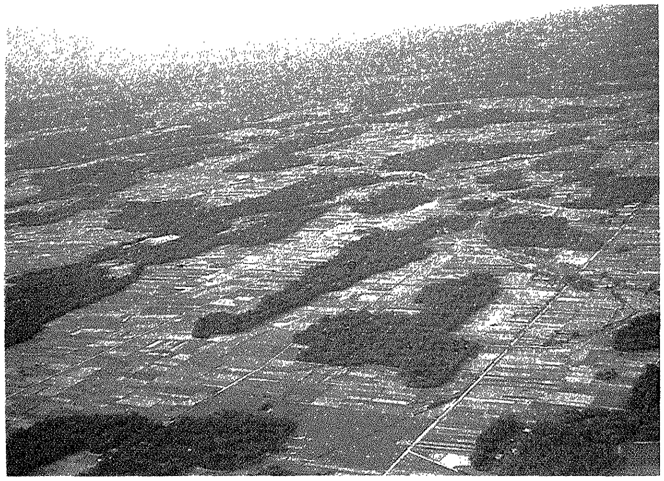


Figure 8–3.—*Rich, level land in eastern Java is heavily populated and intensively cultivated, yet trees have been maintained for centuries for vital fruits, poles, and fuel for the farming population.*

native authority of what is now Benin agreed to make available 400 ha of reserved forest each year for taungya (Clarke-Butler-Coke 1943).

To be successful, the taungya system must be applied where a need for land exists, where soils are adequate to yield reasonable food crops temporarily without excessive soil deterioration, where tree species in demand are of proven adaptability, where a willing farming population exists, and where a local staff is trained to operate the system (Clarke-Butler-Coke 1943, Raghavan 1960b, Raynor 1941).

The system was introduced into West Bengal, India, because natural regeneration had proven unsatisfactory there (Talukdar 1948). Each cultivator was given 0.4 to 0.8 ha to work. In some areas, the cultivator collected the tree seeds, sowed them, and cleaned the plantation for 2 years at no cost to the government. However, in addition, the cultivator was offered up to 2 ha of lowland for a paddy and was allowed to graze two work animals and one cow on the forest land. The cultivators were also permitted forest products for construction and might be loaned food grains until harvesting time. They were paid wages for additional forest work.

A combination of taungya with village forests and grazing has been described as successful in India (Smythies 1938b). An area of some 15,000 ha had historically been used by 86 villages living within 5 km of the forest boundary. Unlimited grazing and wood utilization had deteriorated the forest until 1947, when 5,700 ha were protected from grazing; they subsequently improved. The plan classified 6,700 ha for timber, of which 5,700 were to be established using the taungya system, and 8,700 ha were for village use, of which 6,500 ha were to be fuelwood plantations established by the taungya system.

In Java, the taungya system was used simply because of a need for food crops (Wepf 1954). Corn, peanuts, and peppers were planted (Becking 1951). Manioc and castor oil plants were considered too tall. *Leucaena* was interplanted with the food crops, producing increased litter and N. More recently, dryland rice has been raised with teak in Java, using N and P fertilizer (Atmosoedarjo and Banyard 1978). The fertilizer increased crop yields more than 50 percent and appeared to stimulate the teak as well.

By 1952, the taungya system had been tested in most of west Africa. In The Gambia, Ivory Coast, and Sierra Leone, taungya had proved successful with teak *(Tectona grandis)* and *Senna siamea* (Anon. 1952n, Piolant 1952). In what was formerly Zaire, two types of taungya were used (Collin 1952a). On government reserves, parcels of 5 ha were given to cultivators and prepared for planting by the government. The farmer raised bananas for export at an 8- by 12-m spacing while caring for trees planted by the forest department. On tribal lands, natural regeneration of timber species was allowed to come up between the crops at a wide spacing, averaging 20 m. In Nigeria, two similar systems have operated, depending on ownership; farms range from 0.5 to 2.0 ha per family (Olawoye 1975). There, the taungya system became an important source of both food and employment.

In dry areas of Africa, such as the Sudan, the taungya system has been practiced using corn for 1 year, interplanted with *Acacia arabica* (Jackson and Shawki 1950). Corn, sorghum, and short grasses have also been maintained under *Eucalyptus microtheca* in the Sudan for 3 years without apparent detriment to tree growth. Mean tree height after three growing seasons was more than 3 m (Khan 1966a). Where subsurface water is not too deep, *Azadirachta indica* (neem) has been interspersed successfully with such crops as millet and beans. When trees are planted at 2.4 by 2.4 m, the canopy closes in 3 years (Mackay 1952). In Pakistan, interplanting of *D. sissoo* with cotton proved inexpensive for the government and produced good cotton after 13 months (Khan 1957).

Experience with the taungya system in east Africa (the *shamba* system) showed that cultivators get less harvest from second-rotation cropping than from the primary forest areas cropped the first time (Anon. 1968d). However, repetition of the practice was considered necessary even if nutrients eventually had to be added.

In Trinidad, where the taungya system was long practiced with teak, annual leases have been given for cultivation. The normal practice was to crop areas for 1 to 3 years before abandonment (fig. 8–4; Goodlet 1953).

Figure 8–4.—*A successful result of taungya planting of teak* (Tectona grandis) *in Trinidad; the agricultural cropping has ended and the teak trees have taken over.*

The taungya system has been used successfully elsewhere in tropical America. In what is now Belize, corn has been raised in young mahogany *(Swietenia macrophylla)* plantings (Flinta 1960). In southern Brazil, rice and beans have been cropped for 2 years in *Cunninghamia lanceolata* plantations. In Sao Paulo, rice and cotton have been raised with eucalypts. A test of a *Eucalyptus* taungya system with corn in Brazil showed the significance of spacing (table 8–9; Gurgel Filho 1962). Three rows of corn between the eucalypts produced the most value per unit of land, but because the soils were poor, one row of corn was considered preferable.

In 1968, a worldwide questionnaire about the taungya system (King 1968a) reported that more than 60 percent of the forest departments in tropical countries had planting programs designed to assist farmers. These programs listed 79 tree species and 39 agricultural crops as being used. Crops not generally used included bananas, corn, rice, sugarcane, tobacco, and yams, usually because these produced excessive shade, had too long a cropping period, or tended to climb on the trees. Yields reportedly declined after the first year because of crown closure.

The taungya system has been spectacularly successful as a means of establishing tree plantations under a number of conditions. In the dry zone in what is now Myanmar, with 45 to 110 cm of rainfall annually, village forests were established using 2- to 3-year taungya systems to provide fuelwood from *Acacia* spp., *Albizia lebbek, Senna siamea, D. sissoo, M. azedarach, Prosopis* spp., and eucalypts (Aung Din 1954). The taungya system has also been used successfully to raise four species of pulpwood. For their work, cultivators receive incentives such as credit and grazing privileges. In Brazil, some of the Jari pulpwood plantations of *Gmelina* being established used the taungya system.

This system is not without problems. In some areas, it is difficult to exclude cultivators from a tract once they are working it (Civette 1953). In India, cultivators have been criticized for neglecting the trees and then claiming the site for permanent agriculture (Banerji 1960). At the other extreme, where there is plenty of land, there is little interest in the practice (Anon. 1952h, Cristovao Henriques 1952).

Three factors are seen as increasing the need for the taungya system (Wyatt-Smith 1979): (1) the population explosion in the developing world, (2) recognition that industrial development is not a panacea, and (3) the

Table 8–9.—Yields of *Eucalyptus* and corn from a taungya system in Brazil

Spacing	Corn (kg/ha)	Mean tree size at 18 months D.b.h. (cm)	Mean tree size at 18 months Total height (m)
E. alba alone 1.5 by 3.0 m	0	5.3	7.0
E. alba separated by 1 row of corn 1.0 by 1.5 m	4,600	4.9	6.5
E. alba separated by 2 rows of corn at 1.0 by 1.0 m	5,400	4.0	5.9
E. alba separated by 3 rows of corn at 1.0 by 1.5 m	6,700	3.2	5.1

Source: Gurgel Filho 1962.

need to arrest the undesirable population drift to urban centers by greatly improving the quality of rural life.

The Development of Agroforestry

Agroforestry has suffered from many conflicting definitions. The term appears to have arisen from "agrisilviculture" (Townshend 1952). Subsequently, King (1979a) went on to define "agrosilvicultural systems" as cultivated crops plus trees, "silvopastoral systems" as fodder crops with trees, and "agrosilvipastoral systems" as all three in three-tiered combinations.

Wyatt-Smith (1979) considers "agroforestry" to be an umbrella term that includes agrisilviculture as well as other systems. Richards (1982) used narrower limits than some others by confining agroforestry to practices in which trees are vertically integrated with other crops, that is, one above the other; systems with horizontal integration, such as windbreaks, he termed "farm forestry." This distinction appears to have merit.

Classification of agroforestry systems and accumulated experience have been compiled in an FAO regional office publication (Anon. 1984e), "Sistemas agroforestales en America Latina y el Caribe." The state-of-the-art information about using and producing multipurpose trees in Asia, with many practices of universal applicability, was laid out in the proceedings of a 1984 planning workshop at Kandy, Sri Lanka (Burley and Stewart 1985).

Conceptual Variables. Much of what is being said about agroforestry is merely promotional. True, there are some cropping techniques for rubber, cocoa, and lowland mixed crops (in Indonesia) that for decades have embodied permanence, continuous cropping, and trees as components. But the technology has not yet been fully developed for annual crops on the much larger areas of wornout, marginal, tropical lands.

Recent enthusiasm for agroforestry does not mean that foresters in tropical countries have heretofore ignored the welfare of rural people in forested areas (Wyatt-Smith 1979). They have been preoccupied with creating large, compact, forest estates with sustained management for the benefit of the economy of entire countries and for providing foreign exchange.

With the recent great need to justify reservation of good lands, forestry is being assigned lands that are submarginal for agriculture. Much is also poor for timber production. At the same time, demand for both timber and fuel is increasing. The only solution is to increase the productive capacity per unit of area by better protection and by reducing the production period for new crops through plantations (Wyatt-Smith 1979). Forest departments and the forestry profession have been profoundly affected by these trends.

Typically, forestry planning at a national scale has involved setting goals in terms of future requirements of what have been considered "major" wood products, such as lumber, plywood, particleboard, and pulp and paper (Mackney 1968). Other roundwood products and fuelwood have been considered secondary.

Agroforestry is seen by some as a system for breaking down the false dichotomy between agriculture and forestry (Adeyoju 1980). The broader values of rural development transcend those of conventional forest production and should be incorporated into the training of foresters.

A characteristic of agroforestry that distinguishes it from other forestry is its multidisciplinary complexity. This complexity does not arise chiefly from technical problems, such as those of conventional tree plantations, but rather from the fact that agroforestry's success or failure is largely out of the hands of foresters. Agroforestry is generally practiced on agricultural lands where agricultural crops eclipse tree crops in productivity and importance, and by farmers whose main goal is to produce farm rather than forest crops. Therefore, the forester must deal effectively as a minority partner with agronomists and the farming community. To do so, he or she must learn more about the science and practice of agriculture and the traditions and motivations of farmers. In the final analysis, the future of agroforestry depends more on acceptance and effective efforts by agronomists and farmers than on the convictions of foresters.

All these facets of agroforestry point to one important preliminary and continuing requirement: careful observation. Agroforestry is the work of rural communities as a whole, not just professionals. Its proponents must be involved with and accepted by the community. They must come to know the motivations and aspirations of the people in the community.

Trees, if already in use as a part of local agriculture, may offer a significant starting point. Current practices for producing food crops or forage must be considered, and the role of soils in limiting farm and possibly tree crops must be understood. Current seasonal patterns of mixed cropping must also be explored, as well as the balance between direct consumption and cash crops. Local interrelations between subsistence and commercial agriculture may well parallel the interrelations between agroforestry and commercial timber production.

Whether or not trees are actually a component of local agriculture, current farm practices are probably deeply ingrained, usually for valid reasons. The foremost of these may be security, assurance that a familiar level of yield is certain for farmers who apply timeworn practices. Where livelihood is precarious, security is more attractive than promises of something new. The significance is that new practices should be merged with traditional ones, so they do not merely substitute something unknown for what is known. Gaining acceptance of agroforestry techniques thus must be a gradual process.

Agroforestry systems may be categorized on the basis of their functions and the nature and arrangement of their components (Nair, P.K.R. 1985). Their protective functions include soil conservation, moisture conservation, soil improvement, and shade and windbreak maintenance. They may produce food, fodder, wood, or other products (fig. 8–5). Their components may be crops and trees; pasture and trees; crops, pasture, and trees; or other combinations including aquaculture and apiculture with trees.

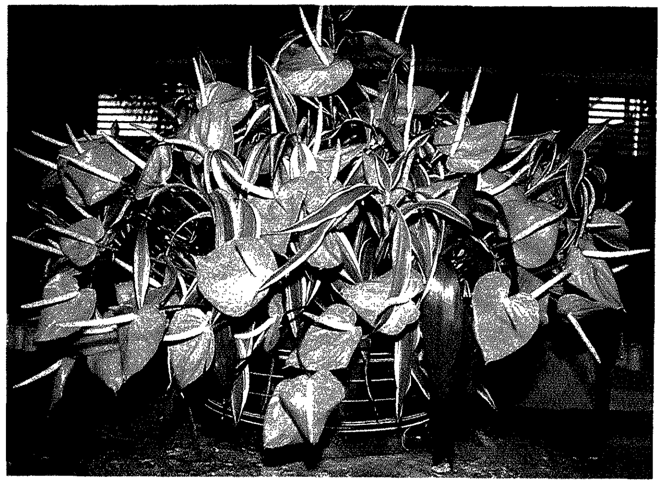


Figure 8–5.—*An important secondary crop of anthuriums marketed for export is produced beneath the wet lower montane forests of Dominica.*

The principal agroforestry systems in tropical America have been listed as follows (Anon. 1984c):

1. Sequential systems
   A. Shifting agriculture
   B. Taungya system

2. Simultaneous associated systems
   A. Trees/cultivated crops
      a. Coffee, cocoa, tea
      b. Trees over annual crops
      c. Trees supporting vine crops
      d. Orchards over kitchen gardens
      e. Mixed perennial crops
   B. Trees and forage crops
      a. Trees over pasture
      b. Grazed natural forests
      c. Forage trees

3. Adjacent tree systems
   A. Shelterbelts
   B. Live fences

Details of these systems in use in the region are presented in "Sistemas Agroforestales" (Anon. 1984e).

Possibilities Versus Limitations. Current farming practices in the Tropics vary, sometimes inexplicably, from place to place. This variation may be due to a lack of communication among farmers, but it is also often due to real differences in local environments, such as climate, soils, or markets. Thus, it cannot simply be assumed that differences in practices are based on ignorance and can, therefore, be eliminated merely by informing farmers of what seem to be better practices elsewhere. First, foresters must make sure that the differences are not a result of many lengthy trials and errors that have led to practices well adapted to each area. If so, any new practices must, at least for a time, coexist with, rather than replace, traditional practices.

Complex, traditional, farm-crop mixtures in tropical areas seem a tempting target for simplification, but the temptation should be resisted, at least until such cropping systems are well understood. Mixtures generally include plants found compatible through long experience. Their growth cycles or harvest times may be asynchronous and, thus, complementary. Their arrangement and representation in the cultivation scheme may be optimum. Their respective canopy heights and light-interception capabilities may minimize competition. Their individual water demands may dovetail temporally. They may also be complementary in their demand for harvesting labor. They may provide a needed balance between subsistence and marketable crops. Their foods may provide diversity needed for security or nutritive balance. The light weight of the crops may make them marketable in areas where trees are not. Any drastic change may thus upset some or all of these complementary features that may be vital to (or, at any rate, not initially negotiable by) the farmers.

As agroforestry applies to tree products and their benefits, it must be seen in light of the needs of an entire nation and usually as a potential supplement to concentrated timber production elsewhere that is unrelated to agriculture. The latter will normally be the primary source of industrial wood for urban populations or for export because centralized control and economies of scale are required for the sustained flow of forest products to support major processing industries and to compete in free markets. Agroforestry is by nature a widely dispersed activity on relatively small areas under individual ownerships. Thus, it is ill adapted to meeting the standards of uniformity in quality and flow required for major timber markets on a national scale. Rather, its potential is for supplying the wood needs of farming communities and possibly some specialty woods for crafts, roundwood, and fuel. Thus, agroforestry must focus first on supplying the needs of the rural communities.

The efficacy of secondary-forest succession in accumulating phytomass suggests that forest culture simulates this process (Holdridge 1959). Studies in Costa Rica showed that subsistence gardens around homes simulate the forest in being diverse and relatively permanent. Mixed-crop agriculture on a larger scale, believed capable of maintaining adequate nutrient recycling without fertilizers, may include an overstory of *Cordia* and pejibaye palm *(Guilielma gasipaes)* with an understory of cacao and a groundcover. During establishment, rice, corn, manioc, and bananas could be used. A complete cycle would be composed of 30 plots of 0.1 ha each, 1 established each year, plus 0.6 ha for a house site, garden, fruit trees, and pasture (Holdridge 1959).

A system in Brazil also focuses on nutrient retention through simulation of natural succession (Uhl and Murphy 1981). The system begins with forbs, grasses, successional woody species, lianas, and even forest trees, using only species of economic value. Practices that assist establishment may include dry mulching, introducing legumes (especially bred crops), and applying lime. The degree to which such a system can survive intensive cropping remains to be seen.

Burley (1980b) concluded that genetic tree improvement for agroforestry must begin now and that the effort must be international in scope. However, the diversity of tree uses in agroforestry is seen by geneticists as complicating attempts to improve tree quality, a process recognized as differing in four major ways from genetic improvement for industrial timber plantations. These are as follows:

- Genetic testing for agroforestry purposes must encompass a range of companion agricultural crops and managerial treatments.
- Character weighing must reflect the wide variety of tree uses.
- Genetic work will normally not be done by the growers; therefore, an extension effort will be required to put results to use.
- Sampling and testing will be complicated by the development of "races" that may already have occurred with many species.

Enthusiasm for what agroforestry appears to promise must not lead to blind efforts to repeat past attempts to develop agriculture everywhere (Sholto Douglas 1968). Many forest areas remain within agricultural regions where tree production alone, serving the rural population, is more appropriate than interplantings of trees and other crops. Examples are wastelands along roadways, canals, parks, and village woodlots (Randhawa 1946). Moreover, even where interplanting seems appropriate because agriculture has otherwise failed, variations in productivity will persist. Therefore, the most favorable areas should receive the most attention, those least favorable possibly being left in fallow or forest until the best areas have been well developed. In other words, there is still a need for separate management of most land that is best suited to either agriculture or forestry, rather than to assume a need everywhere to mix the two (Holdridge 1959).

Adding trees to farm crops unmistakably improves the stability of agriculture in tropical regions. However, the permanence of the combination as a source of adequate subsistence or cash crops without added nutrients remains to be proved. But even if the system does not supply all the nutrients needed, it may still approach self-sufficiency, so only minimum fertilizing would be required.

A review of the literature reveals that agroforestry's possibilities and limitations are really little known because of a lack of firm data (Alvim 1981). The scientific community still considers agroforestry not to be sufficiently documented for immediate and widespread technical application (Gleissman 1981a). This view is due in part to a lack of general acceptance that yields should be assessed on a long-term, diversified basis.

Further application of agroforestry in the Tropics apparently will call for much more than technical acceptability. Even in a society as highly educated and developed as Denmark's, the development of small, privately owned woodlots has required public subsidies (Frolund 1962). Apparently, such incentives will be necessary long into the future.

Prospective Benefits of Agroforestry. Successful agroforestry promises both social and economic benefits. In India (Sangal 1981), the prospect was seen for producing fuel and small timbers outside the closed forest areas, thus reducing rural population pressure on forests needed for industrial wood. Other potential benefits include reduced shifting cultivation, productive agriculture on land not presently tilled, and more employment.

A shift toward perennial crops in agroforestry may itself increase potential yields. For example, a 12-year planting of oil palms can produce 4 t of oil per hectare per year, a yield that cannot be achieved by any annual crop over any long period (Best 1962). Also, the deep-rooted trees serve as nutrient pumps whose litter benefits interplanted, shallow-rooted crops. *Erythrina glauca* roots in Suriname may go three times as deep as the roots of coffee or cacao (Stahel 1949).

Intercropping is beneficial for reasons other than mere crop diversification. Studies in what was formerly Zaire (Sparnaay 1957) indicated that intercropping enhances early development of oil palms. Nor is multiple cropping necessarily harmful to the shaded crop. In Bangladesh, 50 percent shade is considered ideal for tea (Skoupy and Vaclav 1976). In the Solomon Islands, the benefits of tree shade to crops are accepted as counterbalancing the space occupied and the susceptibility of trees to greater storm damage (Yen 1974). A test in what is now Malaysia over a period of 63 weeks showed yields of the grass *Axonopus compressus* of 21.3 t/ha/yr without shade versus 25.4 beneath *Samanea saman* (Jagoe 1949). Shaded sites produced grass with 9.6 to 11.7 percent protein, compared with 9.1 to 10.4 percent protein without shade.

Where fertilizer is not used, coffee yields are typically higher with shade than without it (Ostendorf 1962). The contention that the presence of shade trees always reduces soil moisture is questionable. In arid west Africa, several benefits of *Acacia albida* shading over crops have been noted, including increased relative humidity, reduction in temperature extremes, increased moisture absorption during rains, and better conservation of soil moisture thereafter (Dancette and Poulain 1969).

The benefits of tree litter to associated crops have been shown under many conditions. In west Africa, oil palm production was increased 8 percent by underplanting with coffee, the benefit being attributed to the litter (Sparnaay 1957). Within oil palm plantations, the soil is more productive close to rather than far from the palms (Kang and Moorman 1977). As distance from the palms increased from 0.25 to 4.00 m, the first 30 cm of soil declined in moisture content and increased in bulk density. Organic C, total N, and extractable P, K, Ca, and Mg all decreased at least 50 percent. Not even application of

NPK fertilizer masked the effect. After the palms were removed, a subsequent maize crop still showed significant benefits from the palms as determined by leaf analysis for N, P, K, Ca, Mg, and manganese (Mn).

Leguminous litter may be significantly richer in nutrients than nonleguminous litter, even when leaffall is natural rather than the result of pruning. In what is now Malaysia, leguminous shade produced grass with 13.8 to 14.8 percent protein, compared with 9.6 to 11.7 percent for nonleguminous shade (Jagoe 1949). Shade for tea in Bangladesh is generally provided by leguminous *Albizia* spp., *Gliricidia sepium,* and *Senna siamea* (Skoupy and Vaclav 1976); shade for coffee in tropical America, too, is typically provided by leguminous species.

Food cropping may be extended to 8 to 10 years under some conditions if a leguminous, green-manure crop is included once every 2 years (Newton 1960). Two crops of legumes can increase the yield of the subsequent food crop. This, however, does not alone prove that they are more economical than natural fallow. The value of legumes versus nonlegumes as fallow deserves testing.

Tests in India (Ranganathan and Ghatnekar 1984) illustrate the potential of agroforestry in a region receiving about 200 cm of rainfall per year, all of it from June through September but with supplemental irrigation of 1.5 to 2 L per tree once a month from October through May. *Leucaena* (the K8 variety) spaced at 1 by 1 m yielded 23 t/ha/yr at 33 months. At a spacing of 2 by 2 m, the yield was 12 t/ha/yr. Comparisons of mixed plantings with monocultures showed no clear superiority. In fact, a *Eucalyptus* monoculture yielded about 36-m^3/ha/yr after 33 months compared with 27 m^3/ha/yr for a mixed planting of five species.

Intensive culture in India also showed much promise. Rainfed plantations of K8 *Leucaena* spaced at 0.3 by 0.3 m and cropped eight to nine times in 12 months yielded 13 t/ha/yr, worth 2.9 times the cost. Foliar irrigation, adding 3.5 L of water per tree each week between October and May increased the yield to 23 t/ha/yr, still worth 2.9 times the cost.

According to some definitions, tree shelterbelts at the edge of crop areas may not strictly be agroforestry because their integration with crops is horizontal rather than vertical. Nevertheless, a few principles seem appropriate. In the Temperate Zone, optimum crop gains are most likely from narrow shelterbelts (Stoeckeler 1965). For maximum benefits, they should be oriented perpendicular to the most damaging winds. Single rows do not survive well in dry areas, so belts of up to five rows are recommended. The distance between belts may range from 5 to 25 times tree height, depending on topography and wind velocity. The tree species selected must be well adapted, effective as wind screens, windfirm, resistant to breakage, disease free, fast growing, long lived, and easy to establish (Stoeckeler 1965).

The potential employment value of agroforestry is significant. An experiment with a new oil-palm plantation in what is now Benin showed that intercropping with food crops for the first 4 years, compared with regularly maintained natural cover, could increase employment over the period from 390 to 1,455 days (Sparnaay 1957).

The employment value of some tree crops compares favorably with that of other agricultural crops. Rubber plantations in the Andaman Islands covering 7,400 ha have provided some 6,000 jobs, and oil palm plantations covering 2,400 ha have employed 1,200 workers (Singh, B. 1973).

Some Drawbacks to Mixed Cropping. Crop combinations may be beneficial under certain circumstances, but there are also important limitations. It is rarely possible to maintain optimum conditions for two different crops on the same land (Sparnaay 1957). A combination of rubber and *robusta* coffee lowered yields of both crops and cost more to manage, because neither crop was growing under optimum conditions. Rubber dominates economically and generally determines the suitability of a second crop. The following limitations for crop combinations are quoted from Allen (1955):

1. The second crop should not grow as tall as the main crop, and the root system should exploit different soil horizons.

2. The second crop should be tolerant of partial shade.

3. The second crop should not be more susceptible than the main crop to diseases they have in common.

4. Harvesting of the second crop must not damage the main crop or the soil.

5. The economic life of the second crop should not be longer than that of the main crop.

Most perennial crop combinations with oil palms present problems (Sparnaay 1957). Cacao, for instance, requires more and more light, yet palms steadily increase their shade. Tests in what was formerly Zaire with coffee at various spacings showed that no combinations were economically justified. It was necessary either to prune the palms or to eliminate the coffee too soon after planting.

Shade over cacao intercepts rainwater, reduces solar radiation, lowers temperature, raises humidity, and reduces wind velocity (Hardy 1962b). The net effect is to lower the rate of transpiration of the cacao, adversely affecting mineral nutrition and, hence, yields.

In dry climates, competition for water between crops may be deleterious. This is illustrated by the effects of selective girdling of widely spaced trees in miombo woodlands in Africa (Ward and Cleghorn 1964). Forage grass yields were increased from 355 to 1,460 kg/ha for the subsequent 4 years.

The reduction of yields beneath shade is characteristic of many crops. For example, although 50 percent shade is considered favorable for tea in Bangladesh (Skoupy and Vaclav 1976), tea yields in east Africa decreased 10 to 15 percent when grown beneath 20 to 90 percent shade and even when grown up to 12 m from the shade trees (McCulloch and Pereira 1965). A decline in cacao yields with proximity to *Terminalia ivorensis* shade was demonstrated in Ghana (table 8–10; Bonaparte 1967). The differences in numbers of cacao pods are attributable to distance from the shade trees and are highly significant. The probable explanation is the amount of light, because moisture was plentiful and may well have been greatest near the shade trees (Bonaparte 1967).

Crop Combinations. However incomplete the information may be, many examples of interplanting, even just technically, appear at least temporarily successful. One of the most successful combinations uses rubber as the main crop. In what is now Malaysia, trees planted in rows about 20 m apart and interplanted with well-manured food crops provided an environment that benefitted both crops (Allen 1955). This configuration increased the efficiency of labor, and replanting could overlap. Among the crops recommended were coffee, cocoa, bananas, tea, and oil palms as well as balsa on a 6-year rotation and *Gmelina arborea* on an 8-year coppice.

Table 8–10.—Shade effects of *Terminalia ivorensis* on cacao yields in Ghana

Distance from shade tree (m)	Sunlight (%)	No. of pods per tree	
		Total	Healthy
2.2	38	37	25
4.8	52	44	31
6.5	62	51	36

Source: Bonaparte 1967.

Coffee has been grown under shade for centuries. Although with more intensive management, greater production is generally possible without shade, the use of shade can be expected to continue. The shade crop is generally of less value than the coffee and is typically a leguminous tree such as *Erythrina, Inga,* or *Senna,* which are used chiefly for fuel. Selecting such trees for their spreading crowns indicates the lack of emphasis on wood production (Garcia Gutierrez 1976, Uribe Uribe 1945). Other indications that wood is unimportant compared with coffee have been found in Uganda, where farmers rejected deciduous species and "excessively competitive" genera such as *Casuarina, Cedrela, Eucalyptus,* and *Senna* (Thomas 1940).

The possibility of producing timber in combination with coffee is recognized in Costa Rica, where the recommended tree species are *Cordia alliodora, Enterolobium cyclocarpum,* and *Samanea saman* (Budowski 1959). In India, *Grevillea robusta* has been considered a good companion species, despite insect and disease problems and its reputation for drying out the soil (Rao 1961).

Cacao, like coffee, has generally been produced under tree shade. Species of *Erythrina* are commonly used and clearly benefit the cacao in Costa Rica (Zevallos and Alvim 1967). Cacao was found to be much more productive when growing near the *Erythrina* (2.5 m) than when growing farther from it (8.4 m). However, this improved performance is not caused by shade but rather by the fact that the soil near the *Erythrina* is richer in minerals than elsewhere and is more moist in the top 30 cm.

While forage perhaps does not constitute a "crop" in the usual sense, grazing is important in agroforestry. Combining trees with pasture may favor either the grass or both grass and trees. Spreading, leguminous trees favor the grass alone, whereas combinations of coconut or oil palms with forage grasses may favor both crops. In nonforested northern Argentina, 2.5 ha of tree plantations are needed for every 1,000 head of cattle to provide shelter from wind and storms (Flinta 1960).

Forage values under open stands of *C. alliodora, E. poeppigiana, Gliricidia sepium,* and *S. saman* were studied in Costa Rica (Daccarett and Blydenstein 1968). The 7-year-old trees did not reduce dry-matter production below that of unshaded pasture but did reduce the fiber percentage. Under the three legumes, N in the upper soil layers was slightly higher than under the *C. alliodora* or without tree shade. The protein content of the grasses was significantly higher under the legumes.

With stocking of one animal per hectare, animal-weight increases of 0.25 kg/d were possible even during a severe drought in Mexico under *Pinus caribaea.* The trees had been heavily thinned from 1,330 trees per hectare at age 6 to 740 per hectare and then 500 per hectare at age 9 (Gregor 1973). The grazing beneath the pines also reduced the fire hazard.

A combination of heavy thinning of *P. radiata* and sheep grazing in New Zealand created less conflict with traditional farm practices than did pure forest plantations (Knowles 1972). Animals were excluded until the trees were about 3 m tall; herbicides were used where necessary for weed control. At 4 years, the trees were thinned to 500 per hectare and pruned to 2 m. At a height of 10 m, trees received a final thinning, leaving a crop of 200 per hectare. When the heights reached 14 m, pruning to 8.5 m had been completed. The tree rotation was reduced from 35 to 25 years.

Leucaena leucocephala is one of the most promising agroforestry species because the more vigorous varieties combine rapid wood growth with valuable forage from their foliage. A study in India (Mohatkar and Relwani 1985) shows the combined effect of producing both forage and wood. During a 3-year period, the trees were pruned to 120 cm in height either once or twice per year (table 8–11). Apparently even the closest spacings did not diminish forage yields.

An underdeveloped potential agricultural product from tropical trees is honey. In equatorial lowland rain forests, nectar is so continuously available that native bees have no storing instinct, but wherever the climate is seasonal, European bees do well (Smith 1960). Honeyflow is greatest during the cool or dry season. A few of the meliferous (honey-bearing) trees adapted for agroforestry are *Albizia* spp., *Anacardium* spp., *Azadirachta indica, Cocos nucifera, Coffea arabica, D. sissoo, Eucalyptus* spp., *Eugenia* spp., *Grevillea robusta, Mangifera indica, Melicocca bijuga, Moringa oleifera, Musa* spp., *Persea* spp., *Prosopis* spp., *Psidium* spp., *Roystonea* spp., *Syzygium jambos, Tamarindus indica,* and *Toona ciliata.*

Table 8–11.—*Leucaena leucocephala* wood and forage production in India

Density (no./ha)	3-year yield (t/ha)	
	Dry firewood	Green forage
5,000	44.4	39.1
10,000	44.6	46.1
20,000	53.0	53.7

Source: Mohatkar and Relwani 1985.

Agroforestry plans have been proposed to incorporate apparently compatible crop plants so as to favor subsistence. In Brazil, three systems involving different land areas have been recommended (Bishop 1978). On an area of 2 ha, eight sections of 0.25 ha each were planted to garden crops for 2 to 3 years followed by a fallow of 5 to 6 years with poultry on grass and legume pastures under leguminous firewood trees. A second plan involved 8 ha, or eight plots of 1 ha each, also on about an 8-year cycle. The only difference was that swine were used on the fallow pastures instead of poultry (Bishop 1978). A third plan required 40 ha, with 20 divisions of 2 ha each, and a cycle of at least 20 years. Maize was produced during the period of tree establishment, after which cattle grazed beneath timber, fruit, and nut trees for 19 years.

A plan for combined pasture and tree production in the Brazilian Amazon is based on the assumption that a widely spaced tree plantation, starting with 750 trees per hectare and thinned to 150 to 200 by age 13 to 15, permits development of good pasture (Kirby 1976). The proposal assumes an early crop of beef and adequate control of grazing intensity to prevent site deterioration. The combination is more labor intensive than either crop alone. The need for added nutrients apparently has not yet been reported.

A 12-ha pattern of agroforestry was developed in Quintana Roo, Mexico (Chavelas Polito 1980). The design comprises four concentric rectangles (fig. 8–6). An outer

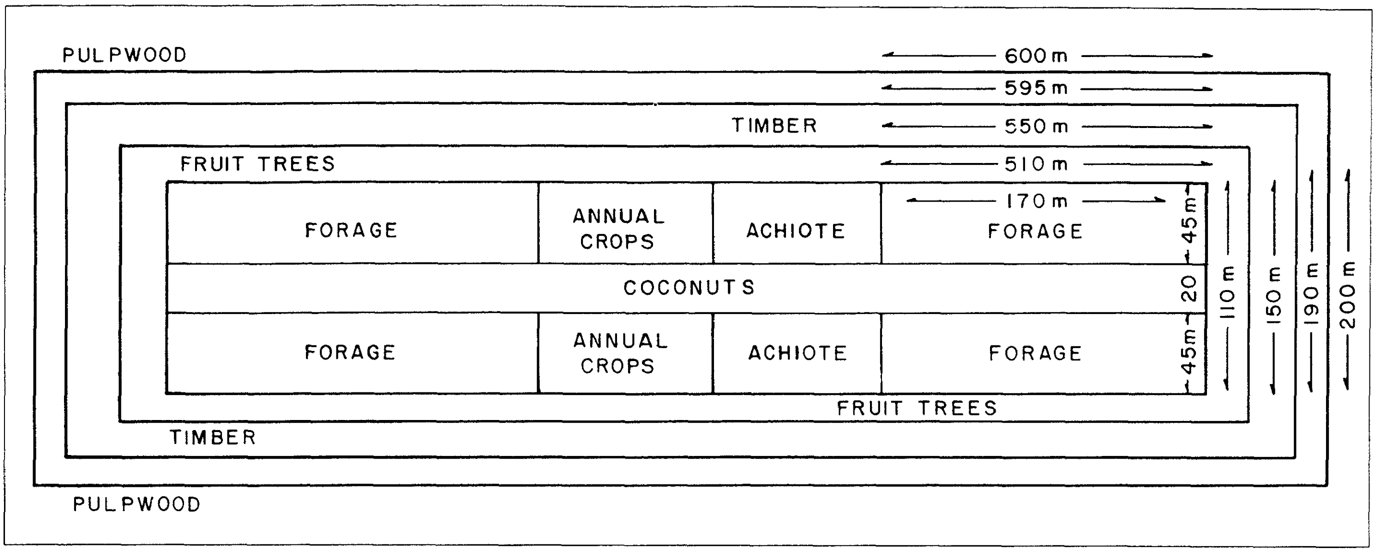


Figure 8–6.—*Multiple-use agroforestry plan for 12 ha in southern Mexico (Chavelas Polito 1980).*

strip, 5 m wide, contains about 0.8 ha of pulp- and veneer-wood trees (*Gmelina arborea* and *Pseudobombax ellipticum*) and a construction species (*Colubrina arborescens*). The next strip inward, 20 m wide and about 3 ha in area, has a mixture of nine timber trees. Inside that, another strip of 3 ha contains a variety of fruit trees and forage grasses. In the center is a rectangle 110 by 510 m that is divided by a central strip 10 m wide planted to coconut palms (*Cocos nucifera*). The remaining area is subdivided into six 0.85-ha plots. Of these, four are put to forage crops and two to a mixture of annual and biennial cultivated crops. The plan proved unpopular because of its testing close to an urban market for cash crops.

A plan for tree "biomass farms" in arid areas, using deep-rooted N fixers such as *Acacia, Leucaena,* and *Prosopis,* has also been proposed (Felker 1981). Intercropping with food staples such as millet, sorghum, and peanuts is contemplated, and irrigation will be required temporarily. On areas of at least 25 cm of annual rainfall, the system can thrive on ground water within 10 m of the surface. Phosphate fertilizer and micronutrients are required as well as rhizobial inoculation so that N can be provided by the plants.

Much of the data that is presented here is conceptual. Data showing the results of actual practices are scarce, and much has been written recently on this subject. Vergara (1985) described the information base of agroforestry as extremely weak and warns that inaccurate information could lead to rejection if results do not live up to farmers' expectations. A general inclination to overestimate the potential of agroforestry is seen by Groenendijk (1988). He points out that knowledge of interactions between trees and crops is still limited.

A lack of "hard data" on agroforestry is also noted by Scherr and others (1989), who point to the paucity of actual farm-survey studies or information on the economics of agroforestry.

These words of caution are not without foundation. Enthusiasm for agroforestry outgrew and still exceeds the available scientific basis. The danger is that decision makers may count on unfounded postulations for increasing pressures on marginal land. There is no doubt that the integration of trees into conventional agriculture in the Tropics holds much promise. This goal may be achieved, however, only with research to support all new proposals.