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Shifting Cultivation and Tropical Soils: Patterns, Problems, and Possible Improvements

Linda Christanty

FAO (1957) has labeled shifting cultivation as the most serious land-use problem in the tropical world. Shifting cultivation has been condemned as destructive and frequently has been seen as the work of ignorant people, thoughtlessly slashing and burning, wasting valuable forest and soil resources, and increasing the danger of runoff and erosion (Grandstaff 1981). Far from ending or even diminishing, shifting cultivation has increased in the twenty-five years since the alarm was sounded. It is estimated that there are over 250 million shifting cultivators worldwide, 100 million in Southeast Asia alone (Hatch and Tie 1979).

In fact, shifting cultivation is an ideal solution for agriculture in the humid tropics (Watters 1971), as long as the human population density is not too high and fallow periods are long enough to restore soil fertility. This agricultural system is ecologically sound and meets a variety of human needs with great efficiency, particularly with regard to labor and other agricultural inputs. However, in many areas where shifting cultivation has been practiced successfully for centuries, the population is growing rapidly, largely due to migration from other areas. People also are opening up new areas that have not been subjected to agriculture before and where shifting cultivation may not be appropriate. As a consequence, many of the destructive effects of shifting cultivation, though sometimes more imagined than real, are increasingly becoming a reality. Unfortunately, no alternative food production systems have yet proven biologically and economically workable for many areas of the tropics (Eckholm 1976).

This chapter reviews effects of shifting cultivation on soils and suggests alternatives that might be useful for dealing with contemporary problems. The chapter draws on a worldwide literature but applies fully to shifting cultivation in Southeast Asia. Soil classification follows the FAO/UNESCO system as described by U.S. Soil Conservation Service (1975).

DEFINITIONS AND CLASSIFICATION

Shifting cultivation is the most widespread farming system whereby annual and short-term perennial crop production is alternated with longer periods of vegetative fallow. Spencer (1966) has pointed out the difficulty of precisely defining shifting cultivation because of the wide range of techniques used in different areas. Certain characteristics, however, are common in most cases of shifting cultivation. These are the use of fire in preparing land for planting and the shift of cropping from one field to another. Other characteristics, such as crop species diversity and field size vary according to landscape, the flora and fauna, cultural pattern, history of application, population density, and social and economic pressures exerted upon the shifting cultivators. The abandonment of fields, however, seems to be the most important element in distinguishing shifting cultivation from other types of agriculture. Of the many definitions of shifting cultivation, Pelzer's (1957) is probably the most useful as a standard. He defines shifting cultivation (shifting-field agriculture) as "an agricultural system which is characterized by a rotation of fields rather than of crops, by short periods of cropping (one to three years) alternated with long fallow periods (up to twenty or more years, but often as short as six to eight years); and by clearing by means of slash and burn."

Many terms have been used to denote shifting cultivation. About 60 percent of the scientific literature uses the phrase "shifting cultivation," but about 15 percent uses the term "swidden" (Kelly 1975). Spencer (1966) lists forty-eight English terms that have been used in place of shifting cultivation or swidden, such as cut-and-burn, fire-field, land-rotation, nomadic, slash-and-burn, and transient cultivation or agriculture. Local vernacular terms are often used to refer to both the kind of plot and the system for its use: *milpa* in Central America; *conuco* in Venezuela; *chitemene* in Central Africa; *ladang* in Indonesia; *ijran, upraon, talaon* in the Himalayas; *taungya* in Burma; and *kaingin* in the Philippines (Pelzer 1945, Conklin 1957, Terra 1958, Spencer 1966). Most of these terms are not widely known outside the limited geographical regions, and they often imply local features that are not universal to shifting cultivation.

"Shifting cultivation" seems to be the most precise term for referring to this system. "Shifting" refers not only to the actual change in the cropping site but also the system of land tenure. The term "slash-and-burn" can be misleading. Although shifting cultivators usually cut and burn the forest prior to planting, it is only a part of the total operation of shifting cultivation. Burning of a forest does not necessarily indicate that the field will be abandoned later and a system of shifting cultivation adopted (Kelly 1975). The term "swidden" was originally a medieval English word meaning "a place on a moor which has been cleared by burning or which still shows signs of burning" (Ekwall 1955). Although an earlier form, "swithen," meant "to burn superficially," most dialects used swidden to refer to land that was cleared by burning. There is thus a difference between "swidden" and "shifting cultivation"; swidden does not necessarily refer to shifting fields but only to land cleared by burning.

Conklin (1957) distinguished "integral" and "partial" shifting cultivation. "Integral" reflects the system as an integral part of a subsistence farmer's way of life. "Partial" indicates the use of shifting cultivation as a technological expedient for cash cropping or some other form of commercial agriculture. Conklin's classification can be summarized as follows:

1. Integral shifting cultivation
   - Pioneer swidden farming—Significant portions of climax vegetation are cleared annually.
   - Established swidden farming—Little or no climax vegetation is cleared annually.
2. Partial swidden cultivation
   - Supplementary swidden farming—A farmer practicing continuous agriculture devotes part of his efforts to shifting cultivation.
   - Incipient swidden farming—A farmer moves into a forest area and cleans part of it for continuous agriculture but may be forced to shift by low yields after a few years.

Watters (1971) proposed a similar classification:

1. Traditional shifting cultivation—This has been practiced traditionally by tribal people whose lives and religions have been closely tied to the natural systems around them.
2. Shifting cultivation imposed by necessity—The cultivator is not linked to a tribal community and usually owns no land or not enough land to support permanent agriculture. Therefore, the cultivator often clears forests for cultivation and starts a cycle of shifting agriculture. This type of shifting cultivation can also be called land-hunger shifting cultivation.

Watters (1960) also classified shifting cultivation on the basis of other activities (e.g., hunting and gathering, pastoralism, and permanent agriculture) that accompany it and the emphasis farmers place on their shifting cultivation compared with the other activities.

Spencer (1966) emphasized that the primary aim of classification should be to analyze the evolutionary development of integral shifting cultivation; he said it is more important to focus on shifting cultivation itself than on its degree of mixture with other aspects of the economy. He divided integral shifting cultivation into three categories depending on whether there is vegetative cropping, seed planting, or a mixture of the two. He further subdivided these categories according to how the shifting is done (e.g., random or cyclic), whether the people also shift their residences, and whether they use a digging stick or a hoe. He classified partial shifting cultivation according to whether it is randomly imbedded in a large forest, at the boundary between agriculture and forest, rotated within an established farmholding, or on an urban fringe. He also classified partial shifting cultivation according to whether it is for subsistence or commercial market.

STAGES OF SHIFTING CULTIVATION

Shifting cultivation typically has two basic stages: removing the old vegetation and managing the new vegetation. Much of the description here is based on summaries by Conklin (1957) and Watters (1960).

Clearing

Forest clearing usually starts at the beginning of the dry season, since many plants dry slowly and have to be cut long before they can be burned. If the area is not forested, grass tops and bushes are generally cut late in the dry season and followed immediately by burning. There are two stages in clearing: (1) slashing and related cutting activities, and (2) felling and related cutting activities. Most small vines, weeds, bushes, easily cut saplings, and underbrush are slashed close to the ground at the slashing stage. They provide a cover of debris that protects the soil from overexposure during the felling stage. Once most of the undergrowth has been slashed, the larger trees are felled to remove unwanted shade and to provide necessary fuel for burning.

Some cultivators completely clear the ground; others leave smaller trees to speed regeneration during the fallow period. In some systems trees are merely trimmed or pollarded. In trimming, only the leafy tips of branches are cut off, while in pollarding the branches are cut off near their bases. Parts of felled saplings or branches are removed from the site for fencing or construction purposes. After slashing and felling (or trimming and pollarding), the leveling process is started by cutting the felled vegetation into pieces as small as possible to facilitate rapid drying and allow the material to be spread evenly over the whole site. It is then left to dry for a month or two prior to burning.

The size of the farm clearing varies considerably, depending upon population density, the number of people to be supported from one family garden, soil fertility, and the size and energy of the labor force. Partial systems, which have other forms of food production or other sources of income, usually have a smaller clearing than integral systems.

Burning

The success of the burn depends on the thoroughness of cutting activities, the type of vegetation, and the weather. The best time for burning depends upon the dryness of the debris. In the dry season three or four weeks are usually adequate for drying. If the field remains unburned for a longer period, weeds and shoots begin to appear and consequently lessen the chances of a complete burn. Sometimes a second or third burning, usually in piles or in small heaps, is necessary in humid areas to clear all debris.

To prevent fire from spreading to the nearby forest, firebreaks may be cut and protective paths of 4–5 m across are made by throwing all debris to the center of the field. This practice suggests a traditional sense of forest conservation.

Cropping

If the physical condition of the soil is favorable following clearing and burning, the planting technique is simple, and seeds are merely scattered on the soil surface or dibbled into holes with a digging stick or hoe. Ridges and mounds may be made if roots are planted as a first crop. Additional cultivation of less favorable soil may be required with simple hand tools prior to planting.

The cropping phase is the most demanding phase of the shifting cultivation cycle. It is complex, since many crops are cultivated simultaneously or in an overlapping fashion producing a constantly changing mosaic of intercropped cultigens in the system. Mixed cropping and intercropping are common practices in the shifting cultivation system, showing the importance of space and time relations for securing a flow of crop production throughout the year. Mixed cropping also provides more complete cover and controls weed growth, thus reducing the labor for weeding.

Conklin (1957) divided the cropping phase into grain cropping (cereals) and nongrain cropping (root crop farming and tree crop farming). The first year of cropping is usually dominated by cereals such as maize or upland rice with a mixture of legumes and vegetables. Annual and semiperennial root crops are then planted shortly after harvesting the cereals, followed by bananas and other perennials. Root crops are harvested during the second and third year. Harvesting of the perennials starts in the third year and may continue several years after the clearing has been abandoned. Usually the farmer starts to abandon the field after the last root crop harvest.

Fallowing

Fallowing is a period in which the land is prepared for the next shifting cultivation cycle by controlled natural reforestation and forest enrichment. This period is important for reestablishing soil fertility. Nutrients are taken up by the fallow vegetation from a variety of soil depths depending on their rooting zones. Part of the nutrients are stored in the vegetation and part are returned to the soil surface in the form of litter and rainwash. The amounts of nutrients stored in the vegetation during the fallow, the quantities returned to the soil, losses from the soil-vegetation system through leaching, and the net amount stored in the soil surface vary with the soil type and the nature and age of the fallow vegetation (Webster and Wilson 1966).

Fallow systems can be classified in several ways:

1. Length of the fallow period
   - Forest fallow—20–25 years

   - Bush fallow—6–10 years
   - Short fallow—1 or 2 years
2. Type of dominant vegetation in the fallow
   - Woody fallow
   - Grassy fallow
3. Tree growth and size
   - Low forest fallow—Herbaceous, shrubs, vines, and low tree growth
   - High forest fallow—Herbaceous undergrowth has disappeared, so woody or bamboo forest predominates.

The long-term success of a shifting cultivation system depends upon how well the fallow period restores or maintains soil fertility. If the fallow period is shortened, the annual addition of organic material will be reduced, leading to soil fertility deterioration.

EFFECTS OF SHIFTING CULTIVATION ON TROPICAL SOILS

Changes Due to Clearing and Burning

Since a large proportion of the mineral nutrients in the ecosystem are stored in the vegetation rather than the soil during a fallow, clearing and burning appear to be the only way to prepare the land for cultivation and incorporate into the soil the nutrients that have accumulated in vegetation. The effects of clearing and burning on soils can be divided into changes in soil physical and chemical properties and changes in soil nutrient status.

Burning raises the soil temperature. The highest temperature during an experimental burn in Costa Rica was reached in the dense litter 1 cm to 2 cm above the soil surface, with an average surface temperature of 200°C (Ewel et al. 1981). The temperature was markedly lower beneath the soil surface. The mean temperature at 1 cm depth was 100°C and was less than 38°C at 3 cm depth. In Thailand temperatures were as high as 650°C in the fuel 2 cm above the soil surface and dropped to 70°C at 2–3 cm beneath the surface (Zinke et al. 1978). Variability in soil temperature during burning depends on the intensity and duration of the burn, fuel quality, and moisture content. Forest clearing can increase evapotranspiration, which in turn affects the top horizons and results in a nonuniform moisture supply.

The effect of clearing and burning on soil structure depends upon soil properties. In soils with allophane clays or high oxides, such as Andepts (volcanic ash soils) and Oxisols (highly weathered soils), the structural changes after clearing are not detrimental. However, in soils with low aggregate stability, such as Vertisols (black soils) and sandy soils, the changes in soil physical properties due to clearing are detrimental (Sanchez 1976).

Soil pH increases after burning due to a liming effect of the ash and then decreases gradually through time due to leaching. The magnitude of the change varies with soil properties. In an Alfisol in Ghana, the pH increased from 5.2 to 8.1 in the top 5-cm layer right after burning and decreased to 7.0 after two years (Nye and Greenland 1960). The pH of yellow latosol (Oxisol) topsoils increased from 3.8 to 4.5 with burning and decreased quickly to the original level in about four months (Brinkmann and de Nascimento 1973). In the topsoil of an Ultisol, the pH increased from 4.0 to 4.5 and remained stable during the first year (Seubert 1975). It seems that the lower quantity of calcium and magnesium in the ashes of Oxisols and Ultisols minimizes the increases in pH. The effect of the changes in pH on plant growth depends on the magnitude of the changes. The very high pH level after burning West African Alfisols has caused iron deficiency in upland rice (Lal 1975), but moderate pH increases in Amazonian Oxisols and Ultisols and in volcanic ash soils in Thailand (Zinke et al. 1978) proved beneficial to plant growth.

The basic cations in the ash cause dramatic increases in exchangeable calcium, magnesium, and potassium after burning. These are followed by a gradual decrease during the cropping period due to leaching and crop uptake. Sanchez (1976) compared the dynamics of exchangeable bases and pH in an Ultisol from Peru and an Alfisol from Ghana and found that in both soils the exchangeable calcium content tripled with burning. Exchangeable magnesium tripled in the Ultisol but only increased slightly in the Alfisol. In both soils exchangeable potassium showed a sharp increase after burning, followed by a sharp decrease. This indicates that potassium leached at a faster rate than calcium or magnesium. After burning, in the Ultisol there was a depletion of the previously mentioned elements in six months, while no significant changes occurred in the base status of the Alfisol for two years after burning.

Although burning volatilizes most of the carbon, sulphur, and nitrogen present in the vegetation, it has little effect on soil organic matter. Both Popenoe (1960) and Nye and Greenland (1964) found that organic carbon and total nitrogen increased after burning, which was probably due to incomplete combustion of the vegetation. In an Alfisol from Ghana, Nye and Greenland (1964) found that the topsoil organic carbon content increased from 0.94 to 1.25 percent with burning, followed by a decrease to 0.94 percent after two years. Therefore, there was no significant organic carbon depletion in relation to the levels before burning.

Changes in topsoil organic nitrogen show a different trend after clearing without burning (Sanchez 1976). Reports on volcanic ash soils in Colombia and Guatemala indicate very little change in nitrogen and a decrease at a much slower rate than that for organic carbon (Suarez de Castro and Rodriguez 1955, Popenoe 1960). The carbon/nitrogen ratio drops sharply in such cases, because increased biological activity produces large quantities of carbon dioxide, but part of the organic nitrogen is either in a fairly resistant form or retained in the soil as microbial tissue. In soils with low organic nitrogen contents, the carbon dioxide ratios remain the same after clearing and cultivation. Changes in organic carbon, nitrogen, or carbon dioxide ratios are limited to the topsoil layer, except when the effect of crop-root decomposition is evident in the subsoil.

Changes in soil pH and organic matter will affect the effective cation exchange capacity (CEC). During the first few months after burning, the effective CEC of a Peruvian Ultisol increased from 2.9 to 3.4 milliequivalents per 100 grams as a result of the increase in pH due to burning. The CEC decreased at later stages because of decreases in pH and soil organic matter content (Sanchez 1976). In two Oxisols in Sierra Leone, a 50 percent reduction in soil organic matter five years after clearing resulted in a 30 percent reduction in CEC (Brams 1971).

The available phosphorus level of a soil increases upon clearing and burning as a result of the phosphorus content of the ash. Popenoe (1960) found that the Bray-extractable phosphorus in the top 5-cm layer of Guatemalan Inceptisol increased about four times, remained at this level for about six months, and then decreased to a level of twice the original value at the end of one year. The decrease in available phosphorus with cropping is probably because of removal in the harvested crop or phosphorous fixation due to a drop in pH. Sanchez (1976) believed that the decline in available phosphorus may be one of the most important reasons for abandoning the field to forest regrowth. Many tropical soils are deficient in phosphorus, but there are no phosphorus deficiency symptoms in mature tropical forests, possibly because of the closed nutrient cycle.

Clearing and burning also cause significant changes in the soil microflora. Burning causes partial sterilization of the soil, followed by a "flush" of microbial population and eventually by a decline approaching new equilibrium levels (Laudelot 1961). A larger proportion of bacteria (compared to fungi) is also found after clearing. The total microbial population decreases during the dry season and increases during the rainy season and with mulching and fertilization. Little is known about the effect of burning on nitrogen-fixing bacteria, but changes in pH no doubt affect their population.

Soil Changes During the Cropping Period

The rapid mineralization of organic matter and additions of ash after clearing and burning provide a sharp increase of available nutrients to the first crop planted in most tropical soils (Sanchez 1973). Yields gradually decline with successive croppings, however, a major reason that cultivators move. There are several reasons for declining yields (Nye and Greenland 1960): increases in pests, diseases, and weeds; topsoil erosion; deterioration in the physical condition or nutrient status of the soil; and changes in the numbers and composition of soil fauna and flora. The fall in crop yields, however, is often due to a decline in soil fertility, which may result from a decline in the amount of humus in the soil, changes in the physical condition of the soil, and changes in the nutrient status.

The decline in humus content during the cropping period is rapid during the first year and becomes progressively slower. Nye and Greenland (1960) have assumed that a loss of humus is not necessarily a serious problem, even over a cropping period of ten or more years, and that the change in humus quality is more important than the change in quantity. Humus affects the soil in many ways, influencing its physical properties, its chemical properties, and its microfauna (Ahn 1974). For this reason humus changes often have been considered as fundamental ones that to some extent lead to most other soil changes. Decreases in the amounts of humus in the soil often lead to the following (Ahn 1974):

- Loss of crumb structure in the topsoil;
- Lower total porosity and lower macroporosity;
- Poorer aeration;
- Poorer rainfall infiltration;
- Increased runoff and surface erosion;
- Lower cation exchange capacity;
- Changes in exchangeable bases, degree of saturation, and soil pH; and
- Lower nutrient levels due to lower amounts of humus mineralized.

All of these factors can play some part in reducing soil productivity under shifting cultivation.

The physical properties of the soil that affect its fertility and may deteriorate with cropping are covered by the term "soil constitution" (Nye and Greenland 1960). The constitution of the soil is governed by the size and continuity of its pores, which determine its permeability and drainage characteristics, the amount of water stored for crops when drainage has ceased, and the exchange of carbon dioxide and oxygen in the root zone. The constitution of the soil is linked closely with its erodibility (Nye and Greenland 1960).

Until the first crop is fully established on cleared land, rapid organic matter decomposition and the battering effect of raindrops on the soil can cause degradation of soil structure (Cunningham 1963). Forest fallow periods promote a humus topsoil with a favorable aggregation. After the land is cleared, however, the impact of raindrops on the bare surface shatters the aggregates and seals the pores with suspended silt. The unhumified organic matter on the immediate surface, which serves to keep the pores open, decays rapidly. Once an effective vegetative cover has formed, further decline in soil constitution is slight.

Natural aggregation of the soil, as distinct from that caused by humus, varies markedly from soil to soil. Ahn (1974) found a relatively low degree of aggregation in some fertile West African forest soils (tropudalf and eutropept) developed over basic rocks. In a range of profiles developed over phyllites and granites of the basement complex, however, microaggregation was greater in Oxisols (haplorthox and eutrorthox) of the older surfaces than in the more widespread Ultisols of contemporary slopes. The degree and stability of natural aggregation indicate to what extent a soil retains a favorable structure and inherent constitution after loss of humus during cropping. For example, there was less decline in soil structure during shifting cultivation cropping on Oxisols than on Ultisols in Brazil (Seubert 1975).

The total nitrogen content of the soil after fallowing is high and is usually sufficient for at least several years of cropping. The mineralization of humus and raw organic matter that is added to soil depends on temperature, moisture content, aeration, vegetation type, the nature of the organic matter itself, and soil pH (Ahn 1974). In Oxisols the rate of nitrogen release from the soil organic matter is low during the fallow period but is markedly increased by the rise in pH after burning. According to Nye and Greenland (1960), the pH of the top 15 cm of Oxisols does not fall below 5.0 even after eight years of cultivation; therefore, there is no significant decline in the rate of mineralization for a two- to three-year cropping period. Nitrification proceeds rapidly in almost all cultivated tropical soils during the first rains following a dry season. Losses of nitrate occur through leaching during the cropping period, especially in the wetter forest regions with continuous rainfall and particularly during the period before a full crop cover is established.

Phosphate availability is increased after burning, and the decline in soil phosphate during the cropping period is due to crop uptake and a decrease in availability, particularly when iron and aluminum oxides are present and there is a drop in soil pH. Leaching losses are negligible. Nye and Greenland (1960) estimate that 27 kg phosphorus per ha is added by a ten-year forest fallow, and about 9 kg phosphorus per ha is added annually from humus mineralization during the cropping period.

Although parts of the ash are washed away by the first rain, the burning of a forest fallow adds considerable quantities of nutrient cations to the exchange complex of the soil (Webster and Wilson 1966). During cropping the quantities of exchangeable cations tend to decline because of leaching and removal by the crop, but they are compensated to some extent by cation release from nonexchangeable forms. The loss of cations tends to reduce their percentage saturation in the exchange complex, as well as their availability, but this may be compensated by an overall reduction in exchange capacity due to humus oxidation (Nye and Greenland 1960).

Except for potassium, there are generally no serious nutrient deficiencies during a cropping period of one to three years. Deficiencies may arise with more prolonged cropping, however, or over successive cropping with intermittent short fallows. Unlike the trees in a natural forest, field crops do not transfer nutrients from the subsoil to the surface. Consequently there can be net losses of nutrients due to leaching beyond the shallow root zone during cropping. Many forest soils are low in exchangeable potassium, an element that can be taken up in large quantities by carbohydrate crops such as cassava and plantain. A consequent decline in yields due to insufficient potash may occur rapidly (Nye and Greenland 1960).

Soil Changes During the Fallow Period

Nutrient changes in the soil occur because organic matter is added from vegetation and because nutrients are recycled from the subsoil, removed by cropping and leaching, or react chemically with the soil (see Figure 2.5).

During the fallow period these changes are closely linked with increases in soil organic matter and soil humus, which helps to hold exchangeable cations added to the topsoil, stores important amounts of phosphorus and sulphur, and acts as a nitrogen reservoir (Nye and Greenland 1960). Under moist lowland evergreen or semideciduous forest, the maximum soil organic matter attained after very long periods of fallow (e.g., twenty to thirty years) averages about 67,000 kg per ha carbon and 6,150 kg per ha nitrogen in the 0–30 cm layer. On free-draining soils, more humus occurs in highland areas when the soils are clayey and when the clay fraction contains allophane-like clay minerals (Kalpage 1974). Using the carbon/nitrogen ratio as a rough guide to the rate of mineralization, Kalpage (1974) estimates the carbon/nitrogen ratio is around 8 to 12 in forest Ultisols and 14 to 17 in forest Oxisols.

Organic matter is added to the soil as litter and from dead roots and root products. Annual litter production in moist tropical forests is about 12 tons of dry matter per ha, about 10–20 percent contributing to soil humus (Kalpage 1974). This compares with an average of 2.5 tons per ha in temperate hardwood forests and 7 to 10 tons per ha in high-grass savanna. The initial rate of increase of humus carbon ranges between 280 and 670 kg per ha annually. Humus carbon decomposes at a rate directly proportional to its amount, and ultimately an equilibrium level is attained. More humus is found in forest fallow soils that have been cultivated and fallowed over many cycles.

Nye and Greenland (1960) have estimated that a typical rate of input of nitrogen to a tropical forest soil is about 40 kg per ha per yr, and the principal source of nitrogen is the atmosphere. Most of the nitrogen stored in the slash is lost in the burn, so only soil nitrogen remains for use by the crop, and most of that is available only after the first year of cropping. In the heavily leached acid soils of some rainforests, symbiotic nitrogen fixation is an important source of soil nitrogen, but in moist semideciduous forest zones, the main input of soil nitrogen comes from nonsymbiotic nitrogen-fixing bacteria. The increase in soil phosphorus under a ten-year fallow level is around 13 to 34 kg per ha in the forest. The amount of phosphorus accumulated in the vegetation is about 34 to 45 kg per ha. Therefore, increasing soil organic phosphorus is probably the most useful function of fallow.

During the fallow period, more nutrients are accumulated in the vegetation than in the topsoil. There is a net transfer of nutrients from the subsoil to the topsoil, however, as a result of the pumping effect of deep roots. Soils under forest contain more total phosphorus and calcium in the surface horizon (0–12 cm) than in the lower horizon. In Africa (Nye and Greenland 1960) exchangeable calcium and exchangeable potassium contents of the topsoil were not altered appreciably during three ten-year cycles of wattle plantation, despite losses by leaching and losses to standing vegetation. These conditions indicate that nutrients brought up from the subsoil and returned through the litter to the topsoil are sufficient to compensate losses.

The change in exchangeable nutrients in the topsoil during the fallow period is the result of a balance between the addition of subsoil nutrients through litterfall and rainwash and a loss of nutrients by uptake from the topsoil by fallow vegetation and by leaching to the subsoil. After a sufficiently long period of fallow, the exchangeable nutrients in the topsoil will be restored nearly to their original levels.

CONTEMPORARY PROBLEMS AND POSSIBLE IMPROVEMENTS

The length of the fallow period is the key to long-term success in shifting cultivation. Because of the rapid increase in human population densities and the high demands for cash crops, however, the practice of shifting cultivation has gradually been intensified. Cropping becomes more intensive and prolonged and fallows are shortened, resulting in a deterioration in the physical condition and nutrient status of the soil.

In the evergreen and semideciduous lowland forest zone, some runoff and erosion occur during the period between burning and the establishment of an effective cover by the first crops, especially on steep land (Webster and Wilson 1966). Therefore, erosion may become a serious problem if more intensive cropping is practiced on steep land. Exposure and disturbance of the topsoil during clearing, cropping, and weeding can lead to acceleration of soil removal by surface runoff.

It is clear that shifting cultivation can be maintained only as long as land is abundant. If the population increases and land becomes scarce, the system eventually will cease to provide sufficient fertile soil. There is a need either to improve shifting cultivation or to replace it with new systems. Because shifting cultivators may be attached to their way of life, improving the system seems to offer a better chance of success than complete replacement by new systems. There are several alternatives for improving shifting cultivation to restore soil fertility during the fallow period and to prevent erosion.

Controlled Shifting Cultivation (Corridor System)

Controlling the crop/fallow ratio can help to maintain soil fertility. The corridor system in Zaire is an example of controlled shifting cultivation. Large forested areas are divided into strips or corridors, approximately 100 m wide and oriented in an east-west direction to maximize sunlight penetration. Every other corridor is cleared every year, and every cultivated corridor is flanked by a forest fallow. The fallow strips provide a good source of tree seeds for regrowth during the fallow and in some cases prevent erosion (Sanchez 1976). This system, however, requires control of the human population, so it would be applicable only in some areas.

Planted Fallow

Replacing natural fallow by an artificial, planted fallow is another alternative to improving shifting cultivation. In densely populated areas with great pressure on the land, improvement based on planted fallows seems preferable to the corridor system. The main purpose of a planted fallow is to restore the soil fertility at a faster rate than the natural fallow. Success depends upon the selection of plant species and cultivation techniques that are both economically attractive and technically feasible. Ahn (1979) has suggested that to be acceptable a planted fallow should restore soil productivity in a way comparable with or better than the natural regrowth vegetation and should provide the farmer with some sort of economic return, such as timber or firewood for sale or forage for livestock. The *talun* system described in Chapter 6 is an example of a planted fallow with a high yield of tree products. Caution is in order when making practical use of planted fallows, since the loss of large quantities of mineral nutrients contained in tree products removed from the site could lead to eventual depletion of soil nutrients.

Improving Soil and Water Conservation

Improving infiltration rates is an important principle of soil and water conservation in the tropics (Okigbo and Lal 1979), and mulching is one technique that has been successful in shifting cultivation areas. Mulches absorb the direct impact of raindrops, thus minimizing soil detachment. Moreover, runoff losses are reduced because the infiltration rate of the soil is maintained at its maximum level. An increase in crop yields by mulching occurs as a result of improvements in soil physical properties and in the general fertility level of the soil. Undecomposed crop residues also can improve the water retention capacity of the soil when applied as a mulch.

Adequate cover crops protect the soil from wind erosion and rainfall erosion and improve soil bulk density and infiltration rates. Mixed cropping practices have been particularly useful, since they are highly productive and conserve the soil. Monoculture cassava has been associated with higher runoff, and therefore water and soil loss, than mixed cropping of maize and cassava (Okigbo and Lal 1979). Increasing planting density is an effective way to improve cover and reduce soil losses (Hudson 1973).

Minimum tillage, which is common in shifting cultivation, is effective for controlling both wind and water erosion. A combination of minimum tillage, mulching, and mixed cropping has been successful in maintaining good yields on a continuous basis (Sanchez 1976). Performing tillage operations and planting crops on the contour rather than up and down the slope often result in reduced soil loss. However, the effectiveness of contour ridges for erosion control decreases with an increase in slope. Ridges are not effective for slopes steeper than 5 percent, especially when soil is of relatively coarse texture and low in soil organic matter. Engineering practices of soil and water conservation, such as terraces and waterways, are expensive and need a high initial capital input that is unlikely to be acceptable to shifting cultivators. Besides, such structures can worsen erosion if they are not constructed and maintained properly (Okigbo and Lal 1979).

In conclusion, maintaining a continuous ground cover is the key to dealing with problems of ecological imbalance caused by forest removal during shifting cultivation. A continuous ground cover may be achieved through minimum tillage, mulching, mixed cropping, and establishing planted fallows during fallow periods.

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