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Bringing the Green Revolution to the Shifting Cultivator

Better seed, fertilizers, zero or minimum tillage, and mixed cropping are necessary.

D. J. Greenland

In recent articles (*1*) the loss of momentum in the Green Revolution was discussed. Various factors which have contributed to the loss of momentum were described, but what the way forward must be was not suggested. Another article (*2*) has offered some suggestions in terms of soil development, but the particular limitations imposed by the lack of capital and other resources of the very small farmer were not discussed.

The Green Revolution was a considerable, but not unprecedented or unpredictable, success for the application of relatively standard plant breeding techniques to the improvement of wheat, rice, and maize for certain less developed countries. Improved varieties, supported by good agronomic practices, enhanced the potential for increased production of these crops by improved irrigation techniques and by increased use of fertilizers, particularly nitrogen. The potential benefits were made reality by the vigorous and enthusiastic efforts of many people who saw their possibilities, and appreciated the magnitude of the food problem (*3*).

These crop varieties and techniques are now an important part of world food production. But there is still a need for greater production in much of the developing world. The improved varieties and methods have been used mainly by the relatively large-scale farmers, utilizing the better soils (*2*). However, there has not yet been as great an impact on the methods and production habits of most of the small farmers living at or near the subsistence level, who are, for the most part, farming the poorer ultisols, alfisols, and oxisols of the tropics. The reason for this is not that the new crop varieties do not do well under the prevailing conditions of the small farm. They often yield better than currently used varieties, but the yield is still low. The limitation is usually the lack of other improvements needed in addition to the new varieties. The technology required for high yields—fertilizers, pesticides, machinery for tillage and harvesting, proper irrigation control, and access to markets—is not available to the small farmer, nor is it adapted to his level of education and normal scale of operations. Furthermore, the small farmer usually does not have the capital or access to credit needed for this type of operation, which in any case does not give him any greater guarantee of a minimum, secure level of production.

On some soils of high quality it has been possible to transfer technology from North America and Europe to parts of the tropics and subtropics (*2*). Where high-yielding, adapted crop varieties were available, very high yields have been obtained (*3*).

For the great majority of farmers in the less developed parts of the tropics and subtropics, who farm poor soils unsuited to intensive mechanized agriculture, transfer of technology is not possible. Farms of less than two hectares, on poor, highly erodible soils, cover a large proportion of the humid tropics. They cannot be cultivated by standard mechanized techniques without consolidation into larger holdings, and they cannot produce enough financial return to give a profit that justifies investment on farm inputs such as pesticides and fertilizers. For their development they require not the transfer of technology, but the devising of new technology.

Much of the work of the International Institute of Tropical Agriculture (IITA) in Nigeria is aimed toward development of farming systems that enhance the ability of the small farmer to benefit from improved crop varieties.

The system currently practiced by most of these farmers, with the exception of the lowland rice farmers, is shifting cultivation. Although in some areas, notably the mountainous areas of South America, the practice has been destructive and rightly castigated as "slash and burn" (*4*), in the majority of the lowland areas of the humid tropics it has been a stable system, providing a limited number of people living on sufficient land a continuing method of food production, requiring little in terms of inputs (*5, 6*). Before attempting to replace this system, it is important to analyze carefully those factors that make it stable and those factors that often make the shifting cultivator adhere to it when offered alternatives.

The Basis of Successful Farming Systems

Although technology may not always be successfully transferred from one agricultural environment to another, the scientific principles on which sound agricultural practice is based are always transferable. For a stable agricultural system, it is necessary (i) that the chemical nutrients removed by crops are replenished in the soil, (ii) that the physical condition of the soil suited to the land utilization type is maintained, which usually means that the humus level in the soil is constant or increasing, (iii) that there is no buildup of weeds, pests, and diseases, (iv) that there is

The author is Director of Research at the International Institute of Tropical Agriculture, Ibadan, Nigeria. He is on secondment from the University of Reading, Reading, England, where he is head of the Department of Soil Science. He was formerly on the staff of the University of Ghana.

no increase in soil acidity, or of toxic elements, and (v) that soil erosion is controlled.

All of these are essential. Under shifting cultivation in the lowland humid tropics these conditions can be met, although as with other systems abuses are not uncommon. When practiced as a stable system, a short cropping period is followed by a longer period when the soil rests under a natural fallow. During this fallow period, nutrient removals by crops are made good by recycling of nutrients through the fallow vegetation. Organic matter added to the soil from the vegetation not only increases the humus content of the soil, but also supports an active biological population, which restores the favorable physical structure. Insect pests and disease organisms fall in numbers in the absence of their hosts, and acidity is controlled by the alkaline ash added to the soil when the fallow vegetation is burned. Soil erosion is minimized for the following reasons. (i) Plot sizes are small so that water runoff has little opportunity to develop into erosive streams. (ii) The usual practice of mixed cropping keeps one or another plant species in the ground throughout the year, affording protection against direct raindrop impact and hence against soil detachment. (iii) Similarly, the usual poor clearing and poor weed control help to maintain a vegetative cover, particularly in the period when the land is abandoned (*7*).

Table 1. No-tillage effects on soil and water loss under maize [IITA, Ibadan (first season, 1973; rainfall, 780 mm; plots 25 by 4 m); unpublished data of Dr. R. Lal, IITA.]

Slope (%)	Soil loss (tons/ha)		Runoff (mm)	
	No tillage	Plowed	No tillage	Plowed
1	0.03	1.2	11.4	55.0
10	0.08	4.4	20.3	52.4
15	0.14	23.6	21.0	89.9

Thus the basic requirements of a stable system are met, but this is true only if the fallow period is sufficiently long to restore the detrimental changes that occur during the cropping phase. For different soils and different ecological zones there are appropriate "land use factors" which express the relative lengths of crop and fallow necessary for the system to be stable (*6*). These factors vary from 1 (equal lengths of crop and fallow) to 20 or more for poor soils. On steep slopes, or where the cultivation practice is poor, erosion may intervene. Plant nutrients and organic matter in many tropical soils, other than hydromorphic soils and those developed on highly basic parent materials, are concentrated in the immediate surface. Consequently the loss of topsoil may result in a reduction in fertility that can be made good only if the soil is left under natural vegetation for periods perhaps as long as hundreds of years.

The system also breaks down if the number of people that the land has to support becomes so great that fallow periods have to be substantially reduced. There are many examples where this type of land pressure is developing in Africa and elsewhere (*8*). Shortening of the fallow period leads to a cycle of crop and fallow periods wherein fertility steadily declines. As an alternative to shortening the fallow, the cropping period may be extended. This usually has more severe consequences, as the seeds, stumps, and roots from which the fallow vegetation normally regenerates when the land is abandoned die or are killed. As a result, the natural soil cover reestablishes slowly, and erosion may intervene so that rebuilding of fertility is delayed or prevented (*9*).

A farmer with his wives who provide his labor, and a typical mixed crop of maize, cassava, and cocoyams. The Green Revolution has not yet had a great impact on smaller farmers of the lowland tropics who live at or near the subsistence level. Much of the research work under the Farming Systems Program at IITA and other international agricultural institutes is aimed at developing systems that will enhance the ability of these farmers to benefit from improved crop varieties.

Improving Shifting Cultivation

What then are the alternatives to shifting cultivation, which is geared to a low level of productivity and bound to become increasingly inadequate as population continues to increase? Technical solutions may seem superficially simple. Fertilizers can replace the slow return of nutrients to the surface soil through the fallow vegetation. When high-yielding crops are grown, the return of crop residues should at least partly compensate for losses of organic matter. Proper use of machinery and mechanized tillage equipment can create the seed beds and tilth desirable for increased crop production. Pests and diseases can be controlled by suitable chemical sprays, and erosion can mostly be controlled by contour ploughing, construction of bunds, and carefully graded water channels.

Unfortunately, few of these remedies are available to the small farmer; nor do they appear to him the simple solution that they appear to those more familiar with the intensive agriculture of Europe and North America.

For the farmer who is a shifting cultivator, to invest in fertilizers of whose effectiveness he is uncertain, but of whose cost he is immediately aware, may well seem ridiculous. He can be assured of an additional yield simply by cultivating more of his fallow land. He may well accept better seed if it is offered, if it is free, and if it is clearly demonstrated not only to yield more but also to produce a harvest that commands as high a price as his usual seed. It will also have to be of a form and quality adapted to local preferences. Normally the size of his farm and his lack of capital will make purchase of farm machinery impossible. If he is persuaded into a cooperative venture, or into machinery hiring arrangements, he will be required to change his planting habits, use monoculture, lose the advantages of mixed cropping and the flexibility of operation inherent to the traditional systems, and introduce engineering techniques for erosion control. The difficulties of establishing agreement between all those concerned over the size of area needed for planned conservation works, when holdings are very small, will usually appear to him to be wasted effort. His traditional practice achieves erosion control much more simply. Direct translation of the technical package of fertilizers, pesticides, mechanization, and erosion control structures, so successful in areas such as the Midwest of the United States, to the shifting cultivator of the lowland humid tropics cannot be expected to be successful.

In suggesting the alternatives, the same principles must be followed, but to these must be added the requirement that capital need should be nil, or nearly so.

One solution is to retain the land in such areas for forestry—tree crops such as cocoa, oil palm, or rubber—or where livestock can be raised, for pastures. These reduce the erosion hazard by maintaining a permanent vegetative cover on the soil and require rather limited inputs. Although the cash returns from such forms of land use may allow food to be purchased, rather than grown locally, the distribution of population and the limited size of land holdings will require food to be grown in association with such forms of land use for many years to come. Integration of limited food crop production with forestry—the taungya system or agrisilviculture (*10*)—by interplanting and underplanting of tree crops with food crops at the initial stages of forest regeneration merit much more attention than they have yet received.

Recent studies (*11*) indicate that, at least on slopes up to 15 percent, food crop production can be practiced without serious erosion risk provided that zero or minimum tillage is used, together with crop and weed residues maintained as a mulch. A comparison of erosion under this system with that under conventional tillage (Table 1) shows that the former results in only slight soil loss. The essential factor is the protection of the soil surface against raindrop impact by the mulch of plant residues and the maintenance of the well developed surface aggregation due to the activities of worms and other soil animals, ensuring rapid infiltration of water. The mulch has the additional advantages of helping to conserve plant nutrients, and reducing soil

Table 2. Yields of cowpea and intercropped cowpea and maize under different tillage methods [IITA, Ibadan (second season, 1974)]. All plots received 30 kg of nitrogen per hectare, 30 kg of phosphorus per hectare, and 30 kg of potassium per hectare as fertilizers [on Egbeda series (Paleustalf); unpublished data of Dr. D. Nangju, IITA].

Tillage method	Grain yield (kg/ha)			
	Sole	Intercropping		
	Cowpea	Cowpea	Maize	Total
Plowed and ridged	1185	665	1705	2370
Plowed, flat bed	1274	725	1675	2300
Strip tillage	1538	1022	2337	3359
Zero tillage	1649	941	2809	3750

temperatures which in bare soils can be sufficiently high to inhibit germination and restrict early growth of some crops.

A further factor in reducing the erosion hazard is the use of mixed and relay cropping techniques to keep a plant cover over the soil for most or all of the year. Yields in excess of those from sole cropping can be obtained (Table 2), and such methods may be particularly advantageous when combined with zero tillage methods. The full potential of mixed and relay cropping has yet to be realized. Considerable advantages are to be expected when breeding programs produce plants adapted to production in the mixed crop situation (*12*). In addition to erosion protection and higher yields for equal effort, the diversity of crops produced improves the nutritional value of the produce.

Reasons for the higher yields from mixed crops are not fully understood (*12*), but one important factor is the reduced importance of many pests and diseases compared with sole cropping. If the plant breeder concentrates his efforts on providing pest and disease resistant material it should be possible to keep the requirement for pesticides at a low level and still obtain high yields.

While the use of pesticides may be avoided, a nutrient requirement is inescapable, because removal of phosphorus, and possibly other nutrients, in products sold off the farm must be compensated for if satisfactory production is to be maintained. In most free draining soils, other than those developed on highly basic parent materials, potassium and perhaps sulfur and some micronutrients may also have to be added (*13*). It should, however, be possible to arrange that the nitrogen removals are at least partially made good by bacterial fixation of atmospheric nitrogen. Although significant amounts of nitrogen may be fixed in the tropical environment by bacteria other than those living in symbiosis with legumes (*14*), the gains to be obtained from rhizobia and the legume symbiosis are at present larger. Further, legumes are more readily adapted to production of human food. Consequently a system designed to be self-sufficient in nitrogen will probably have to be one that includes an important legume component.

There are several tropical grain legumes suited to the lowland humid tropics. These include cowpea (*Vigna unguiculata*), lima bean (*Phaseolus lunatus*), winged bean

Selecting cowpea varieties for disease and insect resistance at IITA. Resistant varieties of cowpeas and other grain legumes not only produce higher yields, but are better able to supply nitrogen to the soil and other crops and to increase protein in human diets.

(*Psophocarpus tetragonolobus*), and others (*15*). Most of these may be grown as mixed crops with maize or other cereals and are largely used in this way. Factors determining the amount of nitrogen fixed by the rhizobia associated with these species, and its transfer to the soil and other crop plants, have as yet been insufficiently studied. Application of the acetylene-ethylene assay technique has shown that several of the indigenous cowpea rhizobia have a highly effective nitrogenase content, with a greater potential for nitrogen fixation than many inocula commonly used for legumes such as soybean (*16*). The legumes of the humid tropics should play a much more important part in both the agricultural system and the diet, than they do at present. The improved varieties of grain legumes now available with greatly increased yield potentials should help this to be achieved.

Soil acidity and removal of cations such as calcium, magnesium, and potassium in leachates and crops undoubtedly pose considerable problems in maintaining high levels of crop production. In many parts of the humid tropics lime is not readily available, and transport costs may make liming a prohibitively expensive soil amendment. Its use on acid tropical soils is also liable to be less successful than anticipated, as many soils of the humid tropics appear to be marginally supplied with zinc, and sometimes manganese and iron, so that raising the *p*H by liming can induce deficiencies of these elements (*17*). Under shifting cultivation, acidity and the nutrient balance are restored by the alkaline plant ash added to the soil after cutting and burning; and, as the ash also contains trace elements, deficiencies do not normally arise.

Any improved farming system involving use of fertilizers and removal of larger amounts of nutrients in crops will need a correspondingly increased return of basic cations for acidity correction. If liming is not a practicable proposition, then an alternative must be sought. This will almost certainly have to be some form of fallow crop which is deep rooting and able to gather cations leached from the surface and return them to the topsoil in leaf litter. The appropriate trees or shrubs, such as *Acioa barteri* used for this purpose in Nigeria (*7*), can be grown in alternation with the crop species, or mixed with them; or they can be grown independently and the trash carried to the cropped area and used as a mulch. The frequency and length of fallowing will depend on the leaching intensity; but by proper selection of plant material the period when the land is rested should be substantially less than under shifting cultivation.

System for the Lowland Humid Tropics

The potential farming systems for the small farmer in the lowland humid tropics, which are developing from this work involve (i) zero tillage, and plant residue mulches; (ii) mixed crops of high-yielding varieties that are disease and pest resistant; (iii) fertilizers to replace the phosphorus and possibly other nutrients removed in produce sold "off the farm"; (iv) legumes, with highly active nitrogen-fixing rhizobia to supply nitrogen to the soil and other crops; and (v) control of acidity by means of ash or mulches of deep-rooted species, or by lime and trace elements where lime is readily available.

The ingredients of this farming system have not as yet been put together and tested as a whole, but fortunately this is not an essential preliminary to their use. All are compatible with existing systems of shifting cultivation, and introduction of any one or more of these into the system should lead to immediate though not always dramatic improvements in production. There will undoubtedly be criticisms because the way forward to "advanced" agriculture is believed by many in positions of influence in less developed countries to be through intensive, large-scale mechanization. The proposed improvements may not appear to offer freedom from "the drudgery of the hoe." However, while the system can be combined with the hoe, it can also offer freedom from the hoe, because genuine zero tillage can be used, with existing vegetation killed by herbicides such as paraquat or glyphosate, and post-emergence herbicides used after germination of the crop. The "ultra-low-volume" knapsack sprayer is a much cheaper item of advanced technology for the small farmer to use than a tractor and plow, and likely to cause far less damage than the erosion that has so frequently been induced by inadequately managed mechanization schemes. Introduction of machines developed for a different type of farming is not the best way to reduce drudgery in farming. Suppression of weeds by mulching and minimum tillage constitute appropriate technology that achieve the same purpose, and the real need is to develop appropriate tools for the operations involved.

As improved seeds of better-yielding, pest and disease resistant materials are made available, as fertilizer is introduced, as legume seeds inoculated with highly active nitrogen-fixing bacteria become more widely distributed and more widely used, yields will rise, and the shortening of fallow periods and the extension of cropping periods in shifting cultivation will have less and less detrimental effect. The evolution to continuous cultivation will follow naturally. Present yields under shifting cultivation are mostly low. This new system should enable them to be at least doubled, and often quadrupled. The elimination, or reduction, of the fallow period may mean a further increase of up to fourfold in productivity in these areas. This should be obtainable for a small additional input in the form of mainly nonnitrogenous fertilizers, and possibly knapsack sprayers.

Considerable progress has been made in recent years in producing high-yielding, disease and pest resistant maize, cowpea, cassava, rice, and other crops. With these, with fertilizers and rhizobia, with appropriate tools, and with the collaboration of enlarged national extension services we can expect higher and more stable productivity to come quietly but quickly to the small farmers throughout the world, and have a more lasting effect than the first phase of the Green Revolution.

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