Current and Future Trends in Tillage in the Humid and Subhumid Tropics

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IITA seeks to develop alternatives to shifting cultivation that will maintain the productivity of the land under continuous cultivation in the humid and subhumid tropics; to develop higher yielding pest and disease resistant varieties of cowpeas, yams and sweet potatoes worldwide, and of maize, rice, cassava and soybeans in Africa, and to strengthen national agricultural research systems by a comprehensive training program and collaborative research.

IITA was established in 1967 by the Ford and Rockefeller Foundations, which provided the initial capital for buildings and development, and the Federal Military Government of Nigeria, who allotted 1,000 hectares of land for a headquarters site seven kilometers north of Ibadan.

IITA is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is supported by the Food and Agriculture Organization of the United Nations (FAO), the International Bank for Reconstruction and Development (World Bank) and the United Nations Development Programme (UNDP). The CGIAR consists of about 50 donor countries, international and regional organizations and private foundations.

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Conference Paper 1

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Introduction

When the International Institute of Tropical Agriculture (IITA) opened its doors a dozen years ago, it was certainly not foreseen that the question of tillage would become a major issue in its research activities to the extent where the Food and Agriculture Organization of the United Nations (FAO) Panel of Experts on Agricultural Mechanization would seek its views on present and future trends in this practices.

At that time it was thought that tillage, as a standard agricultural practice to prepare the soil for crop production, would also play its expected role in the agriculture of the humid tropics. This role is related to the traditional western concern with the need and preparation of an adequate seedbed, in good tilth, adequately aerated and as free of competing weeds as possible. All tillage equipment is designed for this basic function. Other equipment — planters, harrows, interrow cultivators, etc. — are equally designed for use in terrain that is even, smoothly worked, easy to penetrate and free of trash.

The task of IITA as an international agricultural research center of the Consultative Group on International Agricultural Research (CGIAR) system is to tackle the fundamental problems of the food production agriculture in the humid and subhumid tropics through the development of more productive and efficient farming systems, and through the improvement of the main staple food crop varieties. Varietal improvements along classical genetic lines — breeding for disease and insect resistance and yield — have not presented IITA with many fundamental problems. In all the crops it has worked with, substantial improvement has been achieved over the traditional varieties used in the past. Parallel research studies in such areas as tissue culture, virology and biological control have contributed greatly to crop improvement successes.

In the improvement of farming systems — the very complex inter-relationship of production factors and constraints requiring a multidisciplinary approach without clear scientific precedent — the going has been quite a bit rougher. Central to this difficulty has been the fact that the systems under which small farmers operate are dependent and operated by biological, physicochemical and socioeconomic factors all interdependent and hard to quantify, especially in an underdeveloped tropical milieu.

The question of land preparation and management is a key item in the research of IITA's Farming Systems Program and is linked intimately with cropping systems, soil productivity, weed management, farm management economics, etc. It is also tied directly to the issue of mechanization of farming systems since tillage is usually a major energy consumer in the production cycles.

In this paper we will concentrate on the two principal factors affecting mechanization in the humid tropics:

- The need for tillage as a standard practice
- The need for economic and social incentives to introduce mechanization

There appears little reason to detail the deteriorating situation of the agriculture, and especially the food production, in tropical Africa. The very thorough studies by FAO (1), the U.S. Department of Agriculture (USDA) (2), and the World Bank (3) have produced ample evidence of the relatively low availability of food per capita from local production and the increasing reliance in many heavily populated parts of Africa on the importation of foodstuffs formerly supplied entirely by local agricultural systems.

In this surrounding of limited hope, one of the overriding factors appears to be the lack of dynamism of the traditional food producing sector, the small farmer who is part subsistence and part market oriented. And the central theme that surfaces when investigating this lack of growth is the need for frequent bush-fallowing to maintain the basic productivity of the land (4,5). Only a few areas in the humid and subhumid tropics are blessed with recent volcanic ash soils and sedimentary or hydromorphic soils that still retain a high level of basic fertility. But in the vast regions of most of West Africa, and in many other parts, the soils deteriorate in a few years. Shifting cultivation and bush fallow systems are the equilibrium response of local farmers. These systems are inherently limited in their productivity and are unresponsive to increased market demands. They may be responsive to population pressures, where these exist, but at the expense of the equilibrium and the productivity of the soils.

Land management, especially tillage, is intimately connected to the problems of maintenance of soil productivity and to the fundamental efficiency of the farming systems operating under these limitations. Land management is also often crucial in the continuous battle against weeds which present a gigantic and almost uncontrolled problem in the humid tropics. Considerable circumstantial evidence exists that the abandonment of a piece of cropland to fallow is frequently also due to weeds which aggravate the negative effects of soil degradation.

Not only does tillage relate directly to soil and crop production problems, but within the settings of most of Africa's rural societies tillage is a matter directly related to the availability of energy, whether human, animal, mechanical or fossil fuel in origin. And last, tillage has an intimate tie to the control of competitive weeds and pests.

Farm Sizes in the Humid Tropics

The post-World War II record for large scale cropping schemes and farming in the humid and subhumid tropics has been rather dismal, and few of these developments have survived very long. Rather than becoming leading entities in developing stable and efficient food production systems, they have more often led to calamitous ecological destruction. Much of this can be attributed to the unthinking transfer of technology from one ecological region to another without consideration of soil, environmental and socioeconomic factors.

The typical farm enterprise in Africa's tropics is the smallholder with a mixed cropping system, part perennial tree crops such as oil palm, bananas and cocoa, and part annual crops of local staples and vegetable crops, often in complicated mixtures that defy description and typology. In the humid and subhumid tropics this smallholder farming system is generally complicated by the existence of large areas of bush fallow land as a reserve. In many cases the fallow land is two to three times the extent of the productive area, leading to low land use factors of 25% to 30%. The farmer is continuously engaged in clearing land from his reserve for future production, leaving the land that has become unproductive to return to bush for periods of 5 to 10 years.

The size limitation of tropical farms, ranging from 1 to 2½ hectares per smallholding in West Africa, is very much related to available manual labor resources within the farm family. The income generating potential of this size of family unit is evidently very low under the poor farming conditions that prevail in the region. Without a substantial increase in the productive acreage per farm unit, it is highly unlikely that living standards of smallholders can be improved sufficiently to compete with the attractions of urban life and employment.

The major constraints to expansion in Africa's humid and subhumid tropics appear to be the need for continuous land clearing on fallow, which takes from 40% to 60% of the available man-days, and weed control, which varies from 20% to 30% of total labor input (6). Various studies have shown that labor inputs are very high under these low efficiency systems. Man-days used per hectare of food crops range from 265 days/ha in eastern Cameroon (7) to 684 man-days/ha for yams in Nigeria (8). Cassava-maize intercropping took just over 200 man-days in western Nigeria, and rice production in Plateau State, Nigeria, took 205 man-days based on 6-hour work days. The latter study also detailed the overall labor input distribution (Fig.1) which clearly demonstrates the importance of weed control in the labor system. Since rice production is mainly on permanently occupied wetlands, the land clearing factor does not appear in this diagram in its normal preponderance.

Rural Population Trends

Recent studies on population trends in West Africa appear to indicate important changes in the population structures in rural areas. The villages are increasingly made up of older people and children, with a marked lack of both males and females in the 16- to 45-year age group. The attractions of the urban areas, the drudgery of the farm work and the lack of modern facilities and opportunities have made serious inroads in the availability of labor, family or hired, for smallholder enterprises. The result has been a steady increase in hired labor wages and a worsening of the returns of the farms that need to rely on outside hired help for their production system.

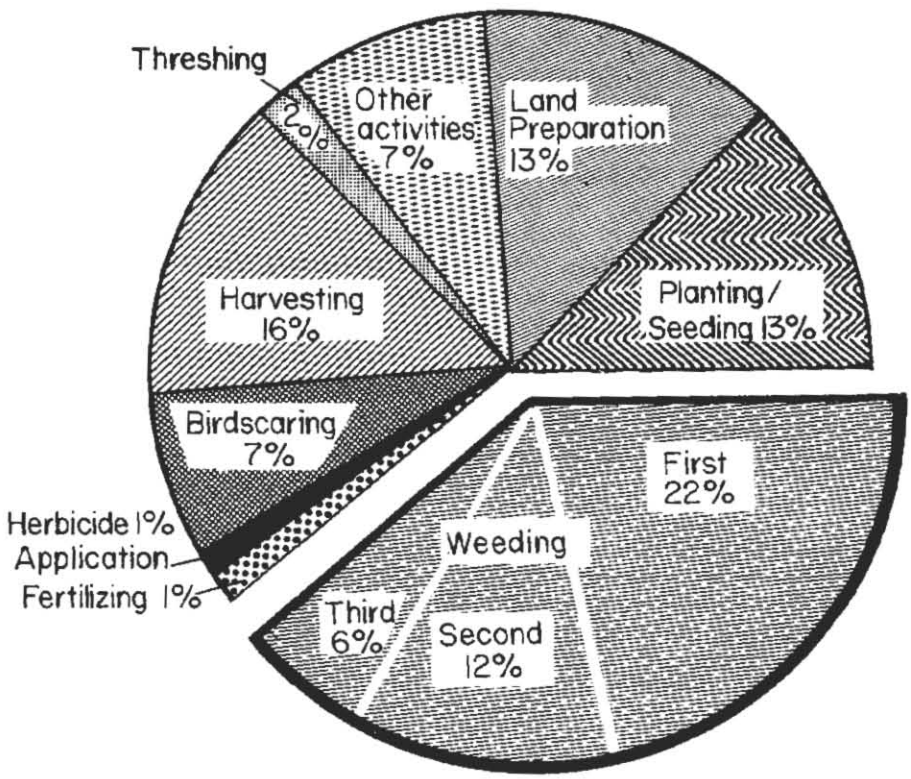

Fig. I. Farm labor inputs for different crop activities during the rice cropping period in Plateau State, Nigeria.

Soils and Environmental Constraints

A large part of the humid and subhumid tropics is covered with the very infertile, leached and highly weathered residual soils — oxisols and ultisols. The alfisols are more predominant in Africa and are slightly more fertile and less acid. The rich inceptisols, andisols, and others are relatively rare in Africa. There are indications that hydromorphic soils may still constitute an important soil resource in tropical Africa, but their management is still very difficult to foresee.

It is now well known that continuous farming on these poor soils results in a rapid decline in productivity due to:

- Soil erosion and loss of colloids
- Rapid mineralization and loss of the soil organic matter
- Deterioration of the soil structure and a decline in nutrient and water retention capacity
- High soil and ambient temperatures
- Nutrient imbalances and increased acidity
- Buildup of hard-to-eradicate weeds

Some of IITA's most important long term experiments have shown this deterioration of productivity often starts right after clearing the forest as a result of destructive mechanized clearing methods that lead to immediate heavy losses of soil from erosion. The subsequent management system is, however, of overriding importance in the maintenance of the land's productive capacity (Table 1).

Table 1. Effects of methods of deforestation on runoff and erosion (9)

Clearing treatment	Runoff (mm)	Soil loss (t/ha/yr)
Traditional	2.6	0.01
Manual clearing - no-tillage	15.5	0.4
Manual clearing - conventional tillage	54.3	4.6
Shear blade - no-tillage	85.7	3.8
Tree pusher - no-tillage	153.1	15.4
Tree pusher - conventional tillage	250.3	19.6

The fundamental management consideration is to maintain better soil structure through (a) continuous ground cover maintenance, (b) high levels of soil organic matter, (c) maintenance of a continuous supply of organic matter to cover the soil surface, and (d) prevention of soil exposure and minimization of the physical impact of raindrops and solar radiation. These practices, which prevent erosion and degradation, depend, of course, on the careful management of organic residues, such as by mulching, growing cover crops, using no-till systems, or alley cropping (Table 2). The maintenance of the soil organic matter at an adequate level is the basic ingredient for managing the acid leached soils of the humid tropics. This cannot be done by the traditional tillage method of plowing in residues, green manures or cover crops. The mineralization of organic crop residues, once incorporated into the soil, is so rapid that its effects on soil organic matter content are negligible.

Table 2. No-tillage effects on soil and water loss under maize (10).

	Soil loss (t/ha)		Runoff (mm)	
Slope (%)	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

The Relevance of Mulch Farming for the Tropics

Research at IITA has clearly indicated that the transformation of forests into agricultural lands should be done in such a way that:

- The ecological balance between the soil, climate and vegetation is not drastically disturbed.
- The soil is continuously covered against intense rains and dessicating insolation.
- The biological activity of the soil is maintained.
- There is a continuous supply of organic material to the surface of the soil.

These precepts are achievable through the replacement of the forest vegetation by an equivalent cover close to the soil surface, facilitating the use of the soil for crop production purposes. The ideal mulch should:

- Rejuvenate itself and be highly productive in biomass.
- Be aggressive against weeds and require little maintenance.
- Be easily controlled by chemical or mechanical means once crops are to be grown.
- Add some plant nutrients, preferably through use of legumes.
- Have some other economic uses, such as fodder, fuel or food (11).

No-tillage and Minimum Tillage Systems and Mulch Farming

It is clear from the foregoing conditions for the maintenance of soil productivity that the question of tillage and land preparation is connected to the requirements for maintaining a surface organic mulch on the land. Research on no-tillage and reduced-tillage systems has shown that soils suitable for limited tillage methods are:

- Coarse textured soils with low activity clays
- Soils with bio-active horizons
- Vertisols with self-mulching properties
- Andisols
- Soils susceptible to severe erosion hazards

Reduced or no-tillage systems are less suitable on soils prone to crusting or compaction, poorly drained and massive structured soils, those with low biotic activity and soils that are very uneven and highly variable. Some form of mulch and organic residue management benefits these soils greatly.

Closely interlinked with mulch farming and the no-tillage approach is the management of weeds within cropping systems. People who have no experience in tropical agriculture cannot imagine the speed with which clean land can be taken over by fast growing and very competitive weeds — weeds that are adapted to the acid and low fertility conditions of the soils and can outgrow and outperform foodcrops — that are more adapted to fertile productive substrata.

Weeds present a major challenge in no-tillage mulch farming since normal mechanical means of intra-crop cultivation are nearly impossible with standard equipment. IITA's research has developed a number of low cost herbicide based management systems that show great promise, but are as yet rather sophisticated and risky for the small African farmer. More promising is the present effort to use an integrated weed management approach where cover crops and some weed suppressing crops such as cassava are used in the cropping system to lower weed population levels at critical times in the cycle. Limited mechanical systems are also being considered within this approach, and we are even attempting to use some weeds for quick mulch production in-situ.

Alley Cropping: A Mixed Fallow/Cropping System

Alley cropping, a promising system developed over the last several years, consists of growing rows of foodcrops between deep rooted trees. The trees are pruned or pollarded at regular intervals to control shade and to

produce mulch materials that are spread on the cultivated land between the rows. In long term experiments at IITA this association of plants has maintained excellent continuous productivity and fertility maintenance. Several leguminous tree species have been used with considerable success and have contributed some nitrogen to the cropping system.

Inter-row tillage is feasible in alley cropping provided the alleys are planted with foresight for equipment width, etc. However, here again a minimum or no-tillage system has shown itself superior. Weed control in this system presents its own problems since alley crops are often sensitive to any herbicide used for weed control.

Animal Power and Tractors

IITA has not been in a position to study animal traction for small farms due to the widespread presence of the tsetse fly in the humid and subhumid parts of Africa. Other institutions have made considerable progress in developing appropriate equipment for animal traction in the arid parts of sub-Sahel Africa.

IITA's emphasis has been on the development of manual and low horsepower equipment for no-tillage and mulch farming systems. The main concentration has been on planting and weed control equipment which has led to the successful development of the rotary injection planter with fertilizer applicator, and the farmobile — an all purpose, low horsepower two-wheel tractor with various attachments (12). Both of these machines appear very adaptable for use on larger than standard smallholder areas. The economics of these machines on 10- to 30-hectare farms appear favorable. They are simple in operation and maintenance.

IITA's Views on Current and Future Trends in Tillage

The future of food production in the African tropics probably will depend on the upwardly mobile smallholder, the farmer who traditionally is a subsistence producer for 50% to 100% of his produce, but who is motivated to expand his production and land cultivation to achieve a market production of 50% to 100%. The farmer will have to achieve this through more efficient methods and labor saving devices and equipment since the energy input based on hand labor by him and his family will never allow conversion to market production. This conversion must be sufficiently attractive to compete with the material glitter of the urban areas in arresting the very serious drift of capable young people away from the villages.

Based on IITA's 10 years of farming systems research, we are convinced that the critical area to bring about improved output from the production systems in the humid and subhumid tropics is in methods to avoid soil degradation and the need for extended bush fallow together with effective and efficient weed control systems. To a large extent this can be achieved by combinations of reduced and minimum tillage and strategic use of mulches and cover crops in the farming systems. Maximizing the crop cover at all possible times by intercropping, alley cropping and other techniques, such as live mulches, will probably become a major consideration for effective productivity maintenance even though light and nutrient competition will limit the yields of the individual components of such complex systems.

Such developments, including the decline in energy needed for bush clearing and tillage, should increase the amount of land production, the efficiency of the system and yields. However, it is just as clear that this expansion in production can only be achieved by the development of appropriate equipment for the small to medium farmer to handle his increased tasks of planting, crop management, harvesting and drying. IITA's experience in these developments is as yet limited. The development of the rotary injection planter and other equipment has eliminated the plant establishment bottleneck, but institute scientists have run into harvesting and crop drying problems that have us temporarily stymied.

Even though IITA's major emphasis is directed toward the small and medium farmer of the humid tropics, some attention is being paid to the application of these same principles to large scale farming. A number of governments in the humid tropics of Africa and other continents have definite policies for the development of

large scale farming in their countries as a device for food security. Earlier reference has been made to the frequency of disastrous results in cultivated large scale agriculture in this climatic zone. Based on the findings reported earlier in this paper, these poor results are not surprising. In none of these development schemes was consideration given to the very essential needs for careful management of organic residues, together with the judicious manipulation of crops and soils. On leached alfisols around IITA's main station at Ibadan, the best western conservation farming techniques led inexorably to production declines in a matter of three to five years.

It is unfortunate that large scale farming under no-tillage and mulch cover conditions presents its own set of bottlenecks which are worse than those for small scale systems. The required use of large machinery for other farm operations on the structurally fragile tropical soils can lead quickly to serious compaction that will negate the benefits obtained from the mulching/no-tillage practices. IITA is testing and looking at various mechanical and biological means to alleviate this problem. Large scale alley cropping and cover cropping present problems that must still be solved. The recent interest of developed countries in mulches and crop residues has brought forth a promising set of new shredders and mulchers that may be useful for developing this form of agriculture.

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