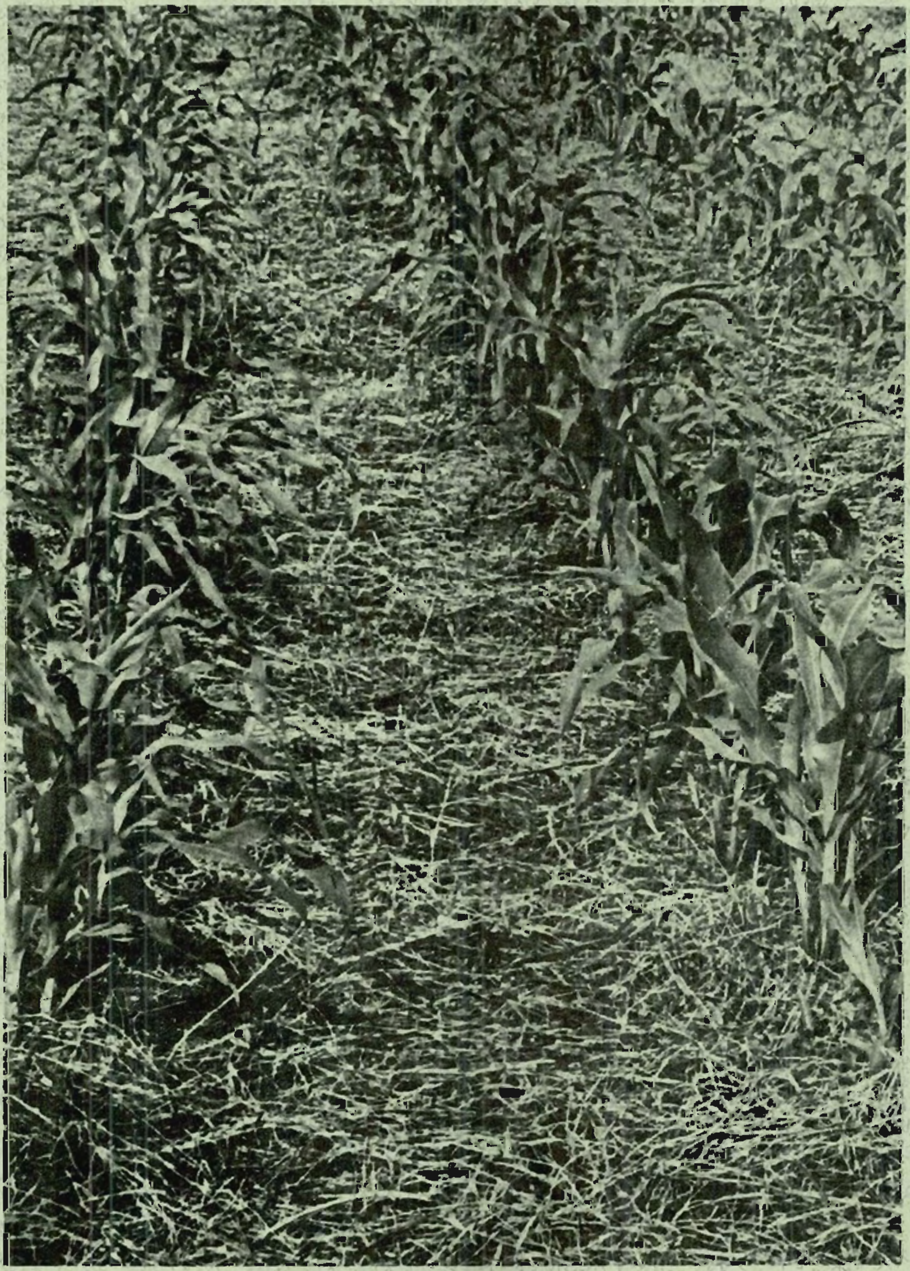
NO-TILL FARMING

Soil and Water Conservation and Management in the Humid and Subhumid Tropics

R. Lal



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FOREWORD

This technical bulletin is an accounting of experiences of a group of dedicated and highly qualified scientists in their search for answers and solutions to one of the central and most perplexing questions for which *IITA* was created. It is the problem of how to manage a farming system for small farmers in the humid tropics that allows a stable, permanent and productive agriculture without ruining the soils and environments or having to resort to shifting cultivation or bush-fallow systems of traditional agriculture.

During my nearly three years at *IITA* I have become increasingly impressed with the amount of experimental information accumulated toward solving this central problem of food production in the humid tropics. It is difficult to decide when the body of knowledge -- the evidence -- is sufficiently clear to publish and disseminate. Scientists are often reluctant to go out on a limb before all the evidence is in. Agricultural research is especially prone to this restriction, frequently creating very long lead times to the solution of agricultural problems. This factor has caused serious delays in the development of acceptable technologies for solving one of the most pressing global problems of the day -- the production of food in the developing world to satisfy the hunger that besets its rapidly expanding populations.

It is fortunate that in this case we have managed to avoid this pitfall, and that the various pieces of a multifaceted system such as *No-Till Farming* have fitted together in a coherent form.

Here then is the point where *No-Till Farming* can be recommended for many of the acid and leached problem soils of the humid and subhumid tropics. The evidence is clear. The key factor for a stable productive agriculture in these regions is soil management in its broadest sense.

The no-till farming system as developed by the staff of the Farming Systems Program at IITA should be seen as a flexible framework that can be adapted, amplified, or reorganized to suit local conditions. Other practices, provided they do not materially alter organic matter maintenance and erosion control, can be incorporated into this system. The Institute will continue its research on no-till farming, especially on other complementary and compatible practices such as alley cropping and live mulch, in order to improve the overall crop and soil management system. In the meantime, IITA is ready to support efforts toward agricultural development where no-till farming can play an essential role.

E.H. Hartmans
Director General

September 1981

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This bulletin is complimentary to IITA Technical Bulletin No. 1 published in 1975. The data presented summarizes 12 years of work conducted by the staff, research scholars and junior scientists in soil physics. Some of the published data quoted in this report are based on the work of Drs. P.O. Aina, A.H. Anastase, M. Armon, D.J. Cummings, D. De Vleeschauwer, H.O. Maduakor, P.R. Maurya, R. Malafa Nganje, S. Osei-Yeboah, and M. Rodriquez. Some of the work referred to is also jointly published by the author with other colleagues of IITA: S. Claassen, D.C. Couper, S.K. Hahn, T.L. Lawson, B.N. Okigbo, R. Wijewardene and G.F. Wilson.

My very special thanks are due to the tremendous contributions made by the entire field and laboratory staff of the soil physics section. Although it is difficult to mention the names of all excellent field staff who have come and gone over the past decade, names of the following staff deserve special mention: S. Ojo, L. Shittu, J. Akintunde, O. Ogunjimi, I. Alayo, R. Oluremi, S. Ewe, L. Agidhi, J. Agboola, R. Yusuf, S. Oyeyemi, and O. Joseph.

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Ibadan
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1. INTRODUCTION

Land is a non-renewable limited resource and should be used, improved, and restored.

The importance of this basic principle of land use and its management should be upheld in view of this ever shrinking natural resource base. There are currently 1,500 million hectares of cultivated arable land area in the world. An additional 2,000 million hectares of land that were once biologically productive have been irreversibly degraded (FAO, 1979; Schulze and Van Staveren, 1980). In addition, about 6 to 10 million hectares of land are being developed annually from tropical forests for arable land use (Boerma, 1975). These large-scale land development programs are being implemented lacking research information that could provide guidelines on the best methods. The land is being developed and managed by practices often least desirable for the harsh climatic environments and fragile soils of the humid and subhumid tropics. As a result, large land tracts where lush green forests once grew are being rendered barren and unproductive.

Numerous large-scale land development programs with mechanized agricultural production are inevitable as attempts are made to rapidly increase food production. What may not be obvious to planners and decision makers is the soil and environmental consequences of these programs, they can develop cultural practices that will minimize their degrading effects. Alternatively, gradual improvements can also be made in traditional farming practices to increase the food production capability of small farmers.

Research scientists, decision makers and planners, under pressure to increase food production rapidly and substantially, are faced with important questions:

1. Why do soils deteriorate in the humid and subhumid tropics under continuous cultivation?

2. How can this degradation be stopped, yet maintain productivity?

Some researchers believe that through technological advances and its timely implementation we can solve problems of land development and soil management in the tropics. Others prophesy imminent disaster. The answer to these questions lies in understanding the basic principles, and in evaluating the chnages, in ecological parameters and their magnitude and consequences. Only then can scientists develop or adopt cultural and agronomic practices of soil management that either maintain a status quo or cause only minimal alteration in ecological factors.

Mechanical seedbed preparation and weed control measures can cause rapid soil deterioration and degradation. The objective of this bulletin is to compile up-to-date research information on the no-tillage method of seedbed preparation. It deals only with those aspects of no-till farming concerned with problems of soil and water conservation and management. An attempt is also made to assess soil factors that affect the choice of appropriate tillage methods. The results presented are based on about 12 years of experiments conducted on Alfisols in western Nigeria. They can be adopted for similar soils and environments elsewhere. Some experiments were also conducted on Ultisols in eastern Nigeria and Liberia.

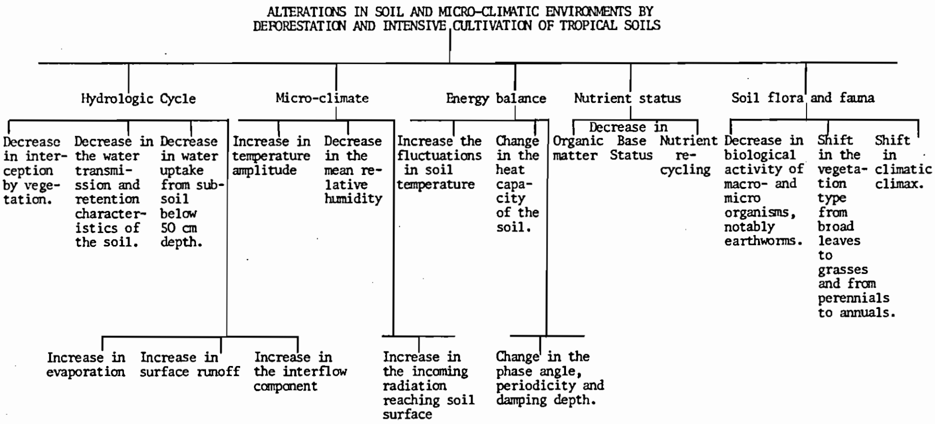
11. SOIL AND ENVIRONMENTAL EFFECTS OF DEFORESTATION

Deforestation affects the hydrologic cycle, microclimate, energy balance, soil physical and nutritional properties, and floral and faunal activity (Table 1). The magnitude of change in different components of these ecological parameters also depends on methods of deforestation (Lal, 1981; Lal and Russell, 1981).

Microclimate

Removal of the forest results in significant changes in air and soil temperature and relative humidity (Figs. 1-3). An increase in the maximum temperature at different heights above the ground surface may be 5-8^{o}C. In addition, there are phase differences in the temperature wave (Fig. 1). The magnitude of change in soil temperature by deforestation is even greater than in air temperature. In general, the maximum soil temperature is proportional to soil disturbance and inversely related to the ground cover. The maximum soil temperature is, therefore, higher on mechanically cleared plots than on

Table 1. Effects of deforestation on ecological parameters (Lal, 1981e)



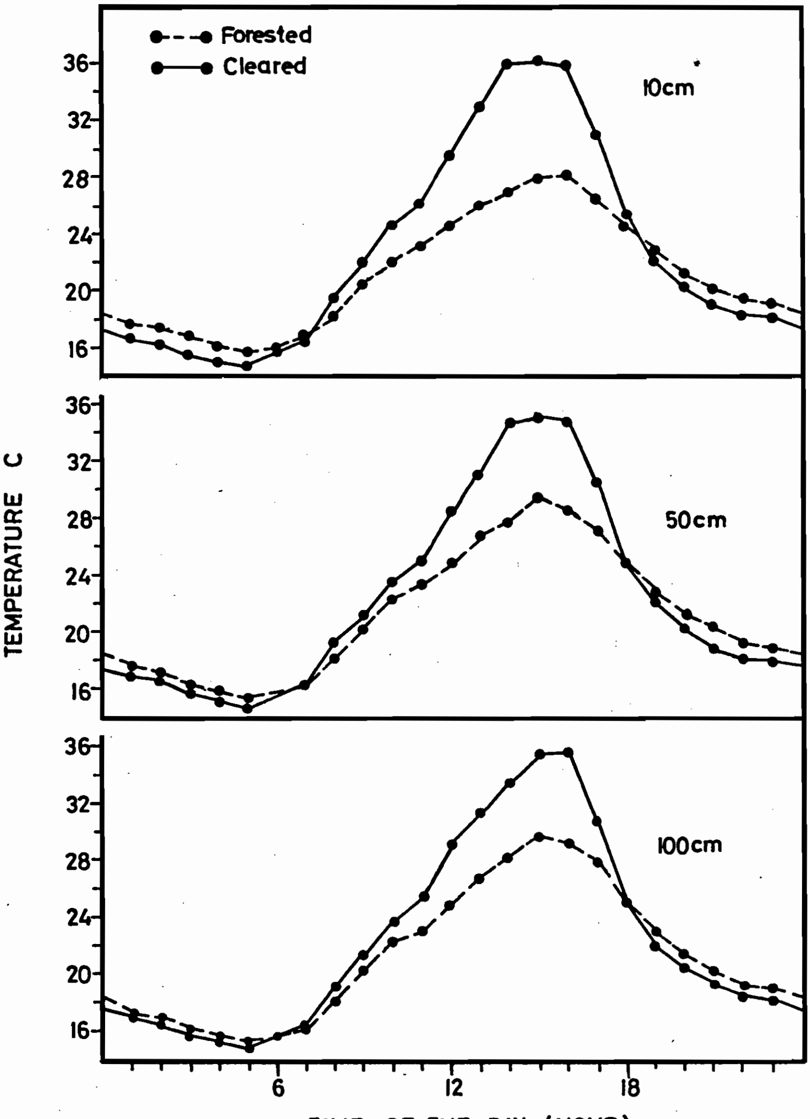


Fig. 1. Effects of deforestation on air temperature (Lal and Cummings, 1979).

those manually cleared, and can be 20-25°C higher than forested control at a 1 centimeter depth. The differences in soil temperature by deforestation are significant even at 5, 10 and 20 centimeter depths (Fig. 2). The relative humidity is generally lower on cleared land than under forest canopy (Fig. 3), and the time minimum relative humidity occurs may be 2-3 hours later on cleared than on uncleared land. Deforestation, therefore, increases the aridity of the microclimate.

Soil physical properties

Deforestation increases soil compaction, decreases total and macroporosity, water retention, and transmission properties. The most significant increase in bulk density and changes in other soil physical properties occurs in the upper few centimeters of the soil (Lal and Cummings, 1979). Forested soil in the humid and subhumid regions of west Africa is generally covered with loose earthworm casts up to approximately 3 centimeters deep. The bulk density of this layer is generally 0.5 to 0.8 g/cm^3. This loosened soil surface is sensitive even to light traffic, which will easily result in soil compaction. Compaction is greater in mechanically than manually cleared land.

Hydrological characteristics

Hydrological balance is drastically affected by deforestation due to an increase in water runoff and seepage flow, and a decrease in soil-water storage in the root zone (Fig. 4). Experiments conducted at IITA and in east Africa (Pereira, 1973) have indicated that a forest ecosystem is a "close system" with little or no runoff. The pumping action of deep root systems of perennial tree species minimizes losses due to seepage and interflow. Deforestation may increase the total water loss from less than 1 percent to as much as 30 percent of the precipitation received. This increases the hazard from erosion and the susceptibility of crops to drought stress even a few days after a heavy rain. The amount of water runoff is higher from mechanically than manually cleared land, and is directly related to compaction and soil disturbance caused during clearing. Experiments conducted at IITA showed that during the first season after clearing, the water runoff was 2.5 mm, 35 mm, and 163 mm from watersheds cleared by traditional, manual, and mechanized methods, respectively (Lal, 1981b). Soil erosion,water runoff, and subsequent degradation with mechanized clearing also depends on the choice of the clearing attachment, soil moisture at the time of clearing, soil properties, skill of the heavy machinery operator during use, and post clearing tillage methods and land management (Lal, 1981b).

Biological activity

Earthworms and other soil animals play a significant role in productivity of tropical soils as is discussed in Section V11-6. A notable effect of deforestation on biological activity is on earthworms (Plate 1). Two types of worm species commonly observed in western Nigeria, *Hyperiodrilus africanus* and *Eudrilus eugeniae* can produce casts at the rate of 50 to 100 t/ha/yr under favorable conditions in a forest ecosystem. The peak activity, which is dependent on the rainfall distribution, is observed during July and September. Earthworms remain dormant or burrow deep into the soil when soil moisture is too low and soil temperature regime is supraoptimal. Compared with a forested control (Fig. 5), mechanical clearing that causes soil compaction and removes the entire biomass from the soil surface results in a drastic reduction in earthworm activity.

111. SOIL EROSION THROUGH DEFORESTATION

The most widely used empirical parametric equation to predict erosion hazard is the Universal Soil Loss Equation (USLE) (Wischmer and Smith, 1978). This equation is defined as:

$$A = RKLS\ CP$$

where A = Soil erosion (t/acre)
R = rainfall erosivity index ($EI_{30} \times 10^{-2}$)
K = Soil erodibility
L = Slope length
S = Slope steepness
C = Crop management
P = Engineering practices

The rainfall erosivity factor R for the humid and subhumid regions of west Africa ranges from 500 to 2000 foot-ton/acre/year (Roose, 1977). By comparison, the maximum erosivity factor is 227 for Belgium (Bolline, et. al, (1980), 147 for Holland (Bergsma, 1980); and 550 for the continental United

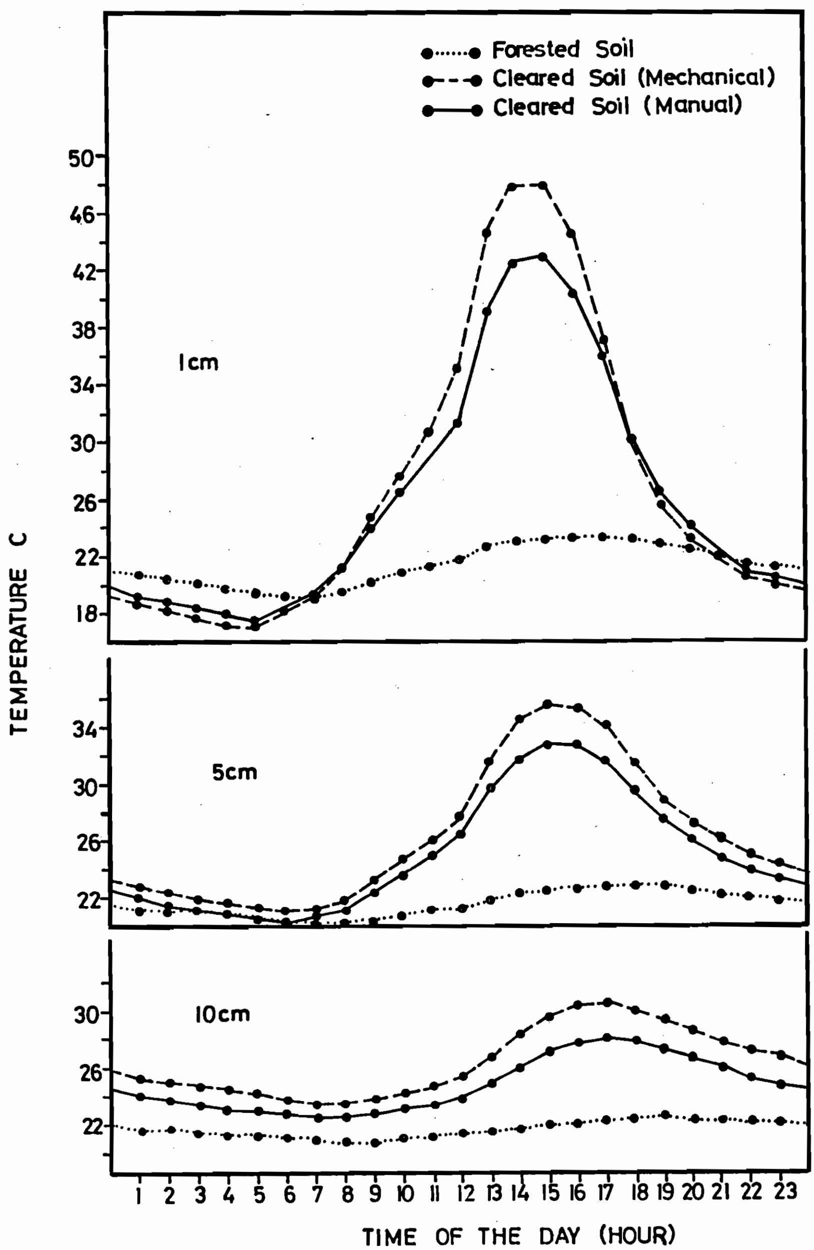


Fig. 2. Effects of deforestation on soil temperature (Lal and Cummings, 1979).

States (Wischmeier and Smith, 1978). Removal of the protective effects of the forest vegetation exposing structurally unstable soil to the driving force of rains results in accelerated soil erosion from arable lands of even gentle slopes (Plate 2). The effects of deforestation on soil erosion are further confounded by the techniques of land clearing and post-clearing soil management (Lal, 1981b). In general, erosion is more severe on land cleared by mechanised than manual farm operations (Table 2) and there are significant differences in erosion due to different attachments used (Plate 3). The driving force of tropical rains as measured by sand splash is significantly correlated with the kinetic energy or momentum of the rainstorm (Figs. 6 and 7). Kinetic energy of 67 Jm^{-2} mm^{-1} of rain and more has been recorded at Ibadan (Lal, 1980) and for northern Nigeria (Kowal et al, 1977). This high energy load is due both to rains with a sustained intensity up to 150 to 200 mm hr^{-1} for a period of 5 to 10 minutes, and to a high median drop size that may exceed 3 mm (Aina et al, 1977 ; Lal et al, 1980; Lal, 1981). Soil infiltration capacity is drastically lowered by mechanized clearing (Lal and Cummings, 1979; Seubert et al, 1977), thereby increasing the erosion hazard.

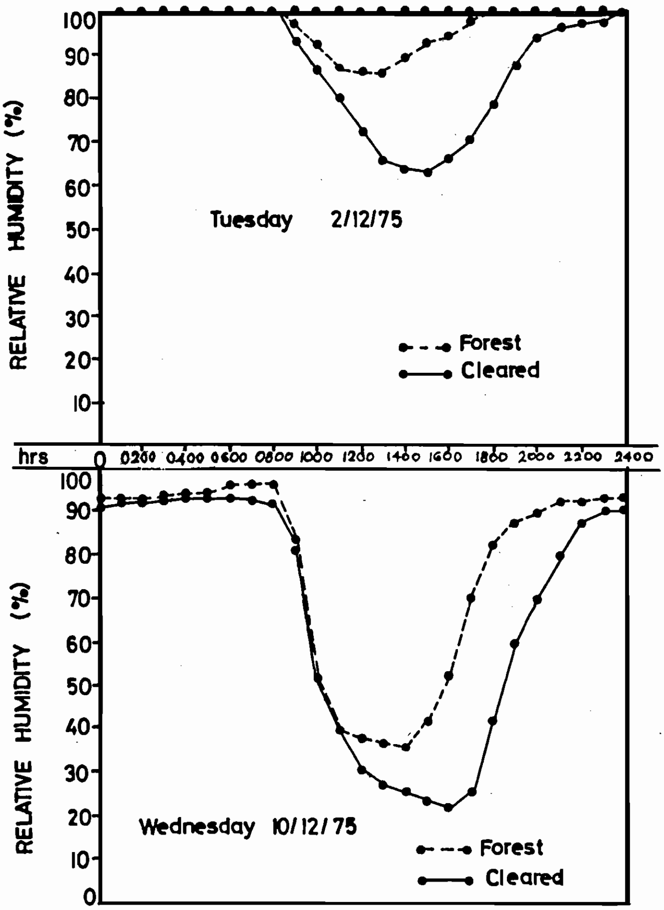


Fig. 3. Effects of deforestation on relative humidity (Lal and Cummings, 1979).

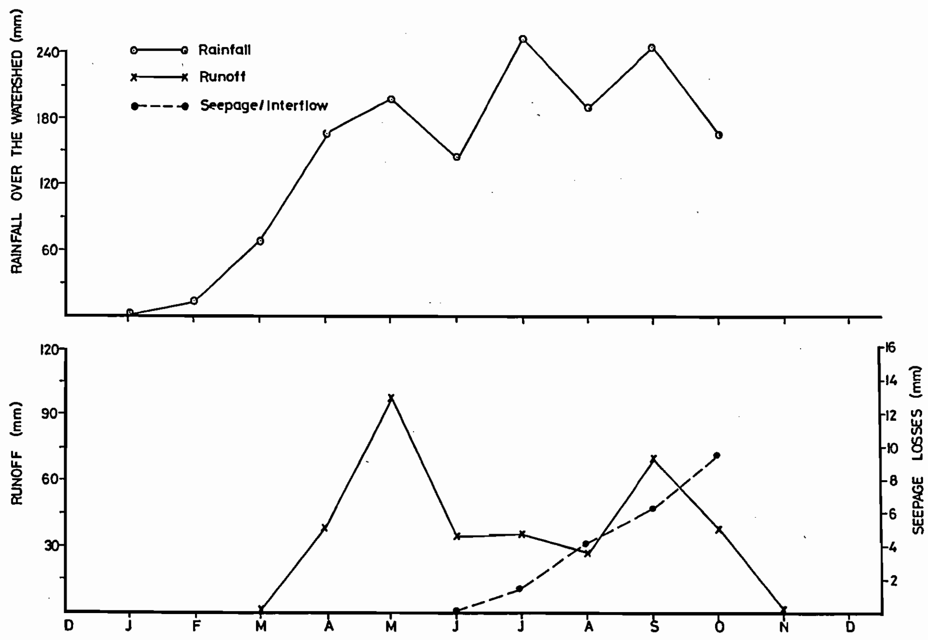


Fig. 4. Effects of deforestation on total water yield (Lawson, Lal and Oduro Afriyie, 1981).

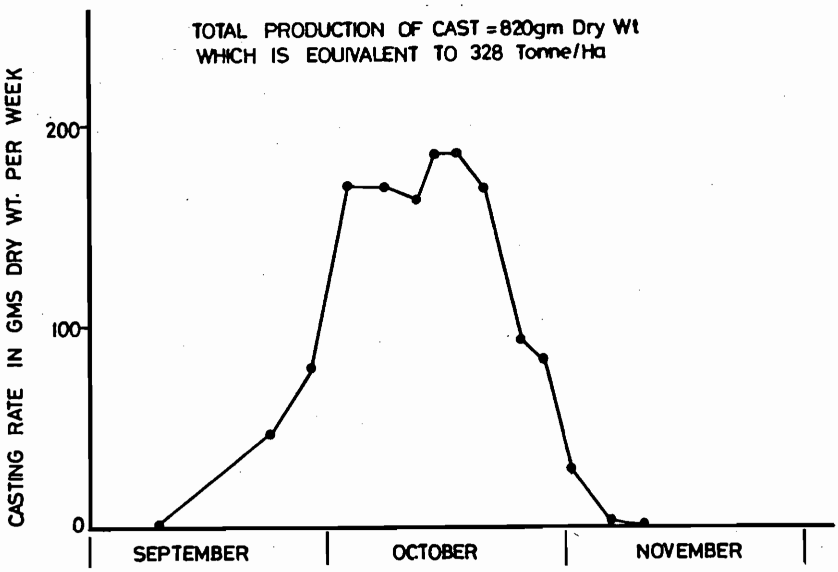


Fig. 5. Seasonal activity of *Hyperiodrilus africanus* under forest

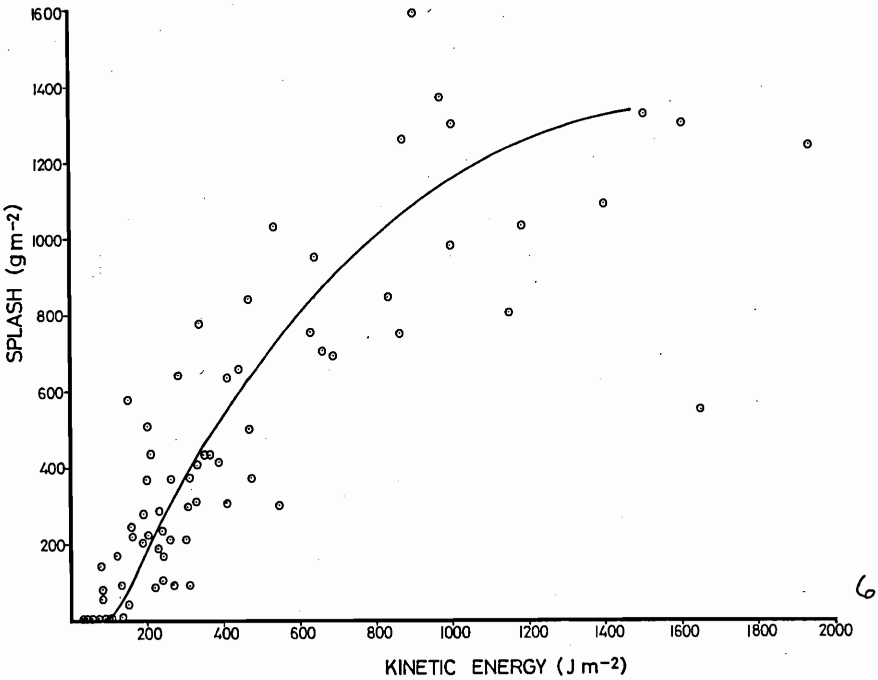


Fig. 6. Sand splash and kinetic energy of tropical rains (Lal, 1980a).

Another important concept is the "soil loss tolerance", defined as the maximum rate of soil erosion that will permit sustained crop productivity and prolong the period of economic land use. Soil loss tolerance is related to soil properties -- available rooting depth, texture and structure, plant nutrients and their distribution, and crop characteristics -- and is independent of agents that cause erosion. The currently used rates of 12.5 t/ha/yr would be excessive for many soils in the tropics. The soil loss tolerance for many soils on a toposequence in western Nigeria ranges from 0.05 to 2 t/ha/yr (Fig. 8) (Lal, 1983). This estimate is based only on yield reduction and does not take into consideration off-site damages caused by soil erosion. Off-site damages include siltation of reservoirs and harbors, flooding and other hazards that erosion may cuse to soils and crops down the slope.

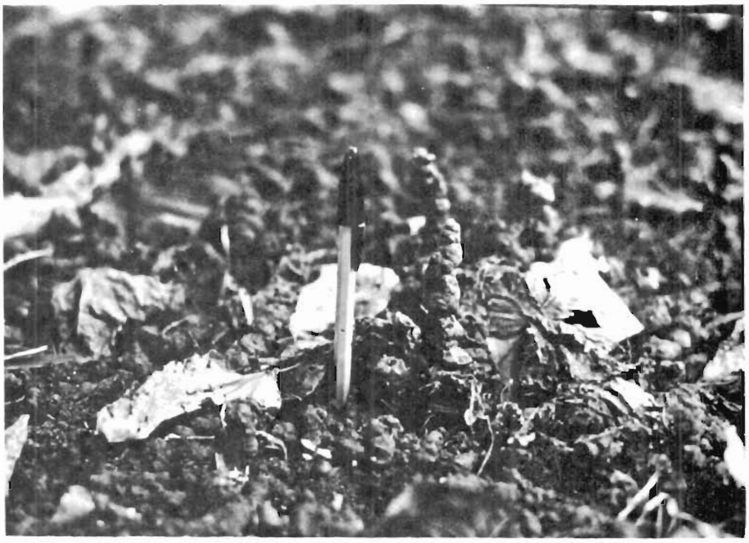


Plate 1. Earthworm activity under forest vegetation cover.

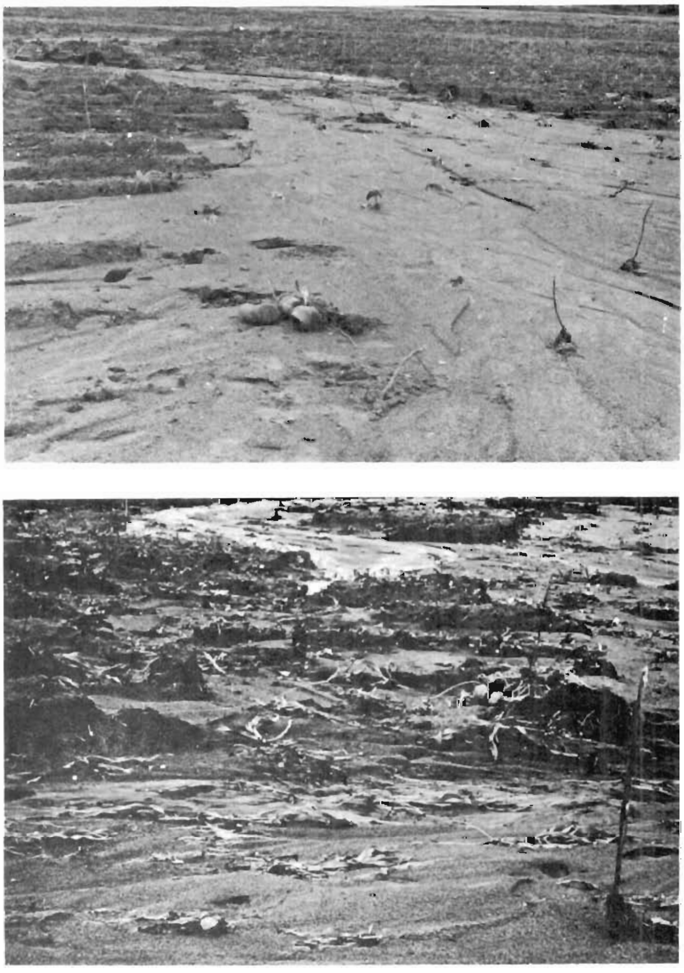


Plate 2. Soil erosion on land prepared with mechanical methods of seedbed preparation (a) erosion on ridged yam (b) erosion in maize.

Table 2. Effects of methods of deforestation and post-clearing soil management on runoff and erosion from an Alfisol for maize-cassava-maize-cowpea rotation from 1979-1981.

Land management treatment	Runoff (mm)	Soil erosion (t/ha)
Forest	<1	<0.01
Traditional farming	6.6	0.02
Manual clearing/no-tillage	16.1	0.4
Manual clearing/conventional tillage	79.7	4.8
Shear blade clearing/no-tillage	104.8	4.1
Tree pusher-toot rake/no-tillage	107.0	15.7
Tree pusher-root rake/conventional tillage	330.6	24.3

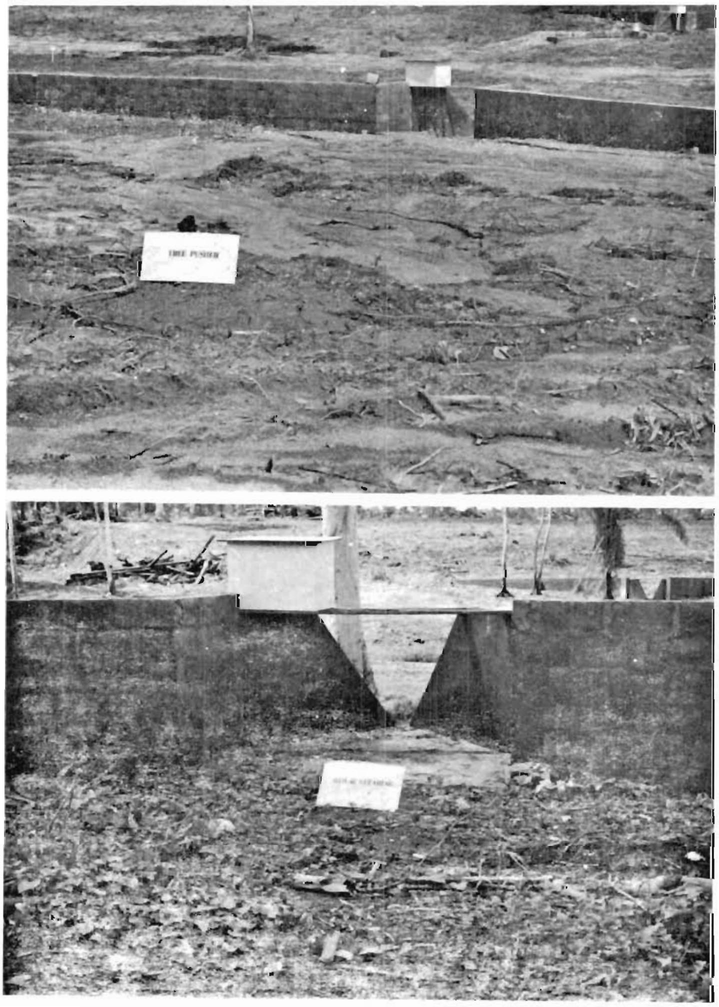


Plate 3. Soil erosion from watersheds cleared by (a) tree pusher/root rake and (b) manual methods

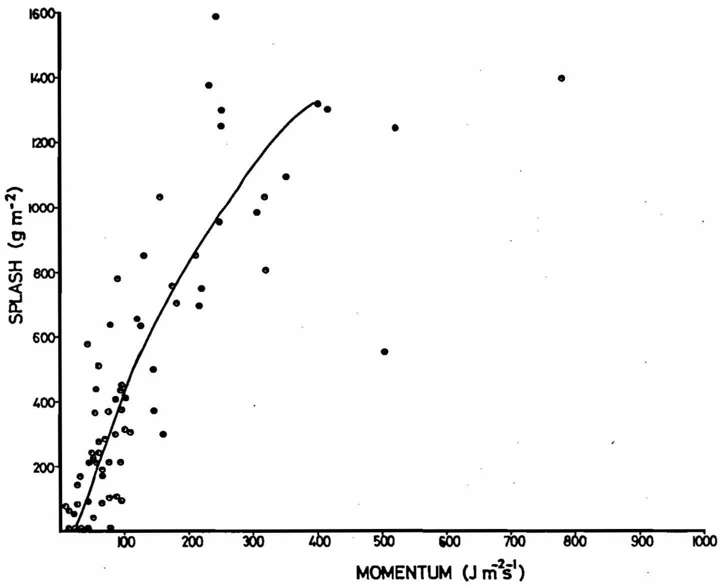


Fig. 7. Sand splash and mementum of tropical rains (Lal, 1980a).

Table 3. Relationship between yield of maize and cowpea with soil erosion (Lal, 1981a)

Slope (%)	Regression equation	Correlation coefficient (r)
Cowpea		
1	$Y = 0.43\ e^{-0.036x}$	-0.85*
5	$Y = 0.64\ e^{-0.006}$	-0.97**
10	$Y = 0.49\ e^{-0.004x}$	-0.91*
15	$Y = 0.29\ e^{-0.002x}$	-0.66
Maize		
1	$Y = 6.41\ e^{-0.017x}$	-0.99**
5	$Y = 6.70\ e^{-0.003x}$	-0.99**
10	$Y = 6.70\ e^{-0.003x}$	-0.89**
15	$Y = 8.36\ e^{-0.004x}$	-0.86*

Y = grain yield (t/ha)
x = accumulative soil loss (t/ha)

Soil erosion is particularly serious if the land productivity cannot be restored by improved systems of management. Data in Fig. 9 shows drastic yield reductions of maize grown on Alfisols with 10 and 20 cm of surface soil removal. Since the nutrients and organic matter contents are concentrated in a few centimeters of soil surface, and exposed subsoil horizons create unfavorable environments of root growth and proliferation, the loss of the fertile surface horizon cannot be compensated even by the addition of heavy doses of commercial fertilizers (Lal, 1981). Restoration of an excessively eroded land is difficult at best. Declines in crop yield due to soil erosion is exponential (Table 3), with an exponent and coefficient that vary for different soils and crops.

Furthermore, soil erodibility is a time-dependent function (Fig. 10), and its magnitude of change with time depends on the soil management system adopted, soil and rainfall characteristics. Soil erodibility increases rapidly with time after deforestation, and the rate of increase is greater for soil degrading than soil conserving systems (Eq. 1). The rapid increase in erodibility after clearing is attributed to a decrease in organic matter content and a decline in the structural stability of the soil.

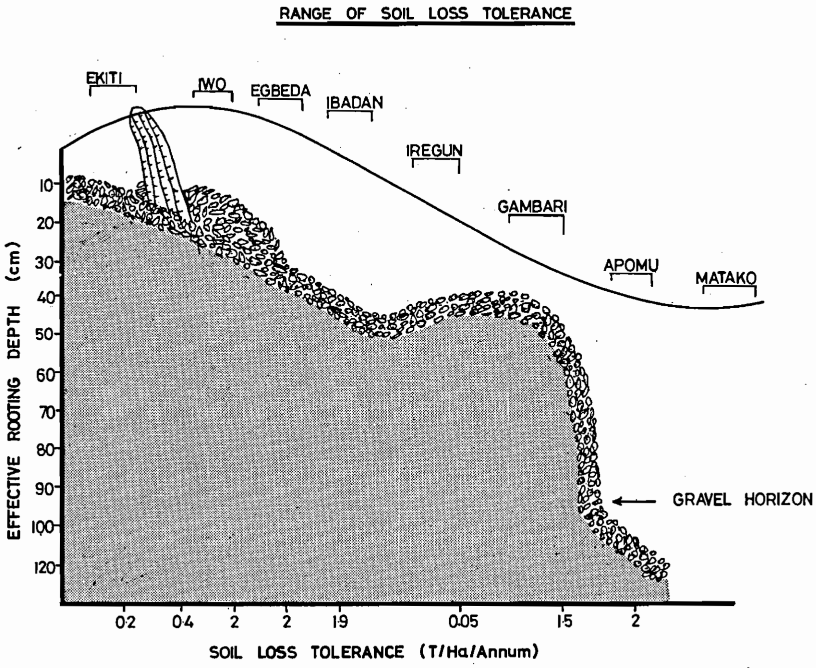


Fig. 8. Soil loss tolerance of different soils on a toposequence of an Alfisol in western Nigeria.

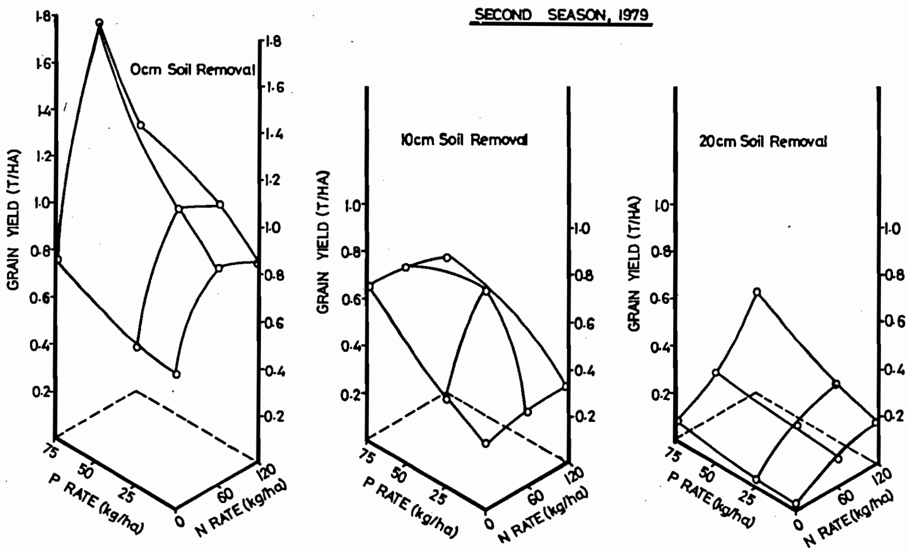


Fig. 9. Effects of artificial soil removal on maize grain yields.

Soil Erodibility K(t) = F(texture, structure, organic matter, iron and aluminium ocides, and management)

$$\frac{d\,k(t)}{dt} = F(\text{management}) \quad \ldots \quad \ldots \quad \text{(Eq. 1).}$$

Erodibility of soils (K) in the humid and subhumid tropics is generally low and ranges from 0.004 to 0.137 (Roose, 1977; Lal, 1976; Lal, 1979b). By comparison, the maximum erodibility of soils in the continental United States is 0.69 (Wischmeier and Smith, 1978). The high susceptibility of tropical soils to erosion by water is therefore attributed to high climatic erosivity and its enormous degradative effects and to low soil loss tolerance.

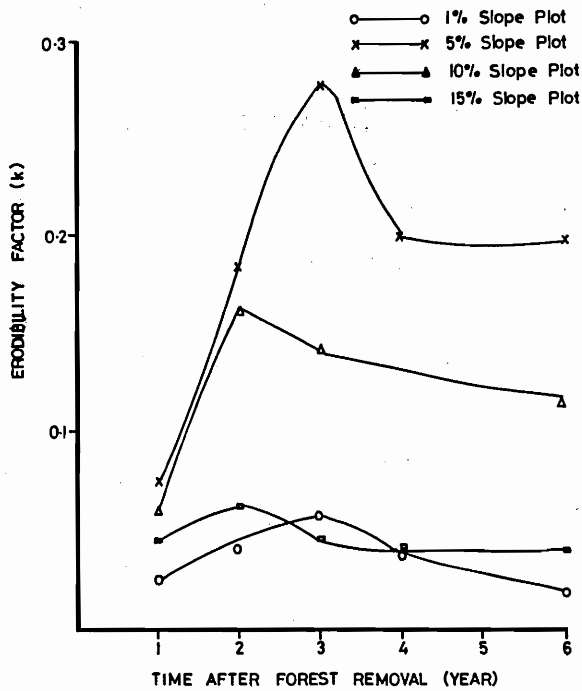


Fig. 10. Changes in soil erodibility with time (Lal, 1981a).

1V. SOIL CONSERVATION: EFFECTIVE MEASURES WITHOUT FOREST CANOPY

Cultural practices that are known to prevent soil erosion are those that maintain similar soil and environmental characteristics, as under native vegetation cover, and those that minimize the ecological imbalance that occurs by reckless deforestation. The basic conservation principle involves the substitution of a tall forest canopy by a low ground cover that permits growth of seasonal and annual crops with minimum soil exposure to impacting rain drops. Cultural practices developed on this principle can sustain and prolong economic crop productivity, and will minimize both on-site and off-site damages to crops and environments. Protecting the soil with a low ground cover (e.g. mulch) is an erosion preventive measure and does not require complimentary curative or reclamative measures for erosion control. These *preventive* measures should be preferred over the *curative* measures because the latter are expensive to install and maintain, are frequently ineffective, and often too late to be useful.

Crop residue mulch at 4 to 6 t/ha has proved effective in preventing soil erosion even on slopes of 10 to 15 percent (Table 4). The coefficient of the exponential equation relating soil erosion with slope steepness generally decreases by several orders of magnitude (1180 times for 0 vs 6 t/ha of mulch for data shown in Table 4) with an increase in the mulch rate from 0 to 6 t/ha, irrespective of slope steepness. Durability and persistence of crop residue mulch also depends on termite activity. Termites may consume the residue mulch rather rapidly, and they are generally more active in the semi-arid than humid regions.

Biological control measures are superior to engineering practices based on safe disposal of excess water runoff because they also improve and restore soil hydrological, physical, and biological properties. Mulch rate is linearly related to infiltration rate, porosity, saturated hydraulic conductivity, available water holding capacity and structural stability (Table 5). Earthworm activity, as determined by the rate of cast production voided on the soil surface, is also related to the quantity, quality, and durability of residue mulch (Lal et al, 1980b). Mulch material and organic matter decompose much faster in the tropics than in the temperate regions (Jenkinson and Ayanaba, 1977). This may imply that the maintenance of a continuous ground cover with adequate mulch rate is easier said than done. For example, the data in Table 6 show that even within 60 days after application, rice straw had decayed 49,

Table 4. Relationship between slope steepness and soil erosion for different mulch rates. (Lal, 1976b)

Mulch rate (T/ha)	Regression equation	Correlative coefficient	Mean soil loss (t/ha)
0	$Y = 11.8\ S^{1.13}$	0.81	76.6
2	$Y = 0.5\ S^{0.87}$	0.35	2.40
4	$Y = 0.07S^{1.05}$	0.57	0.37
6	$Y = 0.01S^{1.0}$	0.46	0.09

Y = Erosion (t/ha)

S = Slope (%)

Table 5. Effects of mulch rate on soil physical properties and earthworm activity. (Adapted from Lal et. al., 1980)

Soil Property	Regression Equation	Correlation coefficient (r)
Porosity (%)	$Y = 53.3 + 0.6\ X$	0.98**
Saturated Hydraulic Conductivity ($cm\ hr^{-1}$	$Y = 60.8 + 9.1\ X$	0.90*
Infiltration Rate ($cm\ hr^{-1}$)	$Y = 37.8 + 2.5\ X$	0.76
Available Water Holding Capacity (cm)	$Y = 5.1 + 0.4\ X$	0.94**
Structural Instability Index	$Y = 0.5 - 0.03X$	-0.99**
Earthworm Activity	$Y = 2.66 + 1.41X$	0.98

X = Mulch rate in t/ha

Earthworm Activity = Casts m^{-2} $month^{-1}$

Table 6. Decomposition rate of rice straw mulch material (Lal et. al., 1980)

Mulch rate t/ha	Regression equation	Correlation coefficient (r^2)
2	$Y = -5.66 + 1.05t - 0.0024t^2$	0.95
4	$Y = -4.93 + 0.89t - 0.0017t^2$	0.95
6	$Y = -4.54 + 0.79t - 0.0012t^2$	0.95
12	$Y = -4.37 + 0.69t - 0.0009t^2$	0.95

Y = Percent decomposition

t = time in days

42, 39, and 34% at 2, 4, 6, and 12 tons ha^{-1} season-1 mulch rates. Leguminous mulch materials decompose even at faster rate than cereals. Termite also remove a considerable amount of crop residue mulch. Dead or living crop residue mulch produced in situ or brought in is a good substitute for the forest canopy in preserving or restoring soil physical, chemical and biological properties, and in preventing soil erosion. Therefore, crop residue mulch prevents raindrop impact and soil compaction, maintains favorable soil temperature and moisture regimes, stimulates biological activity of earthworms, and sustains a high equilibrum level of soil organic matter content. Mechanical practices of soil erosion control are based on principles of the safe disposal of water runoff. A long slope is usually sub-divided into small and easily manageable slope lengths, whereby water runoff is intercepted by a series of graded channel terraces. The system of constructing these terraces is based on arbitrary relationships of computing terrace spacing. The effects of slope length on runoff and erosion are not well understood because of the confounding effects of a multitude of interacting factors e.g. slope steepness, slope aspect, tillage methods, cropping system, and the ground cover. Terraces are expensive to install and maintain, and depending on slope steepness, may take 10 to 15 percent of the land area out of production (Couper et al, 1979). Terraces also require regular maintenance, failing which can cause more severe erosion hazard than without them (Greenland and Lal, 1979).

V. SEED BED PREPARATION

Objective

The objectives of seedbed preparation are to optimize soil and environmental conditions for seed germination, seedling establishment, and crop growth. The short-term objectives are to optimize soil temperature and moisture regimes, minimize weed competition, stimulate root proliferation and development, and decrease labor constraints for seeding and harvesting (Table 7). In the long run, however, the methods of seedbed preparation adopted should be based on the maintenance and restoration of a high level soil organic matter, maintaining soil structure, pore stability and continuity. Tillage methods adopted should therefore meet both short- and long-term requirements for seedbed preparation.

Definition

The term "tillage" should also be reviewed in a broad context. Tillage involves all operations of seedbed preparation that optimizes soil and environmental conditions for seed germination, seedling establishment and crop growth. Whereas mechanical methods are based on conventional systems of plowing and harrowing, weed control is also achievable using chemical herbicides and growth regulators, and by fallowing with an aggresive cover crop that can be easily controlled for direct seeding through its residue mulch. It is important to make a distinction between exploitation of the limited and non-renewable land resources for short-term production gains and consideration of soil and climatic constraints to preserve this resource base.

Factors Influencing The Choice of Methods Adopted

The choice of mechanical, chemical, or biological methods of tillage depends on factors listed in Table 8. In addition to climatic factors, soil profile characteristics influence the choice of tillage methods to be used. The canopy and root characteristics, growth duration, consumptive water use, and whether a crop is soil conserving or degrading, are also important crop factors to be considered. Among the important socio-economic factors are the size of the land holding; production costs, especially labor, the community life of farmers, and infrastructure and marketing facilities. The age of the farmer and his educational background may also influence the choice of tillage system. Whereas soil and environmental factors influence the decision-making processes of both small and large holders, socio-economic factors are especially important for the small land holders.

VI. CROP PERFORMANCE AND MECHANICAL TILLAGE METHODS

Data in Fig. 11 are based on experiments conducted at IITA during 1970. Maize seeded after different methods of mechanical seedbed preparation, and at different times after the onset of rains, produced low grain yields in ridge and mound systems compared with seeding in a flat or furrowed seedbed. A decrease in maize yields using ridge or mound methods was attributed to supraoptimal soil temperature and suboptimal soil moisture regimes, and to severe lodging (Plate 4). Similar observations regarding the adverse effects of ridges have been made for yam (Lal and Hahn, 1973) and cassava (Okigbo, 1979).

Table 7. Objectives of seedbed preparation

OBJECTIVES

- Short Term — To Optimise
  - Aeration
  - Soil Temperature
  - Soil Moisture
  - Root Development
  - Weed Control
  - Labour Requirement
- Long Term — To Preserve And Restore
  - Soil Resources And Soil Structure
  - Soil Organic Matter
  - Ecological Balance

Table 8. Factors affecting choice of tillage methods

TILLAGE METHODS

Climate	Soil	Crop	Socio-economic
1. Erosivity	1. Texture	1. Canopy characteristics	1. Farm size
2. Temperature	2. Structure	2. Duration	2. Infra-structure
3. Precipitation	3. Erodibility	3. Root system	3. Marketing facility
	4. Rooting depth	4. Water requirement	4. Labour
	5. Slope	5. Soil conserving or soil degrading crop	5. Technology
	6. Organic Matter	6. Rotation	6. Resources
	7. Clay mineralogy	7. Susceptibility to pests and diseases	7. Tradition or culture
	8. Iron and Aluminium oxides		
	9. Surface features including residue cover		

Traditionally, farmers mulch these mounds with crop and weed residues. In addition to the beneficial effects of mulch, the practice of mixed cropping also provides a continuous ground cover that protects the soil against erosion and improves soil temperature and moisture regimes. The practice of building mounds is also useful in concentrating the nutrient- rich surface soil. With the native method of cultivation, mounding is definitely beneficial, especially when mixed cropping is practiced with little or no fertilizer input. This practice is not superior to a mulched flat seedbed or when inorganic fertilizers are applied.

Experiments conducted in Zaire and elsewhere in the tropics have shown frequent use of crop residue mulch, even when used on a flat seedbed, can maintain soil fertility better than the application of inorganic fertilizers (Table 9). Beneficial effects of residue mulch on crop yields have also been demonstrated for Alfisols (Lal, 1975; 1978; Maurya and Lal, 1980) and Ultisols (Okigbo, 1965; 1969) in Nigeria.

Plate 4. Lodging of maize grown on ridges.

Table 9. Effect of mulch and fertilizer on yield of cotton in Zaire (kg/ha).

(Adapted from Jurion and Henry, 1969)

Year	Unmulched		Mulched	
	Without fertilizer	With fertilizer	Without fertilizer	With fertilizer
1947-48	1032	-	1127	-
1953-54	200	440	1117	1434
1955-56	186	797	1464	1977
1956-57	124	706	986	1344

Experiments conducted on diverse soils and under agro-ecological environments indicate flat seedbed preparation with crop residue mulch creates less ecological imbalance problems and can produce yields of a range of crops greater than with conventionally plowed and bare flat or ridged surfaces without residue mulch. Establishment of residue mulch can be achieved through no-tillage methods and other complimentary practices e.g. planted fallows.

V11. NO-TILL FARMING

Definition and basic Concepts

The following definitions are used in the context of this bulletin:

No-Tillage: This refers to a system that eliminates all preplanting mechanical seedbed preparation except for the opening of a narrow (2-3 cm wide) strip or hole in the ground for seed placement to ensure adequate seed/soil contact (Plate 5). The entire soil surface is covered by crop residue mulch or killed sod.

Zonal Tillage of Strip Tillage: The seedbed is divided into a seedling zone and a soil management zone. The seedling zone (5 to 10 cm wide) is mechanically tilled to optimize soil and micro-climate environments for seed germination and seedling establishment. The interrow zone is kept undisturbed and protected by mulch. This can also be achieved by chiseling in the row zone to assist water infiltration and root proliferation.

Conventional Tillage: This system is based on mechanical soil manipulation of the entire field, and involves moldboard plowing followed by one or two harrowings.

Traditional Tillage: Farmers in the humid and subhumid regions of west Africa, and in some parts of South America, use their own method of seedbed preparation. Traditionally, weeds and bush regrowth are slashed manually, left on the soil as mulch or are burnt *in situ*. A little mechanical soil manipulation is done with a hand hoe that superficially scrapes the soil surface.

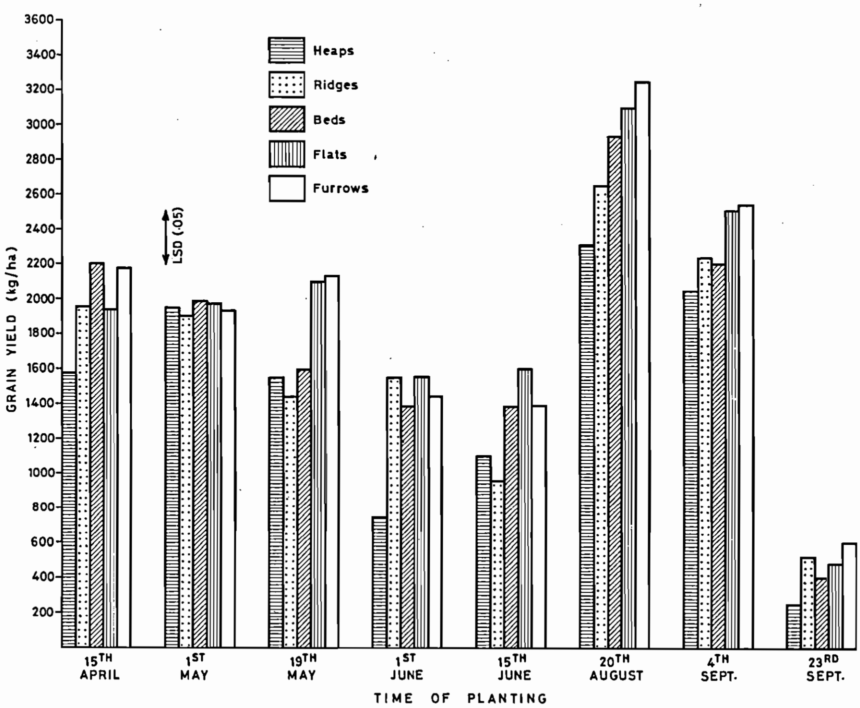


Fig. 11. Effects of different methods of seedbed preparation and planting times on maize yield in western Nigeria (Lal, 1973).

Plate 5. No-till field with crop residue mulch in the interrow zone. (a) maize (b) soybean, (c) cowpea.

Practical Implementation of the No-till System

Basic principles of no-till farming are the same for both small land holders and for large-scale mechanized farms. Seeds are planted in a narrow slit or hole and opened mechanically or by manually operated equipment in the killed sod or previous crop residue. Chemicals are used to control weeds, and inorganic fertilizers are applied over the crop residue mulch, without any further cultivation.

Crop residue mulch is an essential component of the no-till system. For crops following cereals, such as maize, the residue is adequate to provide the protective mulch. Killed weeds are an additional source of mulch. Mulch can also be produced by growing a cover crop for one or two years. The system of growing a crop through the mulch cover without killing it, but by suppressing its growth to minimize competition, is called "live mulch". This latter system is now being investigated by the IITA Farming Systems Program.

It is important to note, however, that the overall benefits of no-till farming system observed in the humid and sub-humid tropics are only partly due to the residue mulch. *No-till* is more than just a method of procuring residue mulch. No doubt mulch regulates soil temperature and moisture regimes, protects the soil against impacting rain drops, and stimulates biological activity. However, the importance of pore continuity; and of the accumulation of organic matter and plant nutrients in the top few centimeters of soil observed only in the no-till system; cannot be overemphasized. For example, it has been observed that the use of crop residue mulch following both primary and secondary tillage operations has been less beneficial in terms of grain yield and soil properties than the same quantity of mulch used with no-till system (Lal, unpublished data). This differential mulch response is attributed to the adverse effects of plowing *per se* on soil structure, compaction and the smearing effect at the plow depth, and in disruption of channels that would otherwise provide continuity between the soil surface and subsoil. This continuity of macropores is a very important factor in deep root system development, and in conducting water through the profile during high intensity rainstorms. Some unpublished data on Alfisols obtained at IITA indicate better yield and more favorable soil hydrological properties for no-till/mulch than for plowed/mulched treatments. This is also the reason why mulch produced *in situ* by growing a cover crop performs better than when mulch is brought-in. Undisturbed channels created by decomposing tap roots of woody perennials can be preferrential mode of root development into deep layers for shallow-rooted seasonals.

V11. MERITS OF NO-TILL FARMING

1. Soil Amelioration: The magnitude and persistence of adverse effects of mechanised land clearing operations depend on many factors, including post-clearing land management and tillage methods. Land cleared with proper methods can deteriorate rapidly if subsequent management is done with mechanized conventional tillage methods. On the other hand, the compaction and degradative effects of heavy machinery can be reduced by adopting the no-tillage system -- especially when used in combination with a cover crop seeded immediately after clearing. The no-tillage system with residue mulch and cover crop improves and restores soil conditions degraded by mechanised land clearing (Lal, 1981b).

2. Soil Conservation: The No-tillage system prevents soil erosion through the protective effect of residue mulch. Consequently, the 'C' factor in the Universal Soil Loss Equation (USLE) is drastically lower for no-till than for conventionally plowed land (Lal, 1976). Water runoff and soil erosion are reduced to levels within the range of soil loss tolerance (Figs. 12 and 13 Soil erosion control is achieved without resorting to expensive and ineffective practices of graded-channel terraces, contour ridges, and other engineering structures. The effectiveness of no-tillage for soil conservation, however, depends on the quantity and durability of the crop residue mulch. The rate of decomposition of residue mulch is much higher in the tropics than in temperate regions, and systems should be developed to ensure an adequate and continuous supply of mulch -- especially during periods when soil is vulnerable to erosion.

3. Moisture Conservation And Water Use Efficiency: A decrease in water runoff and surface evaporation, and an increase in the available water holding and detention capacity of untilled soil makes more water available for crop use in no-tillage than in plowed soils (Figs. 14). Consequently, during periods of short dry spells, crops suffer less from drought stress on untilled

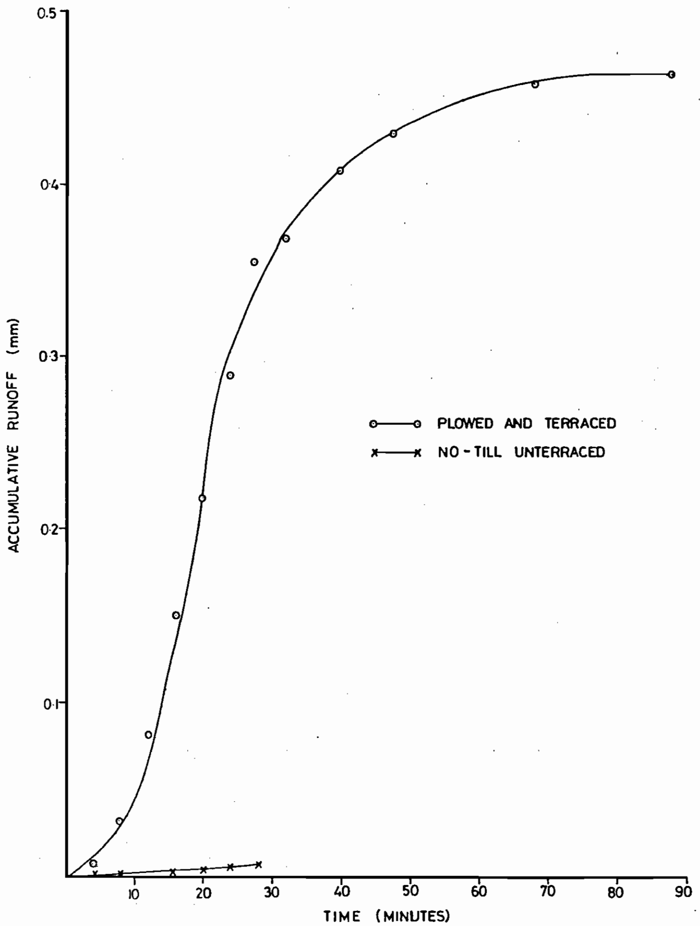


Fig. 12. Effects of tillage systems on water runoff (Lal, 1979b).

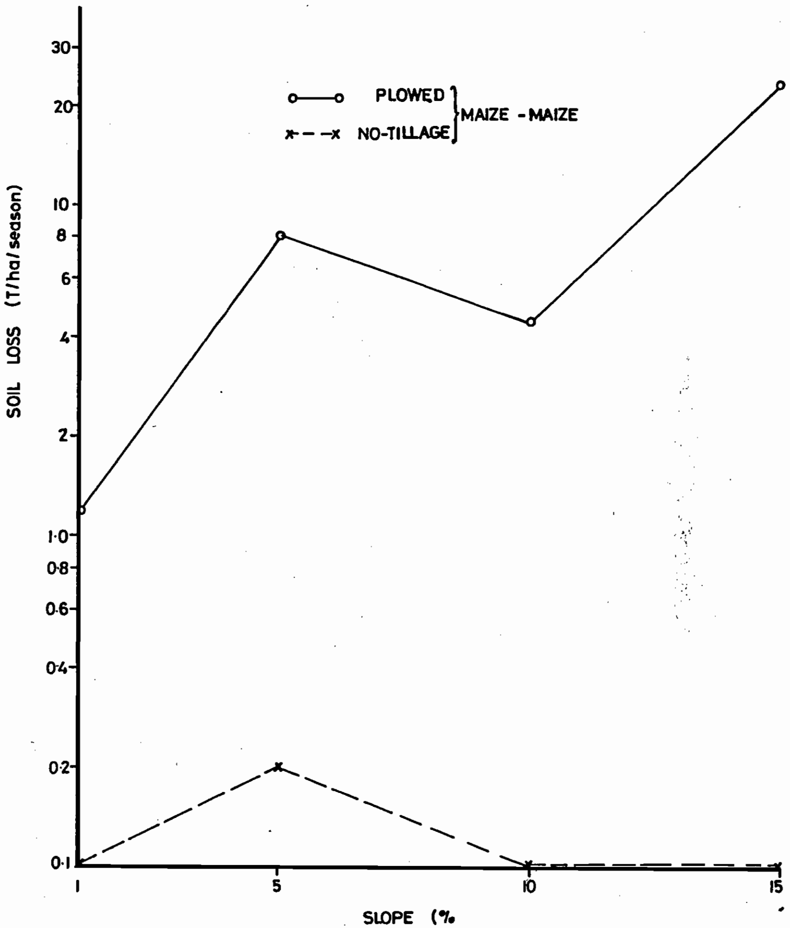


Fig. 13. Effects of tillage systems on soil erosion (Lal, 1976).

than on mechanically tilled soil. The duration and magnitude of internal water stress, as indicated by the leaf water potential, is also more on plowed than unplowed mulched soil (Fig. 15). As a result, the wateruse efficiency for grain and stover production is also superior in no-tillage than on plowed soil (Fig. 16).

4. Soil Temperature: No-tillage affects amplitude, phase angle, and damping depth of the temperature wave. Untilled soil has lower maximum and higher minimum soil temperatures with a pronounced phase shift compared with tilled soil. The differences in soil temperature due to tillage treatments also depend on the quantity of crop residue mulch and canopy characteristics. For example, data in Fig. 17 shows the maximum temperature in untilled soil was lower than mechanically tilled soil by 11, 9, and 6°C for maize, soybean, and cowpea canopy cover. The cumulative degree-hours over 30°C (supraoptimal regime for plant growth) for the first four weeks of growth shown in Table 10 indicate that plants grown in mechanically tilled soil suffered more from high temperature stress than in untilled soil.

5. Root Growth And Development: The total root mass in no-tillage soil is generally more than with convential plowing. However, root distribution with depth is different for the two tillage methods. Root density is generally high immediately beneath the mulch layer in the no-tillage system, whereas root density may be higher within the plow layer of the plowed soil (Fig. 18). A few roots in no-tillage soil can penetrate deep into the profile along the path made by the decomposed roots of the preceding crop, and also through the channels made by the earthworms. The inter-row or the lateral root spread is also greater in no-tillage than in plowed soil.

High root density in the surface layer of no-tillage soil may be attributed to more favorable soil moisture and temperature regimes compared with plowed soil. The mechanical impedance experienced by the roots is a combination of both matric resistance and the soil moisture potential as shown in the following equation:

$$\acute{\sigma} = \sigma - (-\psi)$$

where $\acute{\sigma}$ = The effective mechanical stress

σ = The matric resistance offered by the soil fabric

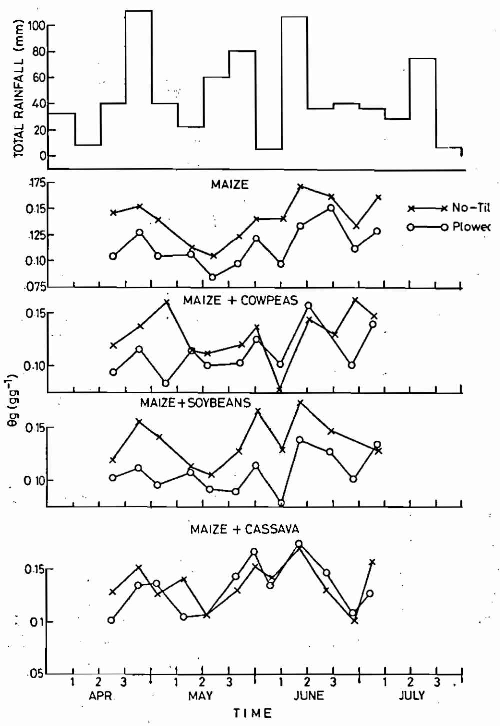
ψ = Soil water suction

The more negative the soil-water suction, the more the mechanical resistance experienced by the roots. Since the soil moisture suction is generally more positive in no tillage than in plowed soil, roots can have more mechanical resistance in plowed than in no-tillage soil (Plate 6).

Soil aeration -- both oxygen concentration and its diffusion rate from the atmosphere into the soil, and that of CO_2 from the soil into the atmosphere -- is also better in no-tillage than in plowed soil. The latter is attributed to the lack of crust formation on untilled and mulched soil, and is due to high macroporosity caused by the activity of earthworms. There is a little quantitative data available describing the effects of tillage and mulch treatments on the aeration status of soils in the tropics, observations indicate that during periods of frequent rains poor soil aeration and anaerobic conditions can be responsible for the stunted root growth in plowed compacted soil. Nevertheless, root growth in plowed and mulched soil can be similar to that of the no-tillage plots provided there is no plow pan formation and the continuity of channels of previously decomposed roots and those made by earthworms is maintained.

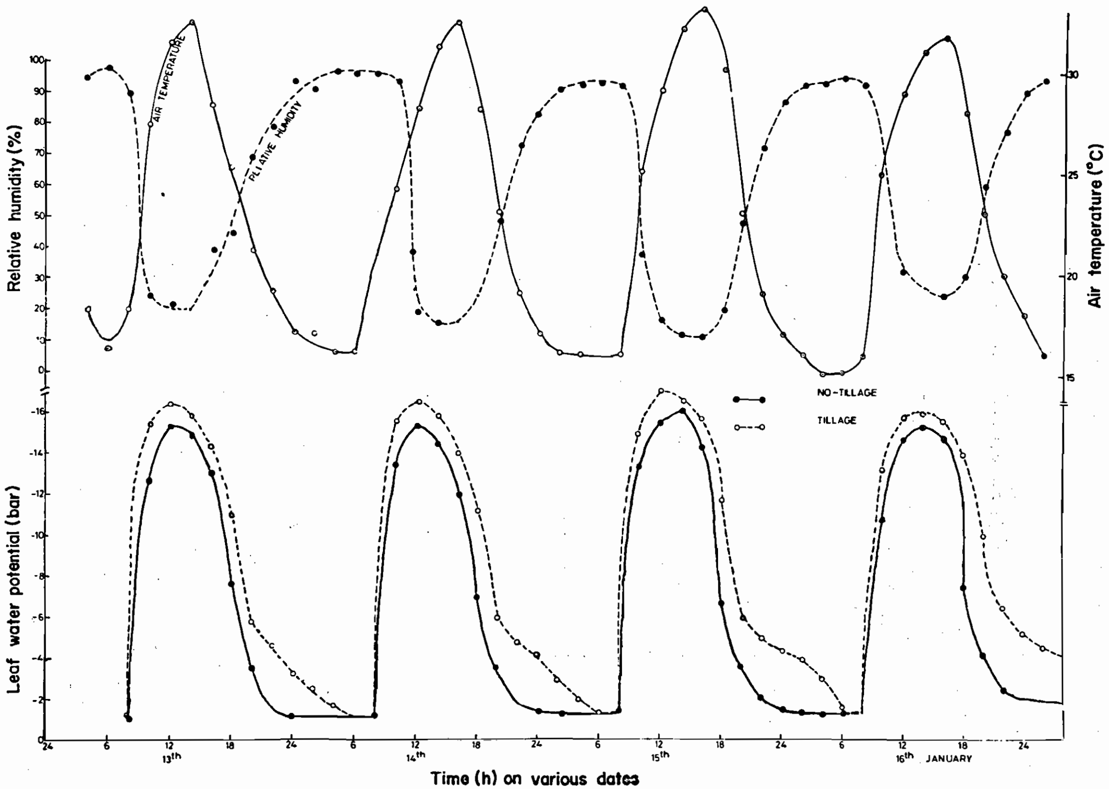
6. Earthworm Activity: Earthworms are important in improving soil structure and porosity, and in the mineralization of soil organic matter. Earthworm activity is related to the amount of mulch material, and to the soil temperature and moisture regimes. High earthworm activity contributes enormously to the mixing of nutrients and organic matter in the soil. Earthworms are, in fact, the best plowing implements for tropical soils. They turnover the soil without causing the erosion problems for which the moldboard plow is so notorious. Earthworms are generally abundant in a fertile and productive soil and play an important role in maintaining soil productivity. Earthworm casts are structurally stable to raindrop impact and contain more silt and clay than the parent soil (De Vleeschauwer and Lal, 1981). The concentration of plant nutrients in casts of earthworms often exceeds that present in the parent soil (Table 11). Earthworms enhance the mineralization of crop residues and make nutrients in organic matter more readily available.

Fig. 14.



Soil moisture reserves for different crop mixtures grown on mechanically tilled and untilled soil (Maurya and Lal, 1980).

Fig. 15.



Development of internal water stress in maize grown with different tillage systems (Lal et al, 1978).

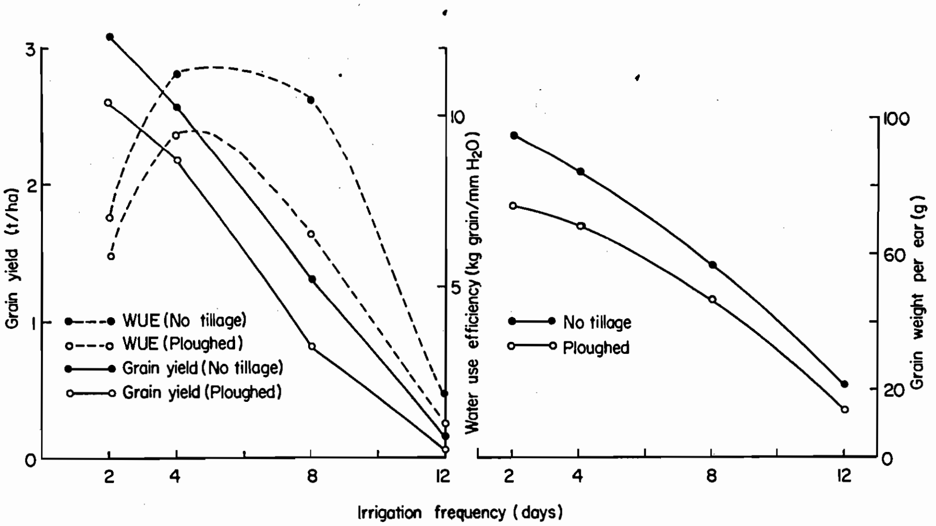


Fig. 16. Effects of tillage methods on water use efficiency of maize grown under different frequencies of irrigation (Lal et al, 1978).

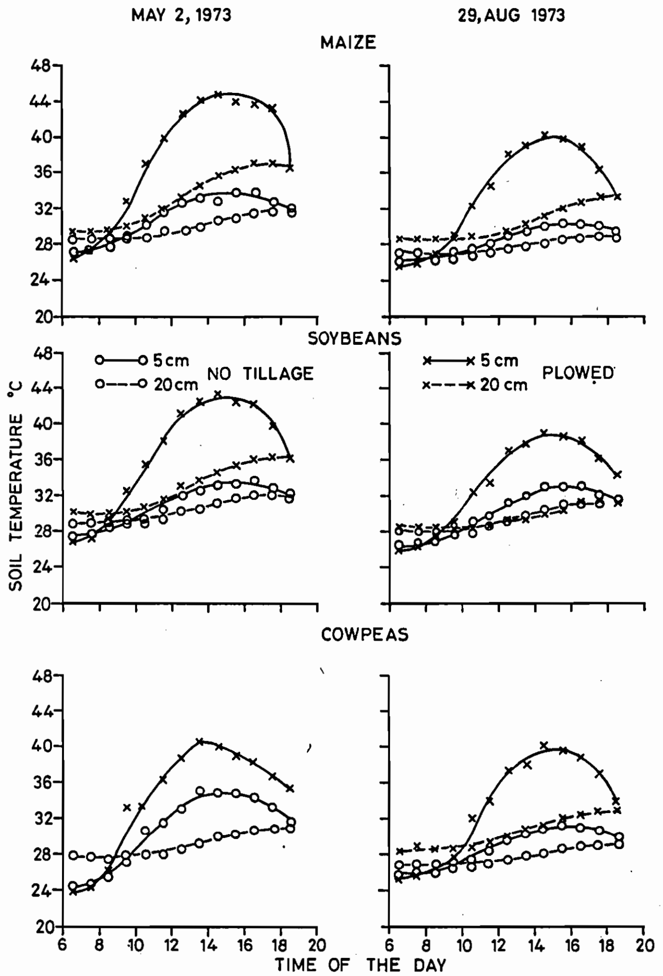


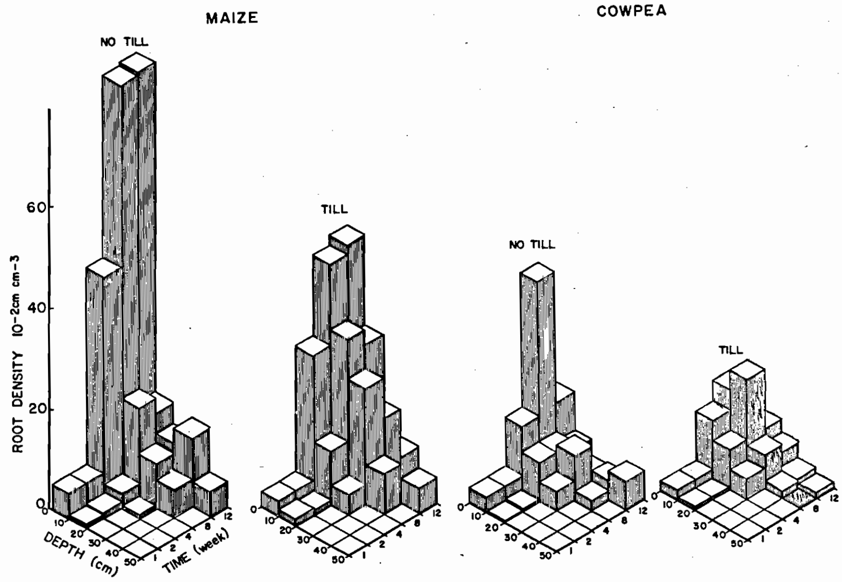
Fig. 17. Effects of tillage methods on soil temperature (Lal, 1976a).

Table 10. Effect of tillage methods of degree-hour of supraoptimal temperature for different crop sequences with no-tillage and conventional plowing. (Lal, 1976a)

Crop rotation	5-cm depth		20-cm depth	
	NT†	P†	NT	P
(a) First season, 1973				
Maize-maize	418	1913	106	873
Maize-cowpeas	912	2172	105	856
Pigeon peas-maize	281	1516	18	412
Soybeans-soybeans	364	1943	143	607
Average	494	1886	93	687
(b) Second season, 1973				
Maize-maize	11	341	0	132
Maize-cowpeas	26	345	0	79
Pigeon peas-maize	116	278	2	30
Soybeans-soybeans	106	343	36	67
Maize-soybeans	3	-	0	--
Average	52	327	8	77

†"NT" refers to no-tillage and "P" to plowed treatments.

Fig. 18.



Effects of tillage methods on root distribution (Maurya and Lal, 1980).

Table 11. Nutrient composition of cast and parent soil (Calculated from Lal and De Vleeschauwer, 1981; and De Vleeschauwer and Lal, 1981).

Soil property	Cultivated land**		*Uncultivated land	
	Cast	Soil	Cast	Soil
pH (1:1 in water)	5.9	6.2	5.6	6.0
Total acidity (meq/100g)	0.32	0.27	-	-
Organic carbon (%)	1.79	0.97	3.02	0.91
Total nitrogen (%)	0.21	0.15	0.33	0.12
Bray-P (ppm)	50.6	36.5	17.8	6.1
ECEC (meq/100g)	17.0	7.0	13.8	3.5
Exchangeable calcium (meq/100)	14.3	5.9	8.9	2.0
Exchangeable Magnesium (meq/100)	1.35	0.45	3.9	1.0

* Mean of 6 different soil types

** One soil type

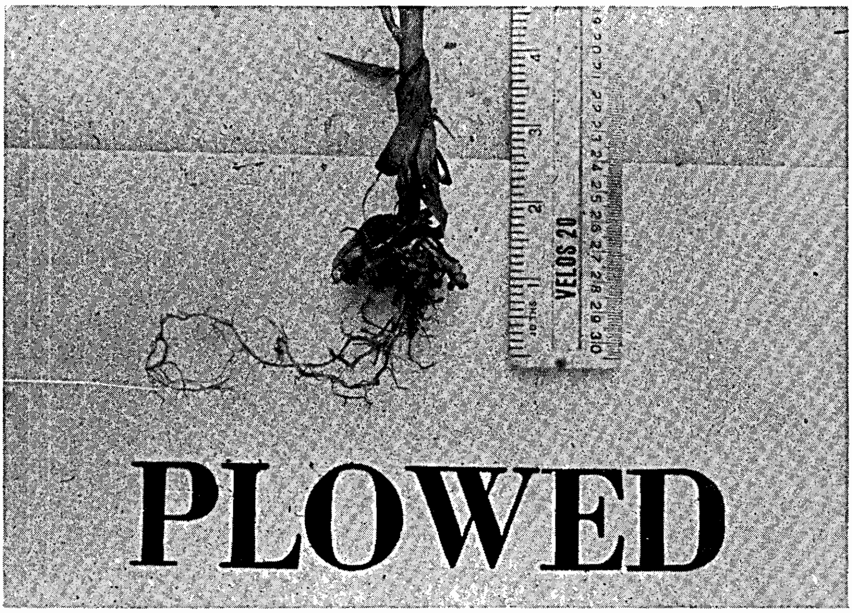


Plate 6. Mechanical impedance to maize roots with conventional tillage of plowing and harrowing.

Casting activity of earthworms is higher in no-till mulched soil than in plowed land (Table 12). High activity and the resulting turnover of the soil results in low bulk density on no-tillage compared with plowed soil, even within a few weeks after the land has been plowed (Fig. 19). Penetrometric resistance and soil strength are also lower in no-tillage than in plowed soil (Armon, et al., 1981).

The fact that casts contain more nutrients than parent soil may also be due to the fact that earthworms feed on soil that is rich in organic matter. To some extent the nutrient status of the soil is reflected in the nutrient concentration in the cast. Data in Table 13 show the higher nutrient status of casts from no-tillage than from plowed soil. This indicates a higher nutrient status and fertility level of the surface layer of no-till compared with plowed soil. Worms may also bring nutrients that were leached out of the root zone up from the subsoil horizon, by ingesting the subsoil and voiding it on the surface. The high concentration of calcium in casts is also attributed to the calcite spheroids originating in the calciferous glands of earthworms. (Wiecek and Messenger, 1972). Earthworms quickly lower the C:N ratio and make N readily available to plants.

Soil physical properties of worm casts are also more favourable than the those of the parent soil. Lal and Oluwole (1983) observed that bulk density of the casts is 12 to 17 percent lower than that of the soil, and consequently the total porosity of cast is more. Furthermore, casts from untilled mulched plots can have more favorable soil physical properties than those from plowed treatments. These differences are particularly obvious and edaphologically significant for the moisture retention characteristics. The data in Table 13b show that the mean moisture retention in casts from no-till and plowed treatments was 45.9 and 32.9, 35.5 and 26.4, 29.9 and 20.6, 24.3 and 15.7, 20.4 and 13.3, 19.2 and 12.5%, respectively, for 0, 0.1, 0.5, 1, 5, and 15 bar suctions, respectively. Similar differences existed even in the moisture retention for the soil samples between the no-till and plowed treatments. Also the casts from the mulched plots may have more water retention capacity than those from unmulched treatments. Consequently, the available water holding capacity of the cast from no-till soil can also be more than from plowed soil. In this study, the average mean weight diameter was observed to be 6.7, 2.4, and 1.0 mm for the casts, 0-5 cm soil and 5-10 cm soil, respectively.

Table 12. Earthworm cast production responses with different tillage methods and crop sequences. (Lal, 1976a)

Cropping sequence	Number of casts/m^2		Equivalent weight, metric tons/ha	
	NT†	P†	NT	P
Maize-maize	1,060	90	41.34	3.51
Maize-cowpeas	1,220	372	47.58	14.50
Pigeon peas-maize	464	100	18.09	3.90
Soybeans-soybeans	42	3	1.64	0.12
Cowpeas-cowpeas	28	36	1.09	1.40
Average	563	120	21.96	4.68

† "NT" refers to no-tillage and "P" to plowed treatment.

Table 13. Effects of tillage methods on nutrient contents in earthworm casts

(Calculated from Lal and De Vleeschauwer, 1981)

Parameter	No-tillage	Plowing
pH (1:1 in water)	5.9	6.0
Total acidity (meq/100)	0.30	0.34
Organic carbon (%)	1.8	1.8
Total nitrogen (%)	0.22	0.21
Bray-P (ppm)	51.8	49.5
ECEC (meq/100g)	19.5	14.6
Exchangeable calcium (meq/100g)	17.0	11.7

7. Nutrient Status: Soils managed with the no-till system have a higher concentration of organic carbon, total N, available P, and exchangeable Ca and K in the surface layer than plowed soil (Fig. 20). Even the less mobile nutrient, such as P, is mixed in 20 to 30 cm of soil within 5 to 6 years of no-till farming. Kang and Yunusa (1977) observed that although the movement of broadcast P was slow with minimum tillage, the method of P application (broadcast, band or hill) was equally effective in supplying adequate P to the maize crop.

The most noticeable effect of the no-tillage system with crop residue return is on soil organic matter. The rate of decline of soil organic matter is drastically lower with no-tillage than with conventional plowing (Fig. 21).

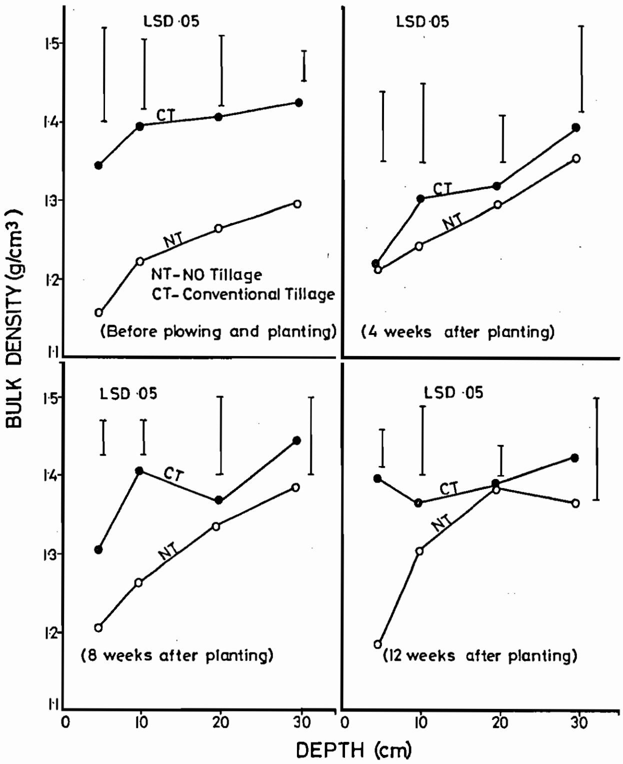


Fig. 19. Effects of tillage methods on soil bulk density (Armon, Lal and Obi, 1981).

Consequently the equilibrum level of organic matter content is greater in untilled than in mechanically tilled soil. Perhaps more important than the gross organic carbon is the bio-active carbon that is generally higher in untilled soil by several orders of magnitude than in plowed soil.

8. Fertilizer Use Efficiency: The efficiency of applied inorganic nitrogen depends on the C:N ratio of the residue mulch, previous land use, and on the level of soil compaction. No-tillage plots with a mulch material of a high C:N ratio may exhibit chlorotic symptoms of nutrient deficiency for zero or low rates of N application during the first one or two seasons of adopting the no-till system (Lal, 1973; Kang et. al., 1980). However, when the immobilization and release of nitrogen have reached a steady state, the fertilizer use efficiency is generally greater on untilled than mechanically tilled soil (Figs. 22 to 24). Higher nutrient efficiency on untilled soil is partly attributable to smaller losses in water runoff and less eroded soil (Lal, 1976). Leaching losses are hard to generalize for different tillage systems. An untilled soil has low water runoff, more percolation, and more water retention than tilled soil. High effective cation exchange capacity (ECEC) and organic matter content are also related to the high nutrient retention capacity of a no-till soil. Therefore, high percolation in no-tillage soil may not necessarily mean high leaching losses.

9. Savings in Fuel and Labor: Fuel requirements are drastically decreased with no-tillage systems due to elimination of plowing, harrowing, and chiseling operations that have high fuel requirements (Table 14). In addition to fuel savings there is a definite saving in time required for seedbed preparation. Different types of farm machinery are no longer required with the no-tillage system.

Savings in fuel do not necessarily mean savings in financial inputs or total energy units required for crop production. Herbicides and growth regulators used for weed control are expensive and require considerable energy inputs for their production.

Labor is a serious constraint in traditional farming systems. Use of herbicides for weed control with no-tillage can drastically reduce labor requirements, and also increase labor efficiency by reducing drudgery.

Table 13b. Effects of tillage methods, fertilizer and mulch application on moisture retention (% by weight) at different suctions for worm casts and soil samples (NT = no-till CT = plowed) (Adapted from Lal and Oluwole, 1983)

Fertilizer	Mulch	0. Bar						0.1 Bar						0.5 Bar						1 Bar					
		Cast		0-5cm soil		5-10cm soil		Cast		0-5cm soil		5-10cm soil		Cast		0-5cm soil		5-10cm soil		Cast		0-5cm soil		5-10cm soil	
		NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
Without	Without	46.3	31.5	37.3	35.3	38.7	34.6	34.0	24.0	12.7	9.4	13.8	9.8	29.3	17.8	9.5	8.0	10.0	8.1	24.5	13.1	8.8	6.0	8.4	7.0
Without	With	45.9	32.6	37.7	36.5	35.6	35.0	36.0	26.1	12.3	10.2	13.6	10.1	29.3	20.4	9.6	8.1	9.3	8.3	24.2	16.1	7.9	6.2	8.4	6.8
With	Without	44.5	32.0	37.9	35.0	35.0	34.3	34.9	26.4	13.1	10.9	12.4	11.7	29.4	20.9	9.0	9.0	9.6	8.9	22.7	16.6	8.3	6.1	7.8	6.8
With	With	46.9	35.4	38.0	37.0	35.4	36.0	37.2	28.9	11.9	11.8	11.1	11.8	31.4	23.2	9.3	9.1	9.0	9.5	25.8	17.0	7.7	7.1	7.2	6.5

	LSD (0.05)	0 Bar	0.1 Bar	0.5 Bar	1 Bar
(i)	Tillage	2.8	2.3	3.2	1.9
(ii)	Fertilizer	2.0	1.7	1.3	1.1
(iii)	Cast-soil	1.6	1.5	1.2	1.0
(iv)	Cast-soil for same tillage method	2.3	2.1	1.7	1.4
(v)	Cast-soil for same fertilizer-mulch treatment	3.2	2.9	2.5	2.0
(vi)	Cast-soil for same tillage and fertilizer-mulch treatment	4.6	4.1	3.5	2.9
(vii)	Cast-soil for same or different analysis	3.1	2.7	3.3	2.2
(viii)	Fertilizer-mulch for same or different cast-soil	3.4	2.9	2.4	2.0
(ix)	Fertilizer mulch for same tillage and same or different cast-soil	4.1	3.6	2.9	2.5
(x)	Tillage for same or different fertilizer-mulch combination and cast-soil	5.9	5.0	5.1	3.6

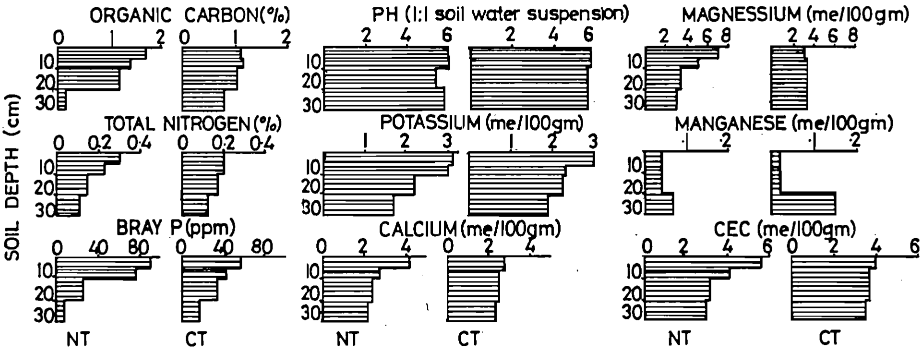


Fig. 20. Nutrient profile of soil under different tillage systems (Arman, Lal and Obi, 1981).

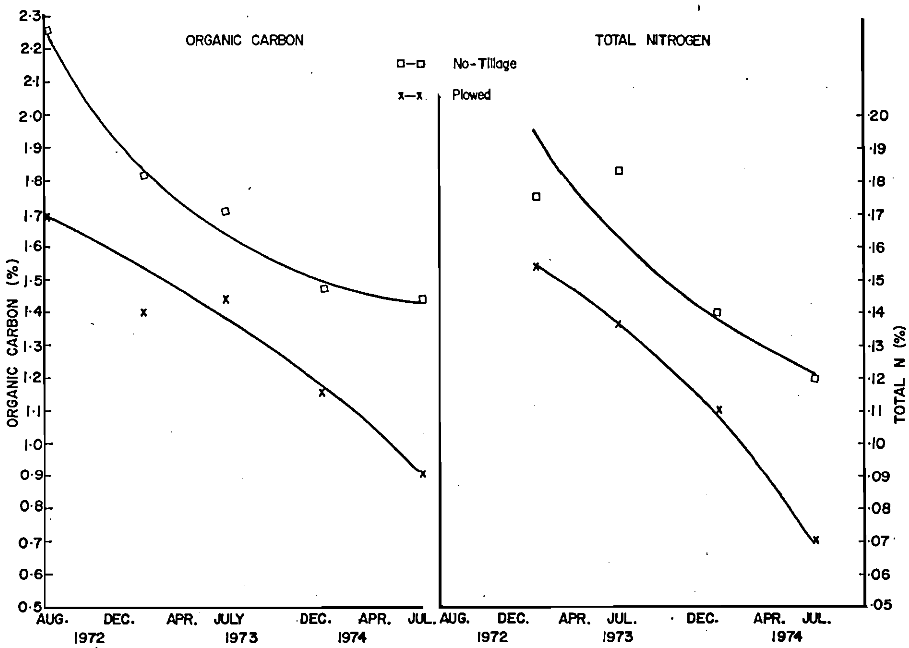


Fig. 21. Effects of tillage methods on rate of decline of organic matter content (Recalculated from Lal, 1976a).

10. Grain yields under different systems of management can be evaluated in terms of production per unit of: (i) inputs (ii) fuel consumption (iii) area (iv) time and (v) soil degradation. Yield potentials should be evaluated over a long period of time. Yield stability is another important criterion that should be used to evaluate different tillage systems. No-tillage generally outyields the conventional tillage systems if the crops suffer from moisture, temperature or nutritional stress. The no-tillage system, therefore, maintains a stable yield. Soil loss, grain yield or runoff loss, and grain yield ratio is always higher for plowed than untilled soil (Table 16).

The measure of a successful technology is different for small and subsistence land holders of the tropics in comparison with large-scale mechanised temperate region farms. While for the substence farmers, a reliable and a stable crop yield in the worst years is the most important measure for adaptive success, the long term average yield and profit may be a better criterion for a capital intensive, mechanised, commercial agriculture. The experience at IITA shows that with manual operations, stable grain yield of cereals or cereals grown in rotation with legumes can be obtained with continuous cultivation for more than 10 consecutive years by using the mulch based no-till system. The no-till system can be further improved by incorporating or integrating into it other complementary and compatible practices such as alley cropping (Kang et al, 1981), and live mulch system (Akobundu, 1980; Wilson et al, 1983).

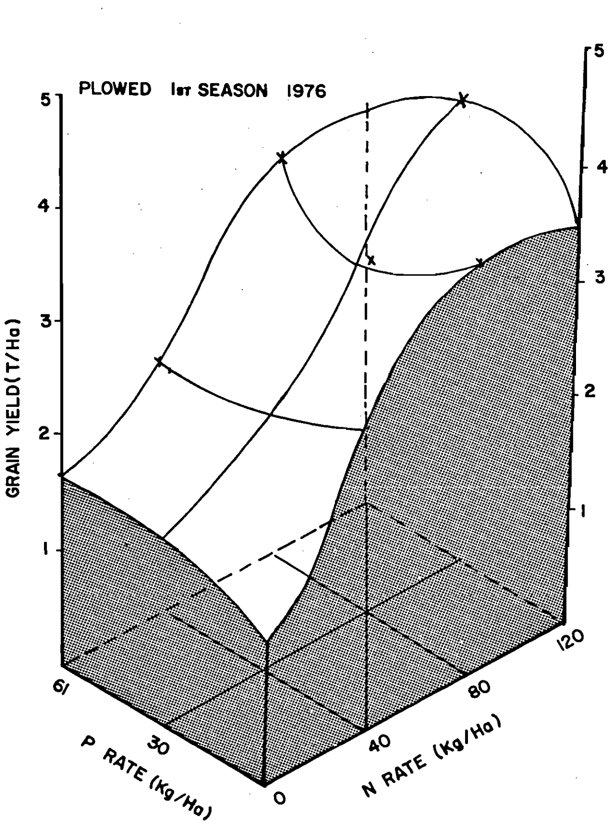


Fig. 22a. Fertilizer response of maize on plowed soil.

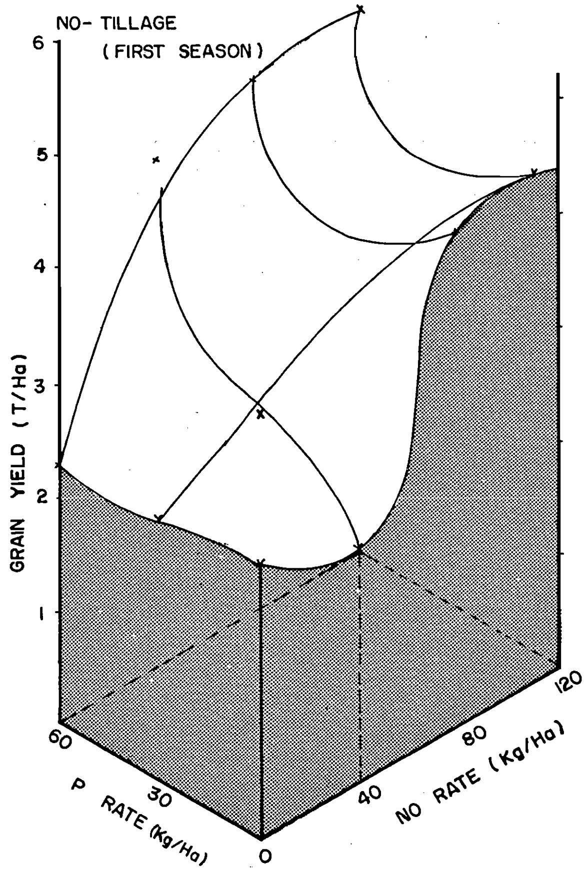


Fig. 22b. Fertilizer response of maize on plowed soil.

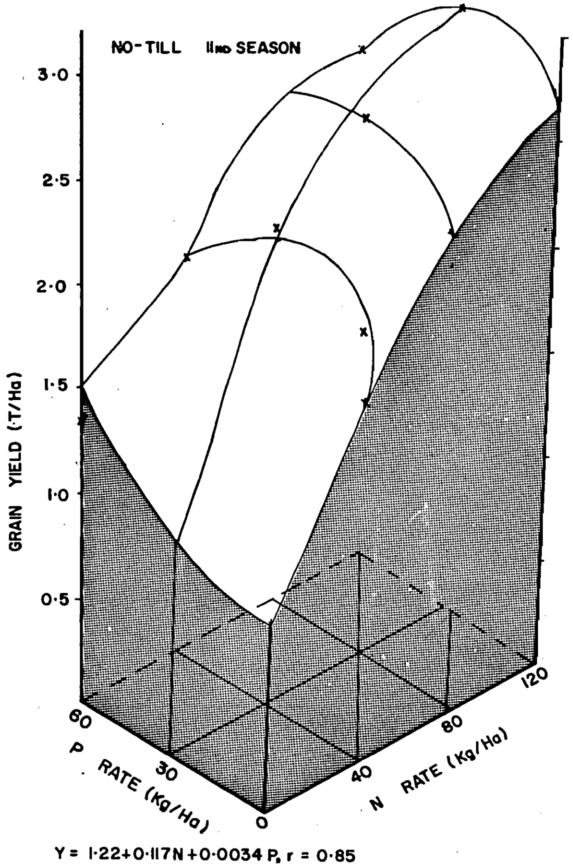


Fig. 23a. Fertilizer response of maize on untilled soil.

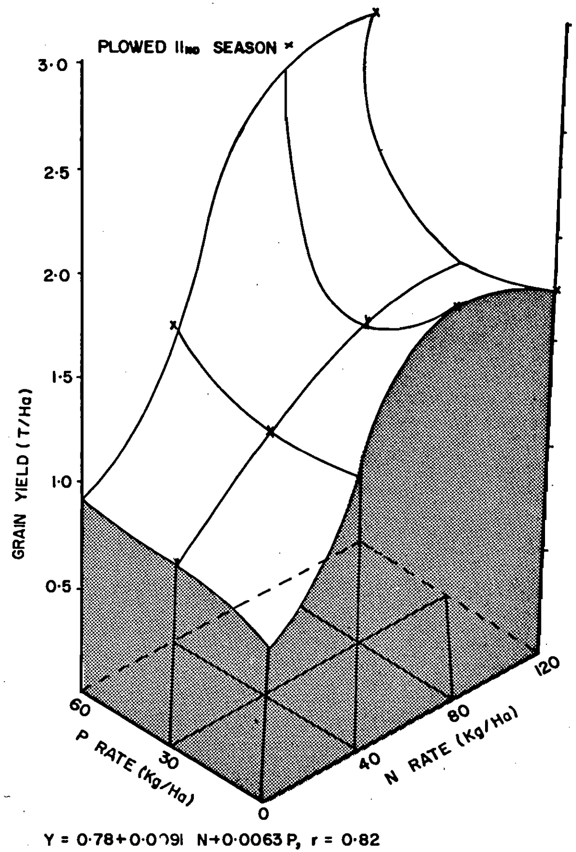


Fig. 23b. Fertilizer response of maize on untilled soil.

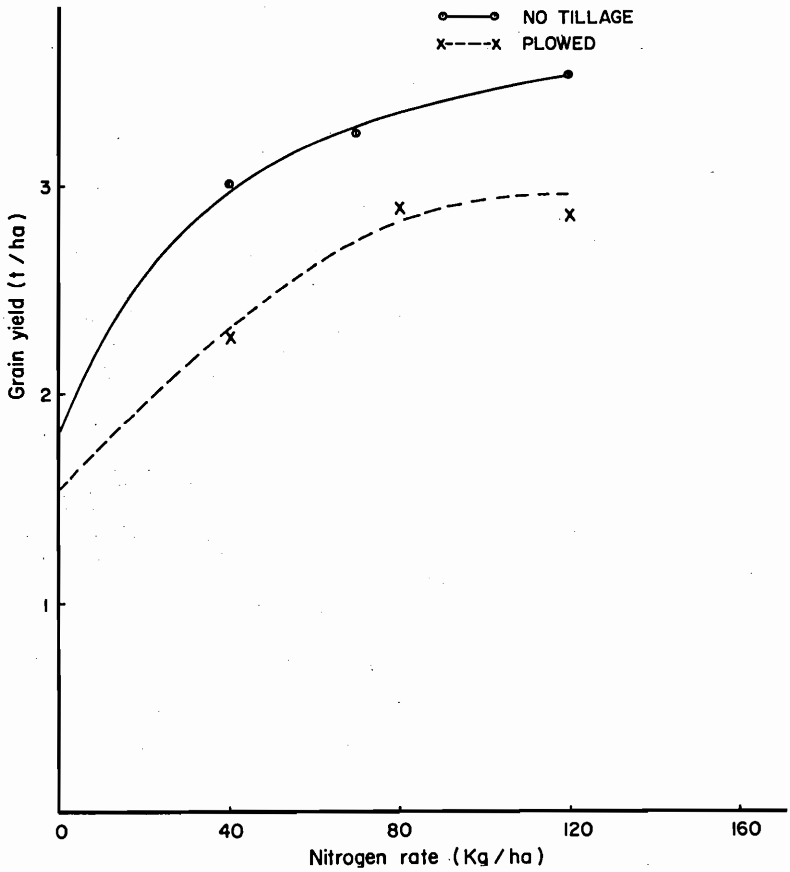


Fig. 24. Fertilizer response of maize on mechanically tilled and untilled soil (Lal. 1979).

Table 14. Fuel and energy requirements for different field operations (1/ha)

Operations	No-tillage	Mechanical tillage
Plowing	-	18
Disc harrowing (twice)	-	14
Sub-soiling	-	(10)
Chisel plowing	(9)	(9)
Spraying	2	1
Mowing	3	3
Fertilizer application (twice)	6	6
Drulling	3	3
Total	14	45

* The operations listed in brackets may not be done every year.

** Herbicide spraying is generally done twice in no-tillage and once in mechanical tillage.

*** The estimates of fuel requirements for different field operations are obtained from Starsfield, 1974 and may differ for different soils.

Table 15. Energy requirement for plowed and no-tillage seeding of maize (Adapted from Wijewardene, 1978)

Tillage method	Operations	Number of passes	Energy used (MJ/ha)
Mechanical tillage	Disc plowing, harrowing (2), seeding	4	235
No-tillage	Spraying, mowing seeding	3	52

Table 16. Soil loss, grain yield and runoff, grain yield ratios for maize grown with plowing and no-tillage system

(Calculated from Aina, Lal and Taylor. 1976)

Slope	Soil loss: grain yield ratio		Runoff: grain yield ratio	
%	No-tillage	Plowed	No-tillage	Plowed
	(kg kg^{-1})		(mm ton^{-1})	
1	0	0.32	44.3	373.1
5	0	18.50	70.5	1741.0
10	0	43.56	93.8	1745.8
15	0	75.14	137.1	1906.1

With annual seeding and harvesting operations to simulate small land holder agriculture, maize yields with no-tillage for 22 consecutive crops were generally superior to conventionally plowed land both at low and high level of fertilizer inputs (Fig. 25). Soil compaction was never a severe problem with the manual operation. Presence of crop residue mulch and perennial shrub regrowth and the stimulated biological activity of earthworms maintained soil porosity and pore stability.

Similar studies were also conducted on 5-hectare watersheds to simulate large-scale mechanized operations. Plowed plots were terraced and no-till plots had no supplementary erosion control measures (Couper et al., 1979). Maize grain yield from these watersheds for six consecutive years, shown in Fig. 26, indicate higher production from no-till than plowed plots. At the end of 6 years in 1980, no-till plots yielded 3 times the plowed plots, i.e. 1 t and 3 t/ha/year, respectively. Maize yields declined from 1979 in both plots. The magnitude of this decline was more in the plowed than in the no-till watershed, and was attributed to a multitude of interacting factors. First there was a change in variety grown in the short second season. The substituted early maturing variety TZE has a lower yield potential than the regular full duration variety. Second, mechanized harvesting was introduced that may have caused some compaction of the soil surface. Therefore, the decline in maize yield in the no-till watershed can only partly be attributed to some degree of soil compaction. On the other hand, a very significant decline in the maize yield of the plowed watershed was due to an overall degradation of soil productivity caused by erosion, compaction and decline in organic matter content and pH (Table 17). Some of the upper contours in the plowed watershed were completely devoid of topsoil, and the surface was covered with a layer of sterile and compact mixture of quartz gravel and plinthite. Even the weeds were unable to grow through this sterile "desert" pavement (Plate 7).

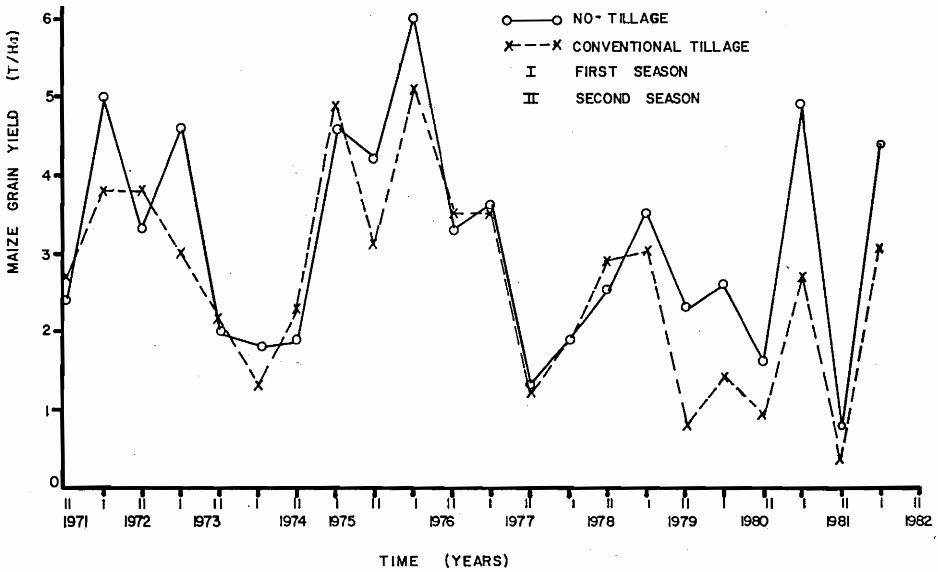


Fig. 25. Effects of no-tillage and conventional plowing on maize grain yield for 22 consecutive maize crops on small plots with manual operations.

11. Environmental Considerations: In addition to reducing soil erosion and water runoff, no-tillage also lessens nutrient losses from agricultural lands (Lal, 1976b). Most of the agricultural chemicals applied to the soil, the main pollutants of natural waters, move as solutes with water runoff or as absorbed ions on soil particles. No-tillage with residue mulch decreases water runoff, soil erosion and the movement of these chemicals from the land. The herbicides loss is (Paraquat, atrazine, etc.) also higher from plowed than the no-till watersheds. Furthermore, most herbicides used in no-till crop production are not as persistent and have less risidual effect than some insecticides and pesticides commonly used. Higher organic matter content in the surface layer of no-till land and in the layer of crop residue mulch also serve as good filter materials that hold herbicides on land for rapid bio-degradation. Some pesticides are degraded to harmless components in the soil in a shorter time under no-tillage than under conventional tillage (Phillips et al, 1980). The no-till system prevents or minimizes the overland flow of agricultural chemicals. The no-till system, in fact, may be less threat to environmental quality than the conventional tillage system. However, the hazards associated with the use of herbicides warrant additional studies regarding their pathways and persistence on and through the soil.

IX. PARAMETRIC ASSESSMENT OF SOIL SUITABILITY FOR NO-TILLAGE

Soil Factors and No-till Performance: Crop establishment and performance with no-tillage depends on initial soil conditions and previous land use. Some important factors for tropical environments are:

Soil compaction: Although the range of optimum bulk densities for various crops and soils may be different for no-tillage than for conventional tillage, compacted surface soil in untilled land increase losses due to water runoff and suppresses crop yield.

Soil Heterogeneity: Micro-relief and an uneven ground surface adversely affect seeding with a no-tillage system. Pest problems with young seedlings, -- rodents and birds -- are also more in untilled and mulched soil than in clean and bare ground surfaces.

Topography: It is safer to cultivate steep slopes with no-tillage than with conventional tillage provided the slope permits mechanized operations. The use of tractor-mounted machinery is difficult on steep slopes, although manual operations can be performed on very steep slopes.

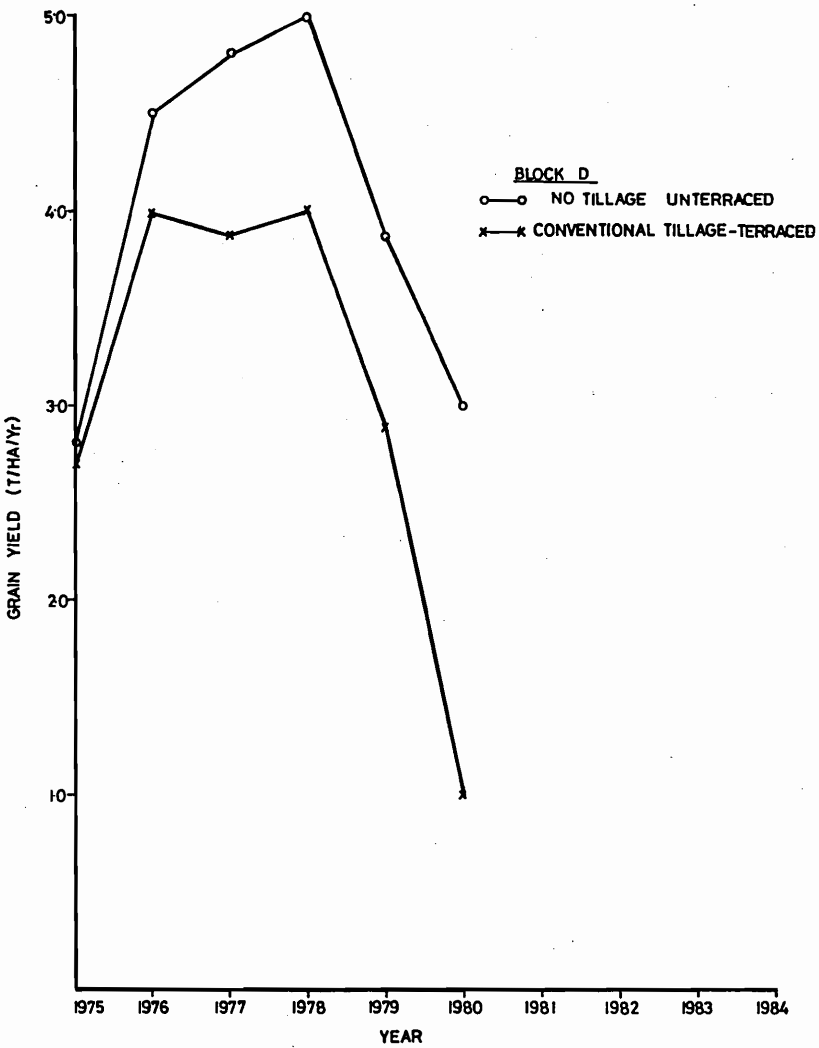


Fig. 26. Effects of mechanized tillage operations on maize grain yield after 12 consecutive crops of maize (Couper, Lal and Claassen, 1979).

Table 17. Effects of Mechanized Tillage Methods on Soil Chemical Properties 6 years after imposing the Tillage Treatments.

Soil Property	Conventional Tillage	No-Tillage
pH (1:1 in water)	4.7	5.3
Organic Carbon (%)	1.35	1.48
Total Nitrogen (%)	0.195	0.191
Bray-P (ppm)	42.8	25.0
Exchangeable Cations (ppm)	-	-
Calcium	374	479
Magnesium	40	59
Potassium	109	67
Manganese	33	8

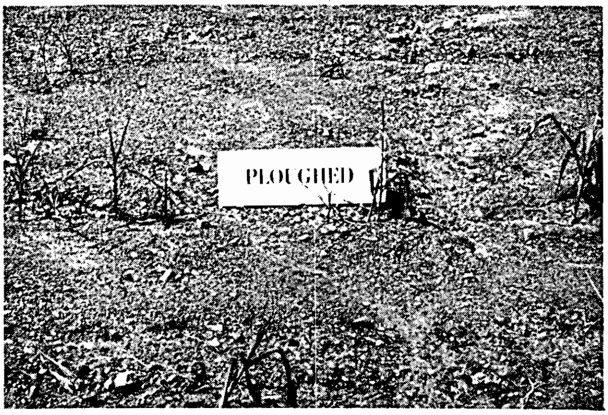


Plate 7. Eroded and compacted soil surface in conventionally plowed and terraced watershed.

Residue Mulch: Lack of or inadequate residue mulch will decrease the benefits of no-till system.

Seed-Soil Contact: Lack of seed-soil contact due to a defective seeder can result in poor crop stand, especially in a clayey soil.

Land Surface Conditions and No-till Performance:

Soil properties that favor the application of the no-tillage method are:

Coarse textured surface horizon or self-mulching clayey soils with initial porosity.

Resistance or less susceptibility to compaction, and a low surface caking tendency.

Good internal drainage for upland crops.

Conditions to support high biological activity of earthworms and other soil animals.

Friable consistency over a wide range of soil moisture contents.

The Choice of No-till System for Problem Soils:

No-tillage is naturally suited for those problem soils that are highly susceptible to erosion, have low water holding capacity and are prone to supra-optimal soil temperature regimes during the seedling stage of crop growth.

Soil and water conservation: With an adequate quantity of crop residue mulch, no-tillage can effectively control erosion and reduce it to the tolerable range of soil loss (Lal, 1976a) and conserve water in the root zone (Unger, 1978). The range of soil loss tolerance for most Alfisols, Ultisols and Oxisols is rather low because of the shallow effective rooting volume and unfavorable physical, nutritional and biological properties of the subsoil horizons (Lal, 1983). The tolerable soil loss is estimated to be generally less than 0.5 t/ha/annum. Soil erosion hazard depends on soil erodibility, rainfall erosivity, slope factor and the land use. Based on these factors a tentative rating has been proposed for the choice of appropriate tillage systems for a given soil. These ratings in Table 18 and other tables in this report are mere guidelines and will perhaps require suitable modifications with more experiments when soil data and climatic records are available for broad range of environments. In Table 18, rating of one is given to those soil and climatic factors that increase the risk of soil erosion and rating of five to those factors that render a soil less susceptible to water erosion. Those soils with high erodibility factor (K), in regions of high rainfall erosivity, on steep slopes with shallow surface horizon, are more susceptible to erosion and crop yield may decline below the level of economic returns a few years after opening new land are given a rating of 1.

Table 18. Rating table for factors affecting soil erosion (Lal, 1981d)

Annual cumulative erosivity (EI_{30}, foot-ton)	Soil erodibility (k)	Soil loss tolerance (t/ha/yr)	Slope (%)	Rating
>1000	>0.6	<0.5	>10	1
800-1000	0.4 - 0.6	0.5 - 2.0	6 - 10	2
600-800	0.2 - 0.4	2.0 - 6.0	4 - 6	3
400-600	0.1 - 0.2	6.0 - 10.0	2 - 4	4
<400	<0.1	>10.0	<2	5

Although the frequency, amount and duration of the rainfall are also important factors, their effect is build into the erosivity parameter EI_{30} as defined in the Universal Soil Loss Equation. Similarly, included in the soil erodibility factor (K) are the permeability, texture, organic matter content and soil structure. The effective rooting depth and physio-chemical and nutritional properties of the subsurface horizon are considered in evaluating the soil loss tolerance. Soil loss tolerance is low for shallow soils and high for deep soils with favorable subsoil horizons.

Hydrothermal regime: Soil temperature and moisture regimes are affected by particle size distribution, structure and organic matter content. Soil thermal characteristics, including heat capacity, thermal conductivity and diffusivity, are governed by soil constitutents and the moisture regime. Soils in the humid tropics have low available water holding capacity and are drought susceptible (Hsiao et al, 1980). Rapid growth rate favored by high temperatures can be sustained only with a continuous supply of readily available moisture in the root zone. High evaporation rates and low thermal capacity create supraoptimal soil temperatures in the seed environments (Harrison-Murray and Lal, 1979). Mulch-based no-tillage is advantageous for those soils with low water holding capacity and where supraoptimal soil temperature regime may adversely affect seedling establishment and growth. The available water holding capacity of the root zone, computed from the *in situ* measurements of upper and lower limits of available water for the specific crops to be grown, is an important consideration in the choice of an appropriate tillage system. Soil temperatures exceeding 40°C at 5 cm depth from 3 to 6 hours a day during the seedling stage can be injurious to crop growth (Lal, 1974). Similar to the available water holding capacity, internal drainage and permeability are also affected by the particle size distribution and soil organic matter content. Soils with free drainage are easily adapted to no-tillage for most upland crops in the humid and subhumid tropics.

On the other hand, hydromorphic and poorly drained soils (Plate 8) are better suited for rice cultivation, particularly if they are relatively flat or are of gentle slope to facilitate water management. No-tillage with proper weed control is feasible for lowland rice production (Lal, 1979). However, a separate section in this report is devoted to rating soil conditions for rice cultivation with no-tillage. Ratings for the hydrothermal regimes are given in Table 19. Those upland soils will respond favorably to no-tillage and mulches that have less than 8 cm of available water holding capacity, soil temperatures exceeding 30°C at a 5 cm depth from 3 to 6 hours per day during the seedling growth, soils with good internal drainage i.e. permeability exceeding 12.5 cm hr^{-1}, and more than 60 percent probability of a consecutive 7-10 day rain-less period during the growing season. The latter information is obtained from frequency analysis of long-term rainfall records as computed for northern Nigeria by Walter (1967).

Plate 8. Clayey soil in Trinidad with impeded internal drainage.

Factors affecting soil compaction: Soil compaction is a more difficult parameter to quantify and characterize in relation to other soil variables. Bulk density, total porosity or the penetrometer resistance can be indirectly related to the degree of soil compaction. However, it is difficult to establish a direct functional relationship between soil compaction and any one or a combination of parameters because of the confounding effects of variations in soil moisture content. The results are further confounded by the presence of a variable concentration of gravels and skeletal material in the soil. Bulk density and total porosity are significantly influenced by the particle size distribution. Furthermore, the optimum bulk density requirements are different for different soils and crops. Plant response is related less to the absolute value of bulk density or total porosity and more to the rate of its change with time. It is the drastic change in bulk density and porosity during the growing period that has more edaphological significance. For example, excessively porous soil caused by repeated mechanical tillage can settle rapidly due to impacting raindrops and subsidence resulting in a quick alteration in total porosity and pore size distribution. Many researchers argue that the "specific volume" and "relative compaction" as defined below may be better indices of soil compaction than the bulk density or porosity *per se* (Soane et al, 1981).

$$\text{Specific Volume: } \frac{\text{Total Volume } (V_t)}{\text{Volume of soil solids } (V_s)} = \frac{\text{Particle density } (D_p)}{\text{Bulk density } (D_b)}$$

$$= (1 + \text{void ratio})$$

$$\text{Relative Compaction (\%)} = \frac{\text{Dry bulk density } (D_b)}{\text{(Maximum dry bulk density } (D_b) \text{ Poroctor)}} \times 100$$

Although both indices are related to bulk density, neither is indicative of the dynamic aspect of the rate of change. Moreover, it is difficult to develop a rating table because the relative compaction also depends on the initial level of soil compaction. Therefore, the rating given in Table 20 applies to those soils that are relatively uncompacted initially. This assumption is valid because we know that no-tillage is not successful for compacted soils. Soils that have high relative compaction and those that are already compacted may be less suitable for no-tillage than those with less relative compaction. Plowing and other mechanical tillage operations may be necessary for obtaining satisfactory crop yields from highly compacted soils.

In addition to soil constituents (texture and organic matter content), traffic induced compaction is also related to the amount of crop residue on the soil surface and the antecedent soil moisture content. Soils with high amounts of crop residue (Plate 9) and with good ground cover are less compacted than those with less residue and bare soil surface. Biological activity of earthworms and other soil fauna is also related to the amount of crop residue on the soil surface (Lal et al, 1980). Soils high in fine sand and silt fraction and those with a wide range of particle size distribution (well graded) are more readily compacted than poorly graded soils. A soil profile shown in Plate 10 is that of a loess soil in Senegal. This soil is easily compacted and requires mechanical ameliorative treatment (Nicou and Chopart, 1979). Soils with less relative compaction, low rate of change in bulk density and a high ground cover at seeding will respond favorably to no-tillage. If seeding is not done with proper seed drill that optimizes the environments in the seedling zone, thick crop residue mulch may adversely affect seed germination and seedling establishment. In addition to the effect of insects and other pests, inadequate seed/soil contact with thick mulch can curtail germination. Rating for soil compaction related parameters is shown in Table 20.

Nutritional properties: Soil acidity and the effective cation exchange capacity are important properties that are related to nutritional characteristics and should be considered while choosing an appropriate tillage system. For example, surface application of lime may not be as effective in neutralizing soil acidity in no-tillage as does its incorporation into the surface layer with the conventional system of plowing and harrowing. Choice of those crops that can tolerate soil acidity (rice, cowpea, cassava, etc.) may be a more practical alternative. Cation exchange capacity is influenced by the amount of clay and organic matter content and the nature of clay minerals. A majority of soils in the humid and subhumid tropics contain low activity clays with non-expanding lattice clay minerals and iron and aluminum oxides and, therefore, have low-to medium cation exchange capacity. Soils of volcanic origin (Andisols) and Vertisols of the semi-arid region have high cation exchange capacity.

The nature and quantity of the clay fraction are also related to soil consistency, workability and trafficability. Tropical soils containing relatively small amount (< 30%) of low activity clays can generally be managed by the no-till system. A relevant example is the case of Alfisols in western Nigeria (Lal, 1976a). Soils containing high amount of low activity clays may develop massive structure, particularly when the organic matter content is low. Soils of volcanic origin (Andisols) have generally good physical condition and can be managed by no-till system. The problem may be with soils containing high amount of high activity clay e.g. Vertisols. Clayey soils with "self-mulching" properties are more adaptable to no-tillage than those with massive structure and a narrow range of friable consistency. Clayey soils that do not possess natural tilth forming properties are not readily adaptable to no-tillage. Ratings in Table 21 apply to soils, including those with high activity clays. Soils with neutral pH, low clay content and containing low activity clays or those with self-mulching properties are suited to no-tillage more than those with high clay content and massive structure.

Relevance of no-till farming in the Tropics

In addition to the benefits to soil of crop residue mulch in preventing raindrop impact and maintaining good soil structure; creating favorable soil moisture and temperature regimes; and adding to the reserves of soil organic matter content, the importance of non-soil disturbance associated with the no-till farming cannot be overemphasised. The continuity of channels created by earthworms and related biological activity, and macropores created by decaying root system of previous crops are important factors in water transmission through the profile during the high intensity storms. It is also the stability and continuity of these channels in the untilled soil that favor deep root system development into the gravelly subsoil horizons (Maurya and Lal, 1980) that are otherwise difficult for roots of seasonal crops to penetrate (Babalola and Lal, 1977a;b, Vine et al, 1980). This implies that the overall benefits of no-till system with crop residue mulch will exceed those of plowing followed by surface mulching with an equivalent amount of crop residue. Mechanical tillage involving plowing and harrowing disrupts the continuity of pore space and create an additional barrier by its smearing action in the plow sole layer. These arguments in favor of the no-till system are further strengthened by significantly more grain yield obtained from the no-till mulch than the plowed mulch treatment (unpublished data of Lal).

Plate 9. Soil compaction without residue mulch can adversely affect maize crop yields with no-tillage. Maize in the background is mulched. Maize in the foreground is unmulched. (Experiment jointly conducted by Dr. A.S.R. Juo and Dr. R. Lal).

Table 19. Factors affecting hydro-thermal regime and their ratings (Lal, 1981d)

Available water holding capacity (cm)	Maximum soil temperature at 5 cm depth on bare soil (°C)	Probability of of 10 days or more rainless periods (%)	Permeability ($cm\ hr^{-1}$)	Rating
<4	>40	>80	>25	1
4 - 8	36 - 40	60 - 80	12.5 -25	2
8 -12	32 - 36	40 - 60	6.25-12.5	3
12 -16	28 - 32	20 - 40	0.5 - 6.25	4
16 -20	<28	<20	<0.5	5

Table 20. Relative compaction and associated factors (Lal, 1981d)

Percent change in bulk density or macro-porosity	Relative compaction %	Percent ground cover	Rating
<10	<10	>80	1
10 - 20	10 - 20	60 - 80	2
20 - 30	20 - 30	40 - 60	3
30 - 40	30 - 40	20 - 40	4
>40	>40	<20	5

Plate 10. Compacted soil in semi-arid region of Senegal near Bambey. This soil contains high amount of fine sand and silt fraction.

Table 21. Rating for suitability of tillage methods in relation to soil properties. (Lal, 1981d)

Soil pH (1:1 in water)	Clay content %	ECEC (meq/100g)	Rating
6.5 - 7.0	<10	<10	1
6.0 - 5.5	10 - 20	10 - 15	2
5.5 - 5.0	20 - 30	15 - 20	3
5.0 - 4.5	30 - 40	20 - 25*	4 (1 or 2)
<45	40 - 50	>25*	5 (1 or 2)

* Self-mulching soils with high-activity clays and high clay content will support no-till farming. Therefore, the rating factor 1 or 2 is proposed for these soils even with high clay content. Soils containing high clay content and with massive structure may require some mechanical tillage operations.

X. APPROPRIATE TILLAGE SYSTEMS FOR THE TROPICS

Integrating all important parameters into one index is a complex task indeed. There are many ways in which it can be done. Numerical addition of rating factors of all fourteen parameters discussed above is a method to provide some guidelines concerning the adaptability and the success of no-tillage and conventional tillage practices for specific soil conditions. This rating is extremely tentative and can be improved upon with a better knowledge of ecological factors, including soil, crops and climatic parameters. For example, the minimum and the maximum rating values will range from 14 to 70 for all factors discussed. Soils acceptable for no-till system are decided to be those with ratings of 2 or 3. This decision is based on the past experiences and the information available in the literature. This implies that the no-till system has better chances of success with rating values of less than 30. On the other end of the scale, if the cumulative rating factor exceeds 45, it is advisable to use some form of mechanical methods of seedbed preparation involving both primary and secondary tillage operations. For soils with intermediate rating, some form of minimum tillage or plowing at the end of the rainy season (stale bed technique) or plowing once every two or three years may be desirable. Appropriate tillage methods for different values of the cumulative rating index are suggested in Table 22.

There are many soils in the tropics that come into the borderline category and are now considered unsuitable for no-till farming. This is because there is a need to develop an appropriate package of cultural practices for a range of soils and agroecological environments for no-tillage methods to be effective. This rating is perhaps better indicative of those soil conditions where the use of some form of mechanical tillage is inevitable than those where the no-till may be applicable. No-tillage is a system as a whole and the agronomic package of practices to support it is not only different from the conventional tillage but is also different for different soils and agroclimatic environments. The index rating in Table 22 can be changed in favor of no-tillage as appropriate packages of agronomic practices become available for a broad range of soil and environments.

<u>Appropriate Tillage Systems For Different Soils And Environments</u>: Based on the available information for soil management and climatic problems for different soils and agroecological environments in the tropics, general guidelines for appropriate tillage systems are depicted in Figure 27a. This diagram is tentative and no claim is made for its application to very diverse soils and agroecological environments as they exist in the tropics. It is evident that in the humid and subhumid tropics with soils of coarse texture in the surface horizon, no-tillage can be successfully applied for upland row crops. In the semi-arid region with heavy textured soils, some type of mechanical seedbed preparation is necessary. The frequency and the type of mechanical operation desired depends on soil characteristics and the crops to be grown.

Table 22. Soil rating index and appropriate tillage system

Cumulative rating index	Tillage system suggested
<30	No-till farming with periodic fallowing.
30 - 35	Chiseling in the row zone.
35 - 40	Minimum tillage in permanent ridge/furrow system.
40 - 45	Plowing at the end of rainy season
>45	Both primary and secondary mechanical tillage.

Several examples of the application of this system are available in the literature. No-tillage has been shown to be effective for production of grain crops on Alfisols in the subhumid environments (Lal, 1979). A semi-permanent ridge furrow system with graded contour furrows is recommended for Vertisols in the semi-arid region (Kampen et. al., 1981), and both primary and secondary tillage operations are required for easily compactable sandy and loess soils in the Sahel (Nicou and Chopart, 1979). However, a considerable flexibility regarding the choice of tillage system may exist within each ecological zone depending on the local variations in soil conditions and predominant farming systems. Perhaps, a better approach to integrate all parameters would be through computing the probability for a soil having a given rating value. This frequency analysis can only be done if we have data base for a large number of soils differing widely in their soil characteristics. Also the number of variables chosen should be less: 4 or 5 rather than 14. Statistical methods of computing these probabilities for few variables are well established (Feller, 1968). It is hoped that this parametric method of assessment can be improved by using standard statistical techniques.

Tillage requirements also vary within the semi-arid or humid tropical environments. Soil water deficit is a major constraint to agricultural production in the semi-arid regions due to features of both climate and soil. Rain-water and surface soil management to maintain soil's water receptivity and channel continuity, and continuous supply of organic matter to the soil surface form the basis of a viable and a stable farming system for the humid tropic environments. Tillage alternatives shown in Figure 27b for the semi-arid environments are based on the moisture regime and specific soil constraints.

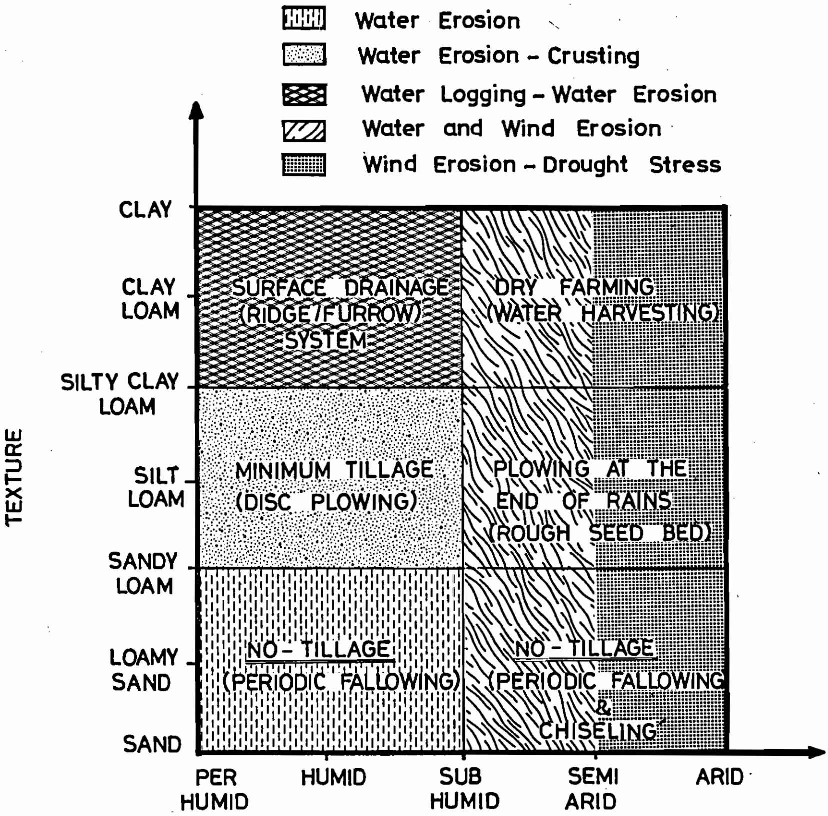


Fig. 27a. MOISTURE REGIME

Guidelines for tillage systems for different soils and moisture regimes. (a) general for the tropics

The moisture regime is computed according to Bailey's (1979) analysis of Budyko's (1976) aridity index. Precautions are taken to consider specific constraints of clayey soils with poor internal drainage and massive structure and of soils with high silt and fine sand fraction that are easily compacted. Although the generalizations presented are rather tentative, it is important to realise that soils with similar moisture regime may have different tillage requirements depending on their physical characteristics. The latter are significantly influenced by the predominant clay minerals present. Although soils of the humid tropics predominantly contain low activity clays (Kaolinite, halloysite or illite), the tillage requirements, of some recently developed Inceptisols or Entisols containing high activity clays will be greatly influenced by them. An attempt is made in Figure 27c to relate tillage needs to soil mositure regime, mineralogical composition, and to soil organic matter content.

The research and development information regarding the application of no-till system in different agro-ecological regions of the tropics is rather scanty. From the limited information available, it is evident that the mulch-based no-till farming is applicable for a wide range of environments provided a package of cultural practices is specifically developed for this system. The rating system to assess soil's suitability for no-till system can also be improved by the knowledge of soil's potential and its production constraints. Once the merits of no-till system are established and its limitations understood, it is important to alleviate the constraints and limitations with an effort to make this system work. For many shallow and structurally unstable soils, there is no choice but to use no-till farming for arable landuse. If used intensively with the conventional tillage system involving plowing and harrowing, the soil can undergo irreversible degradation to the point when restoration is either not possible at all or it will require long time to raise its productive potential. For these soils, it is better to obtain less but stable yield than to mine its productivity.

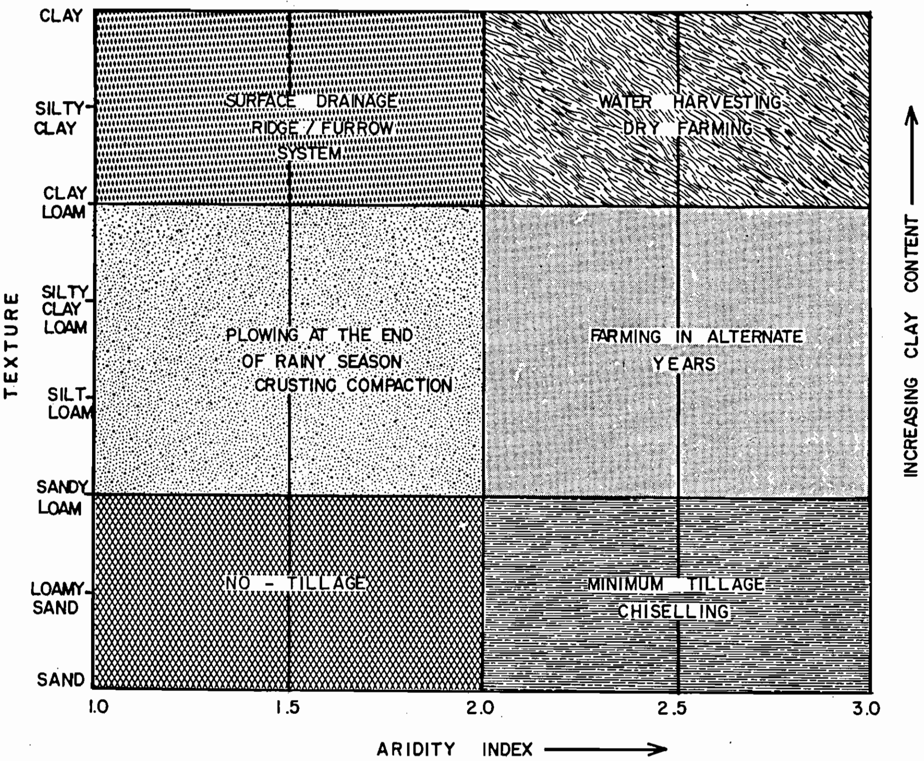


Fig. 27b. Guidelines for tillage systems for different soils and moisture regimes. (b) for the semi-arid tropics.

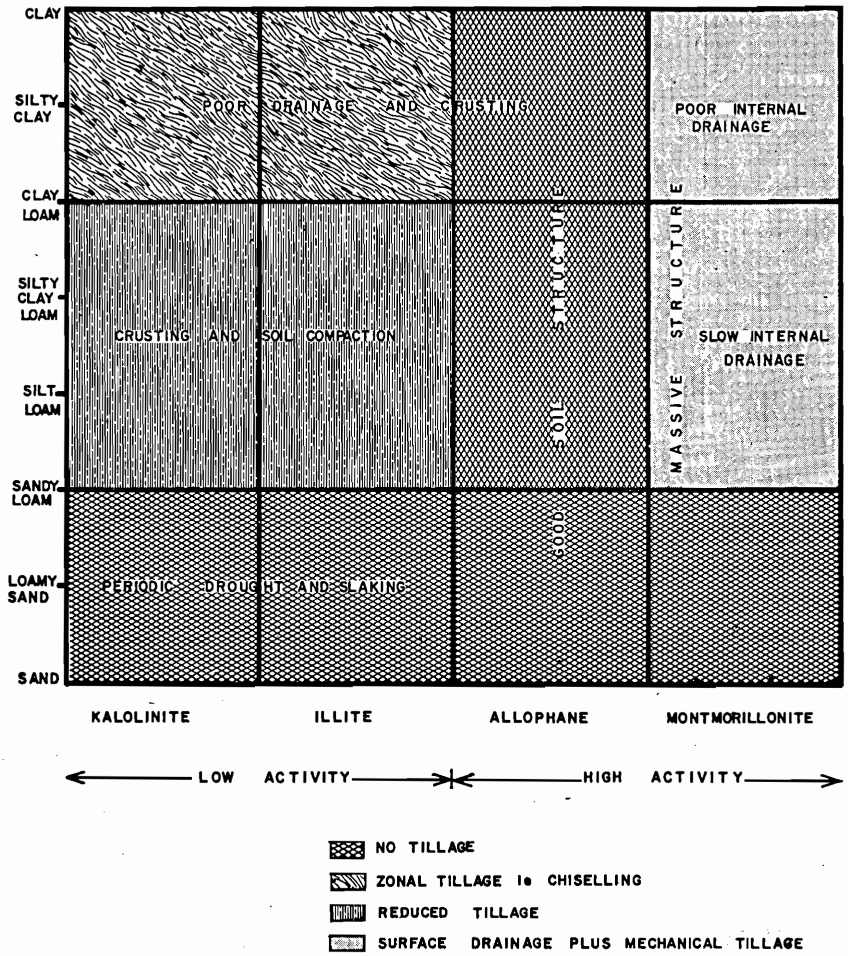


Fig. 27c. Guidelines for tillage systems for different soils and moisture regimes. (c) for the humid tropics.

XI. NO-TILLAGE SYSTEMS ON ERODED, COMPACTED AND DEGRADED SOILS

Prior to starting no-tillage farming on eroded and compacted lands, soil amelioration is necessary. It can be achieved as follows:

<u>Chiseling</u>: Chiseling up to about a 50 cm depth in the row zone with a mole attached to the chisel plow to avoid resettling of the loosened soil can improve infiltration and root development in the subsoil horizon. Incorporation of crop residue mulch in the chiseled trench (vertical mulching) can also avoid resettling and facilitate the lateral flow of water in the soil mass (Saxton et al, 1981).

<u>Occasional Plowing</u>: Plowing every 3 or 4 years, preferably towards end of the rainy season, is also recommended for soil amelioration (Nicou and Chopart, 1979). This practice has proved useful mainly for sandy soils of poor structure and with a low organic matter content.

<u>Drainage</u>: A permanent ridge/furrow system (Kampen et al, 1981) and a "camber bed" technique (Forsythe et al., 1979) can be adopted to provide surface drainage prior to installing no-tillage system on soils with impeded drainage. Farmers in eastern Nigeria make large mounds to facilitate drainage and grow upland crops (Plate 11).

Plate 11. Mounds or hillocks constructed in poorly drained soil.

Planted fallows: Initial fallowing with crops such as *Psophocarpus, Stylosanthes, Pueraria, Centrosems, Panicum*, etc. will improve soil structure and infiltration (Fig. 28), and chemical and nutritional properties (Table 23) and yield (Fig. 29). Even some obnoxious weeds (*Imperata, Talinum*, etc.) can also be controlled by aggressive cover crops. Fallowing with suitable cover crops can be repeated once every 4 or 5 years. Fallowing with leguminous covers is better than with grasses because the latter may be difficult to suppress. The choice of a suitable cover crop depends on many factors, including the ability to be economically suppressed by chemical or mechanical means so that seasonal crops can be grown.

X11. NO-TILLAGE AND ACID SOILS

Incorporation of lime is a limitation with no-tillage systems since lime does not move readily after surface application (Fig. 30). However, crops that tolerate low pH (rice, cassava, yam, sweet potato etc.) can be successfully grown with a no-tillage system in acidic soils (Table 24). Economic production of upland rice depends not only on the rainfall amount and its distribution, but also on the water holding capacity and effective root depth of the soil. Regions with good rainfall amount and favorable distribution can produce profitable crops of upland rice even if the water holding capacity of the soil were medium (e.g. soils in southeast Nigeria). Soils with high water holding capacity and deep effective rooting depth can also produce a profitable crop of rice with a no-tillage mulch system even if the rainfall distribution and amount were slightly unfavorable (Lal and Dinkins, 1979). Upland rice can be successfully grown with the no-till method in humid regions and with soils of low pH (e.g. central Zaire, southeastern Nigeria, Liberia, Sierra Leone etc.).

X111. NO-TILLAGE SYSTEM FOR IRRIGATED LOWLAND RICE

Rice being a semi-aquatic plant grows well in soils that are periodically (hydromorphic) or continuously inundated (irrigated paddies). Under these conditions, soil moisture is not a limiting factor, although some water control and its management is necessary. For soils of heavy texture, no-tillage can be successfully adopted both for direct seeded and transplanted rice (Brow and Quantrill, 1973; Elias, 1969; Maurya and Lal, 1979; Rodriquez and Lal, 1979 (Fig. 31). Data in Fig. 31 do not indicate any beneficial effects of plowing on rice yield. However, rice yield declined slightly in both tillage treatments since 1978. Detailed analysis of soil and biological constraints (insects, diseases etc.) may be required to identify the factors responsible for this trend in yield decline.

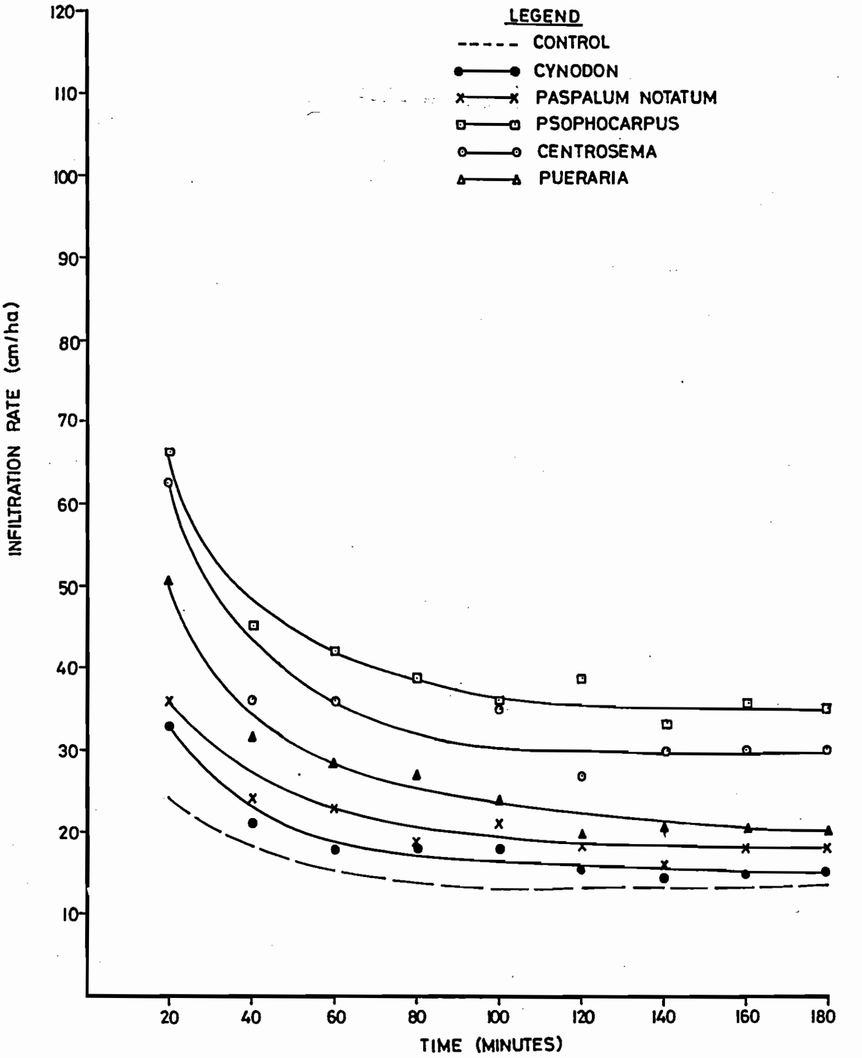


Fig. 28. Effects of different cover crops on water infiltration (Lal et al 1978).

Table 23. Chemical and nutritional properties of soils under different cover crops (Lal et al 1979).

Cover crop	pH		Organic carbon (%)		Total N (%)		Exchangeable K (meq/100g)		ECEC (meq/100g)	
	1974	1976	1974	1976	1974	1976	1974	1976	1974	1976
Brachiaria	5.5	5.2	1.21	1.57	0.12	0.19	0.4	1.0	6.1	8.5
Paspalum	5.7	5.3	1.23	1.45	0.14	0.17	0.5	0.7	7.1	8.2
Cynodon	5.7	5.2	1.30	1.70	0.14	0.19	0.5	0.9	6.9	8.9
Pueraria	5.6	5.1	1.27	1.50	0.15	0.17	0.4	0.8	6.6	7.7
Stylosanthes	5.5	5.3	1.30	1.63	0.16	1.21	0.5	0.9	6.3	8.8
Stizolobium	5.7	5	1.30	1.57	0.14	0.21	0.5	1.0	6.7	10.5
Psophocarpus	5.6	5.6	1.20	1.57	0.15	0.20	0.5	1.0	5.9	10.9
Centrosema	5.5	6.0	1.30	1.53	0.14	0.18	0.6	0.8	6.5	10.0
Control	5.9	4.4	1.33	1.37	0.16	0.17	0.5	0.6	8.2	8.4
LSD (.05)	0.5	0.7	0.50	0.23	0.04	0.03	0.2	0.4	2.3	3.5

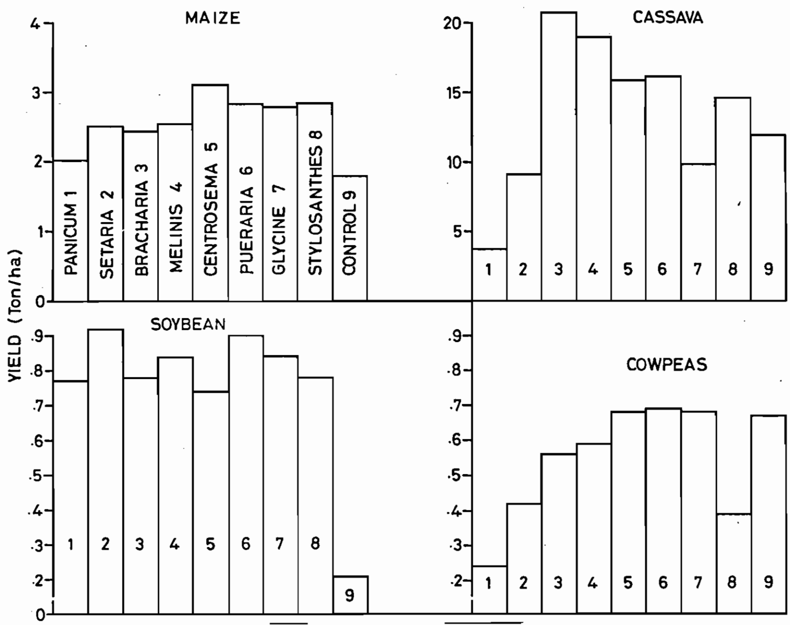


Fig. 29. Effects of different covei crops on yields of four crops (Lal et al 1978).

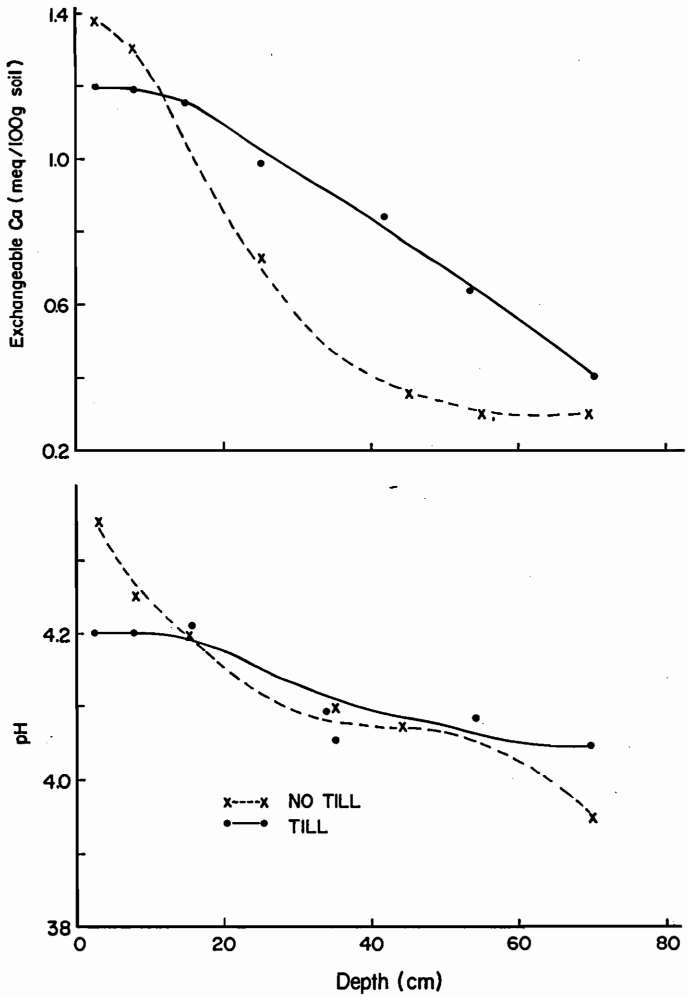


Fig. 30. Effects of tillage methods and liming on soil pH and exchangeable Ca (Maurya and Lal, 1979a).

Table 24. Effects of tillage methods on crop yield for an acid soil (a) Liberia) (Lal and Dinkins, 1979)

Tillage system	Maize grain yield		Rice grain yield		Cassava tuber yield	
	F_o	F_1	F_o	F_1	F_o	F_1
	t/ha					
No-tillage	0.55	2.80	1.24	2.92	3.2	6.5
Plowed	0.10	1.30	1.20	1.91	4.7	8.6
LSD (0.5)	1.50		1.14		3.4	

F_o = Without fertilizer

F_1 = With fertilizer

(b) Eastern Nigeria (Lal and Maurya, 1979)

Crop sequence	No-tillage	Plowed
	kg/ha	
1. Maize (I)	1603	1465
Maize (II)	1884	2084
2. Maize (I)	1473	1938
Pigeon pea (II)	73	85
3. Maize (I)	1274	1768
Cowpea (II)	123	32
4. Cassava	8843	9520
5. Maize + Cowpea	1693 + 194	2152 + 174

For coarse textured sandy soils, however, leaching losses of added inorganic fertilizers can be substantial in an unpuddled and flooded paddy. Nutrient imbalances and toxicity due to anaerobic conditions may also be high for sandy soils as a result of low buffering capacity. Anaerobic conditions can be worsened by the decomposition of crop residues under flooded conditions and this can adversely affect both seedling growth and crop establishment. Rice growth shown in Plates 12 and 13 indicate superior growth with plowing when residue was removed than in no-tillage when residue was left in the standing water and decomposed anaerobically. Residue removal or burning with no-tillage should be a better practice for irrigated lowland rice. As a result, rice yield with no-tillage system may be less than with conventional tillage involving dry and wet cultivation (Fig. 32).

Burning of rice straw prior to flooding may avoid some of the toxicity problems listed above. Soil permeability, and leaching losses of applied fertilisers can be decreased by periodic soil compaction (Table 25), but transplanting in compacted unpuddled soil is slow and hard for manual operations. Appropriate agronomic practices should be developed to facilitate transplanting in hard and compact unpuddled soil. Soil erosion is not a problem for bunded and and levelled paddies developed in the valley bottoms. The advantages of no-till system for rice include savings in fuel, and in time needed for mechanical tillage. The yield of upland crops (soybean, cowpea) followed after rice grown in the dry season is generally more in an unpuddled paddy with better soil structure than in plowed paddies whose structure is deliberately destroyed by puddling. No-tillage method, therefore, facilitates multiple cropping in regions with predominant rice-based cropping systems.

The development of root tubers interacts differently with soil than that of fibrous roots of grain crops or feeder roots of tuberous crops. Not only is a voluminous "root room" required for their development, but the ease of harvesting should also be considered. Mechanized harvesting of root tubers by conventional methods of opening a trench can cause a significant soil disturbance. Manual harvesting of individual plants, however, results in less soil exposure and disturbance. Leaf litter of cassava or sweet potato, if left on the soil surface as mulch, will minimize soil exposute. Cassava tubers exert tremendous pressures on the soil and its feeder roots can penetrate hard and compact soils better than several grain crops (Plate 14). Data in Fig. 33 shows no effect of soil bulk density between 1.4 and 1.8 gcm^{-3} on root length or root weight density of cassava. For sandy, deep soils of at least 30 cm effective rooting depth, no-tillage is a preferable and attractive system for root crops such as sweet potato and cassava (Table 26). Experiments conducted on 3 to 4 hectare watersheds also indicated no effects of tillage methods on cassava tuber yield (Table 27). In any case, the economic benefits obtained from conventional tillage may not justify the additional costs involved in mechanical seedbed preparation involving plowing and harrowing. Harvesting may not be a serious hazard for coarse textured soils of loose and friable consistency. For shallow soils and for those of heavy texture and hard consistency, some mechanical soil manipulation and ridging may be necessary.

Tuberous roots of yam develop in a vertical direction compared with the horizontal orientation of cassava tubers. Yam tubers are forced above ground when grown in hard and compact seedbeds (Plate 15). Under these conditions, farmers grow yam in a hole dug in the ground to facilitate tuber development. The size and shape of the hole determines the tuber size and shape. For shallow soils with a low water holding capacity and supraoptimal soil temperature regime, mulching with crop residue is extremely beneficial for set-germination, establishment and yam yield (Fig. 34). For deep sandy soils

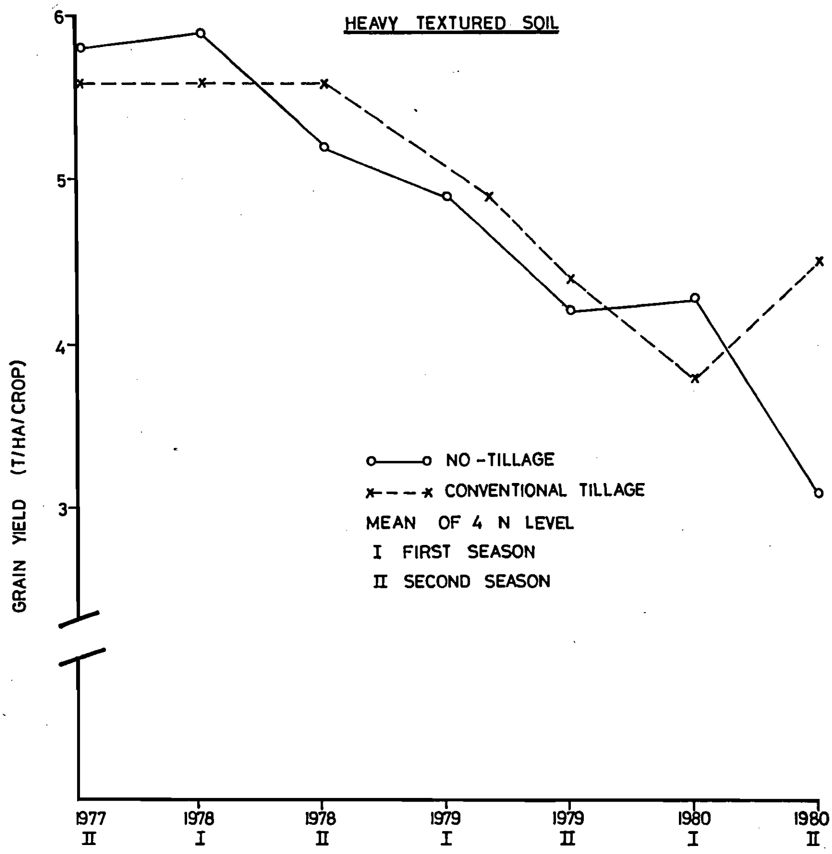


Fig. 31. Effects of tillage methods on rice yield for a clayey paddy.

Plate 12. Rice growth in a sandy paddy using conventional tillage of dry and wet plowing after six consecutive crops of rice.

Plate 13. Rice growth in a sandy paddy using no-tillage after six consecutive crops of rice.

in the humid region of southeastern Nigeria, yams are traditionally grown on an untilled flat seedbed without primary or secondary tillage operation. When grown in poorly drained hydromorphic soils, yams are grown on large mounds to improve aerobic conditions in the root zone (Plate 16).

XV. IS MECHANICAL TILLAGE NECESSARY?

The conclusion drawn from the research and experience gained with tillage systems on Alfisols in west Africa is that a range of upland crops and rice can be successfully and profitably grown with the no-tillage system as long as the following requirements are met:

Crop residue mulch at 4 to 6 t/ha for soil and water conservation in upland crops.

Adequate weed control.

Satisfactory crop establishment through appropriate seeding equipment.

These requirements are not only different for different crops but also vary among soils. Soil properties are extremely important for profitable crop production with the no-tillage system. No-tillage can outyield the conventional tillage system for upland crops on soils with a coarse to medium texture surface horizon and with good internal drainage. High yields are

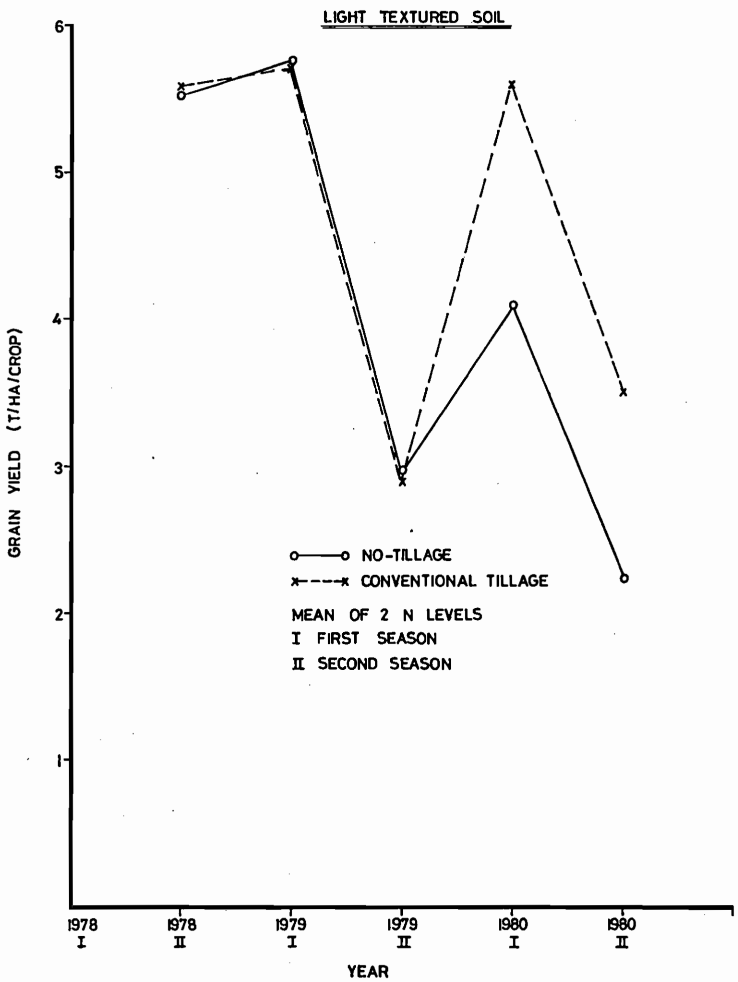


Fig. 32. Effects of tillage methods on rice yield for a sandy paddy.

obtained with the no-tillage system despite low inputs, than with conventional tillage. Furthermore, high yields are maintained over a long period with the no-tillage system, whereas a rapid decline in yield occurs with conventional tillage. Satisfactory rice yields with no-tillage is also reported in paddies and hydromorphic soils (Maurya and Lal, 1979; Rodriquez and Lal, 1979; Lal and Dinkins, 1979). However, a careful appraisal of all factors is necessary for the adaptation of the no-tillage system for small land-holders and large-scale mechanized farms.

In the humid and subhumid regions where traditional methods of farming based on a bush-fallow rotation are widely practiced, small land-holders traditionally cultivate the land without drastic mechanical soil manipulation. The size of the farm and the lack of capital make it difficult to purchase farm machinery. Tractor hiring services for mechanical seedbed preparation are rarely available. The use of herbicides is a preferable alternative, especially when used in conjunction with no-till farming.

For the large-scale mechanized farms in the humid tropics, it seems that presently recommended practices based on mechanical tillage are excessive, expensive, and soil degrading, and these recommendations should be reviewed in view of the recent research developments. This does not imply that chemical or no-tillage is automatically applicable for all soils and crops. It means that unnecessary and wasteful mechanical tillage operations should be avoided in favor of no-tillage, chiseling in the row zone, minimum tillage, or plowing at the end of the rains every 3 or 4 years. The no-tillage concept with a crop residue mulch can be widely adapted as part of a suitable package of agronomic and cultural practices that are specific for the no-tillage system. If this package of agronomic practices is available, mechanical tillage will not be necessary.

Table 25. Rice yield as affected by soil compaction and tillage methods. (Unpublished data of Ogunremi, Lal and Babalola)

Treatment	Rice grain yield (t/ha)		
	First season 1981	Second season 1981	First season 1982
Artificially compacted	7.9 a	4.1 a	7.6 a
No-tillage	5.9 b	3.3 b	5.6 b
Mechanical tillage and puddling	6.6 b	3.5 b	5.1 b

Figures followed by the same letter are statistically the same at the 5% level of significance by the DMR test.

Table 26. Effects of tillage methods on yield of sweet potato and cassava in a tropical Alfisol (t/ha)

Tillage method	Cassava	Sweet potato
No-tillage	16.4	24.5
Plowing	14.6	23.5
LSD	-	16.0

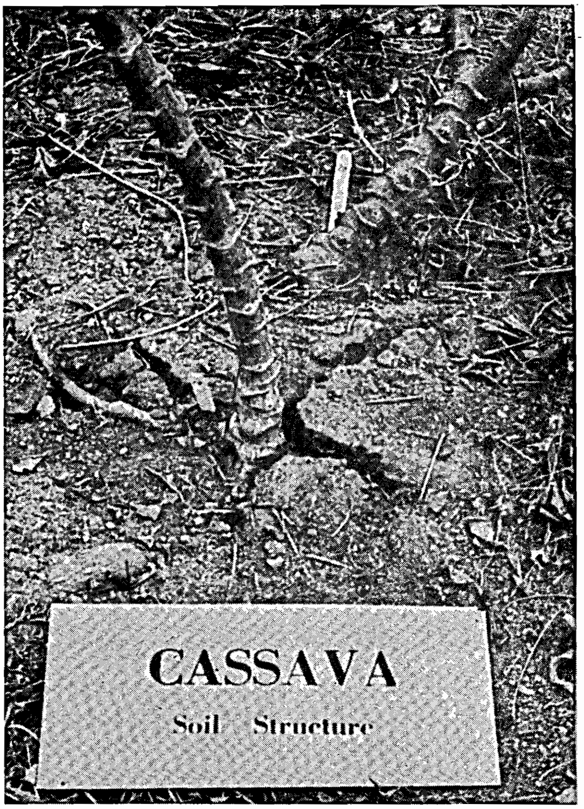


Plate 14. Heaving effect of cassava tuber on soil.

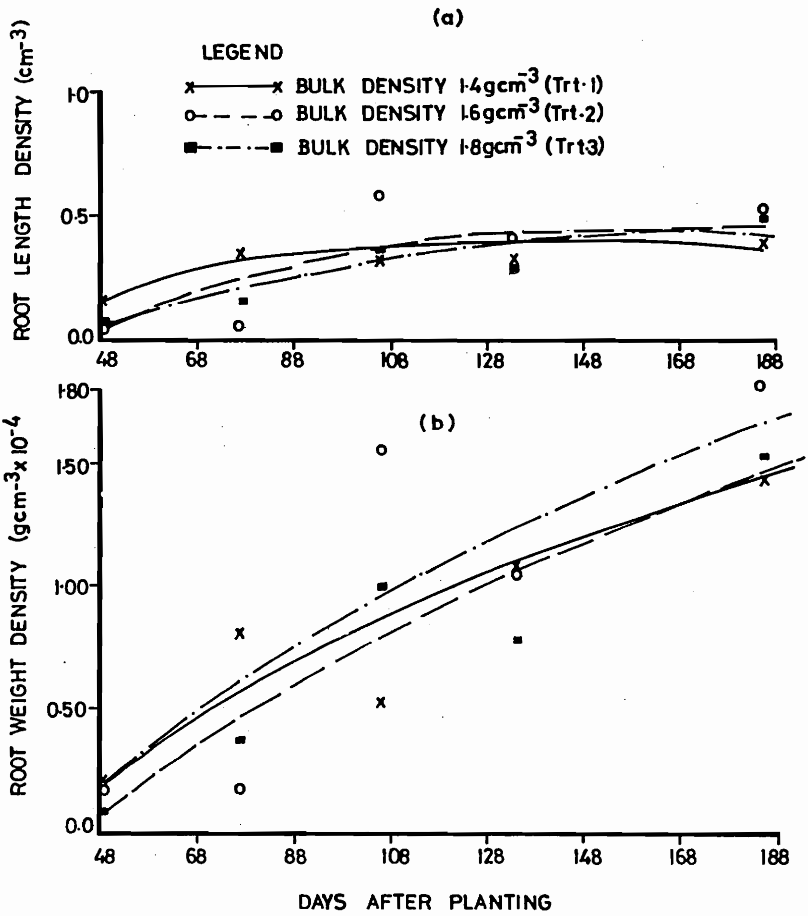


Fig. 33. Effects of soil bulk density on feeder roots of cassava (Maduakor and La, 1981).

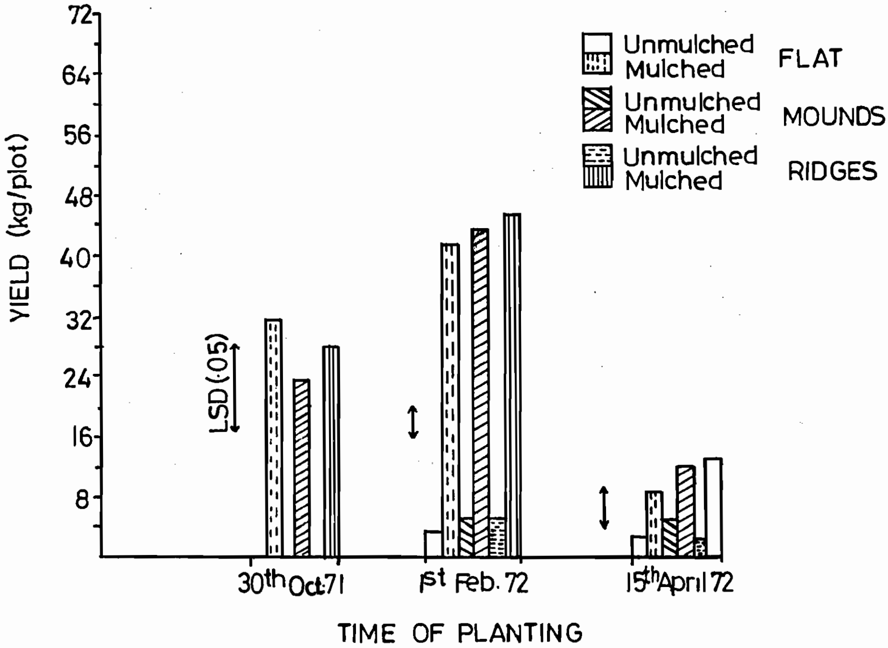


Fig. 34. Effects of methods of seedbed preparation and mulching on yam (Lal and Hahn, 1973).

Table 27. Effects of Land Clearing and Tillage Methods on Cassava Tuber Yield (t/ha)

Treatments	Tuber Yield (t/ha)
Traditional Farming	7.7
Manual Clearing FB No-Tillage	15.0
Manual Clearing FB Conventional Tillage	11.7
Shear Blade FB No-Tillage	24.2
Tree Pusher FUB No-Tillage	10.2
Tree Pusher FB Conventional Tillage	17.5
LSD (.05)	NS

Plate 15. Yam tubers growing above ground on a compacted soil.

Plate 16. Yams growing on large mounds in poorly drained soils in southeast Nigeria.

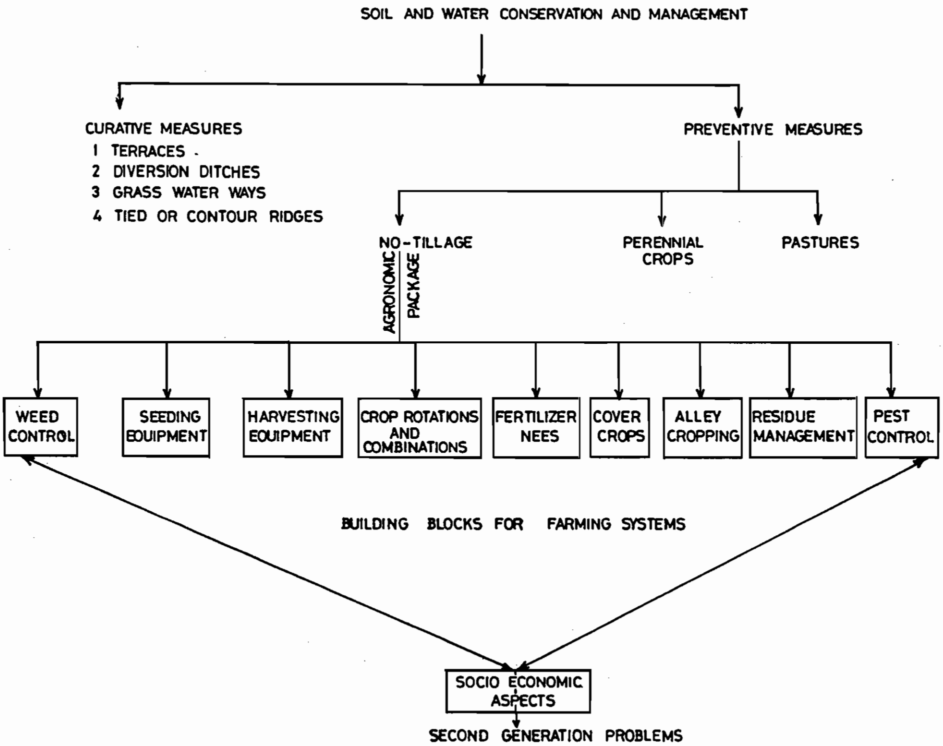


Fig. 35. Package of cultural practices required for no-tillage system.

XVI. AGRONOMIC PACKAGE FOR NO-TILLAGE SYSTEM

The no-tillage system is based on substituting chemicals for mechanical weed control. In no-tillage the presence of a crop residue mulch, combined with little or no soil disturbance, creates different micro-climate and biological environments in the vicinity of the soil surface. This modification in the crop growth environment also shifts the balance of populations of insects and disease producing organisms. Mulch also hides rodents and other pests that may increase the damage to young seedlings. An uneven ground surface and the presence of crop residue mulch requires special seeding equipment that can cut through the mulch and ensure adequate seed/soil contact. Transplanting of rice seedlings into unpuddled paddies may require the use of a special equipment. Appropriate crop rotations are required to ensure an adequate quantity of mulch for soil protection. Other inputs such as the rate and placement of fertilizers and amendments and the timely and precise application of suitable herbicides are some special requirements for the no-till system. Harvesting of tuberous crops (cassava, sweet potato etc.) grown with the no-till method should also be considered with a view to minimizing soil disturbance and facilitating extraction of roots during mechanized harvesting. Therefore, the package of cultural practices and inputs are different for no-tillage than conventional tillage system. The success of the no-till system depends on the availability of this package (Fig. 35). Furthermore, the package of cultural practices is different for different soils and crops, and local adaptive research is necessary to develop this package for a range of soils and agro-ecological environments. The applicability of no-till method for those soils and crops where it has not been successful can be improved by development of this package through local adaptive research.

The no-till method should not be considered in isolation. It must fit in the overall farming/cropping systems of the region. No-tillage provides the necessary framework to which can be added other components or building blocks to develop locally acceptable farming systems. Since the package composition is different for different regions and farmers, a range of farming systems for different environments exists.

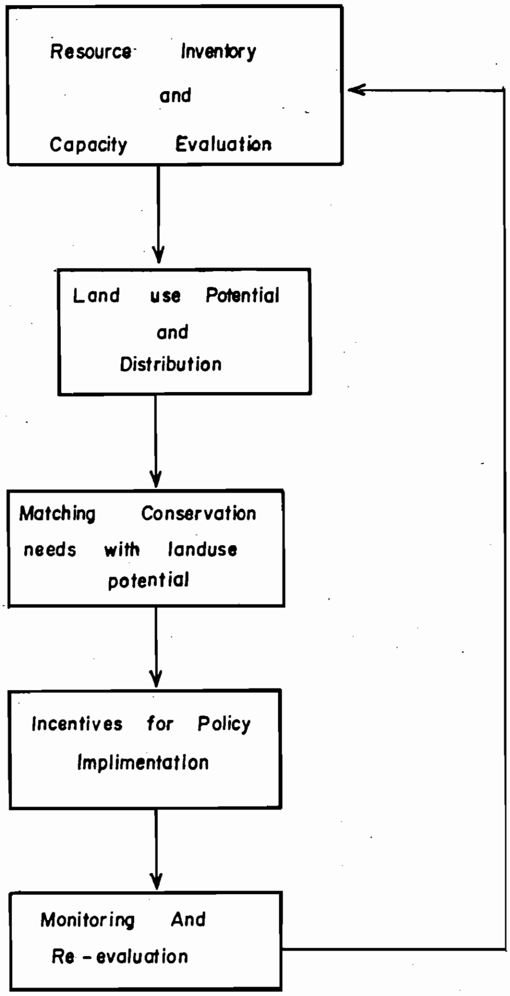


Fig. 36. Sequence of steps required for planning for new arable land development.

XV11. CONCLUSIONS

In order to meet the increasing demand for food, a solution must be found to the problems associated with the transition from the traditional shifting cultivation to a more productive land use systems in the humid tropics. The no-tillage system is a powerful point of entry to solve the problems of soil erosion, degradation and soil fertility management. Maintenance of the soil structure and organic matter content is the basic requirement for any package aimed at recuperating and maintaining the productivity of these soils. Without these basic foundations, other inputs (fertilizers, varietal improvements, disease and pest control, improved machinery) are wasted. The no-tillage system achieves this ecological balance and permits profitable crop production without additional costs for erosion control. It does this with a minimal risk to the soil and environments.

Traditional methods of cultivation are geared towards a low level of productivity, and will become more inadequate with increasing demographic pressure. The productivity of traditional cultivation methods can be increased by incorporating components of the no-tillage system as an improvement of existing methods. Use of systemic or contact herbicides prior to seeding will save labor and provide a protective mulch layer. The drudgery of the seeding operation can be removed by using a rolling injection planter or other manually operated tools such as those developed by the Farming Systems Program. It is better to bring about gradual improvements in the existing system than to replace them by drastic methods developed elsewhere.

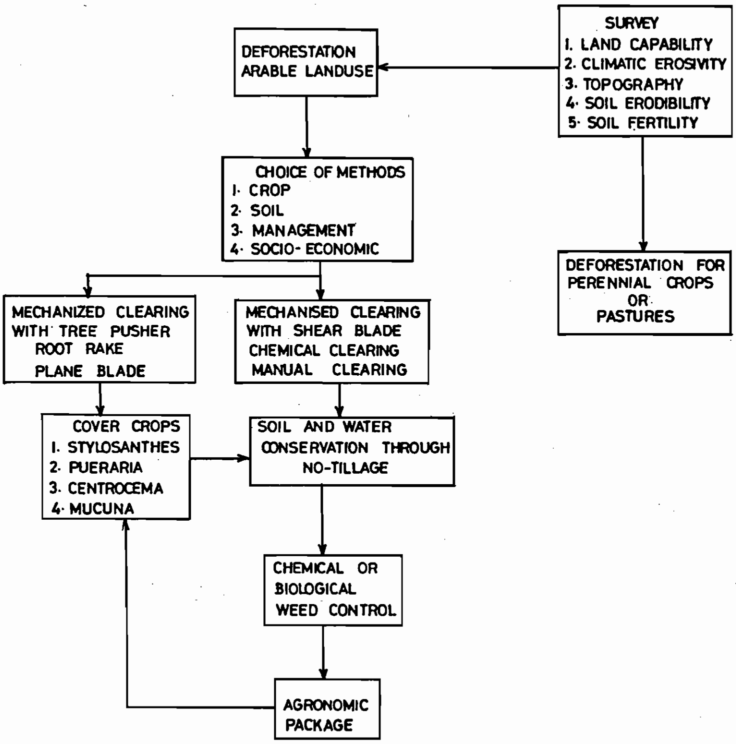


Fig. 37. Land development and management for soil and water conservation.

The accelerated rate of soil degradation and consequent decline in productivity of soils in the tropics can be controlled by adopting conservation-effective farming systems e.g. no-till method with residue mulch. The land development and subsequent management, however, requires a long range planning. It is the improper planning, and project implementation with inadequate resource inventory that has often lead to the failure of many ventures intended for agricultural development in the tropics. A sequence of steps necessary for new land development are outlined in Fig. 36. A careful appraisal of the resource base is necessary for the successful implementation of these development schemes and sustained productivity from tropical soils. More specifically, the use of no-till farming system should also be envisaged right from the initial stages of planning for arable land development. Because the no-till system maintains a status quo in soil physical and hydrological properties, it is logical to develop land by those methods that cause a little change in them.

The planners of large-scale land development schemes have no choice but to adopt the no-tillage system if they wish to grow annual crops and reduce soil erosion and degradation. For mechanized operations, no-tillage is a preferable and an attractive system. The adoption of the no-tillage system should be envisaged at the initial planning stages. The successful application of this system depends on appropriate methods of land development, suitable cropping systems, and the choice of suitable machinery for seeding and weed control (Fig. 37).

No-till farming has definite advantages:

No-till reduces soil erosion dramatically. With no-tillage there is no necessity of developing terraces, diversion channels, or grassed water ways.

There is more water available in the root zone with no-tillage, and the soil temperature is also favorable.

No-tillage maintains soil organic matter at a high level. With it the soil has a high nutrient exchange capacity. Losses of applied fertilizer through runoff, eroded soil or leaching are reduced.

There is a definite savings in capital investment for farm machinery, and in time and fuel required for seedbed preparation.

No-tillage can actually out-produce conventional tillage and can prolong productivity without resorting to a lengthy bush-fallow rotation.

However, for no-tillage to be successful, it is necessary to develop a package of cultural practices for:

Adequate weed control with herbicides.

Crop residue mulch at 4 to 6 t/ha for soil protection.

Crop rotations, including periodic fallowing with grass or legume covers.

Suitable seeding and spraying equipment.

Disease and pest control.

The choice of soil type is also important. Different variations of the no-till system -- strip tillage, minimum tillage etc. -- can be adopted for a range of soils and crops in the humid and subhumid tropics. The adaptation of the no-till system can be done easily for small land-holders as well as for the large-scale mechanized farms, the difference being in the socio-economic considerations. In fact, it is a scale neutral technology.

No-till farming, in combination with suitable methods of land development, provides an alternative to traditional bush-fallow system. It increases food production per unit of inputs, area, and time without causing rapid soil degradation, and with a minimum risk to the environments.

Although much progress has been made in understanding the basic principles of no-till system, much also remains to be done in adapting the technique to a range of soils and environments in the tropics. Research coordination is needed in empirical testing of recommendations for different crops and soils. Much also remains to be done in delineating the limits of adaptability of different variations in the no-till system. To be specific, additonal research information is needed for the following:

Soil compaction and Its Alleviation: Characterization of soil compaction and evaluation of crop response to compaction for different tillage systems is necessary to develop agronomic practices, plan farm operations, and choose appropriate machinery and attachments to minimize this hazard.

Residue Requirements for No-till system: The quantity of crop residue required dor effective soil and water conservation varies with different soils, crop sequences, and rainfall characteristics. This information is needed to define the optimum crop residue requirements so that the surplus can be removed from the field for alternate uses.

Modelling Tillage Effects on Soils: There is a need to assess and develop appropriate physical models that can predict the effects of tillage systems on properties -- compaction, water transmission and retention, soil temperature regime etc. -- in a range of soils in the tropics.

Soil suitability for No-till Farming: Field investigations are required to assess the applicability of the proposed rating method to evaluate suitability of different soils for no-till farming. Appropriate modifications may be necessary in the rating procedure depending on the basis of crop response to no-till method for a range of soils in the humid and subhumid tropics.

Soil Restoration: Restoration of degraded and eroded soils is necessary prior to the implementation of the no-till method. Research information is required for the effective restorative measures for a range of soils in the different agro-ecological environments. These restorative measures may include planted fallows, use of soil amendments, sub-soiling etc.

No-till Farming and Alley Cropping: Maximum utilization of nutrients in the residue mulch from a perennial leguminous alley crop may necessitate its incorporation in the soil. However, basic research information is lacking concerning the effects of tillage methods on mineralization, leaching etc.

Earthworm Activity and Tillage Methods: Earthworm activity plays a significant role in improving soil physical and nutritional properties. However, the effects of agricultural chemicals (herbicides, pesticides, amendments) on earthworm activity are unknown. Procedures for an effective recolonization by earthworms on degraded soils for their restoration are also not known. The depth from which earthworms bring the subsoil and void it to the surface has implications in terms of soils management because the continuity and stability of the channels created by them are important media for root proliferation and development, and water and nutrient movement. All these aspects of soil-earthworm interactions need to be thoroughly investigated.

Crop Residue Management In Paddy Soils: The effects of anaerobic decomposition of crop residue in paddy soils in relation to tillage methods need to be investigated.

No-Till Farming and Pollution of Environments: The mechanized no-till farming systems are based on heavy inputs of herbicides and pesticides. The surface application of fertilizers and soil amendments is also necessitated by this method. There is little available information regarding the fate of these chemicals in tropical environments. Research should be conducted to assess the movement of these chemicals in surface runoff, with eroded soil, and in percolation water. Research information is also required for the residual accumulation of those chemicals in soils and their bio-degradation.

Fertilizer, Soil Amendments and Their Application: Chlorotic symptoms of nutrient imbalance are observed in crops grown with no-till methods when crop residue mulch has a wide C:N ratio. The losses of applied fertilizers (leaching and volatilization) may be different in no-till than in conventional tillage methods, and need to be assessed. The rate, time of application, method of application, and even the nature of fertilizer to be applied may be different for no-till than conventionally plowed soils. This type of soil-specific research is also needed for different soils and crops in the tropics.

The Research needs and priorities listed emphasize the importance of a team approach involving a coordinated effort by soil and plant scientists, biologists, engineers, and social scientists. The realization of potential benefits of no-till system depends on this multi-disciplinary team approach to solve these complex problems.

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