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A SOIL SUITABILITY GUIDE FOR DIFFERENT TILLAGE SYSTEMS IN THE TROPICS

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ABSTRACT

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A tillage guide is needed to give systematic adoption of tillage technology in the tropics. A rating system is proposed for assessing the applicability of tillage and no-tillage practices for different soils. Soil and climatic properties considered in developing the rating system include erosivity, erodibility, soil loss tolerance, compaction, soil temperature regime, available water holding capacity, cation exchange capacity and soil organic matter content. Also included is the quantity of crop residue on the soil surface at seeding. The minimum and the maximum cumulative rating values for all factors ranges from 14 to 70. No-till is applicable for soils with cumulative ratings of less than 30 and conventional tillage system of plowing and harrowing for soils whose cumulative rating values exceed 45. For soils with intermediate rating some form of minimum or reduced tillage is suggested. Separate rating systems are suggested for rice and for tropical root crops.

INTRODUCTION

The estimated potentially arable land in the tropics ranges from 1500 to 1800 million ha of which only 700—800 million ha is currently being used (FAO, 1978; Schulze and Van Staveren, 1980; Dudal et al., 1982). The remaining land reserves for future expansion are primarily available only in central and south America and tropical Africa, where it may yet be possible to increase food production through an increase in the area under cultivation. Once fertile land is, however, being rendered unproductive at an alarming rate because of inappropriate cultural practices. Consequently, irreversible degradation of soil is shrinking the natural resource and its productive potential (Kovda, 1977; FAO, 1978).

This alarming rate of soil degradation can be curtailed by the techniques of conservation farming. The no-tillage system of cultivation with crop residue mulches is the basis of conservation/stubble-mulch farming. Stubble-mulch farming is a system of maintaining a protective cover of residue from previous crop on the soil surface at all times. This is achieved through a no-till method of planting crops that requires no seedbed preparation other than opening the soil for seed placement at the intended depth. The no-till system of cultivation with crop residue mulches is the basis of conservation farming because it conserves water, prevents erosion, maintains organic matter content at a high level and sustains economic productivity (Lal, 1976b; Greenland, 1981).

However, the continuous use of no-tillage system may cause soil compaction especially with mechanized crop seeding and harvesting. Some soils are naturally compacted and others attain high bulk density because of continuous traffic or grazing. When this happens, ameliorative measures such as chiseling (Allmaras et al., 1977), controlled wheel traffic (Lindstrom and Voorhees, 1980), plowing at the end of rains when soil surface is relatively dry (Moreau, 1978; Nicou and Chopart, 1979), and the use of cover crops, planted fallows and residue mulches (Kannegieter, 1969; Lal et al., 1978, 1980) have proven to be advantageous. Vertical mulching (Saxton et al., 1981) is also a useful technique to improve water infiltration through a compacted soil surface. Soils with slow internal drainage often respond to no-tillage after appropriate drainage measures have been taken.

An important benefit of no-till farming with residue mulch is the reduction or prevention of soil erosion and the maintenance of soil fertility. In addition, there are definitive savings in machinery investment and time required for seedbed preparation. This system of conservation farming may also abate pollution from agricultural lands. Among the disadvantages are more difficult weed control, specific machinery and cropping systems requirements, and soil specificity. No-tillage has proven to be an attractive alternative for maize (*Zea mays* L.) and other row crops on coarse-textured soils in the humid and subhumid tropics. Can this practice be applied for a wide range of diverse soils as they exist in the tropics? What are the soil characteristics where mechanical tillage is necessary?

The objective of this report is to assess tillage requirements for different soil conditions and specify soil requirement for the no-tillage to be successful. An attempt is also made to characterize those soils that must receive both primary and secondary mechanical tillage operations for economic levels of crop production. The ideas are based on present research knowledge, especially in the humid tropics, and may require modification as further information and experience accumulate.

SITE FACTORS AND NO-TILL PERFORMANCE

Even on coarse-texture soils with an adequate quantity of crop residue mulch, crop establishment and performance with no-tillage depends to a large extent on the initial soil conditions and previous land use. Some of the factors that are considered important for temperate regions may not attract serious considerations for the tropics. For example, in the tropics,

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an inadequate amount of crop residue, rather than its excess, is an important determinant to crop performance. Moreover, soil temperature regimes in the tropics during the seedling stage may be supra-optimal rather than the sub-optimal range observed in the temperate regions. Soil in temperate regions may be too cold and too wet in the seedbed, but just the opposite is usually the case in the tropics. There may be other factors that are rather specific for a given agroecological region and some that are equally valid in all ecologies. Some important site-soil factors for tropical environments are as follows.

Soil compaction

Seedling emergence, crop establishment, and root growth can be adversely affected if the surface horizon is excessively compacted. Although the range of optimum bulk density for different crops and soils may be different for no-tillage compared to conventional tillage, excessively compacted surface horizons can increase runoff and thereby prematurely expose the crop to drought stress. Soils that are easily compacted, such as those that predominate in the fine sand and silt fractions in the Sahel, may require periodic ameliorative operations prior to the adoption of no-tillage (Charreau, 1977; Nicou and Chopart, 1979).

Soil heterogeneity

Micro relief and an uneven ground surface adversely affect seeding performance of a no-till planter, because seeds may be dropped on the surface in the depression and seeded too deep in the elevated portions. Both contribute to uneven stand. Uneven seeding can also be caused by the presence of stones and gravels in the vicinity of the soil surface. In the case of compacted soil surface, depressions are also easily water-logged creating anaerobic environments in the root zone. In addition, uneven distribution of crop residue mulch may also affect micro-climatic environments in the seedling zone needed for crop establishment. Crop residue and shrub growth also harbor birds and rodents that destroy young seedlings and seriously affect crop stand and growth.

Topography

No-tillage is safer with respect to erosion than conventional tillage on steep slopes, provided the predominant slopes permit mechanized operations. Within the range of slopes that can be managed with mechanized operations, micro-relief becomes a more important factor than the general topography of the landscape.

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CONSIDERATION OF SOIL FACTORS

Soil property influences on the choice of tillage operation have been reviewed by Soane and Pidgeon (1975), Cannell et al. (1978) and Osborne et al. (1979) for soils in U.K. and by Cooperative Extension Service (1977, 1982) in the USA. The adaptability of no-tillage from 1 soil and agro-ecological environment to another should be done with consideration for soil properties. Soil properties that will favor the application of no-tillage include the following: (i) coarse-textured surface horizons or self-mulching clayey soils with high initial porosity; (ii) resistance or less susceptibility to compaction; (iii) high biological activity of earthworms and other soil animals; (iv) good internal drainage for upland crops; (v) friable consistency over a wide range of soil water contents.

Self-mulching property has a significant favorable importance to machine operation or performance in no-till. However, a quantitative evaluation of this property is difficult to make. For other soils, an appropriate soil conserving land use system or other suitable tillage operation should be adopted in association with soil conserving practices to minimize soil degradation.

SOIL FACTORS WHICH PARTICULARLY FAVOR NO-TILLAGE

No-tillage is naturally suited for those problem soils that are highly susceptible to erosion, have a 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). Tolerance for soil loss from most Alfisols, Ultisols and Oxisols is low because of the shallow effective rooting volume and unfavorable physical, nutritional and biological properties of the subsoils horizons (Lal, 1983). Tolerable soil loss is generally less than 0.5 Mg ha^{-1} $annum^{-1}$ and is often below 2 Mg ha^{-1} $annum^{-1}$. 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 I 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 I, a rating of 1 is given to those soil and climatic factors that increase the risk of soil erosion and a rating of 5 to those factors that render a soil less susceptible to water erosion. Those soils with a high ero-

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dibility factor (K), in regions of high rainfall erosivity, on steep slopes with a thin surface horizon, are more susceptible to erosion. Where these factors may cause crop yield to decline below economic parity within a few years after opening new land, a rating of 1 is given. Since the 4 factors in Table I are not necessarily correlated, the cumulative rating ranges from 4 to 20.

TABLE I

Factors affecting soil erosion and the need for no-tillage in the tropics

Annual cumulative erosivity (EI_{30}) $\left(\frac{MJ \cdot mm}{ha \cdot h \cdot year}\right)$	Soil erodibility $\left(\frac{Mg \cdot ha \cdot h}{ha \cdot MJ \cdot mm}\right)$	Soil loss tolerance (Mg/ha·year)	Slope (%)	Rating
>17 000	>0.08	<0.5	>10	1
13 500—17 000	0.05 —0.08	0.5—2	6—10	2
10 000—13 500	0.03 —0.05	2—6	4—6	3
6 500—10 000	0.015—0.03	6—10	2—4	4
< 6 500	<0.015	>10	<2	5

The frequency, amount and duration of the rainfall are important factors, which are included in the erosivity parameter EI_{30} as defined in the Universal Soil Loss Equation Included in the soil erodibility factor (K) are the permeability, texture, organic matter content and soil structure. The physico-chemical and nutritional properties of the subsurface horizon and the effective rooting depth 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

Because particle size distribution, structure, organic matter and moisture regime affect soil thermal properties they also affect soil temperature regimes. Soils in the humid tropics have low available water holding capacity and are drought susceptible (Hsiao et al., 1980). Rapid growth favored by high temperatures can be sustained only with a continuous supply of readily available water in the root zone. High evaporation rates and low thermal capacity create supra-optimal 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 supra-optimal soil temperature regimes 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 temperature exceeding 40°C at 5 cm depth 3—6 h a day during the seedling stage can be injurious to

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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 adopted to no-tillage for most upland crops in the humid and sub-humid tropics.

On the other hand, hydromorphic and poorly drained soils 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.

TABLE II

Factors affecting hydrothermal regimes and their ratings for no-tillage in the tropics

Available water holding capacity (cm)	Maximum soil temperature at 5-cm depth on bare soil (°C)[a]	Probability of a rainless period ≥10 days (%)[b]	Soil permeability (μm s^{-1})	Rating
<4	>40	>80	>70	1
4—8	36—40	60—80	35—70	2
8—12	32—36	40—60	17—35	3
12—16	28—32	20—40	1—17	4
16—20	<28	<20	<1	5

[a]Soil temperature exceeding 28—30°C at 5-cm depth during the seedling stage has adverse effects on crop growth. An occurrence of a high soil temperature favors stubble-mulch farming with a no-tillage system.
[b]Crop establishment and growth in the tropics is greatly affected by the occurrence of a rainless period at least 10 days long. The period of 10 days is chosen because the water-holding capacity of most upland soils can meet the evaporative demand for about this duration. This is a "drought index".

Ratings for the hydrothermal regimes for uplands are given in Table II. Although the cumulative rating ranges from 4 to 20, the scale is non-linear because available water and maximum temperature at 5 cm are correlated, and so are the temperature and the probability of rainless periods. Those soils will respond favorably to no-tillage and mulches when available water-holding capacity is less than 8 cm, soil temperatures exceed 30°C at 5-cm depth for a 3—6 h period per day during the seedling growth, the permeability exceeds 35 μm s^{-1}, and there is at least a 60% probability of a consecutive 7- to 10-day rainless period during the growing season. The latter information is obtained from frequency analysis of longer rainfall records as computed for northern Nigeria by Walter (1967), and this factor will differ for different parts of the tropics depending on the evaporative demand.

Factors affecting soil compaction

Soil compaction is a more difficult parameter to quantify and characterize in relation to other soil variables. Compaction and soil moisture are both dynamic; therefore, it is difficult to establish a direct functional relationship between soil compaction and other soil properties. Variable concentrations of gravel and skeletal material also compound the assessment of compaction. A drastic change in bulk density or porosity during the growing period has significant edaphological significance. For example, a soil rendered excessively porous by repeated tillage can undergo a quick alteration in total porosity and pore size distribution when it settles rapidly from forces of impacting raindrops and wetting (Czeratzki, 1972). 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). Void ratio has also been proposed as an index of soil compaction (Hartge and Sommer, 1979), and is related to the specific volume (V_{sp}):

$$V_{sp} = V_t / V_s = D_p / D_b = 1 + e$$

where V_t is total volume, V_s is the volume of soil solids, D_p is the particle density, D_b is bulk density and e is the void ratio. Relative compaction (C_R) is defined as: C_R in % = 100 $D_b / D_{b\ max}$, where $D_{b\ max}$ is the proctor maximum bulk density. 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 III applies to those soils that are relatively uncompacted initially. This assumption is valid because no-tillage is not successful for compacted soils. Soils that have a potential to reach a 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

TABLE III

Compaction related characteristics and the soil rating for no-tillage in the tropics

Change in bulk density (%)[a]	Relative compaction (%)	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

[a]The bulk density index is computed on the basis of percent increase in bulk density relative to that at seeding

operations may be necessary for obtaining satisfactory crop yields from highly compacted soils. Once loosened, every attempt should be made to prevent re-compaction by traffic control, cover crops and mulching, so that no-tillage system can then be satisfactorily established.

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. Mulches encourage soil biological activity and therefore, compaction is less likely to cause damage at least permanently (Lal et al., 1980). Soils with less relative compaction initially, low rate of bulk density increase and a higher percentage of ground cover at seeding will respond favorably to no-tillage.

A rating for soil compaction related parameters is shown in Table III. The cumulative rating in Table III is 3—15, but again the scale is non-linear because initial bulk density and relative compaction are correlated. In this table, the "relative compaction" refers to the value shortly before seeding. The rate of increase in bulk density is applicable over a certain range for a given soil type. The effect can be both soil- and crop-specific, and the critical range of bulk density is different for different soils and crops. This research information is relatively scarce for soils in the tropics and for tropical crops.

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 when incorporated into the surface layer with the conventional system of plowing and harrowing. Choice of those crops that can tolerate soil acidity (rice (*Oryza sativa*), cowpea (*Vigna unguiculata*), cassava (*Manihot esculenta*)), 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 a low—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 also affect soil consistency, workability and trafficability. Tropical soils containing a 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 a high amount of low activity clays may develop massive structure, particularly when the organic matter is low. Soils of volcanic origin (Andisols) have generally good physical condition and can be managed by a no-till system. The problem of successfully es-

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tablishing a no-till system may be with clayey soils of massive structure. 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 IV 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.

TABLE IV

Nutritional and chemical properties of soil and their suitability for no-tillage in the tropics

Soil pH[a]	Clay content (%)	Cation exchange capacity (mmol kg^{-1})	Rating
6.5—7	<10	<100	1
6.0—6.5	10—20	100—150	2
5.5—6.0	20—30	150—200	3
5.0—5.5	30—40	200—250	4
4.5—5.0	40—50	>250	5

[a]Soil pH is measured in 1:1 soil:water suspension.

RELEVANCE OF NO-TILL FARMING IN THE TROPICS

The continuity of channels created by the 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 of 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) which are otherwise difficult for roots of seasonal crops to penetrate (Babalola and Lal, 1977a,b; Vine et al., 1980). The overall benefits of no-till system with crops 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 creates an additional barrier by its smearing action in the plow sole layer. These arguments in favor of the no-till system where soils are suitable are further strengthened by significantly more grain yield obtained for the no-till mulch than the plowed mulch treatment (R. Lal, unpublished data, 1983).

A PARAMETRIC ASSESSMENT OF SOIL SUITABILITY FOR NO-TILLAGE SYSTEM

Integrating all important parameters into 1 index is a complex task indeed. There are many ways in which it can be done. Numerical addition of rating factors for each of all 14 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 tentative and can be improved upon with a better knowledge of ecological factors, including soil, crops and climatic parameters. For an example, the minimum rating sum for all 14 factors should range from 14 to 70. Soils acceptable for no-till system are those with ratings of individual factors of 2 or 3. This decision is based on past experiences and 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 method 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 2 or 3 years may be desirable. Appropriate tillage methods for different values of the cumulative rating index are suggested in Table V..

TABLE V

Accumulative tillage rating index and the appropriate tillage system in the tropics

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

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 agro-ecological environments for no-tillage methods to be effective. This rating is perhaps better indicative of those soil conditions, where the use of some forms 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 V can be changed in favor of no-tillage as appropriate packages of agronomic practices become available for a broad range of soil and environments.

APPROPRIATE TILLAGE SYSTEMS FOR DIFFERENT SOILS AND ENVIRONMENTS

Based on the available information for soil management and climatic problems for different soils and agro-ecological environments in the tropics,

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general guidelines for appropriate tillage systems are depicted in Fig. 1. This diagram is tentative and is tenuous when applied to very diverse soils and agro-ecological 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 fine textured soils, some type of mechanical seedbed preparation is necessary. The frequency and type of mechanical operation desired depends on soil characteristics and the crops to be grown.

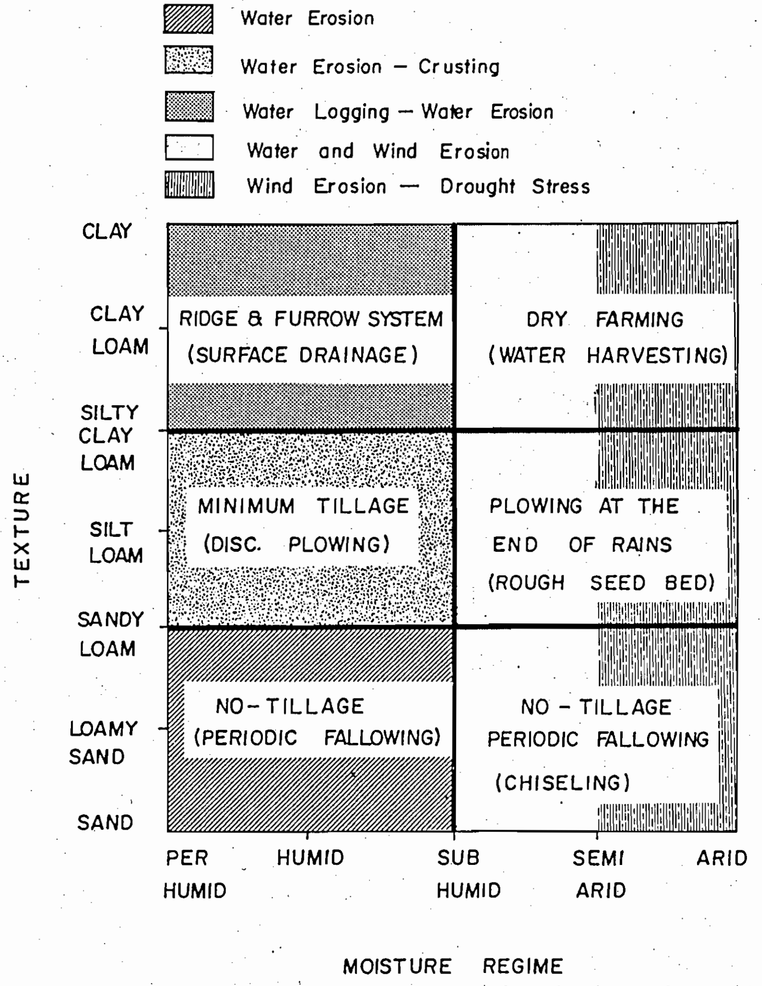

Fig. 1. Tillage systems and (conservation objectives) for the tropics depending on soil texture, climatic moisture regime, and major soil conservation problems.

Several examples of the application of this system are available in the literature. No-tillage is 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, 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.

A better integration of all parameters would be accomplished by computing the probability for a soil to have a given rating value. This frequency analysis could be done if a data base were available 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 because some factors are correlated among each other. Statistical methods of computing these probabilities for few variables are well established (Feller, 1968).

Tillage requirements also vary within the semi-arid or humid tropical environments. Soil-water deficit is a major constraint to agricultural pro-

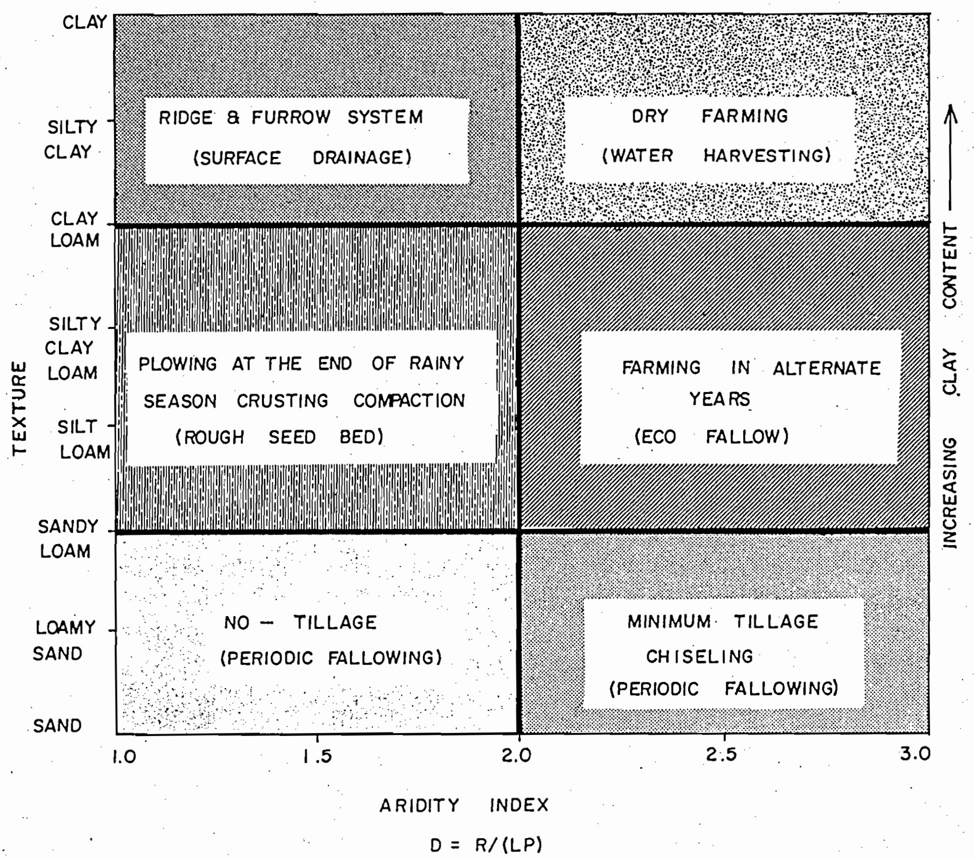

Fig. 2. Tillage systems for the semi-arid tropics in relation to aridity index, soil texture, and soil conservation problem.

duction in the semi-arid regions due to features of both climate and soil. For a viable and stable farming system in the humid tropical environment, rain-water and soil surface management are both necessary to maintain a continuous supply of organic matter and continuity of water conducting channels to the surface. Tillage alternatives for the semi-arid environments in Fig. 2 are based on moisture regime, soil clay content and soil conservation constraints. The moisture regime is computed according to Bailey's (1979) analysis of Budyko's (1974) aridity index.

Soils with similar water regime may have different tillage requirements depending on their physical characteristics. The latter are significantly

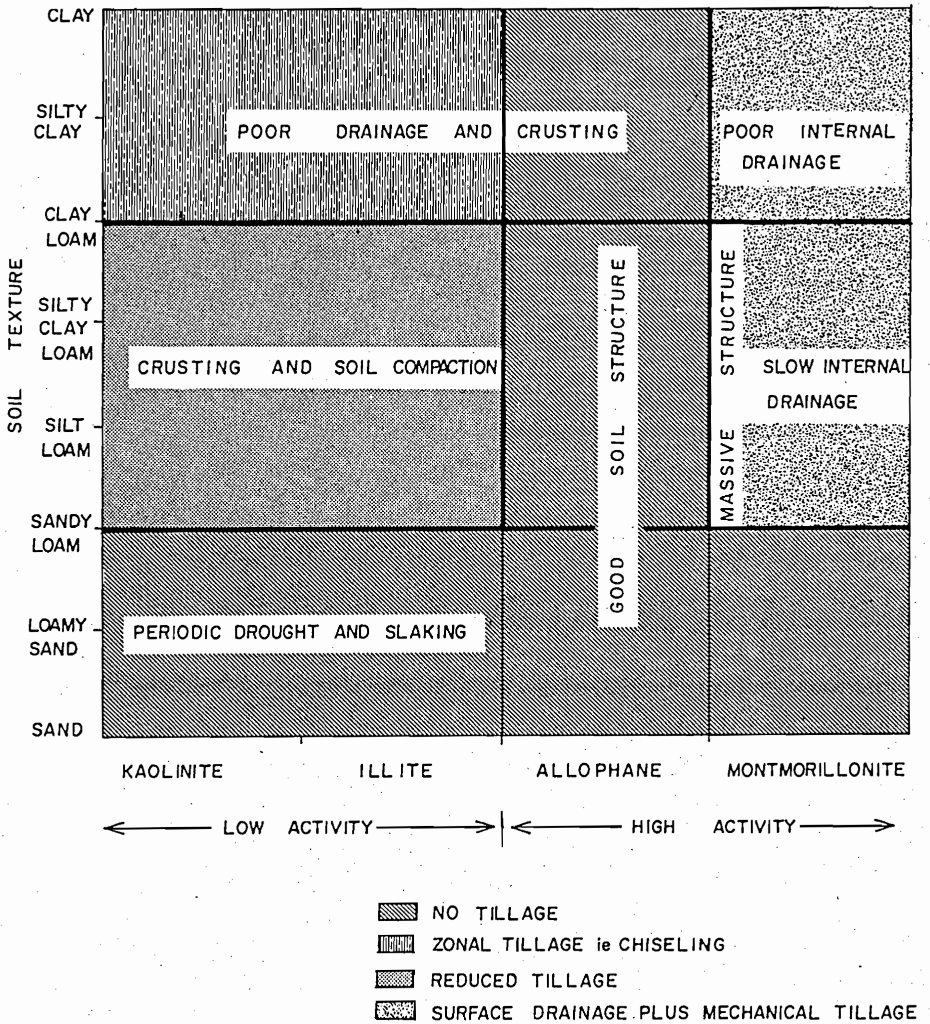

Fig. 3. Tillage systems in the tropics as related to predominant clay minerals, soil texture, and soil management problems (clay mineral activity relates to shrink-swell characteristics).

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 Fig. 3 to relate tillage needs to soil moisture regime, mineralogical composition and soil texture.

TILLAGE SYSTEMS FOR RICE

In drought-susceptible soils with shallow effective rooting depth and low water-holding capacity, maize (*Zea mays*) may be a more appropriate cereal crop than rice. For these soils and environments, rice can be successfully grown in periodically inundated valley bottom soils, provided the system of drainage can be developed for proper water control and management. Adequate conditions for rice production in these regions are a flooded paddy with controlled irrigation and proper drainage. Under paddy conditions, no-tillage can be successfully adopted, both for direct seeded and transplanted rice on soils of fine texture (Elias, 1969; Brown and Quantril, 1973; Maurya and Lal, 1979a,b; Rodriguez and Lal, 1979). Perhaps plowing once every 5—6 years (after 10 or 12 rice crops) during the dry season may be necessary to ameliorate the soil of any harmful effects of the reducing or anaerobic conditions that may prevail. Ideally, a rotation with an upland crop, such as soybean (*Glycine max* L.), grown during the dry season should provide an opportunity for avoiding buildup of pests and pathogens.

Tillage requirements for paddy with sandy permeable soils are different from those for soils of fine texture. Leaching losses of fertilizer, and especially that of nitrogen, are generally high under unpuddled conditions. This implies additional nitrogen requirements for no-tillage. Although nutrient imbalances and toxicities cannot be entirely ruled out, a sizeable

TABLE VI

Soil and climatic factors related to the tillage system needed for production of lowland paddy rice in the tropics

Clay content (%)	Cation exchange capacity (mmol kg^{-1})	Soil permeability ($\mu m\ s^{-1}$)	Endurance to traffic	Days available for seedbed preparation	Rating[a]
<10	50	>70	Very good	<15	1
10—25	50—100	35—50	Good	15—25	2
25—40	100—150	17—35	Fair	25—35	3
40—55	150—200	1—17	Poor	35—45	4
>55	200	<1	Very poor	>45	5

[a]The lowest rating number favors no-tillage and as the rating number increases the tillage intensity should increase.

portion of yield reduction with no-tillage may be attributed to leaching losses of applied fertilizer.

With adequate chemical weed control, upland rice can be grown in a wide range of soils in the humid and subhumid tropics with annual rainfall exceeding 2000 mm. Under these conditions, rice can be grown under upland conditions even if the available water-holding capacity of the root zone is 5—10 cm, because the rainfall events are generally frequent.

Each of the factors listed should be rated separately according to the numerical values as listed in Table VI. The accumulative ratings for all 5 factors will range from a low of 5 for soils with less than 10% clay to 25 for soils of fine texture with clay content exceeding 55%. Coarse-textured soils with relatively less contents of low-activity clays are highly permeable and suffer from high internal drainage and attendant losses of soluble plant nutrients. These soils may respond better to soil compaction for reducing its permeability than to wet or dry plowing (Ogunremi, 1983). Plowing for growing the subsequent upland crop may alleviate the adverse effects of soil compaction. On the contrary, fine textured soils and especially those containing high-activity clays have low permeability. The advantages of wet plowing do not always justify the extra time, labor, water inputs and energy involved in seedbed preparation according to the conventional methods of wet and dry plowing (Maurya and Lal, 1979a,b; Rodriguez and Lal, 1979). Direct seeding or transplanting without primary or secondary tillage operations can produce yield equivalent to conventional tillage, and also will support better growth and yield of the subsequent upland crops. On the other hand, destruction of the structural aggregates can have adverse effects on yield of upland crops. However, periodic plowing, particularly done during the dry season, may be necessary to alleviate the adverse effects of reducing conditions that prevail with continuous adoption of no-till and that may create anaerobic environments. For heavy-textured soils, perhaps a permanent ridge/furrow system may also be usefully adopted, whereby upland crops are grown on raised beds and the rice can be grown in the furrow.

Anaerobic decomposition of crop residue mulch with the direct seeding has been shown to cause adverse effects on seedling establishment of both direct seeded and transplanted rice. These adverse effects are likely to be more on coarse-textured soils of low buffering capacity than in clayey soils of high effective cation exchange capacity. For these soils, it is appropriate to dispose of the crop residue by burning or putting it into alternative uses (Larson, 1979). Plowing in the residue during the dry season for succeeding upland crops in a sandy soil or occasional plowing for a fine-textured soil may also alleviate the adverse effects of anaerobic conditions.

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TILLAGE SYSTEMS FOR TROPICAL ROOT CROPS

Tuberous roots interact differently with the soil than the fibrous roots of the grain crops. Not only is a voluminous "root room" required for their development, the ease of harvesting should also be considered. For sandy deep soils of at least 30 cm effective rooting depth, no-tillage is a feasible system for root crops such as sweet potato (*Ipomea batata*) and cassava. In any case, the economic benefits obtained from the conventional tillage may not justify the additional cost required with the conventional system of seedbed preparation (Maurya and Lal, 1979b; Int. Inst. Trop. Agric., 1981). Harvesting may also not be a serious hazard for these coarse-textured soils of loose and friable consistency. For shallow soils, on the other hand, and those with a fine texture, hard consistency, and a narrow range of water content for firable tilth, some mechanical means of seedbed preparation may be necessary. Under these conditions, yam (*Dioscorea* spp.) cultivation may be better with conventional system of plowing followed by ridging than planting on a flat untilled seedbed. For very shallow and gravelly soils, yams are customarily planted in a vertical hole dug about from 15 to 20 cm deep and filled with loose surface soil and organic matter content.

CONCLUSION

A simple rating method is suggested to assess tillage requirements for diverse soil conditions in the tropics. These are tentative guidelines that should be evaluated for local soils and environments. These ratings are indications of soil conditions where mechanical tillage is absolutely necessary. Rating evaluations can be improved as additional information becomes available on soils, crops and cropping systems and agroclimatic environments. This guide is critically needed to systematize the application of tillage technology in the tropics.

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