AGRICULTURAL POTENTIAL OF LOW ACTIVITY CLAY SOILS OF THE HUMID TROPICS[1]

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INTRODUCTION

Much attention has been given to the disadvantages of the well drained upland soils of the humid tropics. Some characteristics do constitute important limitations to productivity, while others, which appear to most observers to be limitations, can be used to advantage by skillful management and thus enhance the agricultural potential of such soils.

Dominant Soils of the Humid Tropics

The climatic conditions which have prevailed in the humid tropics generally favor the development of deep, highly leached soils, poor in weatherable minerals, characterized by 1:1 type, mainly kaolinitic, low activity, clay minerals, and iron and aluminum oxides, thus the term "low activity clay" or LAC soils. Sanchez (1976) estimates that approximately 70 percent of all the soils in regions of rainy and seasonally wet tropical climates (2.5 out of the 3.6 x 10^9 ha total) are comprised of Oxisols, Ultisols and

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Alfisols[3]. An even higher percentage (estimated at ± 75%) of the soils in humid tropical South America are comprised of these three orders. The balance is made up of very sandy and shallow soils, moderately weathered soils with medium to high base status, hydromorphic and alluvial soils.

Moorman and Van Wambeke (1978) in a review of the areal distribution of major soils in rainy tropical climates, contend that the Oxisols are characteristic of the South American and African tropics with udic (nearly continuously wet) moisture regimes. However, they also state that they are dominant in the stable areas of the central plateau of Brazil and extensive in the Llanos of Colombia and Venezuela, areas characterized by a ustic (wet-dry) moisture regime.

Aubert and Tavernier (1972) present a map which indicates approximately equal areas of Oxisols (over 500 x 10^6 ha) on each continent. In contrast, Oxisols occur only rather sporadically in the Asian humid tropics as inclusions developed on highly weatherable parent rocks. Sanchez (1976) has made calculations based on the Aubert and Tavernier map which indicate that Ultisols are apparently more extensive in Asia (± 250 x 10^6 ha) and the Americas (±200 x 10^6 ha) than in Africa (± 100 x 10^6 ha). The Alfisols which are similar to the Ultisols but less weathered and generally more fertile are far more extensive in Africa (± 550 x

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3/ The names of soil orders are from Soil Taxonomy, USDA (1975).

10^6 ha) than in the American tropics ($\pm$ 150 x 10^6 ha) and Asia ($\pm$ 100 x 10^6 ha). These differences are due primarily to variations in stability of land forms in the three areas. South America, with its two major old continental shields (Guianan and Brazilian) and very large basins of sedimentary soils between these shields and the Andean uplift, is the more stable area. The African landscape is characterized by more general orogenic activity but again there are extensive plateaus and large basins of sedimentary materials which are deeply weathered (eg. the Niger and Congo basins). Tropical South Asia has relatively few extremely weathered soils due to intense orogenic activity which has interrupted the weathering process excepting for relatively small areas. The same is true of continental and insular Southeast Asia (Moorman and Van Wambeke, 1978).

These major differences in soil resources are reflected in agricultural productivity and land use patterns. Farmers in the Asian tropics have for centuries produced food for large populations and managed to produce surplus grain and other products. At the other extreme, the American humid tropics generally support a very sparse population with little or no surplus production of food or other products.

Within the vast areas of highly weathered soils on the old shield surfaces and in some of the sedimentary basins, more productive soils often occur, usually on steeper slopes, rejuvenated by the erosion process which strips away weathered materials and exposes primary minerals as sources of plant nutrients. These soils and those formed on recent alluvium have served as the basis for the development of traditional agriculture in the tropics. Where population pressures are great, the more productive soils with higher inherent fertility are nearly all used intensively. In South America, where population pressure on a continental scale is not nearly as high as in other tropical areas, there are still rather fertile soils which remain unused primarily due to distance to markets and lack of access routes or because of poor drainage or other conditions too costly to alter at present cost/benefit ratios.

"New Lands" for Increased Agricultural Production

In regions where large areas remain unexploited, there are two major strategies for increasing agricultural productivity. One is to increase the productivity of lands presently being farmed through adoption of modern agricultural technology along with necessary credit and technical assistance. The other strategy is to increase production through expanded area either by draining alluvial lands, developing irrigation projects or by opening frontier areas with new access routes.

At the Centro Internacional de Agricultura Tropical (CIAT), both strategies have been pursued. Work with beans, rice and corn is directed almost exclusively toward increasing production in traditional agricultural areas. In cassava, both strategies are followed, with emphasis on increased production on marginal soils in existing agricultural areas and on expansion into new areas of low fertility soils. In the Tropical Pastures Program the effort is almost exclusively directed to the expansion of production in the "new lands", which are generally marginal for most annual crops with respect to soil fertility and acidity. Therefore, much of the present discussion relates to the very large expanses of Ultisols and Oxisols which currently contribute very little to total food production but which promise great potential for the future when economic conditions favor their use.

Characteristics of Dominant Soils and Management Implications

Large areas of Alfisols, which are characterized by low activity clays, occur in Africa. Unlike the Ultisols and Oxisols, they usually combine good to excellent native fertility with favorable physical properties. Their inherent fertility is due to parent material and/or rainfall regimes which have resulted in less leaching. They constitute a major potential for increased crop production, their major restraint being their relatively low water holding capacity. When reference is made to low fertility and/or extreme acidity in the balance of this discussion, the Alfisols are excluded.

The Oxisols and Ultisols will be treated together even though there are some important differences between the two. The Oxisols are generally older soils, more highly weathered and better drained with more favorable physical properties than the Ultisols.

The major characteristics of these low activity, clay soils are shown in Table 1 and reference is made to the advantages and/or

TABLE 1

MAJOR CHARACTERISTICS OF LOW ACTIVITY CLAY SOILS OF THE HUMID TROPICS AND RESULTANT ADVANTAGES AND LIMITATIONS

CHARACTERISTICS	ADVANTAGES	LIMITATIONS
1. Low fertility.	Low initial weed potential.	Limited range of adapted species. High initial cost of fertilizer required by non-adapted species.
2. Extreme acidity.	Permits use of low solubility P sources. Increases the availability of minor elements with exception of Mo. Controls some soil-borne diseases. Fewer adapted weed species.	Limited range of adapted annual crop species. Al and Mn toxicity. High initial cost of lime required by non-adapted species.
3. Low cation exchange capacity.	Lower lime requirement. Lower initial fertilizer requirement. Ca and Mg more easily leached to ameliorate subsoil infertility.	Limited reserve and retention of bases.
4. High P fixing capacity.		Low efficiency of P fertilizers.
5. Low water holding capacity.		Crops are susceptible to even short drought periods. Susceptible to high leaching losses.
6. Lack of primary minerals.		Limited reserve of nutrients.
7. Predominance of 1:1 type clay minerals.	Soils are generally friable and easily tilled.	Lack the basis for recovery of structure once it is lost.
8. High sesquioxide content.	Stable micro-structure. Good internal drainage and aeration, easily tilled.	Weak macro-structure; very susceptible to erosion. Very susceptible to leaching losses.
9. Relatively smooth topography.	Easily mechanized.	
10. Deep profiles generally free of physical obstacles to root penetration.	Permits deep rooting of adapted species. Good subsoil moisture reserve.	
11. Presence of laterite.	Very useful for road building and general construction.	Impedes tillage and cultivation if superficial.

limitations of each characteristic.

Low Fertility

It may be difficult to imagine that low fertility can be turned to an advantage. However, just such an example is found in recent research conducted in the eastern plains of Colombia in the development of low cost methods of pasture establishment on Oxisols (CIAT, 1977). These soils remain weed free for many months after native savanna is broken for planting if no fertilizer is applied. This is due primarily to low fertility but also to the general lack of weed seeds in savanna dominant regions. Several trials have demonstrated the feasibility of preparing land and seeding a number of pasture species at very low density, applying fertilizer only to the "mother" plants, creating optimum conditions for the development of these plants to provide coverage for the entire area via seed, stolons or trailing stems. In the initial trial, populations of 1000 hills /ha were used with fertilizer applications of 0.2 to 4.0 kg of P and 0 to 1.2 kg of K/ha, all applied in the hill, with the balance of the fertilizer applied only after pasture establishment was assured. From 1000 plants of *Andropogon gayanus*/ha planted in September of 1977, stands of 150-200 plants/m^2 were obtained in April 1978. Most of the species were ready for permanent stocking by June of 1978.

Low inherent fertility does constitute a major limitation and initially is much more serious in savannas than in jungle regions where most subsistence farming is found. The major reason for this is that a much greater biomas is accumulated in jungle growth than in savanna. Savanna vegetation rarely accumulates more than 5 t/ha dry matter and nutrients released when it is burned are not sufficient for even one cycle of cropping. However, when the jungle is cleared and burned, the release of nutrients which have accumulated in up to 500 t/ha of dry matter in above ground growth brings about a drastic change in soil fertility and chemical properties in the upper part of the horizon. The ash neutralizes the acidity in the top soil and provides a good supply of essential plant nutrients. The fertility thus created is surprisingly stable as indicated in recent work reported by Toledo and Morales (1978) and Serrão, et.al. (1978). The major decline in productivity after 2-3 years is reported to be due to a very rapid reduction in phosphorus availability after the jungle is felled and burned, due to fixation. In the past, it has been thought that the reason for abandoning cleared areas after only a few years of cropping was primarily due to a general decline in soil fertility and increasing acidity. However, this recent information would indicate that phosphorus may be the principal limiting fertility factor.

<u>Extreme Acidity</u>

Very acid soils are generally characterized by high levels of exchangeable aluminum and/or excessive concentrations of active manganese. Both elements are quite toxic at high concentrations to most cultivated crops. To overcome this problem, farmers have for centuries taken advantage of species that are acid soil tolerant to reduce or eliminate the need for lime and to assure deep rooting, thereby reducing the effects of drought. In recent years, scientists have become aware of the possibility of selecting species and cultivars within species for acid soil tolerance as well as systematic breeding for this characteristic to reduce production costs in areas where distance or lack of transportation routes make the use of lime economically unacceptable (Spain, 1977). This concern for acid soil tolerant species will perhaps become less important with time if and when relative costs of inputs are reduced and absolute yields become more important. It should be noted that subsoils are very difficult if not impossible to lime, therefore the importance of acid soil tolerance in drought resistance is not likely to change much with time in areas of considerable drought hazard where irrigation is not possible or economical.

Extreme soil acidity can also be advantageous. Recent work at CIAT has shown that rock phosphate can be used very efficiently by acid soil tolerant perennial species. The rock is "acidulated" by the soil, thus increasing markedly its agronomic value. Micronutrients are also more available in an acid soil medium, with the exception of molybdenum. However, micronutrient reserves are often extremely low in highly weathered soils and are usually required to maintain yields in extractive cropping systems.

Several plant diseases are absent in acid soils but become serious when these soils are limed. Examples include "Take all" of wheat (*Ophiobolis graminis*, *Gaumenomyces graminis*) Potato scab (*Synchy-*

trium endobioticum) and certain fusarium wilts of tomato.

It must be emphasized that even the most acid soil tolerant species still require Ca, Mg and K as nutrients and that these elements are almost always deficient in extremely acid soils.

Low Cation Exchange Capacity

This characteristic can be an advantage in that less lime is required to neutralize exchangeable acidity. Therefore, when it is necessary to lime for annual crops, relatively low rates are required for adequate crop performance. Low CEC results in less retention in surface horizons of nutrient cations such as K, Ca and Mg in regions of high rainfall. The leaching of bases from the surface can ameliorate the extreme subsoil infertility common to many Oxisols and Ultisols, thus increasing rooting depth of acid soil tolerant species. However, it is usually more difficult to maintain adequate surface horizon fertility in these soils than in soils with greater cation exchange capacity. It is also more difficult to meet the nutrient requirements of annual crops such as corn during their periods of very rapid growth when rates of nutrient uptake are extremely high.

High P Fixing Capacity

This characteristic is a major limitation. It results in low efficiency in the use of P fertilizers, especially for annual crops. It can be overcome in part by placement of fertilizer to reduce soil-fertilizer contact. Examples include banding of fertilizer at planting and surface application of fertilizer in established pastures and other perennial crops.

Low Water Holding Capacity

Another very important disadvantage of LAC soils is their low water holding capacity. Most annual crops are relatively limited in their capacity to penetrate into the deep subsoil and are very susceptible to relatively short periods of drought even during the rainy season when the subsoil is always moist.

Lack of Primary Minerals

Most LAC soils are highly weathered to considerable depth, therefore, contain few primary minerals and limited reserves of nutrients.

Predominance of 1:1 Clay Minerals

This characteristic generally results in soils that are friable and easily tilled over a wide range of moisture content. However, due to the absence of 2:1 (swelling) clays, they lack an important mechanism for the recovery of structure, once it is destroyed.

High Sesquioxide Content

Sesquioxide cementation results in very stable micro-structure and good internal drainage and aeration. On the other hand, it generally leads to weak macro-structure and soils that are quite susceptible to erosion. Because of their good internal drainage, they are susceptible to leaching losses. Both of these limitations can be offset by maintaining a growing plant cover on the soil as continuously as possible, and through the use of deep rooting perennial species capable of efficiently recycling nutrients from the subsoil.

Relatively Smooth Topography

Most Oxisols and Ultisols landscapes are smooth to gently rolling and lend themselves to efficient mechanization and modern farming systems.

Deep Profiles

On smooth landscapes, most LAC soils are characterized by deep profiles free of obstacles to root penetration, thus permit deep rooting of adapted, acid soil tolerant perennial species. This results in good subsoil moisture reserve and efficient recovery and recycling of nutrients which leach down the profile.

Presence of Laterite

There is a widely held belief that great danger exists in the opening up of rainy tropical areas to more intensive land use. The literature on tripical ecology and soils continues to propagate the myth of the widespread threat of laterization; the fear that most tropical soils when cleared of rain forests or savannas will dry up and harden into brick-like surfaces through the process of laterization. Laterization takes place where plinthite (firm, iron rich soil nodules) and other iron rich soil materials occurring in the upper part of the soil profile are exposed to drying and subsequently harden irreversibly into laterite nodules or massive laterite ironstone. Plinthite generally occurs only in soils which are subjected to a fluctuating water table in the upper part of the profile. Alternating oxidation and reduction result in the precipitation of iron as it is oxidized near the soil surface during the dry season. Moorman and Van Wambeke (1978) estimate the extent of such active plinthite formation to be less than 2 percent of all tropical lands and it is rare that even on these soils the plinthite would be exposed in such a way that it would harden irreversibly when put into agricultural use. Buol and Sanchez (1978) estimate that plinthite exists in the upper 1.25 m in 7 percent of the soils in the Oxisol-Ultisol regions of South America and that the same percentage holds for the Ultisols in Southeastern United States.

Kellogg (1975) points out the great usefulness of laterite as a building material in the tropics. The author has observed plinthite-laterite blocks used in ancient Malaysian temples that were apparently cut from the subsoil while still relatively soft and hardened irreversibly once exposed to the atmosphere. Laterite gravel is used extensively for road building in the Colombian Llanos and many other savanna regions.

The special role of forage based agriculture in areas of low activity clay soils

Soil fertility is a relative matter and depends on the scale used to measure it. If the fertility of Oxisols in the Colombian Llanos is measured with maize, the soils are as infertile as can be found. However, when their fertility is measured with *Stylosanthes capitata* or *Brachiaria decumbens* an entirely different answer results (CIAT, 1977). The soil "looks" quite fertile and in fact is, in terms of productivity for those particular species. Obviously, the more acid the soil and the more limited the availability of the essential plant nutrients the more restricted the range of plants that can be grown with minimum inputs.

Fortunately, many tropical forage grasses and legumes are very tolerant of soil acidity and low fertility. They have evolved in savanna regions characterized by these conditions. Many of them have excellent potential for the production of grazing animals with minimal inputs required. The recycling of nutrients on well managed pastures is efficient and nutrient removel (export) in the harvested product (meat) is very low.

Forage based livestock systems can be quite stable and represent relatively low risks to the ecosystem while providing a means of building capital during the initial phases of development of new areas. In many cases, the production of beef and milk from predominantly beef herds is a step in the direction of much more intensive development and land utilization, especially on soils with more favorable physical conditions and topography. Some soils which will never be suitable for cropping are used successfully for very intensive high input livestock production with extremely high yields (Vicente-Chandler, et.al., 1974).

The use of grazing animals also overcomes some of the disadvantages of low fertility in other ways; they can be used to concentrate fertility from large to small areas in an around corrals, which then can be used for food crop production, primarily for direct on-farm consumption.

Conclusion

The major limitations to greater production on the low activity clay soils of the humid tropics can be readily removed by careful and judicious management and with the application of fertilizer and/or lime. When these restraints are removed, many LAC soils become highly productive. The inputs required vary from soil to soil and crop to crop but always cost money. That money will be spent when tropical farmers and ranchers have access to markets and are assured a fair return on their investment.

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