AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
Batch 98
ARD

1. SUBJECT CLASSIFICATION

A. PRIMARY: Food production and nutrition — AF25-0000-G302

B. SECONDARY: Soil fertility, fertilizers, and plant nutrition--Latin America

2. TITLE AND SUBTITLE

Properties and potentials of soils in the Amazon Basin

3. AUTHOR(S)

Van Wambeke, Armand

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1978	11p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Cornell

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)

(In Interciencia, v.3, no.4, p. 233-242)

9. ABSTRACT

An attempt is made to highlight the diversity of the soils in the area, and their distinct potentials for development. Land evaluation, based on land qualities, is employed a means of suggesting optimum land uses.

Soils of the hot lowland rainy humid tropical climates share a common soil moistur regime, and a uniform soil temperature regime. The soil qualities are highly correlated wit the degree of weathering. The more highly weathered soils, while often having a physical st ture favorable to plant growth, are nutrient-poor and drought susceptible. Soft plinthite is only found to be a problem in 2% of the soils. More important limits on plant root-syste development include surface erosion, and calcium deficiency or aluminum toxicity which prevents deep rooting.

Nutrient supplies are small in the highly weathered soils. While the mineral frac tions of most are very poor in nutrients, the soils have varying levels of soil organic matt As long as the natural cycle of nutrients through roots into plant tissues and from plant residues back into the soil is uninterrupted or is closely simulated, the intrinsic fertilit of those soils can be preserved. Changes in the ecology, however, can quickly deplete these soils.

Development alternatives inclule intensification of agriculture by fertilizers, or adapting land use to the environment by crop adaptation. More attention should be given to permanent agricultural production systems before the illusion of limitless land resources in the area leads to the irreversible destruction of soils and creation of fertility deserts.

Soil conservation and erosion prevention are crucial variables in the development of the area. There is reason for optimism in the development of the Amazon basin if planners and scientists work together to maximize the efficient and conservative use of its resources.

10. CONTROL NUMBER
PN-AAG-355

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Soil properties
Weathering
Soil fertility
Soil water
Tropics
River basins
Latin America
Amazon Basin

13. PROJECT NUMBER
931050500

14. CONTRACT NUMBER
AID/ta-C-1104 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

PROPERTIES AND POTENTIALS OF SOILS IN THE AMAZON BASIN

A. VAN WAMBEKE

SUMMARY

This paper deals with the multiple properties and potentials of the soils of the Amazon basin. An attempt is made to highlight the diversity of the soils in the area, and their distinct potentials for development. Land evaluation, based on land qualities, is employed as a means of suggesting optimum land uses.

Soils of the hot lowland rainy humid tropical climates share several common properties which condition land use. These are a common soil moisture regime, and a uniform soil temperature regime. These factors have significant implications for soil management.

The diversity of soils in the Amazon basin is highly correlated with the degree of weathering to which particular soils have been subjected. Weathering and leaching leads to a diminution of plant nutrients in the mineral fraction of the soil. The more highly weathered soils, while often having a physical structure favorable to plant growth, are nutrient-poor and drought susceptible. Soils exhibit differential degrees of weathering due to the interaction of many environmental variables and the chemical composition of the rocks from which the soils derive.

Land qualities including anchorage for plant roots are site specific. Soft plinthite, often wrongly described as a major barrier to agricultural development in the Amazon, is in fact only found to be a problem in 2% of the soils. More important limits on plant root-system development include the seasonal flooding of some soils, surface erosion, and the coincidence of calcium deficiency and aluminum toxicity which prevents deep root penetration.

Nutrient supplies are small in the highly weathered soils of the region. While the mineral fractions of most are very poor in nutrients, the soils have varying levels and qualities of soil organic matter. The vast majority of these soils' nutrients contents are concentrated in the vegetation and in the humus. As long as the natural cycle of nutrients through roots into plant tissues and from plant residues back into the soil is uninterrupted, or is closely simulated, the intrinsic fertility of those soils can be preserved. Changes in the ecology, however, can quickly deplete these soils, and restoration through regrowth is much more problematic than is often assumed.

The diversity of soils, while a function of weathering and environmental variables, is also landscape specific. Topography favors particular vegetation and soil types. The greatest diversity of soils and land use potentials can occur within an average of 80 meters of altitude differential between rivers and the plateaus they divide. Land utilization will be most efficient if it is based on optimizing soil landscape and plant need complementarity.

Development alternatives include intensification of agriculture through the use of fertilizers to improve soil conditions, and adapting land use to the environment by crop adaptation and extensive land use patterns. More attention should be given to establishing permanent agricultural production sites, before the illusion of limitless land resources in the area leads to the irreversible destruction of soils and the creation of fertility deserts. Real costs of short-term land use patterns are often ignored. Fertilization is more promising than is often suposed. Extensive production systems, especially those which approximate the steady state nutrient cycle conditions in native rainforest, also have a significant potential. Shifting cultivation, perennial crops, tree plantations, forestry, and grazing all can be used, if care is given to site selection and proper management, with low risk of soil degradation. The dangers involved with using low fertility soils increase with the magnitude of the changes introduced into the system. Crop adaptation also has a great deal to offer.

Soil conservation and erosion prevention are crucial variables in the development of the area. It is incorrect to think that all soils in the tropics are highly erosion resistant. Moreover, the idea of soils in the tropics being completely renewable resources is misleading.

There is reason for optimism in the development of the Amazon basin if planners and scientists work together to maximize the efficient and conservative use of its resources. Sufficient land is available to allow development only under the most optimal conditions.

Research, training, teaching facilities, and proper dissemination mechanisms for extension should be strengthened at all levels of the development process.

The Amazon basin is the largest area drained by a river system in the world. It covers more than 450 million hectares in Brazil alone, and extends into Guyana, Bolivia, Colombia, Ecuador, Perú, and Venezuela. It is covered by many types of vegetation and a diversity of soils. Its rivers cut through uplands on old continental platforms, drain immense, flat, frequently-flooded bottom-lands, and dissect the eastern flanks of the Andean mountain chain. Virtually all types of rocks, which form the parent materials for soils, can be found within its boundaries. Nevertheless, many contradictory and misleading generalizations have been made about the, in fact, extremely diverse environments which are to be found in the basin.

In an attempt to focus attention on certain key factors which condition the utilization of soils, a first and probably most important statement should stress the diversity or variability of soils in the Amazon. Some generalizations will have to be made, of course, but the terms which appear in the title: *properties, potentials,* and *soils,* emphasize, in their plural form, the multiple factors which, together with origin, are essential to gaining a better, albeit incomplete understanding of the complexity of problems that must be faced in planning the use and development of this region.

In this discussion, emphasis is placed on land evaluation: a decision-making process which concentrates on "land qualities" (FAO, 1976) as a means of discriminating between distinct environments in terms of their suitability for plant and animal production. Land qualities are mainly defined in terms of the interaction of soils and

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other environmental variables, especially as they influence anchorage for plant root systems, the ability to furnish nutrients to roots, and the potential for conserving these factors without a deterioration of the environment. Given specific social and economic conditions, land qualities indicate whether a particular area has the potential to produce sufficiently to provide a satisfactory standard of living for those people who choose, or have no other alternative than to select that location as a place for permanent settlement, agricultural or livestock production.

Properties common to soils in the Tropics

The soils of the hot tropics, including those of the Amazon basin, share some common properties which distinguish them from soils of other regions. These differentiating characteristics will seem trivial to a number of readers. For those who live and work in the Amazon they are a constant for the entire region and, because they do not change from one locale to another, have no significance in the decision-making process. Individuals from other areas will find these same factors irrelevant to the management of soils in their own region. Nevertheless, these factors can be crucial if their influence is ignored. Some land qualities, or their lack, can be the variables which lead to failures in the transfer or introduction of new technology from temperate or other regions. Project designs, for example, which overlook the cost of remedies for such unanticipated inherent limitations in calculating the feasibility of producing a crop which has to compete on the world market, are bound to fail. A brief summary of these common denominators is therefore appropriate.

The properties which are common to all well-drained soils of the lowland rainy humid tropics are related to characteristic seasonal cycles of available soil moisture content, and a common soil temperature regime.

Soil Moisture

In terms of moisture, there is, in these areas, always a high rate of evapotranspiration of water from the soil, even if fields are not cropped during a dry season. There are only a few places in the tropics where rainfall always exceeds evapotranspiration. In areas with only seasonal rains, there is no rest period during which the soil can store water for later use by a subsequent crop. At the beginning of the growing season (near the end of the dry season), plants have not yet developed a root system sufficient for extracting water from a large volume of soil, nor can they count on an adequate water reservoir in the soil. Moreover, at the beginning of the rainy season, rains are often intermittent and dry spells can kill seedlings after a few days. For young plants, soils in the tropics, when not irrigated, are unreliable sources of moisture. The length of the rainy season varies from about six up to twelve months in length in the Amazon basin.

Soil Temperature

The second common denominator of soils in the lowland areas of the tropics is that there are no extreme changes in soil temperatures from one month to another or throughout the year (USDA, 1975). Soils which do not warm up slowly cannot regulate plant growth and thus insure gradual increases in water demand. It is also relevant to note that soils in these areas do not freeze. From a soil management perspective, this has several consequences. If soil structure in the plow-layer deteriorates, frost will not restore the frag-

APPARENT UNIFORMITY AND ACTUAL DIVERSITY OF SOILS AS REPRESENTED ON SMALL AND LARGE SCALE SOIL MAPS

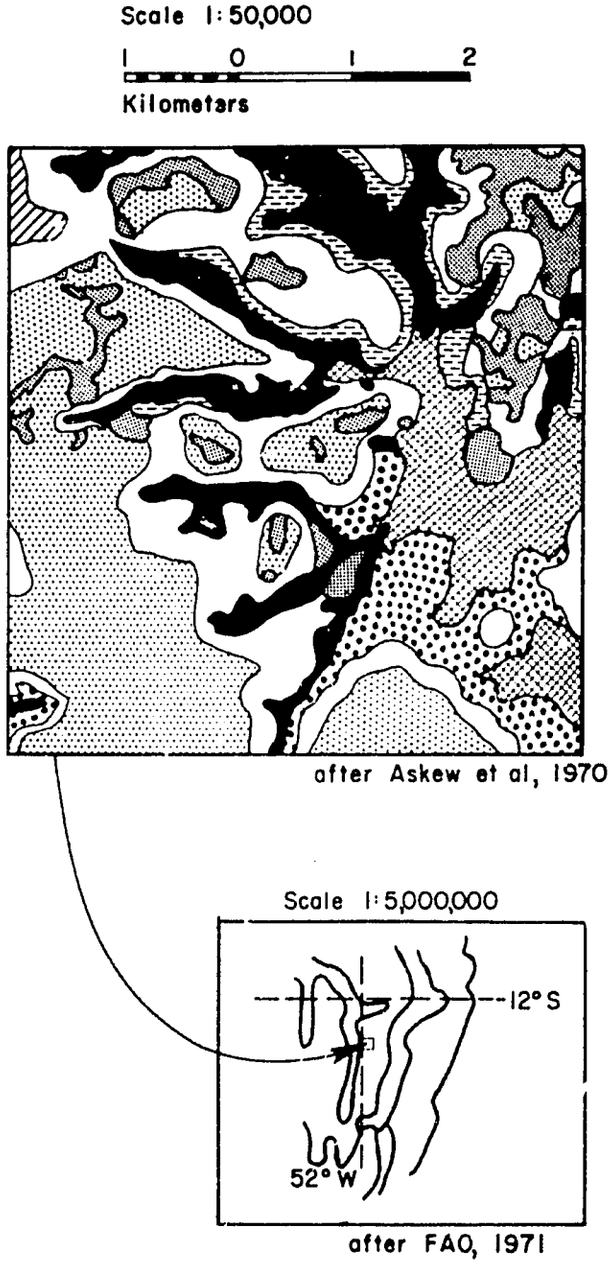


Fig. 1: - Smaller scale soil maps, while useful for macro-planning, conceal the actual diversity of soils in the landscape. Larger scale maps, based on more intensive surveys, are necessary for adequate settlement and farm planning. The intensity of surveying required depends on soil variability in the region as well as projected land uses.

mentation of the soil mass which must be maintained at optimum levels to insure pore space for air, water, and root penetration. In those soils of the tropics where structure and porosity are primarily a function of the amount of organic matter, conservation of humus is a high priority.

Dominant properties

There are other soil properties which are shared by most, but not all soils of the Amazon. These, however, are not unique or limited to the tropics. Their diversity restricts the validity of generalized statements, and in some instances can distort general conclusions drawn in attempts, on the macro level, to evaluate the agricultural potential of land areas. It is in these instances that soil classifications can aid in accurately defining the appropriateness of a particular technology transfer or development project to a specific area. References to soil classification systems include FAO (1974), and USDA (1975).

An important part of the mineral (as contrasted to the organic) fraction of the most prevalent kinds of soils in the Amazon is a weathering product of the rocks from which these materials derive. Weathering (decay by biological, chemical, and physical decomposition) breaks down rocks into soil-size fragments. In the Amazon basin, most soils are similar in nutrient status, in that almost all soluble decomposition products have been removed by the leaching effect of percolating water under free-drainage conditions. The materials which tend to remain are predominantly the unchanged unweatherable minerals and what are called low activity clays. These clays are characterized by their low mineral adsorption capacity. They are mixtures of kaolinite, and iron and aluminum oxides, which, as a rule, can only retain very small amounts of essential nutrients such as calcium, magnesium, and potassium. At the same time, they may have a strong affinity for phosphorus and can reduce its availability to plants below critical levels. Thus, the most common products of weathering processes under hot humid tropical conditions, the low activity clays, do not provide an effective medium for the temporary storage and ready availability of plant nutrients. Unless nutrients are built into plant tissues, which may reenter the surface soil as organic matter, they will be lost by leaching, or as in the case of phosphorus, fixed chemically in forms unavailable to plants. This creates completely different problems for soil management than are experienced in soils with other types of clay and less severe leaching. The regionalization of soil management practices is not the result of physico-chemical processes and principles of plant nutrition being different in the tropics than elsewhere, but rather reflects a significant change in the parameters (climate, etc.) which condition their operation.

The processes of weathering and soil development which have been described above are slow, and several intermediate phases between the incipient soil stage and the final inert end-products have been recognized in the Amazon basin. Soil scientists have given them names such as Inceptisols, Alfisols, Ultisols, and Oxisols (USDA, 1975). During most of this evolutionary process, leaching losses may be balanced by the continuing decomposition of weatherable minerals, which can provide a sufficient base for the supply of nutrients to crops, and sustained agricultural production. When these mineral reserves are exhausted, however, at the end of the evolutionary sequence, the smallest decrease in nutrients becomes critical.

While a predominance of low activity clays is neither unique to nor universally found in the hot rainy tropics it is sufficiently widespread to command attention as one of the main characteristics of extensive upland areas in the region. Although these soils present fertility problems, where those factors can be overcome, they offer definite advantages for agricultural production. Low activity clays create good physical conditions for aeration and root penetration. If enough clay is present (for example, more than 30%), aggregates in such soils will seldom slake, and crusts which mechanically impede the germination of seeds will rarely form. Rainfall acceptance, even under heavy storms, is better than in soils with other clay mineralogies. In general, they drain quickly, and are easy to work and plow. Thus, less energy is needed to prepare a suitable seedbed. On the other hand, the water storage potential in low activity clay dominated soils is not always favorable: on the average, only 1 cm of water per 1 dm depth can be held in a form available to plant roots. This condition increases the drought susceptibility of crops grown in these soils.

To summarize introductory statements about the properties of most upland soils in the Amazon, two qualities sould be mentioned: low nutrient supplying power and drought susceptibility.

Land qualities

Anchorage

Soils should offer adequate space, air, and moisture for plant roots to develop. The majority of the soils in the Amazon are deep enough to provide adequate rooting volume for most plants. It would not be necessary to raise this point, were it not for the persistent recurrence of erroneous statements in the agricultural, ecological, and geological literature, usually published outside the tropics by writers unfamiliar with the zone, about the danger of tropical soils indurating irreversibly into hard rock after a few years of cultivation. Friable, soft, fertile topsoils supposedly harden into ironstone after forests are cleared and surface layers are exposed to direct sunlight. Such a hard iron crust would completely block root penetration.

A September 1977 publication (Science Policy Research Division of the U. S. Library of Congress), speaking specifically of Brazil, for example, states that "agricultural research has not yet found the answer to a problem characteristic of all tropical lands: when jungle areas are cleared, the land turns into cement after only a few years' exposure to the sun". This contrafactual statement is no doubt derived from earlier publications.

McNeil (1964), described "laterization" as a process which converts vast areas of the earth's soil into deposits of bauxite and iron oxide ores. She concluded that agricultural intervention in these areas by man would accelerate the formation of hard laterites and lateritic soils. Because of the lack, at that time, of adequate soil surveys, a proper understanding of prerequisite conditions, and the process of formation of such soils, as well as a tremendous confusion in the use of the terms "laterite" and "lateritic", her conclusions about the origin and extent of soft soil materials which may harden into ironstone in the tropics were incorrect. Today's increased knowledge about the geography of soils in the Amazon indicates that the present-day formation of soft soil materials which have the potential to harden into ironstone (called plinthite in the modern literature), is restricted to soils with impeded drainage, where the water table fluctuates at a shallow depth during certain periods of the year. These soils occupy specific locations in the landscape and present distinct morphological characteristics which can be recognized by competent soil scientists. Sombroek (1966) emphasized these points in relation to the Amazon. Later surveys confirmed his view. The induration of soft plinthite into ironstone in large areas was essentially the result of a lowering of the water table, usually due to normal, slow, geologic erosion processes during which rivers dissected old geomorphic surfaces. Most ironstone crusts and gravel layers were formed thousands, if not millions of years ago, and today are considered fossil relicts by most geologists and geomorphologists. Indurated ironstone crusts should not, then, be considered as the inescapable final stage of the only evolutionary pathway which all soils under hot tropical climates will reach at the end of their weathering cycle. They should rather be regarded as special cases resulting from specific environmental conditions, as already noted. The total area of soils which contains soft plinthite at shallow depth is relatively small (approximately 2%), and certainly is not commensurate with the importance given to it in that literature which stresses the peculiarity and curiosity of the induration phenomenon without consideration of its actual geographic extent.

A majority of the soils in the Amazon region are, therefore, suitable for the development of adequate root systems. There may be some problems in given locations which are not related to induration or the occurrence of rock close to the surface; for example, bottomlands may be flooded seasonally, and surface drainage may cause erosion between individual plants which are finally undermined and lose anchorage in the soil. These sites are readily recognized in the field, and can easily be avoided with proper survey inputs to planing efforts. In upland soils, root growth of annual plants such as corn may be restricted due to a lack of calcium in the subsoil: such cases, however, are never so severe that the plants' anchorage in the soil is weakened mechanically. Instead, a low Ca content in the subsoil, and the co-varying tendency to high aluminum content and a consequent root-toxicity, affects the water uptake of plants by restricting the volume of soil into which the roots can reach.

ADAPTATION OF LAND UTILIZATION TYPES TO SOIL LANDSCAPES

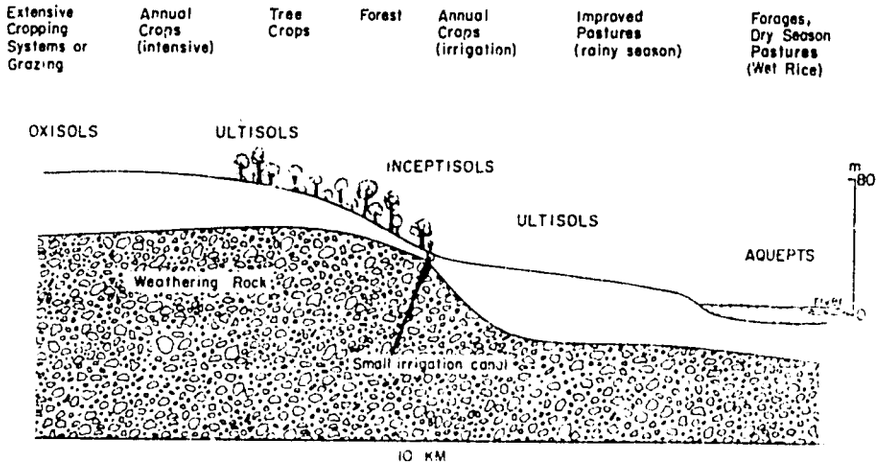


Fig. 2: - This is a generalized example of the correlation of land utilization types with kinds of soils, shape and gradient of slope, and position in the landscape in order to optimize both the utilization and conservation of soils. Matching plant requirements and land qualities is particularly needed in regions where environmental conditions are marginal.

Nutrient Supply

When Amazon soils are placed, conceptually, in the evolutionary sequence of weathering stages already described, it appears that a majority have nearly reached the end of the process, being relatively acid, dominated by low activity clays, and having minerals of low solubility in subsoil layers. Some of the more important exceptions to this include minor occurrences of soils recently developed on mineralogically rich basic rocks and recent river alluvium. Land utilization patterns in the Amazon uplands will, therefore, generally have to be adapted to the prevailing conditions of low inherent fertility which are common to the area. In order to have a better understanding of the problems involved, and possible solutions, it will be useful to consider the major sources of plant nutrients supplied by soil components to plant roots.

Soil scientists make a sharp conceptual distinction between the mineral and the organic components of soil. As has already been noted, in most Amazon conditions the mineral fraction has been exhausted of its reserves of minerals which could provide Ca, Mg, and K to plants. Moreover, colloidal clays formed in these soils do not have sufficient sorption capacity to prevent these elements from being leached out of the soil profile. As a result, the majority of the available nutrient stock is concentrated in the first 10 to 15 centimeters of the topsoil (organic fraction or humus), which builds up by the addition of plant residues. The balance or remainder of the environment's total nutrient pool is contained in the vegetation.

The importance of the organic fraction in the surface layer of strongly weathered soils cannot be overemphasized. It increases the sorption capacity of the soil and retains cations for uptake by roots. The supply of nitrogen from natural sources is largely dependent on it. The content of the nutrient reserve stored in the soil organic matter may to some extent relate to the types of rocks which form the substratum: for example, on basic geologic formations such as basalts, more Ca, Mg, and P will usually be found in the humus than is the case in landscapes which have developed on more acid granite rocks. The poorer the mineral fraction, the higher the organic matter content must be to support plant growth.

Soil organic matter, whatever its nutrient content, is extremely fragile in the hot rainy tropics. It will persist at certain concentrations only as long as the ecology remains essentially constant. Erosion removes it from the topsoil. It decomposes rapidly when the soil temperature rises, and only rebuilds slowly when soil temperatures drop. Management practices such as clearing, plowing, shading, mulching, and fallowing, therefore, have a great effect on the organic matter content and nitrogen cycles in the soils. Clearing the land by burning, for example, involves significant losses of nitrogen from the nutrient pool to the atmosphere by combustion, although at present this is the only practical method of land preparation for both primary forests and regrowths.

In established farming systems, where the humus content of soils does not change much, the annual additions of plant residues and nitrogen, and their losses due to decomposition, leaching, and plant uptake are in balance. Put in a general way, in the case of nitrogen, which is one of the most critical factors limiting crop production, in a given year the soil can only provide as much to the plants as has been received annually. This results in extremely low yields, which only rarely provide economic returns beyond subsistence. Sustained intensive cultivation of annual crops in acid soils of the Amazon, without fertilization, will rarely be possible. Many development projects have been falsely encouraged, based on first year yields obtained after clearing the forest, where crops draw on the rapid, though short-lived, release of nutrients from decomposing organic matter or the ashes produced by burning. After a few crops, however, yields drop to equilibrium levels. Once the nutrient reserve has been depleted, restoration becomes extremely difficult, especially under ecologic conditions which favor savannah regrowth.

Soil landscapes and diversity

The all-too-common conception of the Amazon basin as an essentially flat area is misleading. Although the difference in elevation between river beds and adjacent plateaus seldom exceeds 80 meters, it is precisely within this range of variation that the greatest diversity of land qualities is found. While alluvial valley floors are essentially flat, most land surfaces and terraces have been dissected by the dense river system. Landscapes often consist of a repetitive sequence of convex shoulders, short steep slopes, and concave lower transitions to swampy alluvial flats. The most frequent soil taxa associated with these landforms are, respectively: Oxisols, Inceptisols, and Ultisols, and the Aquepts. The Oxisols and Ultisols which are characteristic of the uplands are highly weathered and leached, and while their physical makeup is favorable for

agriculture, their nutrient status is quite marginal. The Inceptisols, Ultisols, and occasional Alfisols which are found on slopes are usually less weathered and offer greater agricultural potential in terms of intrinsic fertility, availability of nutrients, and mineral reserves, if the gradients are not too steep. The Aquepts, which are wet soils found in bottomlands, have variable agricultural potentials depending on the materials which the rivers have deposited on the alluvial flats. The divides between major rivers may be level plateaus or smoothly rolling hills. On these, the Oxisols are most common. The smaller water catchment areas, however, are strongly undulating. And while the Inceptisols and Ultisols which are characteristic there offer a better potential for crops with high nutrient requirements, a great deal of care is necessary to avoid erosion because of the topography of the terrain.

The foregoing description of soil landscape variability and the accompanying list of soil taxa is not merely an academic exercise. It is intended to reflect the practical importance of soil survey data for development planning and the proper use of soil resources. And the examples given are only a few of the many sequences which exist. In a specific instance, a given landscape with its characteristic soil has specific qualities which only match the needs of a limited number of crops. Farmland should therefore be divided into parcels where pastures, forests, and annual and perenial crops, find optimum conditions for growth, thereby maximizing the efficiency of agricultural projects. As elsewhere, this cannot be achieved through grid or checkerboard patterns of land allocation, because however efficient that might seem for land tenure and other administrative purposes, it may bear little or no relationship to the optimum utilization of soil resources in farming systems established on marginal land.

The Amazon basin, which for development purposes is sparsely inhabited and has not yet suffered from over-parcelization of land into small individual plots, offers excellent opportunities for the careful matching of land utilization types to the natural distribution of soils in the landscape It also allows planners the freedom to start development on the best soils, which is usually not possible in other areas, where demographic pressure forces them to settle people on less promising lands.

Development alternatives

Soil scientists have explored several alternative means to development in the Amazon. The first, intensification, involves modifying soil conditions with amendments which increase the productivity of land per unit area, and the second entails adapting farming systems to the existing environment. The latter can be achieved by modifying crop requirements to soil conditions (crop adaptation), or by utilizing larger areas, clearing new land, and shifting from one parcel to another as needed (extensive land-use). These alternatives are all potentially applicable, and should be considered as possible components of strategies for rural development of the region.

Intensification

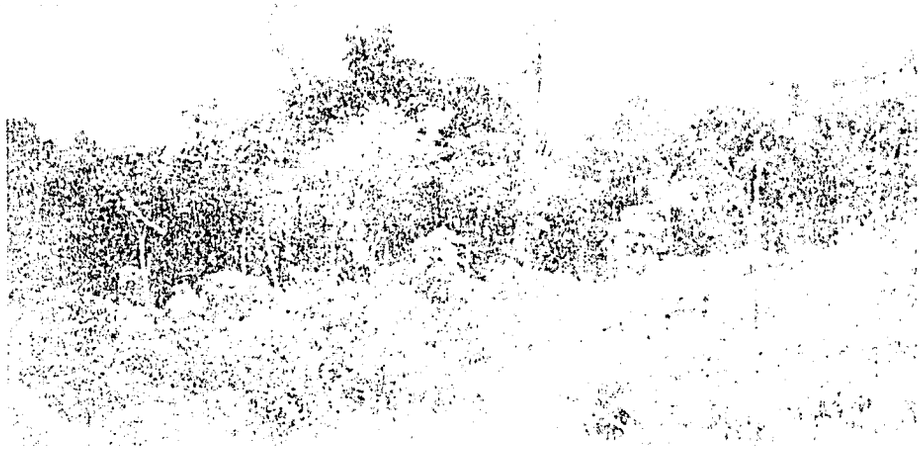
In the Amazon region, the intensification of agricultural production through modifications of soil potentials will inevitably imply the use of chemical fertilizers. Significant advances in their use have been made during recent decades. From a purely technical viewpoint, there is no doubt that with adequate fertilization, high yields can be obtained from almost all welldrained soils of the region. As a rule, chemical fertility is easier to maintain or correct than are physical soil conditions. In this respect, the Amazon basin offers an extremely interesting field for soil fertility research, with minimum problems of poor structure, lack of aeration, or mechanical impedance to root penetration which are found in soils of many other areas. Cost of fertilization, however, is a significant limitation.

Decision-making regarding improving soils is not simply a matter of determining one's ability to pay the initial costs of fertilization and other technological inputs. Soil management through the application of fertilizers involves a continuing commitment of both financial and natural resources. If lands are to be integrated into either national or international market economies, production costs have to be kept below the levels set by normal price-determining forces. But for such a program to be viable, the farming systems established on a given soil will have to produce sufficient harvests over the long run to offset both original investments and continuing inputs while supporting the people who work and live on the land, and remain competitive with other producers operating on more favorable soils. It is realized that other factors (for example, providing locations for settlement of otherwise under- or unemployed urban populations, reaching a degree of national self-sufficiency in the production of staples as a buffer against fluctuations in world market-prices of cash-crops, reducing imports and improving balance-of-trade deficits, etc.) may mandate farming on marginal land, and that in this case a continuing program of subsidies and/or tariffs will have to be provided. Many variables may influence development planning beyond strictly monetary cost/benefit or input/output ratios; this paper, however, limits the discussion to the technical and economic aspects of the problem.

Low activity clay soils in the Amazon are seldom competitive in the production of commodities which can be grown elsewhere, if one us strict market criteria. The maintenan of adequate fertility levels in acid, leac ed, strongly weathered soils is relativel expensive, even though soil fertility r search has increased the efficiency applied fertilizers by careful attention composition, rate of release of nutrien to plants, timing of applications, an the placement of the fertilizers in relatio to plant root-systems. Whatever level efficiency is attained, overall results see to indicate inferior benefits compared t profits obtained in soils producing th same crops in other regions.

The efficiency of nitrogen fertilizers is, at present, quite low At intensive levels of application, on th average only 30 to 50% is utilized; th rest is lost, mainly by leaching. Phosphorus deficiencies can be overcome by various methods: banding (the placemen of concentrated phosphorus in small a mounts close to plant roots), heav broadcast applications throughout the soi which quench the soils' fixation capacit and maximize residual effects, and block ing potential adsorption/fixation site with cheaper chemicals have all prove effective. Combinations of these techniques may greatly improve cost/benefit ratios. Acid leached soils usually have a high aluminum content in the soil solution, which must be lowered by liming. If toxic aluminum concentrations occur in the upper part of the subsoil, the lime has to be incorporated mechanically, unless there is sufficient rainfall to allow soluble calcium ions (such as those released by sulfates contained in superphosphate fertilizers) to percolate into the subsoil and correct the imbalance.

Agricultural development programs which are based on drastic modifications of soil environments in order to make them suitable for intensive production of annual crops with high yields per unit area on a permanent basis are still in the experimental stage. The prognosis for success in such efforts is dependent on the proximity, availability, price, and technology needed for the application of soil amendments, as they interact to determine costs. Up to the present time, it has generally been hard to convince governments and private enterprise to make the rather substantial initial investments necessary to convert the acid, highly weathered soils in remote areas of the Amazon into permanent agricultural lands through programs involving the massive incorporation of fertilizers. Several reasons for this reluctance to change development policies are usually given: the abundance of land available and its consequently low purchase price are cited, as well as the short-term benefit that can be derived from agricultural operations which have little concern with the conservation, let alone the permanent improvement of the land. As long as opening new fields is thought to be cheaper than maintaining or creating fertile soils, efforts to establish continuous cropping



conservative development projects. The critical ratio between lengths of cropping and fallow seasons depends on the kind of soils and land qualities.

Even if sufficient land is available for long fallow periods, the distances within and between large farms, communities, and villages set limits on productivity. There is a critical maximum extension of infrastructure (road systems, etc.) beyond which settlement costs per unit area of productive field become prohibitive (Moran, 1976). It is a fallacy to assume that low levels of productivity can be offset by the opening of more and more farmland in what are all too often thought to be inexhaustible land areas. Very quickly a break even point is passed and transportation costs outweigh possible benefits. It is extremely difficult, however, to predict optimal farm sizes without accurate estimates of the potential of the land.

The risks involved in using soils with low fertility increase with the magnitude of the changes that are introduced into the system. It is commonly accepted that plantations of tree crops such as oil palm, rubber, and cacao, and carefully managed coffee, can replace the rainforest and keep environmental conditions similar to the original situation. Once a plantation has reestablished a cover over the soil, fertility management entails maintaining optimum levels in the soil, and a balance between the export of soil nutrients by the harvest, and returns to the soil by plant residues. Successful tree plantations simulate the closed cycling of nutrients which occurs in the virgin rainforest. Selective forestry coupled with programs to reestablish timber stands, and similar operations in combination with short-term agricultural and animal production projects, can also approximate previous ecological conditions and be a viable pattern of land utilization if reforestation is insured. Generally speaking, the best adapted utilizations of the forested regions of the Amazon basin involve the growing of tree and other perennial crops.

In extensive systems, savannah areas are better used for livestock production through grazing on natural vegetation in a majority of cases. In some areas with relatively higher fertility, grazing and mixed farming will, in the foreseeable future, constitute the major viable type of land-use, unless the intensive use of fertilizers is begun.

Photo 2 — Combinations of tree crops and cover crops which avoid the contrast conditions of the open field, which promote erosion and excessively high soil temperatures which degrade the soil. The soils which these conditions are shared in most upland Amazon soils. Photograph taken by the author near Belém, Brazil.

Crop Adaptation to Stress Conditions

Plant breeders have been increasingly successful in selecting crop varieties which are adapted to adverse soil conditions, including deficiencies, toxicity, and drought (Wright, 1977). Screening techniques have been improved as well. The advantages of this approach are obvious upon considering the conditions which prevail in the Amazon basin, especially in terms of the cost of fertilizers. At the same time, tolerant germplasm and cultivars probably exist in the region, and should be researched. Breeding programs will have to increase tolerance to aluminum and manganese toxicity, and phosphorus deficiency, all of which are common to the area. Da Silva (1977), for example, has described the results of adaptation of wheat varieties to the acid soil conditions of the Brazilian Amazon. Spain (1977), conducted screening programs with rice, cassava, cowpeas, peanuts, corn, and beans in the acid soils of Colombia. He concluded that a few crops produce high yields with little or no added lime; cassava was very tolerant to soil acidity. Many tropical forages are also well-adapted to acid soils. Care needs to be taken in such programs, of course, to insure that new varieties will fill all the needs which varieties being replaced met in the total farming system, and that cultural preferences including taste are adequately understood insofar as they might influence acceptance of new cultivars and crops.

Soil conservation

Two important aspects of soil conservation have already been stressed: the concentration of soil fertility in the surface layers and the special care needed to protect it, and the strongly dissected landscapes. Tropical rains are extremely intense and potentially destructive (Kowal and Kassam, 1977). This is particularly the case in areas where the length of the dry season impedes forest growth and the establishment of a protective cover of foliage which breaks the intensity of the rainfall on the ground. These factors combine to render Amazon basin soils very vulnerable to degradation, once the land is cleared and the soils are exposed to the direct impact of rainfall. Notwithstanding the reputed resistance of soils in the tropics to erosion, soil conservation is, in fact, a major problem in the area.

There are many well-known rules concerning the prevention of erosion in soils. These involve slope gradients, length and shape of declivities and other factors which must be considered in land management. At present, a more than adequate amount of land is available in the Amazon if it is properly managed. As soil surveys have already or can provide adequate data, the main task in the rainforest area is to avoid clean weeded utilizations of land which has excessive erosion potential. In savannah areas, more efforts should also be made to protect existing cropland and grassland from erosion. If these matters are not attended to, the initial costs of development will be re-incurred repeatedly in new areas with very little return on the investment and at great human and environmental costs.

Soil conservation is more than prevention of erosion. Since no nation has unlimited capital, its long-term interests demand that, after land is cleared and worked, it be conserved at no less than its original value, whether in terms of the number of people it supported prior to being opened, its inherent fertility level, development costs, or some other measure.

Unfortunately, such conservation often does not take place. All too often, forests on marginal soils have been cleared, the land has been cropped for several years, and then converted into pastures which degenerate into extremely poor savannahs. Soil capability scales (see, for example, Ministério Das Minas e Energia, 1975), which give relative measures of suitability could be used in the planning and limitation of forest-clearing operations to the more appropriate soils.

Development potential

Soils, as a natural resource for agricultural development, are most often considered in terms of their limitations, rather than their potentials. This has particularly been the case in the Amazon, which, along with some other tropical areas, has remained essentially unpopulated and undeveloped.

Land potentials cannot be expressed in absolute figures. With complex entities such as soils, they depend on comparisons with other soils, measured in terms of parameters which vary according to projected purposes, and social and economic variables.

Planning in the Amazon basin has been somewhat distorted by the assumption that soil is always a completely renewable resource and that because the total amount of land available is so huge, land qualities can, in large part, be ignored. Erosion, leaching of nutrients, and fast decomposition rates are among the many factors which cause the degradation of soils. In too many cases, the damage which can result from mismanagement cannot be repaired, either because of the extraordinarily long recovery time which these soils require if they are ever to regain their previous fertility, or because of the excessive cost involved in the purchase, transportation and incorporation of the soil amendments necessary to reverse the degradation process. At any rate, in all cases, people are involved, and human resources are wasted.

During the last decade, considerable progress has been made in the accumulation of knowledge about the soils of the Amazon, especially through surveys and agricultural experiments which have been conducted throughout the area. As has been noted, these have indicated the diversity of soils, as well as shared characteristics. Perhaps the foremost is the predominance of soils with low inherent fertility. Recent experimental results indicate that fertility barriers are not technically insurmountable. Up to the present, however, the information available has either been narrowly site-specific, or else too short term to be considered reliable, and, in any event, has not been properly utilized in development project planning. Serious communication gaps exist between academic disciplines involved in rural development planning, as well.

While generalizations are dangerous, given the diversity of soils in the Amazon, some prevailing characteristics should be stressed. It can be said that, at present, these soils yield inferior financial returns when used for the production of annual food crops which can be grown elsewhere. It will probably be a long time, if ever, before they will be able to compete commercially on world markets with soils of other regions in the production of these commodities, unless prices of products rise drastically in relation to inputs. Therefore, beyond subsistence production, short—and intermediate—range planning must concentrate on growing cash crops of those plants indigenous to the hot tropics, on maximizing profits from extensive animal production, on well-managed tree plantations and forestry, and on the development of crop varieties which are selected and adapted to predominantly acid soil environments.

Precisely because there is so much land available in the Amazon basin, and because of its diversity, one may be optimistic about the potential of the region if planning efforts take into account the information available and do everything possible to promote undertakings with the highest potential for success. The logical place where permanent agricultural development of the region will start will be around mining and other resource extraction sites in the Amazon itself, in areas with optimum soil conditions, thus providing a market for produce without the need for extensive transportation systems. These programs could provide valuable lessons for the future. Further research, of course, is needed. Long-term experiments, which cover several decades, are necessary in order to gain a better understanding of soil rehabilitation processes and aid in the proper management of land in the area. A great need remains for experimental data which will allow planners to predict what transformations soils will undergo with ten, twenty and more years of utilization. Real settlement and rural development must be understood as a long-term process.

There is no point, in these few pages, in trying to summarize ongoing research, or establishing a comprehensive list of priorities for research and development planning. Soil science has a significant contribution to make in this regard. As has been noted, information already available could be made more accessible. Efforts to strengthen all phases of the information and technology dissemination process are needed. More publications, better library systems, effective systems of access to and correlation of soil survey and other research data, and increased support for interdisciplinary approaches to development questions, including on the decision-making level, are all essential. Soil scientists could accelerate the process by developing, or where available fully utilizing equated or correlated soil classifications, nomenclatures, and terminologies. This would facilitate the transfer of technology within and between regions, as well as maximizing the potential for retaining the lessons of past experience. In the end, teaching institutions, together with national and international research institutes, will all have an important role to play in the development of the Amazon basin. The latent potential of the area, both in terms of benefits to the region itself and to the world, demands nothing less.

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PROPIEDADES Y POTENCIAL DE LOS SUELOS EN LA CUENCA AMAZONICA

A. VAN WAMBEKE

RESUMEN

El presente trabajo describe las múltiples propiedades y el potencial de los suelos en la cuenca amazónica. Se intenta destacar la diversidad de los suelos en el área, y sus diferentes potenciales para ser desarrollados. La evaluación de tierras, basándose en su calidad, se utiliza como medio para sugerir sistemas óptimos de utilización.

Los suelos de los climas pluviales de las tierras bajas tropicales, tienen en común diversas propiedades que condicionan la utilización de la tierra. Ellas son: un régimen común de humedad del suelo y un régimen uniforme de temperatura de suelo. Estos factores tienen implicaciones importantes en el manejo de los suelos.

La diversidad de los suelos en la cuenca amazónica está altamente relacionada con el grado de meteorización al cual han estado sometidos. La meteorización y lavado intenso causa una reducción de los nutrientes de las plantas en la fracción mineral del suelo. Los suelos más meteorizados, aunque frecuentemente tienen una estructura física que favorece el crecimiento de las plantas, carecen de nutrientes y son susceptibles a la sequía. Los suelos muestran diferentes grados de meteorización debido a la interacción de muchas variables ambientales y a la composición química de las rocas originales.

Las cualidades de la tierra, incluyendo el anclaje de las raíces de las plantas, son específicas de cada sitio. La plintita blanda, que con frecuencia se describe equivocadamente como un gran obstáculo para el desarrollo agrícola en el Amazonas, de hecho constituye un problema en sólo el 2% de los suelos. Hay limitaciones más importantes al desarrollo del sistema radical de las plantas, tales como la inundación estacional de algunos suelos, la erosión de superficie y la coincidencia de deficiencia de calcio y toxicidad de aluminio, lo cual impide la penetración profunda de las raíces.

El suministro de nutrientes es escaso en los suelos altamente meteorizados de la región. Aunque las fracciones minerales de la mayoría de los suelos contienen muy pocos nutrientes, el contenido y calidad de la materia orgánica presenta niveles variables. La mayor parte del contenido de nutrientes de esos suelos está concentrado en la vegetación y en el humus. Mientras el ciclo natural de nutrientes, a través de las raíces hacia los tejidos de las plantas y desde los residuos vegetales de nuevo hacia el suelo, no se interrumpa, se puede conservar la fertilidad intrínseca de esos suelos. Cambios ecológicos, sin embargo, pueden agotar rápidamente esos suelos, y la restauración por medio del crecimiento secundario es mucho más problemática de lo que frecuentemente se supone (Véase Herrera y otros, en este mismo número).

Aunque la diversidad de los suelos es una función de la meteorización y de variables ambientales, también es específica de la topografía, la cual favorece tipos de vegetación y de suelos específicos. La mayor diversidad de los suelos y del uso potencial de la tierra puede ocurrir dentro de un promedio de 80 metros de diferencia altitudinal, entre los ríos y las mesetas que ellos dividen. La utilización de la tierra será más eficiente si se basa en la optimización de las relaciones entre topografía de los suelos y las necesidades de las plantas.

Las alternativas de desarrollo incluyen la intensificación de la agricultura mediante el uso de fertilizantes para mejorar las condiciones del suelo y la adaptación del uso de la tierra al ambiente por medio de la adaptación de los cultivos y de patrones extensivos del uso de la tierra. Se le debería dar más importancia al establecimiento de sitios de producción agrícola permanentes, antes de que la ilusión de que hay recursos ilimitados de tierra en el área lleve a la destrucción irreversible de los suelos y a la creación de desiertos de fertilidad.

Con frecuencia se ignoran los verdaderos costos de los patrones de utilización de la tierra a corto plazo. La fertilización es más prometedora de lo que a menudo se supone. Los sistemas de producción extensivos, especialmente aquellos que se aproximan a las condiciones de estado en equilibrio del ciclo de nutrientes en el bosque pluvial natural, tienen también un potencial significativo. Agricultura itinerante, cultivos perennes, plantación de árboles, silvicultura y pastoreo, son todos sistemas utilizables, si se toma cuidado en la elección del sitio y el manejo apropiado, con poco riesgo de deterioro del suelo. Los peligros de utilizar suelos de baja fertilidad aumentan con la magnitud de los cambios introducidos en el sistema. La adaptación de cultivos también tiene mucho que ofrecer.

La conservación de los suelos y la prevención de la erosión son variables cruciales en el desarrollo del área. No es correcto pensar que todos los suelos en los trópicos tienen gran resistencia a la erosión. Es más, la idea de que los suelos en los trópicos son recursos completamente renovables es errónea.

Hay motivos para ser optimistas en cuanto al desarrollo de la cuenca amazónica si los planificadores y los científicos trabajan conjuntamente para aumentar al máximo el uso eficiente y conservador de sus recursos. Hay suficiente tierra disponible para permitir el desarrollo, pero sólo bajo las condiciones más apropiadas.

La investigación, el adiestramiento, las instalaciones para la enseñanza, así como los mecanismos apropiados de diseminación de las técnicas de uso de la tierra, deben ser reforzados a todos los niveles del proceso de desarrollo.

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PROPRIEDADES E POTENCIAL DOS SOLOS NA BACIA AMAZÔNICA

A. VAN WAMBEKE

RESUMO *O presente trabalho descreve as múltiplas propriedades e o potencial dos solos da Bacia Amazônica. Procura destacar a diversidade dos solos da área, e suas diferentes potencialidades para serem desenvolvidas. A avaliação de terras, baseando-se na sua qualidade, é utilizada como meio para sugerir sistemas ótimos de utilização.*

Os solos dos climas pluviais das terras baixas tropicais têm em comum diversas propriedades que condicionam a utilização da terra. Elas são: um regime comum de umidade do solo e um regime uniforme de temperatura do solo. Estes fatores têm importantes implicações no manejo dos solos.

A diversidade dos solos na Bacia Amazônica está altamente relacionada com o grau de meteorização ao qual têm sido submetidos. A meteorização e o lavado intenso causam uma redução dos nutrientes das plantas na fração mineral do solo. Os solos mais meteorizados, ainda quando frequentemente têm uma estrutura física que favorece o crescimento das plantas, carecem de nutrientes e são susceptíveis à seca. Os solos mostram diferentes graus de meteorização devido à interação de muitas variáveis ambientais e à composição química das rochas originais.

As qualidades da terra, incluindo a base das raízes das plantas, são específicas de cada lugar. A "plintita" terra, que frequentemente é descrita equivocadamente como um grande obstáculo para o desenvolvimento agrícola no Amazonas, de fato constitui um problema emsomente 2% dos solos. Há limitações mais importantes ao desenvolvimento do sistema radical das plantas, tais como a imundação estacional de alguns solos, a erosão de superfície e a coincidência de álcio e toxidade de alumínio, o que impede a penetração profunda das raízes.

O fornecimento de nutrientes é escasso nos solos altamente meteorizados da região. Ainda quando frações minerais da maioria dos solos contêm muito poucos nutrientes, o conteúdo e a qualidade da matéria orgânica apresentam níveis variáveis. A maior parte do conteúdo de nutrientes desses solos está concentrada na vegetação e no humo. Enquanto o ciclo natural de nutrientes, através das raízes para os tecidos das plantas e desde os resíduos vegetais novamente para o solo, não se interrompa, pode ser conservada a fertilidade intrínseca desses solos. Mudanças ecológicas, entretanto, podem esgotar rapidamente esses solos, e a restauração através do crescimento secundário é muito mais problemática do que frequentemente se supõe. (Veja Herrera e outros, neste mesmo número).

Ainda quando a diversidade dos solos é uma função da meteorização e de variáveis ambientais, também é específica da topografia, que favorece tipos de vegetação e de solos específicos. A maior diversidade dos solos e do uso potencial da terra pode ocorrer dentro de uma média de 80 metros de diferença de altitude entre os rios e as mesetas que eles dividem. A utilização da terra será mais eficiente se se baseia na optimização das relações entre a topografia do solo e as necessidades das plantas.

As alternativas de desenvolvimento incluem a intensificação da agricultura, mediante o uso de fertilizantes, para melhorar as condições do solo e a adaptação do uso da terra ao ambiente, por meio da adaptação dos cultivos e de padrões extensivos do uso da mesma. Dever-se-ia dar mais importância ao estabelecimento de locais de produção agrícola permanentes, antes que a ilusão de que há recursos ilimitados de terra na área leve à destruição irreversível dos solos e a criação de desertos de fertilidade. Frequentemente se ignoram os verdadeiros custos dos padões de utilização da terra a curto prazo. A fertilização é mais prometedora do que normalmente se supõe. Os sistemas de produção extensivos, especialmente aqueles que se aproximam às condições de estado em equilíbrio do ciclo de nutrientes no bosque pluvial natural, têm também um potencial significativo. Agricultura itinerante, cultivos perenes, plantações de árvores, silvicultura e pastoreio são todos sistemas utilizáveis, se se toma cuidado na eleição do lugar e no manejo apropriado, com pouco risco de deterioração do solo. Os perigos de utilizar solos da baixa fertilidade aumentam com a magnitude das mudanças introduzidas no sistema. A adaptação dos cultivos também têm muito que oferecer.

A consevação dos solos e a prevenção da erosão são variáveis cruciais no desenvolvimento da área. Não é correto pensar que todos os solos nos trópicos têm grande resistência à erosão. Ainda mais, a idéia de que os solos nos trópicos são recursos completamente renováveis é errônea.

Há motivos para ser otimista em relação ao desenvolvimento da Bacia Amazônica se os planificadores e os cientistas trabalham conjuntamente para aumentar ao máximo o uso eficiente e conservador de seus recursos. Há terra suficiente disponível para permitir o desenvolvimento mas somente sob as condições mais apropriadas.

A pesquisa, o treinamento, as instalações para o ensino, assim como os mecanismos apropriados de disseminação das técnicas de uso da terra, devem ser reforçados a todos os níveis do processo de desenvolvimento.