

$$p(t) = 100 - 0.01t^2$$

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ABSTRACT

The humid tropics of Latin America are caught between the need to expand agricultural production and the need to preserve an ecosystem of extreme diversity. Soils are acknowledged as a crucial factor for a balanced approach. The Latin American humid tropics have a higher proportion of acid soils than their counterparts in Asia and Africa, with 81% covered by Oxisols, Ultisols and Dystropepts. The most widespread soil constraints in the Amazon are phosphorus deficiency (90% of area), aluminum toxicity (73%) drought stress (53%) and low nutrient reserves (50%). Concerns about laterite formation and low soil organic matter contents are not supported by data. Traditional slash and burn clearing or bulldozing with a shear blade are the recommended land clearing methods. Long-term research suggests a series of soil management options for specific soils, landscape positions and level of infrastructure development. These options include paddy rice cultivation on alluvial soils, intensive mechanized crop rotations in acid soils, with suitable topography, low input cropping systems for the same locations if they have poor infrastructure, legume-based pastures, and agroforestry. Without appropriate soil management technology development of the humid tropics will fail in economic and ecological terms. With appropriate technology and market infrastructure development is feasible and may produce a rational balance between cleared areas and rainforests.

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The humid tropics encompasses those areas of the world with high and constant temperature, a dry season of less than four consecutive months and a tropical rainforest or seasonal, tropical forest native vegetation. About 45 percent of the world's humid tropics are located in Tropical America (Table 1) and three-fourths of that in the Amazon. The humid tropics is one of the world's crucial ecosystems, where the need to expand agricultural land to relieve population pressure is in direct conflict with the need to preserve an ecosystem of extreme faunal and floral diversity. Soil constraints are acknowledged as a major limitation of the region. Knowledge of soils and their management is crucial for a balanced approach between these opposing forces.

During the last two decades, significant advances have been made in the characterization and management of soils of the Latin American humid tropics. Individual soil survey reports, many of them listed in this paper's bibliography, have been brought together under a common legend, along with comparable data on climate, topography and vegetation (Cochrane, 1984).

Research to find sound soil management systems for the rational use of the humid tropics has also advanced in the region. This paper attempts to summarize some of the available information about the geographical distribution of soils, some common misconceptions about them, soil constraints, land clearing methods and soil management options for the American humid tropics. Emphasis is given to the Amazon because of its size, preponderance of acid soils and the level of research effort.

SOIL GEOGRAPHY

The geographical extent of soils of the humid tropics is given in Table 1 using soil taxonomy terminology (Soil Survey Staff, 1975). The translation of this terminology into the FAO legend, 1938 USDA, French and Brazilian soil classification systems is shown in Table 2.

Acid soils, classified as Oxisols, Ultisols and the Dystropepts cover large areas of the humid tropics, but their relative importance is greater in Latin America (82%) than in Africa (56%) or Asia (38%) as shown in Table 3. The inverse occurs with moderately fertile, high base status soils which cover as much as 33% of humid tropical Asia, 12% of humid tropical Africa but only 7% of humid tropical America (National Research Council, 1982). Most of these fertile soils in Asia are already under intensive cultivation; therefore, the potential for area expansion into good soils is very limited. This is not the case in humid tropical America and Africa where considerable areas of alluvial soils or other high base status soils occur within oceans of acid soils. Representative soils profile data of experiment stations or key areas are described in Table 4.

COMMON MISCONCEPTIONS

Three common misconceptions about soils in the humid tropics deserve clarification at this point. They relate to laterization, organic matter contents and the distribution of nutrients between plant biomass and soil under tropical rainforests.

Laterite Formation

The dangers of laterite formation after clearing tropical forests are limited (Moormann and Van Wambeke, 1978; Buol and Sanchez, 1978). In

the Amazon, only 4% of the region has soft plinthite in the subsoil, a substance capable of hardening into laterite if this layer is exposed by erosion. These soils are mainly classified as Plinthaquults or Plinthaqualfs. Since most of these plinthic soils occur in flat, poorly drained topographical positions, the danger of laterite formation is minimal, as it would require massive soil erosion for exposure.

Hardened laterite of geologic origin occurs in scattered areas in the humid tropics where it serves as excellent road building material. In areas like the Peruvian Amazon, which is essentially devoid of these laterite formations, low cost roads are definitely inferior in comparison with those of the State of Pará in Brazil where laterite outcrops occur. The laterite hazard, still frequently mentioned in the literature, is therefore, of little importance in the humid tropics as a constraint. On the contrary, where laterite outcrops occur they are definitely an asset to development.

Organic Matter Contents

Soil organic matter contents in the humid tropics compare very favorably to those found in soils of temperate forests. Soils in the humid tropics have somewhat higher organic carbon and total nitrogen levels in the topsoil as well as the entire solum than their temperate counterparts (Table 5). Sanchez, Gichuru and Katz (1982) also found no significant difference in organic matter contents between soils of tropical vs. temperate regions, between Oxisols of the tropics and Mollisols of the temperate region or between tropical vs. temperate Ultisols. Calculations of fresh organic matter additions and decomposition rates explain the lack of differences (Sanchez and Buol, 1975). As in all forested ecosystems, soil organic matter

is more concentrated in the topsoil than in the subsoil. This premise holds for tropical forests as well as temperate ones.

Plant Nutrient Storage

Another commonly held view is that tropical rainforest ecosystems hold most of their nutrients in the plant biomass component (Goodland and Irwin, 1975). Nutrient cycling studies that include the entire soil, however, show that most of the ecosystem's nitrogen and phosphorus is located in the soil component (Table 6). This is not the case with potassium, calcium and magnesium, the bulk of which remains in the above-ground biomass. An exception to the latter statement occurs on high base status Alfisols, which also contain the bulk of their bases in the soil. For more details, the readers are referred to an excellent review by Salati and Vose (1984).

SOIL CONSTRAINTS IN THE AMAZON BASIN

Soil classification data provide a broad geographical picture of the kinds of soils that exist in the humid tropics but what this means in practical terms is only implied. This is because soils are mapped and classified as natural bodies, and not directly according to what problems they present for a specific use. Soil survey information can be interpreted in terms of constraints to agricultural development drawing from soil taxonomy plus additional properties of the topsoil layer which is where most of the plant-soil interactions take place. Soil classification systems, such as soil taxonomy, do not include many of the transient properties of topsoils because they can be changed by management. In order to have a proper interpretation of what are the major constraints of these soils, it is necessary to consider the measurable parameters that characterize the kinds of problems to be

indicated. The Fertility Capability Classification System (FCC) is one way to quantify soil constraints (Buol et al., 1975). A rough estimate for the humid tropics as whole is shown in Table 7.

When using a fairly detailed data base, meaningful interpretations can be made for planning and assessment purposes. This has been done for the Amazon by Cochrane and Sanchez (1982) at the scale of 1:1 million. The highlights of this study appear below, as an example of what kind of information may be useful to obtain in other humid tropical regions. Table 8 shows a summary of the main soil constraints in the Amazon region as a whole. The most widespread ones are chemical rather than physical.

Phosphorus deficiency is found in 90% of the Amazon, but the severity of such deficiency will depend on which crops are to be grown. Aluminum toxicity, the main cause of soil acidity, covers the second largest territorial extent with about three quarters of the region. It is important also to note that about 27% of the Amazon does not have significant aluminum toxicity problems. These are primarily in the alluvial areas and the well-drained high base status soils. Drought stress is found in 53% of the area, mainly in the near-ustic regions.

Low nutrient reserves are widespread in half of the region, suggesting the need for potassium fertilization in about half the Amazon.

Poor drainage and flooding occur on one-fourth of the region, including alluvial areas (várzeas) and inland swamps (aquajales). Many of these várzea regions are not severely threatened by floods and have a high production potential. This particular figure also indicates that about three-fourths of the Amazon region has well-drained soils.

About 16% of the Amazon soils have the capacity to fix large quantities of phosphorus into relatively insoluble forms. These are mainly the

Oxisols and Ultisols of clayey topsoil texture. Comparing this number with 90% of the Amazon that suffers from phosphorus deficiency, most soils of the Amazon that are inherently deficient in phosphorus are not likely to require large quantities of phosphorus fertilizers. This situation is certainly a less difficult one than in the acid savannas where high phosphorus fixation is widespread. Research conducted on phosphorus fertilization in the Amazon confirms this supposition (Serrão et al., 1979; Benites, 1983). Nevertheless, there are 77 million hectares of soils that are both deficient in phosphorus and have a high fixation capacity.

About 13% (64 million hectares) of the Amazon has soils with effective cation exchange capacity (ECEC) values below 4 meq/100 g. Many nutrient cations can be rapidly lost by leaching, particularly in well-drained soils. Also, low ECEC soils are poorly buffered, indicating potential nutrient imbalance problems. In Yurimaguas, Peru, for example, potassium applications can cause magnesium deficiency by creating a nutritional imbalance between these two elements (Villachica, 1978).

Table 8 also indicates only about 8% of the Amazon has a severe erosion hazard. This is partly due to the overall level to gentle (0-8%) slopes found in 73% of the Amazon (Cochrane and Sanchez, 1982) and partly to the favorable structure of many Oxisols and Ultisols. The 39 million hectares of highly erodible soils are located mainly on steep slopes and deep soils with an abrupt clay increase. These soils, mostly classified as Ultisols or Alfisols, are often quite susceptible to erosion unless protected by a plant canopy during periods of heavy rains.

The above statements should not imply that erosion is not a problem in the Amazon, because all soils can be eroded by mismanagement and sheet

erosion can occur in nearly level, well-drained Oxisols and Ultisols. It implies that compared to other major regions of the world, the erodibility of the main soils of the Amazon is not high. Most of the obvious gully erosion in the Amazon is caused by civil engineering, rather than agriculture--along roads, building sites and improper city sewage and drainage systems. This situation, however, could change drastically if the plant cover is removed and not replaced sufficiently rapidly by another plant canopy. This seldom happens in the forested regions of the Amazon because when crops or pastures fail, weeds and secondary forest regrowth rapidly produce a new plant canopy. Gullying along cattle trails in overgrazed pastures, however, is an increasingly serious concern. Also, sheet erosion has been reported in poorly managed pastures at the beginning of the rainy season in the seasonal forest region. Actual erosion estimates have been provided by Navas, Munévar and Perea (1977), McGregor (1980) for the Colombian Amazon and by Ranzani (1980) for the Brazilian Amazon.

About six percent of the Amazon has soils with no major limitations other than nitrogen deficiency. These are the well-drained soils high in native fertility classified mainly as Alfisols, Mollisols, Vertisols and well-drained Inceptisols and Entisols. Nevertheless, they represent a total of 32 million hectares and where they occur permanent agriculture has a better chance of success. This is the case in the Terra Roxa soils (Rhodustalfs) which combine high native fertility with excellent physical properties. Many of the successful cacao plantations are located in such soils. High base status soils are found near Altamira, Ouro Preto (Rondônia) and Rio Branco in Brazil, in the Oriente of Ecuador associated with relatively recent volcanic deposits, and in the Huallaga Valley of Peru.

LAND CLEARING METHODS

The choice of land clearing methods is the first and probably most crucial step affecting the future productivity of farming systems. Several comparative studies conducted in the Amazon confirm that land clearing methods that involve burning are superior to different types of mechanical clearing because of: (a) The fertilizer value of the ash, (b) soil compaction caused by bulldozing, and (c) topsoil displacement in mechanized land clearing.

Nutrient Additions by the Ash

The direct measurement of the nutrient content of the ash in the Amazon has been determined after burning several types of vegetation in an Oxisol from Manaus, Brazil and an Ultisol from Yurimaguas, Peru (Table 9). The ash added significant inputs to the soil which resulted in beneficial effects in soil chemical properties (Seubert *et al.*, 1977; Smyth and Bastos, 1984).

Variability in the quantity and nutrient content of ash occurs because of differences in soils, clearing techniques and the proportion of the forest biomass actually burned. Silva (1979) estimated that only 20% of the forest biomass was actually converted to ash when burning a virgin forest on an Ultisol of southern Bahia, Brazil. Silva also analyzed the composition of ash adjacent to individual tree species and observed very wide ranges (0.8-3.4% N, 0-14 ppm available P, 0.06-4.4 meq Ca/100 g, 0.11-21.03 meq Mg/100 g, and 34-345 meq K/100 g). This suggests the presence of fallow species that can accumulate specific nutrients.

The fertilizer value of the ash is likely to be of less importance in fertile soils. Cordero (1964) observed that the increases in P and K

availability caused by burning a forest on an Entisol of pH 7 in Santa Cruz, Bolivia, did not increase crop yields. The soil was already high in these elements. In fact, ash additions to Alfisols with pH 6 have triggered iron or zinc deficiencies in Africa (Lal et al., 1975). Similar effects have been observed under large ash depositions in Oxisols of Manaus.

In addition to the nutritional value of the ash, the extent to which the ash is incorporated into the topsoil is important. Around Manaus, shifting cultivators prefer to clear loamy or sandy Ultisols on steep slopes than nearly level areas of clayey Oxisols. One reason is that the ash is not incorporated well in the Oxisols, while apparently this is not a problem in the less clayey Ultisols.

Soil Compaction

Conventional bulldozing has the clearly detrimental effect of compacting the soil, particularly sandy and loamy Ultisols. Significant decreases in infiltration rates, increases in bulk density and decreases in porosity have been recorded in such soils in Surinam (Van der Weert, 1974), Peru (Seubert et al., 1977; Alegre et al., in press) and Brazil (Schubart, 1977; Silva, 1979).

Topsoil Displacement

Another consideration is the degree of topsoil displacement by the bulldozer blade and by dragging uprooted trees and logs. Although no quantitative data are available, topsoil scraping in high spots and accumulation in low spots is commonly observed. The better jungle regrowth near windrows of felled vegetation suggests that topsoil displacement can result in major yield reductions. For example, Lal et al. (1975)

in Nigeria observed that corn yields decreased by 50% when the top 2.5 cm of an Alfisol was removed. Similar data on Oxisols and Ultisols of the Amazon are not available.

Improved Mechanized Methods

The negative effects of bulldozer land clearing are becoming better known to farmers and development organizations. Government credits for large scale mechanized land clearing operations have been sharply reduced in the Brazilian Amazon since 1978. Other alternatives consist of mechanized clearing followed by burning, using two bulldozers dragging a heavy chain, or large tree crusher machines which literally walk over the felled forest (Toledo and Morales, 1979; Baena, 1985; Toledo and Navas, 1985). The most effective method however, is the use of shear blade, followed by burning and heavy disking. Unlike the straight bulldozer blades, the floating-type or shear blades, cut the trees at ground level, avoiding much topsoil carryover since no tree roots are dragged and the blade seldom touches the soil. A comparison between clearing by slash and burn, straight blade bulldozing by Alegre (1985) and shear blade bulldozing in Yurimaguas shows that the traditional manual method caused the least disruption in terms of water infiltration rates and topsoil bulk density, mean weight diameter of aggregates or organic carbon (Table 10). The shear blade treatment significantly decreased many of these properties three months after clearing, but these differences largely disappeared after two years of continuous cultivation. In terms of crop production, straight blade bulldozing decreased yields by about half, but the differences between slash and burn vs. shear blade + burn + heavy disking were minor (Table 11). The use of a shear blade, therefore, is recommended if mechanical clearing is to be practiced.

SOIL MANAGEMENT OPTIONS

Long-term research in Yurimaguas, Peru and other areas in the Amazon has led to the development of sustainable soil management options for the different soils, landscape positions and levels of infrastructure development. Sanchez and Benites (1983) suggested several alternatives for the Peruvian Amazon which can be made applicable to other countries with minimum modifications (Figure 1). Not all the soil-landscape combinations illustrated in this figure are likely to occur in any given area, but they indicate the range observed in the humid tropics.

Three types of alluvial positions are indicated in Figure 1. The "barriales" are beaches exposed during the dry season along the deposition shores of large Amazonian rivers. These soils are the youngest in the world, being formed and eroded away every year. The "bajial" and "restingas" are the first and second flood plains, respectively. They roughly correspond to the low and high "várzeas" of Brazil. The bajiales are likely to be flooded every year while the "restingas" may be flooded once every 10 years or so. Bajial soils are mainly Aquepts while restinga soils are Aquepts, Aqualfs, Udalfs or, in some cases, Udolls--all with high native fertility. An exception to this rule occurs when the source of sediments are other than the Andean mountains. Rivers originating in watersheds on the Guyanan or Brazilian shields, or around Spodosol areas within the Basin are not likely to produce alluvial soils of high native fertility (Hoag, unpublished data).

The upland areas, called "terrenos de altura" in Peru and "terra firme" in Brazil can be divided into high terraces, flat to gently undulating and suitable for mechanized agriculture, and the hills with slopes

of 15 to 30% which are not mechanizable. About 50% of the Amazon has well drained, flat topographies with less than 8% slopes, while 21% of the basin corresponds to the hill area (Cochrane and Sanchez, 1982). The steeplands constitute about 6% of the Amazon, but are quite important around the western end of the Amazon.

Irrigated Rice in Alluvial Soils

The Amazon has vast areas of poorly drained, high base status soils located in topographic positions that preclude annual flooding. These areas are commonly known as "várzeas altas" in Brazil and as "restingas" in Peru. Given the high native fertility of most of these Entisols, Inceptisols and Alfisols and their proximity to rivers, efforts have been made to develop intensive utilization of "restingas" for irrigated rice production. Irrigated rice is usually the best option because of the assured market and the yield stability under a paddy rice system. An example from Yurimaguas illustrates the point. Restingas with soils classified as clayey Eutric Haplaquepts are producing an average of 6 tons/ha of supplementary irrigated rice per crop, with 2.5 crops per year (Table 12). No fertilizer response has been observed during the first two crops, but nitrogen response to 50 kg N/ha is now evident from the third crop (Arévalo et al., 1983). Fortunately Azolla has spontaneously appeared in the paddies, and its management may contribute to decrease fertilizer inputs. Water management trials indicate the need of irrigation to obtain high rice yields. Rainfed rice production averaged 4.6 tons/ha while irrigated rice averaged 6.3 tons/ha (Arévalo et al., 1983).

Transplanting, however, poses major constraints to the limited labor supply of the Selva. Puddling and transplanting are convenient in order

to obtain adequate water leveling. After two crops, broadcasting pregerminated seed is as effective (Table 12).

This technology has been adapted rapidly by new settlers migrating into the Amazon from rice-producing areas in the coast of Peru. Approximately 25,000 hectares of new irrigated rice land has been put into production within the last three years in the Peruvian Amazon (INIPA, 1984).

Completely mechanized rice production has been established at the other end of the Amazon where 4,000 hectares of paddy rice are produced in "várzeas" off the Jarí river (Briscoe, 1983). In these areas, sulfur deficiency is as important as nitrogen deficiency (Wang et al., 1976).

Intensive Crop Rotations

A second option is to fully capitalize on the potential of flat, well drained acid soils which, as mentioned earlier, cover about half of the Amazon. For areas with sufficient road, market and credit infrastructure, the correction of nutrient deficiencies by fertilizers and liming and the use of mechanization is an attractive and usually highly lucrative option.

Promising results have been obtained by growing three crops a year in an upland rice-corn-soybeans or upland rice-peanuts-soybean rotations at Yurimaguas. These rotations are adapted to the rainfall pattern and keep the ground covered most of the year. Continuous monoculture of the same crops, however, has not produced sustained yields because of pathogen buildups (Valverde and Bandy, 1982).

Thirty consecutive crops have been harvested from the same field since it was cleared by slash-and-burn in October 1972 and cultivated to the rice-corn-soybean rotation in Yurimaguas. Without fertilization,

yields dropped to zero after the third consecutive crop. With complete fertilization, the long-term average of this rotation, which was replicated in three fields, is 7.8 tons of grain per hectare per year (Sanchez, Bandy, Villachica and Nicholaides, 1982).

Figure 2 shows the long-term yields of 88 harvests of these four crops with and without adequate fertilization during eight years. Upland rice, soybean, and peanut yields are excellent, but corn yields are moderate. Figure 2 also indicates a reasonable yield stability for the four crops. Continuous production, therefore, can be achieved in the Amazon with adequate fertilization. A similar experiment is ongoing in Oxisols of Manaus and is now in its eighth consecutive crop.

The term "adequate fertilization" was not arrived at lightly. It took about four years to gather conclusive data on the changes in soil properties that occurred after clearing and burning a 17-year old secondary forest and growing annual crops continuously. The nutrient dynamics have been monitored after each harvest since October 1972 and provided the key to continuous cultivation (Sanchez, Villachica and Bandy, 1983).

Table 13 presents lime and fertilizer recommendations developed during 12 years of research at Yurimaguas. Like all sound fertilizer recommendations, they are site-specific. Nevertheless, they are representative of the level of fertilizer input required for continuous crop production in Ultisols. These fertilizer levels do not differ substantially from those used to grow corn, soybeans, and peanuts in Ultisols of the southeastern United States. On-farm trials around Yurimaguas show that the system is economically viable under a wide range of crop and fertilizer prices, levels of capital and labor force composition (Hernández and

Coutu, 1981). The practical limitation in many areas, however, is a sufficient infrastructure to assure the flow of inputs and products.

Although it is commonly believed that cultivation degrades soils in the humid tropics, our results indicate that soil properties improve with continuous cultivation systems that combine intensive management with appropriate fertilization. After 20 consecutive crop harvests at Yurimaguas, Sanchez, Villachica and Bandy (1983) reported that the topsoil pH increased from a very acid 4.0 before clearing to a favorable level of 5.7. Organic matter content decreased by 27%, but most of this loss occurred during the first year. Exchangeable aluminum decreased from very high levels to minimal amounts; exchangeable calcium increased 20-fold (a consequence of lime applications), and exchangeable magnesium doubled. Exchangeable potassium did not increase despite the application of large quantities of potassium fertilizer, suggesting rapid utilization by crops and perhaps losses due to leaching. Effective CEC doubled as a consequence of the pH-dependent charge of kaolinite and iron oxides. Fertilization also increased available phosphorus from below the critical level of 15 ppm (Olsen method) to substantially above it. The same trend occurred with zinc and copper. Available manganese, however, decreased to levels approaching deficiency. Available iron remained considerably above the critical range of 20 to 40 ppm. On the whole, these changes indicate improvement in the topsoil's chemical properties.

There have been no unfavorable changes in the soil's physical properties thus far because of the protection three well-fertilized crops per year provide against the rains (Table 14). Although crop residues are left in the field until the experimental plots are tilled for the next

planting, the soil is exposed for up to 30 days before a full crop canopy is reestablished. Occasional runoff losses have been observed, but they have not been of sufficient magnitude to affect yields.

Yurimaguas is not the only location in the Amazon where continuous cultivation has improved topsoil, chemical and physical properties. An analysis of continuously cultivated farms in the Bragança region of North-eastern Pará in Brazil by Falesi, Baena and Dutra (1982) showed similar positive results.

Acid, infertile subsoils of Oxisols and Ultisols frequently act as chemical barriers to root development. Crop roots are unable to enter a subsoil highly saturated with aluminum ions and very low in exchangeable calcium (North Carolina State University, 1980; Ritchey et al., 1980). This produces shallow root systems (the subsoil may still have plenty of water, but the plants cannot reach it). With time, however, continuous cultivation leads to an alleviation of this problem. We observed significant increases in calcium, magnesium, and effective CEC and a decrease in aluminum saturation in subsoil 15 to 45 cms (Figure 5). Fertilization promotes the downward movement of these basic cations, which results in a more favorable environment for root development than before clearing.

Attempting continuous cultivation without adequate fertilization, however, did result in soil degradation. The lack of a full crop canopy left the soil exposed for most of the year. Fertility was so limiting that even weed growth was suppressed. Although not measured, runoff losses from these plots must be considerable as the soil surface appears more sandy and is highly compacted.

Intensive continuous cropping has also been practiced on fertile alluvial soils not subject to flooding with success by farmers. The higher native fertility and higher ECEC of these soils precludes the need to lime and result in lower rates of fertilizers required. Weed control, however, becomes more critical in these better soils.

Low Input Cropping

Intensive, fertilizer-based continuous cropping is likely to be limited to humid tropical areas with relatively good access to inputs and markets. Research on a second option was initiated to develop alternatives that would minimize chemical input use according to low input technology concepts (Sanchez and Salinas, 1981). This option is based on three main strategies, the use of crop varieties tolerant to acid soil stresses maximum crop residue return to the soil, and the use of managed fallows as an intermediate alternative between continuous and shifting cultivation.

Germplasm collected from various institutions, believed to have high yield potential under humid tropical conditions, was tested in limed and non-limed plots in Yurimaguas at aluminum saturation levels of about 20 and 80%, respectively. Germplasm was considered highly tolerant if its yields in acid soils were 85% or more of those obtained in the limed plots, and moderately tolerant if the relative yields were between 65 and 85% (Nicholaides and Piha, 1985). The overall results, shown in Table 15, indicate a high degree of acid tolerance in upland rice and cowpea, an absence of acid tolerance in the corn, soybean and winged bean germplasm tested and evidence of moderate tolerance in peanuts and sweet potatoes. Some local peanut cultivars appear highly aluminum-tolerant in growth vigor, but not in yields.

The upland rice-cowpea rotation was selected as the basis for a low input cropping system. It is designed to mesh with the traditional shifting cultivation practices. After slash and burn, the traditional upland rice variety is sown with a planting stick ("tacarpo") at conventional spacing, using broadleaved post-emergence herbicides as conventionally done. Improvements are then introduced at the time farmers normally abandon the field, after the rice harvest. All the rice straw is cut low and spread evenly. The acid-tolerant improved rice variety "Africano Desconocido" is planted by a "tacarpo" at 30 x 50 cm spacing. It is then followed by acid-tolerant cowpeas (Vita 6 or Vita 7 from IITA) planted also with tacarpo. After threshing, all rice straw and cowpea tops are spread evenly to the field, in spite of the extra labor involved. The results of a one-hectare field cleared of a 10-year old secondary forest on an Ultisol with pH 4.6 after burning are shown in Table 16 (Benites and Nureña, 1985). The field included a fertilizer differential, either zero or 30 kg N/ha, 50 kg P_2O_5 /ha and 60 kg K_2O /ha applied to each rice crop except the first one. The results show high yields of six consecutive crops harvested, without a significant fertilizer response. Such results are quite different to the check plot yields of the intensive rotations, where yields drop to practically zero after the second consecutive crop without fertilization (Figure 2). The combination of acid-tolerant cultivars, no tillage and complete residue return may be responsible for the difference.

There is no assurance that these yields will be sustainable and in fact, a yield decline in the sixth crop is apparent. After about two years, the stumps have rotted out, providing several alternative uses.

One is to shift to intensive, mechanized continuous cropping. Others include established pastures, agroforestry or managed fallows. The low input cropping system, therefore, may be considered as transition technology at this point.

Managed fallows provide another alternative, giving farmers a safe way to rest the soil without major weed encroachment. Research with kudzu (Pueraria phaseoloides) fallows at Yurimaguas show some advantages as well as limitations. Kudzu grows luxuriously in the Amazon and, contrary to temperate-region experience, it is relatively easy to eliminate by cutting and burning it during the drier part of the year. Alternating one year of cropping with one year of kudzu fallow has produced respectable yields, while providing total soil protection during the fallow period. Crop yields however, are declining with time (Table 17) and the decline seems to be related to potassium deficiency.

The effect of kudzu fallows in pumping nutrients from Ultisol subsoils, however, has been of little relevance (Bandy and Sanchez, 1981). In these very acid and infertile subsoils, no significant nutrient recycling occurred in contrast to areas with high base status subsoils. Nevertheless, cutting and burning two to three years' growth of kudzu fallow produced similar crop yields as cutting and burning a 25-year old secondary forest fallow. Additional advantages of kudzu fallows include the maintenance of the residual effects of previous liming and fertilization, and its grazing potential as a "protein-bank" combined with adjacent grass pastures. Also, kudzu fallows provide virtually total protection against erosion.

Pastures

Pasture-based beef and dairy production is the largest single activity of cleared land in the Amazon basin, and a major source of controversy, particularly in Brazil. There are about 3.7 million hectares of cultivated pastures in the Amazon, according to estimates by Serrão et al. (1979). Most of them consist of Panicum maximum, without legumes or fertilization, and have a carrying capacity of one animal unit/ha, producing about 100 kg/ha of annual liveweight gain. After the first three to four years, pasture productivity begins to decline, secondary growth invades and the pasture slowly changes into secondary forest fallow. Serrão et al. (1979) estimate that 20% of the area planted to pastures in the Brazilian Amazon is in some state of degradation. This has raised serious questions as to the value of this important farming system in the Amazon (Goodland and Irwin, 1975; Schubart, 1977). The Brazilian government has reduced credits for new land clearing for pasture and is concentrating its research efforts to reclaim degraded pastures.

A series of studies conducted primarily in the ustic Eastern Amazonia has shed light on the soil dynamics through time in pasture production (Falesi, 1976; Baena, 1977; Serrão et al., 1979; Fearnside, 1978; Hecht, 1983). Soil samples were taken in pastures of known age in several farms. Although the sample size is small, time and space are confounded and variability is high, a clear trend has emerged from these studies: Pastures retard the rate of fertility decline, maintaining for several years some of the benefits of burning, particularly a high soil pH, elimination of aluminum toxicity, high calcium and magnesium and, for the first four to five years, sufficient levels of available phosphorus. Serrão et al.

(1979) attribute this decline to nitrogen and phosphorus deficiency, and the poor adaptation of Panicum maximum to this environment.

Figure 5 summarizes the data for a clayey Oxisols from Paragominas and a loamy Oxisol from Northern Mato Grosso. The data suggest a remarkable degree of nutrient recycling and maintenance of soil fertility under pastures in the eastern Amazon. Observations on animal productivity indicate that its decline is associated with available phosphorus levels decreasing below 4 ppm P. Serrão et al. (1979) state that the speed of this decline is faster in clayey than in loamy soils. Since phosphorus fixation in Oxisols and Ultisols usually increases as a function of topsoil clay and iron oxide contents (Sanchez and Uehara, 1980), it is not surprising that the clayey Oxisols show pasture degradation symptoms earlier than the loamy ones. Since Panicum maximum responds very strongly to phosphorus fertilization, it is also not surprising that it tends to disappear and is overtaken by jungle regrowth. Serrão and coworkers found that excessively high grazing pressures also accelerate pasture degradation. A look at Figure 5 suggests that these pastures are periodically burned as the sharp increases in bases and available phosphorus are evident.

The solution to this apparently hopeless situation is remarkably simple: Clear the jungle regrowth ("juquira") by hand, burn the pastures, and broadcast 25 kg P/ha, half as single superphosphate and half as rock phosphate and plant aluminum-tolerant species such as Brachiaria humidicola and Pueraria phaseoloides. When Serrão and coworkers (1979) did that in a 13-year old degraded pasture at Paragominas, the pasture recuperated with increases in carrying capacity (Serrão, 1981; Serrão and Homma, 1982).

In the udic Amazon of Peru, considerable advances have been made in developing legume-based pastures to replace the degraded "torourco" complex (Paspallum conjugatum and Axonopus compressus) which rapidly becomes dominant once planted Panicum maximum disappears (Toledo and Morales, 1979; Ara *et al.*, 1982). A wide range of grass and legume accessions from CIAT's Tropical Pastures Program has been tested at Yurimaguas, Pucallpa, Tarapoto, Tingo María, Puerto Maldonado and other locations of the Peruvian Amazon (Reátegui, 1984). The various accessions were planted at Yurimaguas on Ultisols with pH 4.0 and 90% aluminum saturation and received only 50 kg P_2O_5 /ha and 50 kg K_2O /ha. Four grass species and five legume species have been identified as promising for the Peruvian Amazon (Table 18). They all combine growth and persistence under acid soil stress with reasonable tolerance to insects and diseases.

Some of these species were combined in 0.45 ha. grazing plots, on land previously cropped at the Yurimaguas station. Unlike temperate region experience, the legumes established themselves quickly but the grasses suffered from poor establishment, partly because of excessive tillage and partly because of vigorous weed competition. During the first year, continuous grazing was used at an average stocking rate of 4 animals/ha. This resulted in modest liveweight gains and in some mixtures as excessively high proportion of legumes. Grazing management was changed to rotational grazing at 42-day intervals during the second year. The first three years of grazing produced relatively modest animal weight gains but very high annual liveweight gains per hectare due to the high stocking rate (Table 19). More time is needed to ascertain the persistence and productivity of these grass-legume mixtures, as well as learning how

to manage them in a rainforest environment. Nevertheless, the productivity of 200 to 700 kg/ha/year of liveweight gains underscores a significant potential for legume-based pastures in the region, considering that annual liveweight gains on degrading pastures is on the order of 50-100 kg/ha/year.

The maintenance of grass-legume pastures in the humid tropics is not fully understood. Annual maintenance fertilizer applications of about 25 kg/ha of phosphorus, potassium and possibly some quantities of magnesium and sulfur are probably needed. Grazing management is of utmost importance to maintain an acceptable grass-legume balance. Most of our understanding of grass-legume mixtures in the tropics comes from ustic soil moisture regimes where the main objective is to maintain a supply of green forage during the strong dry season. This is mainly accomplished by the legume component which remains green while the grasses mature and dry out. In the humid tropics, grasses remain green throughout the year, posing a question of what is the role of legumes under this environment. Many of these grasses have lower nutritional quality than expected from savanna experience. Research is underway to provide a better understanding of pasture quality, the role of legumes, nitrogen transfer and nutrient recycling.

Perennial Crops and Agroforestry

Many scientists believe that the "natural vocation" of the Amazon is trees and that ultimately a tree canopy should replace crop or pasture canopies. Experience in the Amazon on soil-perennial crop relationships lags far behind that of humid tropical Asia. Most of the research knowledge is based on cacao plantations in Alfisols of the State of Bahia, Brazil (Alvim, 1979, 1982; Cabala and Alvim, 1984), although successful coffee

and oil palm plantations exist in the humid tropics of Colombia, Ecuador, Peru, Brazil and Costa Rica. Knowledge and appreciation of the myriad of agroforestry systems practiced by native tribes and settlers in the humid tropics is increasingly becoming available (Peck, 1982; Hecht, 1982; Valencia, 1982; Denevan et al., 1983). Information on forestry species is also emerging (Russell, 1983; Romero and Romero, 1984).

Some advances have been made on how tree plantations affect soil properties in the humid tropics (Sanchez et al., 1985). A major difference in soil acidity and base status was observed between mature Gmelina arborea and Pinus caribaea plantations in the Jarí Ultisol (Figure 6). The topsoil under Gmelina had a pH of 5.2 while that under Pinus was about the same as under native rainforest, pH 3.9. The rise in pH under Gmelina is accompanied by an actual increase in exchangeable calcium reserves of 860 kg Ca/ha as compared with 40 kg Ca/ha in the forest and 100 kg Ca/ha for Pinus plot. Gmelina seemed to act as a calcium accumulator under acid soil conditions while Pinus maintained the rainforest level. Gmelina maintained exchangeable magnesium, exchangeable potassium and total nitrogen at pre-clearing levels, while the soil under Pinus suffered considerable decreases. Gmelina also tripled the available soil P contents compared with the original forest or Pinus.

Other fast-growing tree species have also produced increases in exchangeable bases. Silva's (1983) results on an Oxisol in Brazil indicated a doubling or tripling of topsoil exchangeable bases after 10 years under Cordia trichotonia and Caesalpinia echinata relative to the native forest, but the precious wood species Dalbergia nigra did not produce significant increases over the native forest. Silva's results are presented in Table 20.

Leaching losses under tree plantations are also being quantified. Russell (1983) measured negligible losses of phosphorus and measurable losses of potassium, calcium and magnesium at all sites, including the virgin rainforest (Table 21). Large leaching losses of bases occurred after the forest was cleared and burned, and prior to the establishment of tree cover. This explains in part the decreases in nutrient availability observed in some cases during the establishment phase. Leaching losses during the mature growth stage and even 1.5 years into the second rotation were actually lower than those under the rainforest. Consequently, the nutrient cycling mechanism seems to work effectively under Pinus caribaea.

Nutrient inputs from atmospheric deposition were also determined by Russell (1983). The balance between atmospheric deposition and leaching is presented in Table 22. This calculation shows a virtual absence of net nutrient losses from the rainforest, the mature Pinus caribaea plantation, and even from the 18-month old second rotation of pine preceded by Gmelina arborea.

The question of leaching in perennial crops has also been examined. Santana and Cabala (1984) developed a balance between nutrient inputs and outputs in a high-yielding, mature 17-year old cacao plantation with a leguminous tree shade on a fertile Alfisol in Itabuna, Bahia, Brazil (Table 23). The balance between inputs (atmospheric and litter) and outputs (harvest and leaching) is positive for nitrogen, phosphorus, potassium and calcium and neutral for magnesium. The efficiency of this system is outstanding considering it is operating at very high yield levels. When such plantations are fertilized, nitrogen leaching losses decrease; Santana and Cabala (1982) attribute this to a stimulating effect of NPK

fertilization on the development of cacao rootlets, which presumably absorb more nutrients and prevent them from leaching. The perspective of such efficient use of nutrients under ideal conditions in perennial crop production augurs well for the efficiency of well-managed, well-fertilized tree plantations.

The information on agroforestry systems per se is not in progress on alley cropping on acid soils, managed fallows, soil dynamics under natural fallows and the management of promising indigenous Amazonian palms such as Guilielma gasipaes.

Other Options

Additional options include the use of forest-agriculture mosaics, barrial farming (Sanchez and Benites, 1983), water buffalo production in várzeas (Nascimento et al., 1979), recuperation of degraded lands (Benites et al., 1984) and others.

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Table 1. Geographical distribution of soils of the humid tropics based on dominant soil in FAO maps at a scale of 1:5 million.

Soil Order and Suborders	Humid Tropical America ¹ /	Humid Tropical Africa ² /	Humid Tropical Asia and Pacific ³ /	World's Humid Tropics Total	%
----- million hectares -----					
Oxisols	332	179	14	525	35
Ultisols	213	69	131	413	28
Inceptisols:					
Aquepts	42	55	23	120	8
Andepts	2	1	9	12	1
Trobepts	17	19	58	94	6
Total	61	75	90	226	15
Entisols:					
Fluvents	6	10	34	50	3
Psamments	6	67	17	90	6
Lithic groups	19	14	39	72	5
Total	31	91	90	212	14
Alfisols	18	20	15	53	4
Histosols	4	4	23	31	2
Spodosols	10	3	6	19	1
Mollisols	--	--	7	7	-
Vertisols	1	2	2	5	-
Aridisols ⁴ /	3	1	1	5	-
TOTAL	673	444	379	1,496	100

¹From Sanchez and Cochrane (1980) plus recent adjustments.

²From FAO-UNESCO (1975) and Duda1 (1980).

³From FAO-UNESCO (1977, 1978). Includes 46 million has of the humid tropics of Australia and Pacific Islands.

⁴Saline soils only (Salorthids).

Table 2. Translation of soil taxonomy terminology used in the humid tropics into the other classification systems.

Soil Taxonomy	FAO Legend	1938 USDA System	French	Brazilian
Oxisols	Ferralsols	Latosols	Sols ferrallitiques, fortement désaturés, typiques ou humifères	Latossolos, Terra Roxa Legítima
Ultisols	Acrisols and Dystric Nitosols	Red Yellow Podzolics	Sols ferrallitiques, lessivés	Podzólico Vermelho-Amarelo
Inceptisols: Aquepts Andepts Tropepts	various Gleysols Andosols Cambisols	various Low humic gleys Andosols Brown Forest	Sols peu évolués Sols hydromorphes Andosols Sols brunifiés tropicaux	Solos com horizonte B Solos hidromórficos --- Solos com horizonte B, incipiente
Entisols: Fluvents Psamments	various Fluvisols Arenosols and Regosols	various Alluvials Regosols	Sols minéraux bruts Regosols	--- Regossolos, Areias Quartzisolas
Lithic groups	Lithosols	Lithosols	Sols lithiques	Litossolos
Alfisols	Luvisols, Eutric Nitosols, Planosols	Eutric Red Yellow Podzolics, Terra Roxa, Planosols	Sols ferrugineaux tropicaux lessivés	Podzólico Vermelho-Amarelo equivalente eutrófico, Terra Roxa Estruturada, Planossolos

Table 2 (Continued).

Soil Taxonomy	FAO Legend	1939 USDA System	French	Brazilian
Histosols	Histosols	Peats and bogs	Sols Organiques	Solos orgānicos
Spodosols	Podzols	Podzols	Podsols	Podzols
Mollisols	Rendzinas, Phaeozems	Rendzinas Chernozems		Brunizems
Vertisols	Vertisols	Grumusols	Vertisols	Grumusols
Aridisol (Saline)	Solonchaks	Solonchaks	Sols halomorphes	Solonchak

Table 3. General distribution of main kinds of soils in the humid tropics. Calculated from Table 4.1.

General Soil Grouping	Humid Tropical America	Humid Tropical Africa	Humid Tropical Asia and Pacific	World's Humid Tropics
	----- % -----			
1. Acid, low native fertility soils (Oxisols, Ultisols, Dystropepts).	81	56	38	63
2. Moderately fertile, well-drained soils (Alfisols, Vertisols, Mollisols, Andepts, Tropepts, Fluvents)	7	12	33	15
3. Poorly drained soils (Aquepts)	6	12	6	8
4. Very infertile sandy soils (Psammments, Spodosols)	2	16	6	7
5. Shallow soils (lithic Entisols)	3	3	10	5
6. Organic soils (Histosols)	1	1	6	2
Total	100	100	100	100

Table 4. Some representative profiles of soils of the Latin American Tropics. From Sanchez and Silva (1984).

Horizon	Clay	Silt	Sand	pH	Org. C	Exchangeable				ECEC	Al Sat.	Available Mod.				
						Al	Ca	Mg	K			P	Zn	Mn	Fe	Cu
cm	-----	%	-----	H ₂ O	%	-----	meq/100 g	-----	-----	-----	%	-----	ppm	-----	-----	-----
1. FLORENCIA, Colombia. Typic Tropudult, clayey, kaolinitic, isohyperthermic (FCC=Cak)																
0-16	37	16	47	4.8	2.0	3.60	0.95	0.80	0.23	5.58	64	14.5	4.3	290	-	1.7
16-85	52	18	30	4.7	0.5	7.76	0.22	0.43	0.03	8.44	92	2.0	4.3	26	-	1.1
85-173	49	21	30	4.9	0.2	6.50	0.10	0.47	0.08	7.15	91	2.0	4.0	48	-	1.2
173-208	28	31	41	4.9	0.1	7.00	0.10	0.41	0.13	7.64	92	-	-	-	-	-
208-228	20	24	56	4.5	0.1	6.80	0.20	0.56	0.11	7.67	89	-	-	-	-	-
2. NAPO, Ecuador. Orthoxic Tropudult, clayey, kaolinitic, isohyperthermic (FCC=Ca)																
0-13	51	38	11	4.7	1.0	0.30	2.06	0.50	2.15	5.01	5	1.6	3.1	26	111	4.6
13-25	61	30	9	4.3	0.6	1.97	0.20	0.09	0.64	2.90	68	0.7	3.9	31	82	4.0
25-40	64	27	8	4.0	0.5	2.07	0.20	0.06	0.18	2.51	82	0.0	3.8	26	44	3.1
40-60	71	23	6	4.2	0.2	2.27	0.22	0.17	0.04	2.70	84	0.0	5.4	13	21	2.5
60-120	50	41	9	4.1	0.1	1.80	0.26	0.19	0.13	2.38	76	0.0	3.4	10	17	1.9
3. YURIMAGUAS, Peru. Typic Paleudult, fine loamy, siliceous, isohyperthermic (FCC=Leak)																
0-10	6	21	73	4.4	1.7	1.29	1.13	0.60	0.28	3.30	39	9.5	1.7	8	934	1.3
10-30	13	21	66	4.4	0.5	3.31	0.29	0.14	0.08	3.82	87	2.5	0.9	2	544	1.0
30-50	16	24	61	4.6	0.4	3.87	0.29	0.22	0.07	4.45	87	4.1	0.8	1	494	1.3
50-70	16	22	62	4.5	0.3	4.26	0.29	0.16	0.07	4.78	89	1.6	1.1	0	309	0.7
70-100	22	21	56	4.4	0.4	4.80	0.29	0.13	0.14	5.36	90	0.0	2.0	0	83	1.5
100-150	23	19	57	4.3	0.1	6.15	0.16	0.05	0.09	6.45	95	0.0	2.6	0	23	0.7
4. IQUITOS, Peru. Typic Paleudult, clayey, kaolinitic, isohyperthermic (FCC = LCak)																
0-16	30	36	34	4.0	2.4	5.9	1.0	0.2	0.20	7.30	81					
16-35	40	30	30	4.5	1.0	6.7	0.4	0.1	0.08	7.28	92					
35-70	54	26	20	4.3	0.5	9.5	0.2	0.1	0.08	9.88	96					
70-100	54	26	20	4.5	0.3	11.6	0.2	0.1	0.06	11.96	97					
100-150	46	34	20	4.5	0.3	10.9	0.2	0.1	0.08	11.28	97					
150-240	28	20	52	4.7	0.2	5.4	0.2	0.1	0.08	5.78	93					

Table 4 (Continued).

Horizon	Clay	Silt	Sand	pH	Org. C	Exchangeable				ECEC	Al Sat.	Available Mod.					
						Al	Ca	Mg	K			P	Zn	Mn	Fe	Cu	
cm	-----	%	-----	H ₂ O	%	-----	meq/100 g			-----	%	-----	ppm				-----
5. PUCALLPA, Peru. Aquic Paleudult, clayey, mixed, isohyperthermic (FCC = LCga)																	
0-3	27	38	35	5.2	3.7	0.2	4.2	2.1	0.52	7.02	3	2	-	-	-	-	-
3-21	45	38	17	4.3	1.1	4.0	2.2	1.2	0.40	7.80	5	1	-	-	-	-	-
21-62	59	26	15	4.2	0.6	8.7	0.8	0.9	0.32	10.72	81	1	-	-	-	-	-
62+	57	22	21	4.1	0.3	11.6	0.4	0.7	0.24	12.94	90	1	-	-	-	-	-
6. TINGO MARIA, Peru. Fluventic Eutropept, fine loamy, mixed, isohyperthermic (Lk)																	
0-17	29	40	31	5.7	1.8	0.44	16.61	1.86	0.14	19.05	2	24	2.1	87	511	3.6	-
17-40	23	43	34	5.7	0.3	0.06	13.81	1.86	0.14	15.87	0	18	0.6	16	121	1.5	-
40-60	16	48	36	5.5	0.3	0.33	14.58	1.93	0.12	16.96	2	33	1.0	9	125	1.8	-
60-78	15	50	35	5.5	0.1	0.45	13.81	1.78	0.14	16.18	3	28	0.7	11	150	1.3	-
78-100	31	50	19	5.5	0.3	0.75	19.15	2.61	0.12	22.63	3	29	1.5	14	196	2.6	-
7. MANAUS, AM, Brasil Typic Acrorthox, clayey, kaolinitic, isohyperthermic (FCC = Ceaik)																	
0-8	76	9	15	4.6	3.0	1.1	1.7	0.3	0.19	3.29	33	2	-	-	-	-	-
8-22	80	8	12	4.4	0.9	1.1	0.2		0.09	1.39	79	1	-	-	-	-	-
22-50	84	8	8	4.3	0.7	1.2	0.2		0.07	1.47	82	1	-	-	-	-	-
50-125	88	5	7	4.6	0.3	1.0	0.1		0.04	1.14	88	1	-	-	-	-	-
125-265	89	6	5	4.9	0.2	0.2	0.1		0.11	0.31	65	-	-	-	-	-	-
8. BARROLANDIA, BA, Brasil. Typic Paleudult, fine loamy, siliceous, isohyperthermic (FCC = Leak)																	
0-10	10	13	77	4.7	1.3	0.7	0.8	1.3	0.07	2.87	24	-	-	-	-	-	-
10-23	16	14	70	4.7	1.0	0.9	0.0	0.6	0.06	1.56	58	-	-	-	-	-	-
23-49	23	14	63	4.8	0.5	1.0	0.0	0.6	0.04	1.64	61	-	-	-	-	-	-
49-79	34	14	52	4.6	0.3	1.1	0.0	0.3	0.03	1.43	77	-	-	-	-	-	-
79-150	49	8	43	4.8	0.3	1.0	0.0	0.6	0.02	1.62	62	-	-	-	-	-	-
150-175	49	11	40	4.8	0.3	1.0	0.0	0.5	0.02	1.52	66	-	-	-	-	-	-

Table 4 (Continued).

Horizon cm	Clay ----- % -----	Silt ----- % -----	Sand ----- % -----	pH	Org. C ----- % -----	Exchangeable ----- meq/100 g -----				ECEC ----- % -----	Al Sat. ----- % -----	Available Mod. ----- ppm -----				
						Al	Ca	Mg	K			P	Zn	Mn	Fe	Cu
9. PARAGOMINAS, PA, Brasil. Typic Acrorthox, clayey, kaolinitic, isohyperthermic (FCC=Cdhik)																
0-6	88	10	1	4.2	2.8	1.45	2.08	0.88	0.14	4.55	32	1	-	-	-	-
6-23	88	10	1	4.1	0.9	1.86	0.64	0.56	0.07	3.13	59	1	-	-	-	-
23-60	96	4	0	4.7	0.7	1.03	0.48	0.48	0.04	2.03	51	2	-	-	-	-
60-107	89	11	0	5.1	0.5	0.41	0.32	0.32	0.03	1.08	38	-	-	-	-	-
107-155	84	16	0	5.4	0.3	0.41	0.32	0.32	0.03	1.08	38	-	-	-	-	-
10. PORTO VELHO, RO, Brasil. Orthoxic Palehumult, clayey, kaolinitic, isohyperthermic (FCC=Ceak)																
0-5	54	17	29	4.5	3.1	2.2	0.6	0.20	3.00	73	2	-	-	-	-	-
5-20	63	12	25	4.2	1.3	1.4	0.1	0.08	1.58	93	1	-	-	-	-	-
20-40	68	11	21	4.4	1.0	1.1	0.1	0.05	1.25	88	1	-	-	-	-	-
40-60	70	11	19	4.7	0.7	1.0	0.1	0.04	1.14	88	tr.	-	-	-	-	-
60-80	79	11	20	4.3	0.8	0.3	0.2	0.07	0.57	53	1	-	-	-	-	-
11. OURO PRETO, RO, Brasil. Ultic Tropudalf, fine loamy, mixed, isohyperthermic (FCC=L)																
0-12	18	32	50	6.5	1.3	0	6.5	1.6	0.31	8.41	0	6	-	-	-	-
12-32	22	26	52	6.3	0.9	0	2.6	1.6	0.24	4.44	0	-	-	-	-	-
32-47	22	29	49	6.2	0.5	0	3.1	2.1	0.15	5.25	0	-	-	-	-	-
47-70	26	30	44	5.8	0.3	0	3.1	2.1	0.17	5.37	0	-	-	-	-	-
70-112	34	24	42	5.8	0.2	0	3.1	2.1	0.24	5.44	0	-	-	-	-	-
112-125	36	23	41	5.7	0.2	0	5.0	1.9	0.28	7.18	0	-	-	-	-	-
125-200	49	30	21	5.3	0.2	0	0.8	0.6	0.08	1.48	0	-	-	-	-	-
12. ALTAMIRA, PA, Brasil. Oxic Rhodic Paleustalf, very fine, kaolinitic, isohyperthermic (FCC=Cdik)																
0-20	48	18	34	5.9	1.5	0	5.59	1.20	0.16	6.95	0	-	-	-	-	-
20-40	57	19	24	5.8	1.1	0	4.40	0.62	0.06	5.00	0	-	-	-	-	-
40-60	69	12	19	6.0	0.6	0	2.62	0.58	0.04	3.24	0	-	-	-	-	-
60-80	62	22	16	5.9	0.5	0	2.30	0.82	0.04	3.16	0	-	-	-	-	-
80-100	71	14	15	6.1	0.4	0	2.18	1.06	0.04	3.28	0	-	-	-	-	-

Table 5. Mean organic matter contents of soils from tropical and temperate forests. Source: Sanchez, Gichuru and Katz (1982).

Parameter	Depth (cm)	Tropical Forests	Temperate Forests	Significance
% C	0-15	1.89	1.35	**
	0-50	1.14	0.56	***
	0-100	0.70	0.33	***
% N	0-15	0.182	0.082	*
	0-50	0.122	0.046	**
	0-100	0.086	0.030	***
C/N	0-15	11.3	17.6	*
	0-50	10.3	13.2	ns
	0-100	9.0	11.3	ns

*p = 5-10%; **p = 1-5%; ***p <1%.

Table 6. Proportion of ecosystem nutrient storage in biomass and soil compartments under native humid tropical forests.

Location	Soil	N	P	K ⁺	Ca ⁺⁺	Mg ⁺⁺⁺
		% of total in the soil				
Manaus, Brazil ^{1/}	Oxisol	73	69	11	0	8
Merida, Venezuela ^{2/}	Inceptisol	81	91	14	31	31
Carare, Colombia ^{3/}	Oxisol	71	85	28	5	21
Kade, Ghana ^{4/}	Alfisol	81	-	56	61	61

Sources: ^{1/}Fittkau and Klinge (1973); ^{2/}Fassbender (1977); ^{3/}De las Salas (1978); ^{4/}Greenland and Kowal (1960).

Table 7. Area distribution of soil constraints in humid tropical regions.
Calculated according to Sanchez, Buol and Couto (1982).

Soil Constraint	Tropical America	Tropical Africa	Tropical Asia	Humid Tropics
	----- % of region -----			
Low nutrient reserves	66	67	45	64
Aluminum toxicity	61	53	41	56
High P fixation	47	20	33	37
Acid, not Al toxic	11	22	33	18
Slopes steeper than 30%	18	5	33	17
Poor drainage	11	14	19	13
Low ECEC	8	20	5	11
Shallow depth	7	4	12	7
No major limitations	3	2	2	3
Shrink-swell	1	1	2	1
Allophane	1	-	2	1
Acid sulfate soils	-	1	3	1
Gravel	-	1	1	1
Salinity	-	-	2	-
Sodic soils	1	1	-	-
Total	100	100	100	100

Table 8. . Summary of main soil constraints in the Amazon under native vegetation.
(Based on Sanchez and Cochrane, 1982.)

Soil Constraint	Million Hectares	% of Amazon
Phosphorus deficiency	436	90
Aluminum toxicity	353	73
Drought stress	254	53
Loss potassium reserves	242	50
Poor drainage and flooding hazard	116	24
High phosphorus fixation	77	16
Low cation exchange capacity	64	13
High erodibility	39	8
No major limitations	32	7
Steep slopes (> 30%)	30	6
Laterite hazard if subsoil exposed	21	4

Also nitrogen, sulfur, magnesium and zinc deficiencies are very widespread.

Table 9. Nutrient levels in the ash from burning three types of vegetation at two locations in the Amazon.

Location and Soil	Vegetation	Ash Dry Weight	N	Ca	Mg	K	P	Zn	Cu	Fe	Mn	S	B
			kg/ha										
MANAUS, Brazil (Typic Acrorthox)	Primary forest	9.2	80	82	22	19	6	0.2	0.20	58	2.3	-	-
	Secondary forest (12 years old)	4.8	41	76	26	83	8	0.3	0.10	22	1.3	-	-
	Kudzu fallow (4 years old)	1.5	24	16	6	15	3	0.1	0.03	7	0.4	-	-
YURIMAGUAS, Peru (Typic Paleudult)	Secondary forest (25 years old)	12.1	127	174	42	131	17	0.5	0.24	4	11.1	24.2	0.3
	Secondary forest (17 years old)	4.0	67	75	16	38	6	0.5	0.30	8	7.3	-	-
	Kudzu fallow (4 years old)	1.2	6	18	15	77	17	0.7	0.07	3	2.3	2.5	0.1

Sources: Seubert et al. (1977), Smyth and Bastos (1984), Bandy and Sanchez (unpublished data).

Table 10. Effects of land clearing methods on topsoil physical properties and organic carbon on a continuously cropped Ultisol in Yurimaguas, Peru. Adopted from Alegre (1985).

Clearing Methods	Months after clearing	Infiltration rate	Bulk density	Mean	Organic C
				Weight diameter	
		mm/hr.	g/cc	mm	%
Before Clearing	0	324	1.16	0.48	1.04
Slash & burn	3	204	1.27	0.42	1.05
Straight blade	3	14	1.42	0.29	0.82
Sheer blade	3	22	1.28	0.36	0.87
Slash & burn	23	107	1.32	0.38	1.03
Straight blade	23	15	1.42	0.36	1.02
Shear blade & disk	23	110	1.32	0.36	0.89

Table 11. Effects of land clearing and post clearing management on the relative yield of five consecutive crops after clearing a 25 year old secondary fallow on an Ultisol of Yurimaguas, Peru. Source: Alegre (1985).

Clearing Method	No tillage No fertilizer	Tilled, fertilized
	---- % cumulative maximum yields*-----	
Slash and burn	27	93
Straight blade	7	47
Shear Blade	14	65
Shear Blade and burning and heavy disk	28	89

* Maximum yields of 5 consecutive crops in tons/ha: upland rice, 4.0; soybean, 2.3; corn, 5.2; upland rice 2.5, corn 3.3.

Table 12. Performance of flooded IR4-2 rice in different land preparation systems in an Eutric Haplaquept at a "restinga" in Yurimaguas, during the first 26 months after clearing.

Land preparation	Planting system	First crop	Second crop	Third crop	Fourth crop	Fifth crop	Mean per crop	Mean Annual Production
----- Grain Yields (ton/ha)-----								
Puddled:	Transplanted	7.9	5.2	7.1	6.0	6.8	6.6	15.2
	Broadcast*	3.2	4.9	6.4	4.8	6.7	5.2	12.0
Dry:	Transplanted	8.3	6.7	6.2	5.6	6.3	6.6	15.3
	Broadcast*	6.3	5.6	4.9	4.6	6.0	5.5	12.6

Source: Arevalo et al., 1983.

Table 13. Fertilizer requirements for continuous cultivation of annual rotations of rice, corn, and soybeans or rice, peanuts, and soybeans on an acid Ultisol in Yurimaguas. Source: Sanchez, Villachica, Bandy and Nicholaides (1982).

Input*	Rate	Frequency
Lime	3 tons/ha	Once every 3 years
Nitrogen	80 to 100 kg N/ha	Rice and corn only
Phosphorus	25 kg P/ha	Every crop
Potassium	80 to 100 kg K/ha	Every crop, split application
Magnesium	18 kg Mg/ha	Every crop (unless dolomitic lime is used)
Copper	1 kg/ Cu/ha	Once a year or once every 2 years
Zinc	1 kg Zn/ha	Once a year or once every 2 years
Boron	1 kg B/ha	Once a year
Molybdenum	20 g Mo/ha	Mixed with legume seeds only

* Calcium and sulfur requirements are satisfied by lime, simple superphosphate, and magnesium, copper and zinc carriers.

Table 14. Effects of completely fertilized continuous cropping on selected soil physical properties.

Years after cropping	Infiltration Rate	Bulk density (15 cm)
	(cm/hr)	(g/cc)
0 (1 month after clearing)	10.6	--
1 year	9.6	1.51
4 years	12.7	1.44
6 years	10.0	1.55

Adapted from Subert et al. 1977; NCSU 1980.

Table 15. Summary of varietal testing for acid tolerance at Yurimaguas

Species	Accessions tested	Very tolerant* (RY > 85%)	Tolerant (RY = 65-85%)	Sensitive (RY < 65%)
Rice	32	8	16	8
Cowpeas	30	22	7	11
Soybeans	22	0	0	22
Corn	20	0	0	20
Winged beans	16	0	0	16
Sweet potato	10	0	2	8
Peanuts	10	0	1	9

* Tolerance based on relative yield = $\frac{\text{Yields at 80\% Al satn.}}{\text{Yields at 20\% Al satn.}}$

Source: Nicholaides and Piha (1985).

Table 16. Productivity of a low input system after slash burning a 10-year old secondary forest in a Ultisol of Yurimaguas during the first 29 months (September 1982 - January 1985).

Crop Sequence	Planting date	No fertilizer or lime	Fertilized crops 2, 4, 6
cv.		-----Grain Yields (ton/ha)-----	
1. Rice cv. Carolino	Sept. 1982	2.44	2.44
2. Rice cv. Africano	Feb. 1983	2.99	3.11
3. Cowpea cv. Vita 7	Sept. 1983	1.09	1.24
4. Rice cv. Africano	Dec. 1983	2.77	3.22
5. Cowpea cv. Vita 7	May 1984	1.19	0.94
6. Rice cv. Africano	Sept. 1984	1.84	2.02
Total grain yield in 29 months		12.32	12.98

Source: Benites and Nureña (1985 and unpublished data).

Table 17. Performance of minimum input system with kudzu fallow rotation with no lime or fertilizer addition.

Year	Management	Corn Yields (1st crop after burn)	Rice Yields (2nd crop after burn)
----- tons/ha -----			
1977	Burn 20 yr. old secondary treat., plant	4.0	3.3
1978	First kudzu fallow	--	--
1979	Burn kudzu, plant	1.1	1.7
1980	Second kudzu fallow	--	--
1981	Burn kudzu, plant	0.7	1.5

Source: Bandy, unpublished.

Table 18. Promising pasture accessions for the Peruvian Amazon based on tolerance to acid stresses pathogens and adaptability.

Grasses	Legumes
<u>Andropogon gayanus</u> 621	<u>Desmodium ovalifolium</u> 350
<u>Brachiaria decumbens</u>	<u>Stylosanthes guianensis</u> 136,184
<u>Brachiaria humidicola</u>	<u>Centrosema hybrid</u> 438
<u>Brachiaria dictioneura</u>	<u>Pueraria phaseoloides</u>
	<u>Centrosema macrocarpon</u>

Table 19. Productivity of mixed pastures in Yurimaguas. Source: Reátegui et al., 1985.

Grass/legume associations	gr/animal/day			kg/ha/year		
	year			year		
	1	2	3	1	2	3
A. gayanus / C. pubescens	-	435	553	-	884	449
A. gayanus / S. guianensis	219	402	570	390	713	689
B. decumbens / D. ovalifolium	398	419	316	639	846	513
B. humidicola / D. ovalifolium	-	-	453	-	-	735

Table 20. Effects of 10-year growth of various timber species on topsoil (0-30 cm) properties of an Oxisol from Porto Seguro, Bahia, Brazil. Adapted from Silva (1983).

Plantation	% C	Ca	Mg	K
		(meq/100 g)		
Native rain forest	1.65	0.70	0.50	0.05
<u>Cordia trichotonia</u>	2.18	1.70	0.95	0.12
<u>Caesalpinia echinata</u>	1.40	1.75	1.00	0.13
<u>Dalbergia nigra</u>	1.92	0.95	0.60	0.07
LSD	0.23	0.90	0.35	0.03
.05				
CV (%)	12	35	25	23

Table 21. Annual leaching losses from different stages of tree plantations in a sandy Ultisol of Jarí, Pará, Brazil. Source: Russell (1983).

Site	P	K	Ca	Mg
	kg/ha			
Rainforest (virgin)	0.04	12.7	16.7	8.1
Rainforest, logged	0.08	37.1	39.1	16.1
Rainforest logged and burned	0.21	199.5	103.7	146.6
Pine I - 6 mos. old	0.16	89.9	89.4	74.7
Pine I - 10.5 years old	0.05	9.6	12.1	6.1
Pine II - 1.5 years after 8.5 years of Gmelina I	0.08	9.9	17.5	6.3

Table 22. Net annual gain or losses of nutrients to the ecosystem. Balancing atmospheric input with leaching losses in a sandy Ultisol of Jarí, Pará, Brazil. Source: Russell (1983).

Site	P	K	Ca	Mg
	kg/ha			
Rainforest	+0.10	-2	-0.3	-5
Rainforest logged	+0.06	-25	-22	-12
Rainforest logged and burned	-0.06	-181	-84	-137
Pine I - 6 mos. old	-0.02	-80	-73	-71
Pine I - 10.5 years old	+0.06	+1	-1	-3
Pine II - 1.5 years after 8.5 years of Gmelina I	+0.09	+1	+1	-3
Mean atmospheric input:	0.14	10	16	3

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Table 23. Nutrient inputs and outputs of a high-yielding 17-year old cacao plantation shaded by *Erythrina fusca* on a fertile Typic Tropudalf of Itabuna, Brazil (mean of 2 years).

	N	P	K	Ca	Mg
	kg/ha/yr				
<u>Inputs:</u>					
Rainfall	23	3	21	18	12
Litter	112	13	25	162	53
Total	135	16	46	180	65
<u>Outputs:</u>					
Harvest 1 ton/ha of wet beans + 1 ton/ha of pods	44	10	20	1	3
Leaching	68	0.5	2	38	63
Total	112	10	22	39	66
Balance	+23	+6	+24	+141	-1

Calculated from Santana and Cabala (1984).

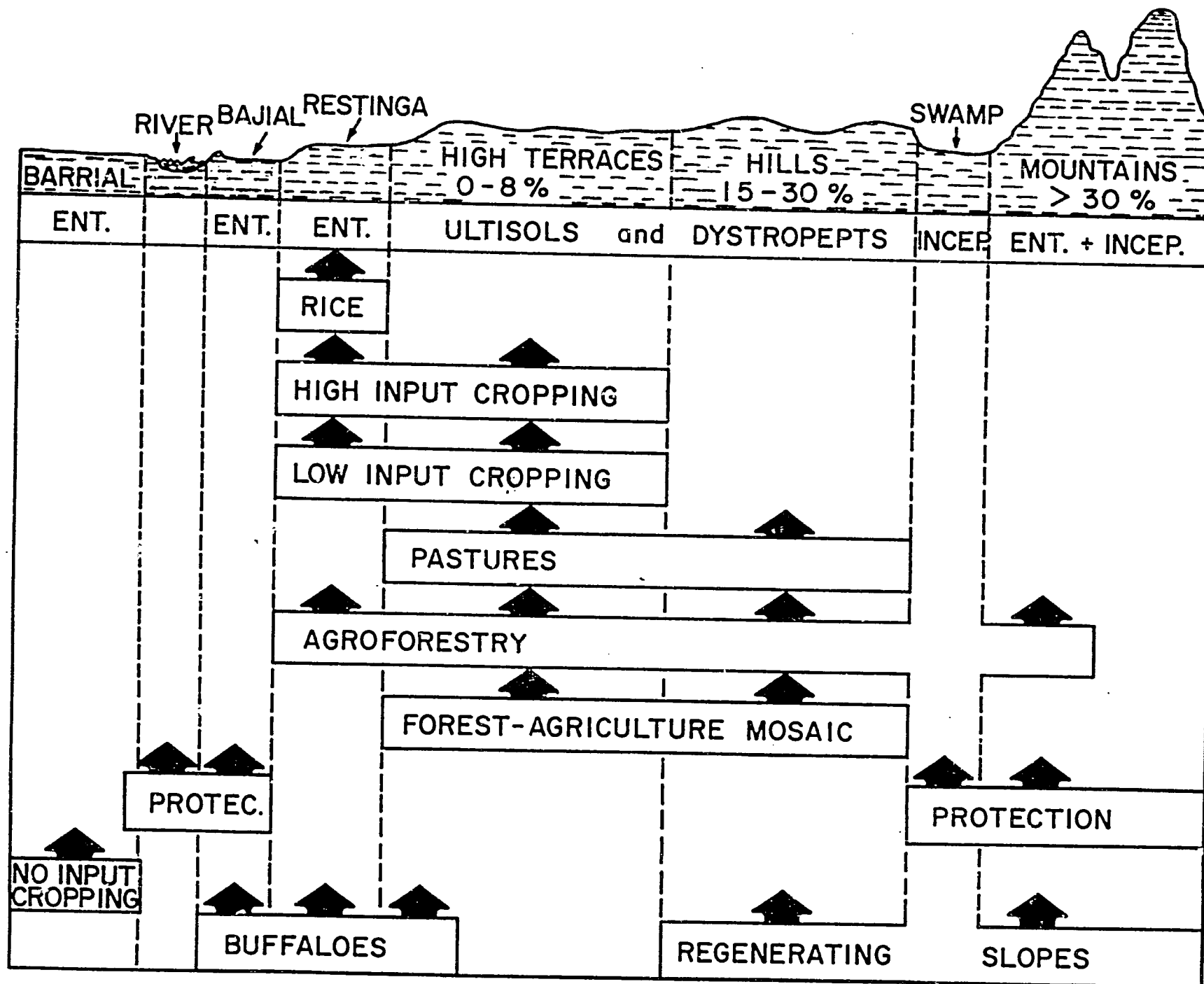


Figure 1. Soil management options for the Peruvian Amazon. Source: Sanchez and Benites (1983).

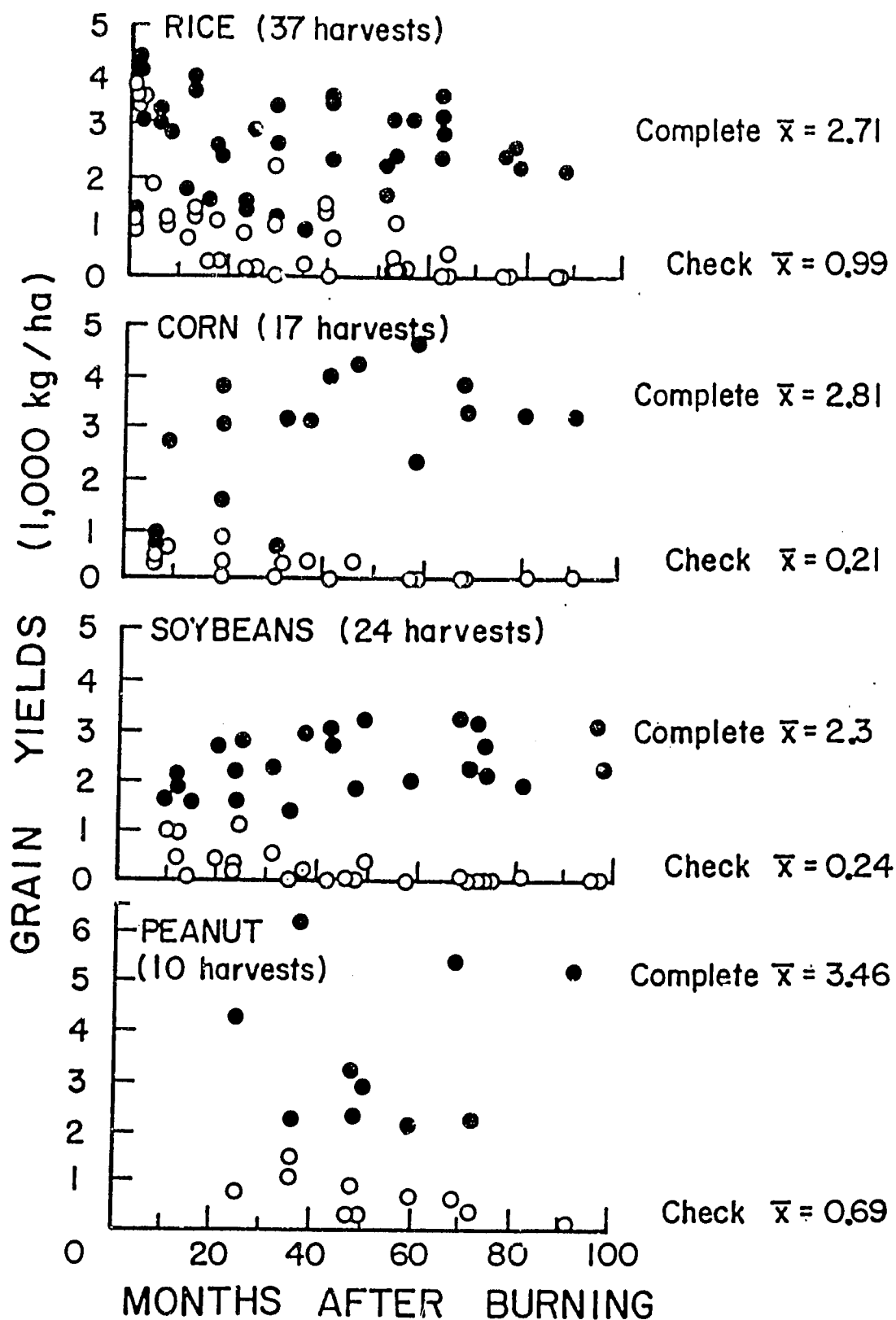


Figure 2. Crop yields as a function of time after clearing with (●) and without (○) complete fertilization. Each point is mean of four replications. Source: Sanchez, Villachica, Bandy and Nicholaides (1982).

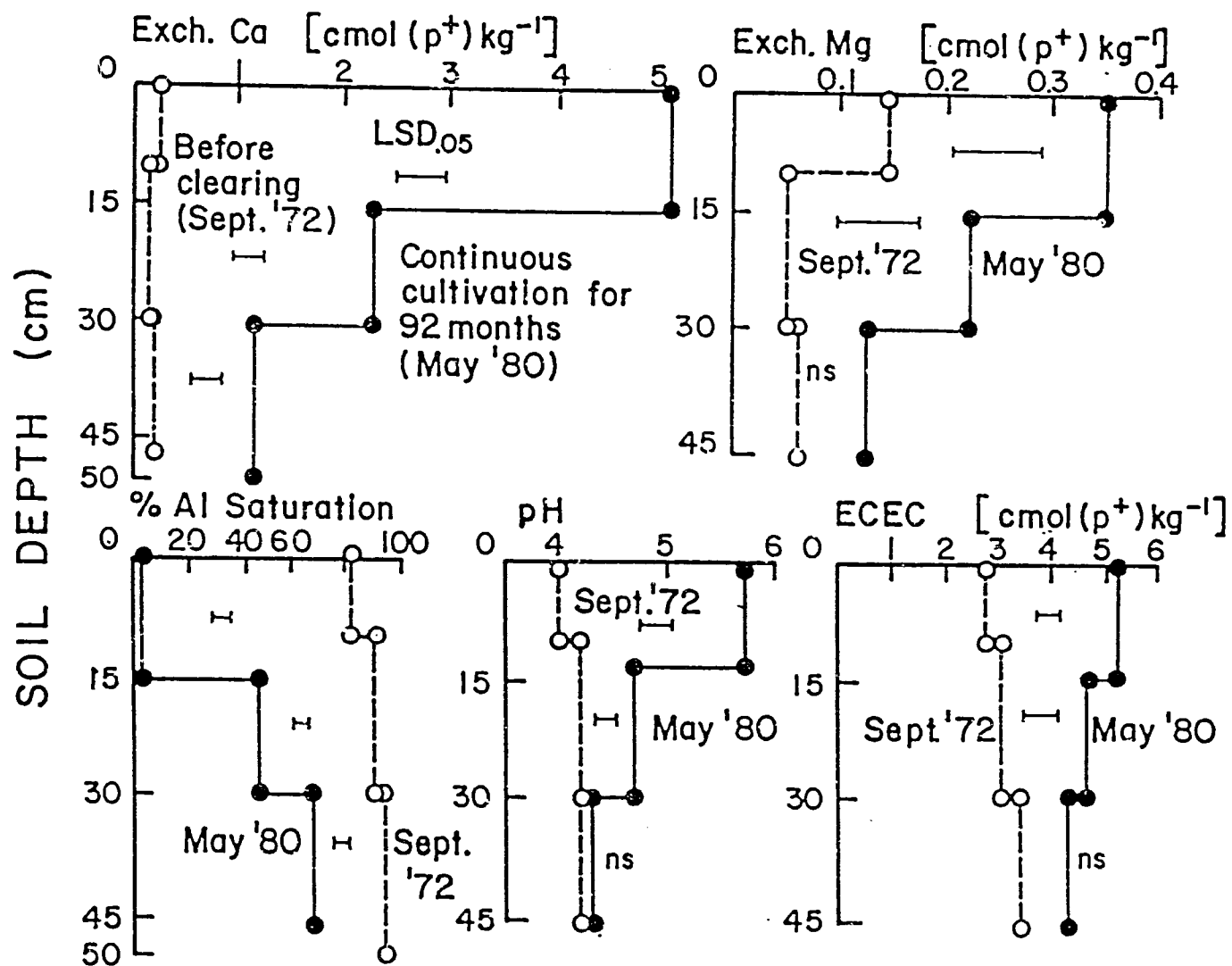


Figure 3. Improvement in subsoil chemical properties after 7½ years of continuous cultivation of a rice-corn-soybean rotation in an Ultisol of Yurimaguas, Peru. Source: Sanchez, Villachica, Bandy and Nicholaides (1982).

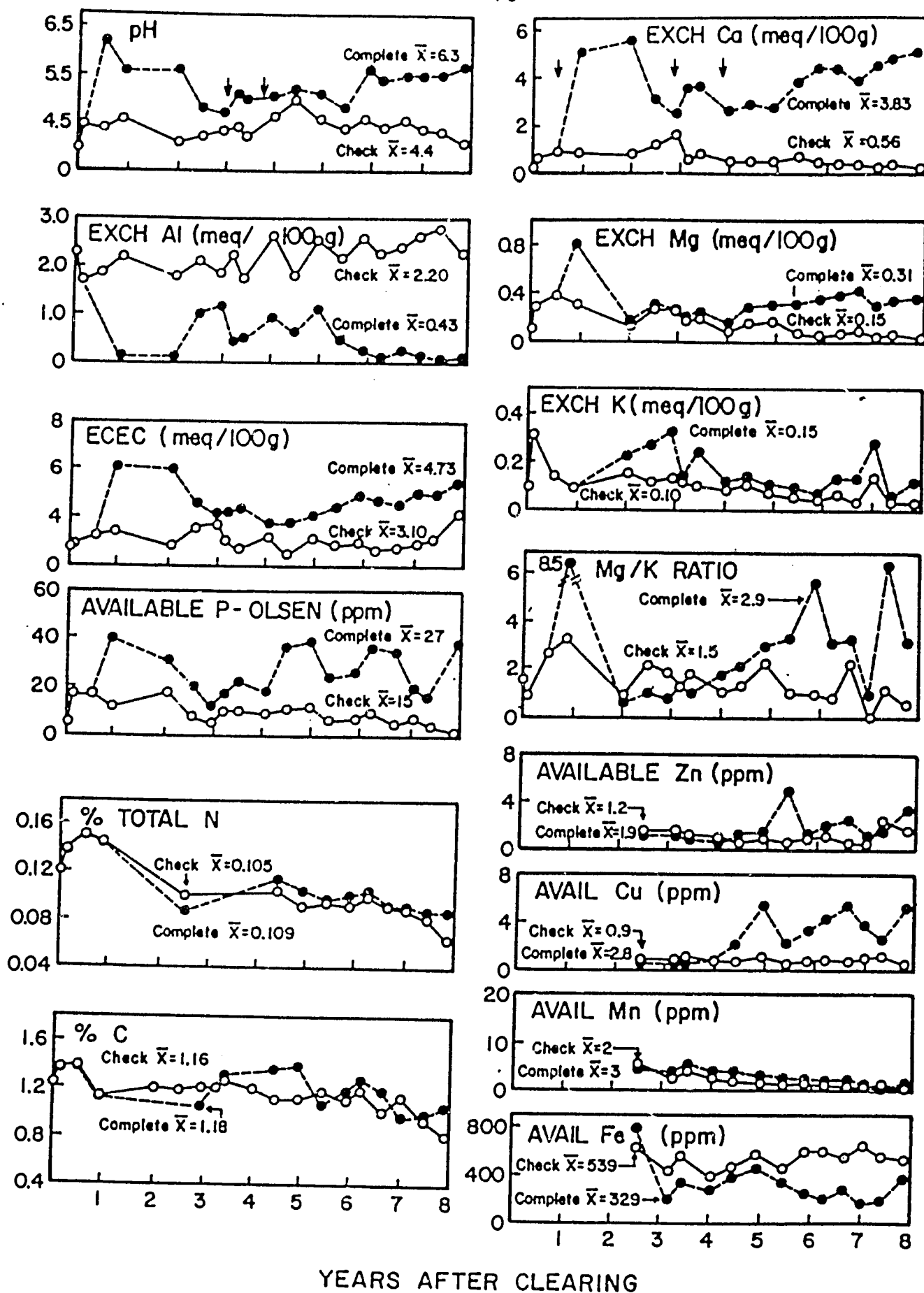


Figure 4. Topsoil fertility dynamics within eight years after clearing an Ultisol in Yurimaguas, Peru and grown to a three crop per year rotation without fertilization or liming (check, or with complete fertilization. Source: Sanchez, Villachica, and Bandy (1983).

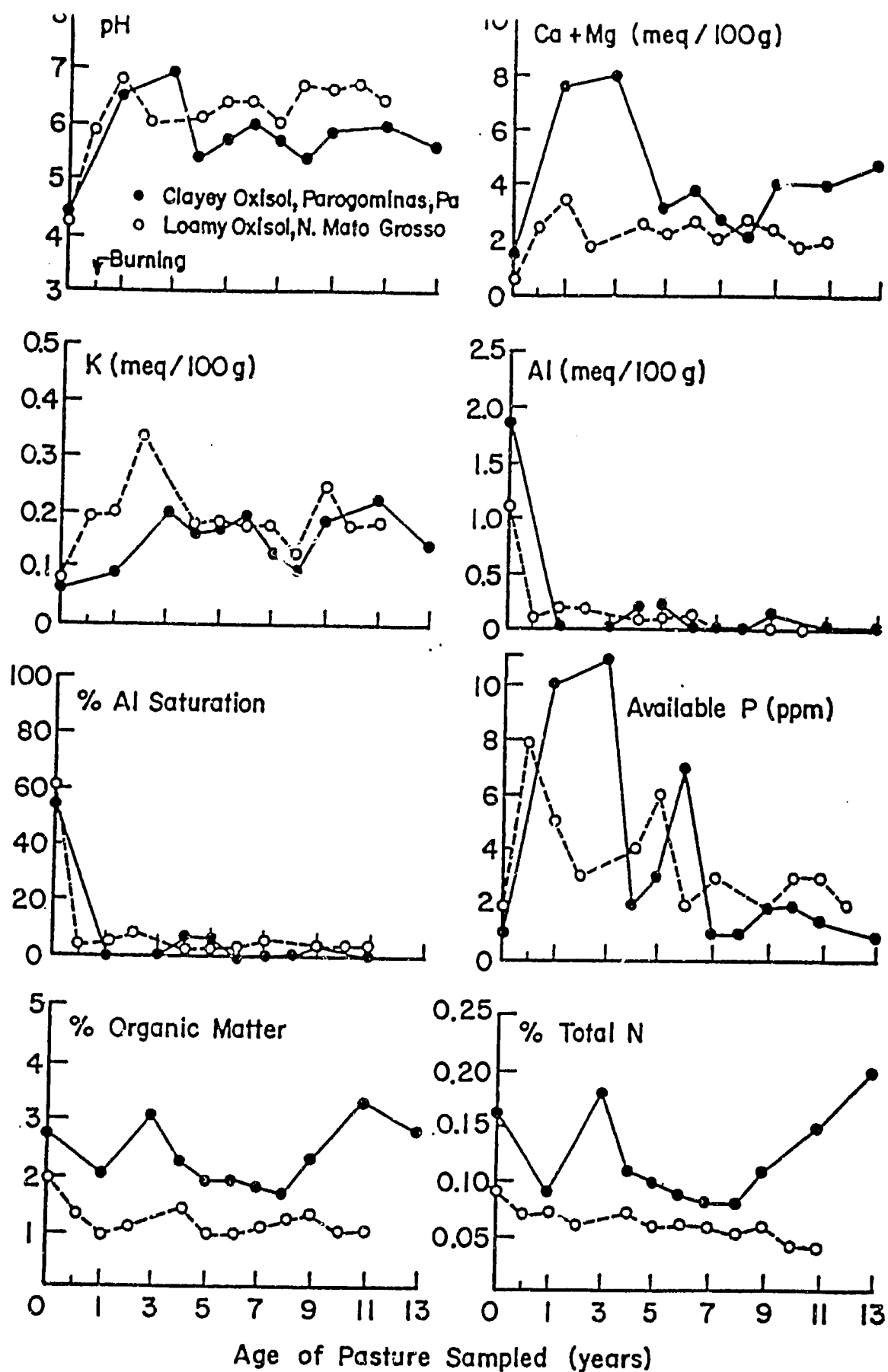


Figure 5. Changes in topsoil properties of *Panicum maximum* pastures of known age in eastern Amazonia (sampled at the same time). (Source: Adapted from Serrão *et al.*, 1979.)

JARÍ, BRAZIL - GMELINA AND PINE - ULTISOL

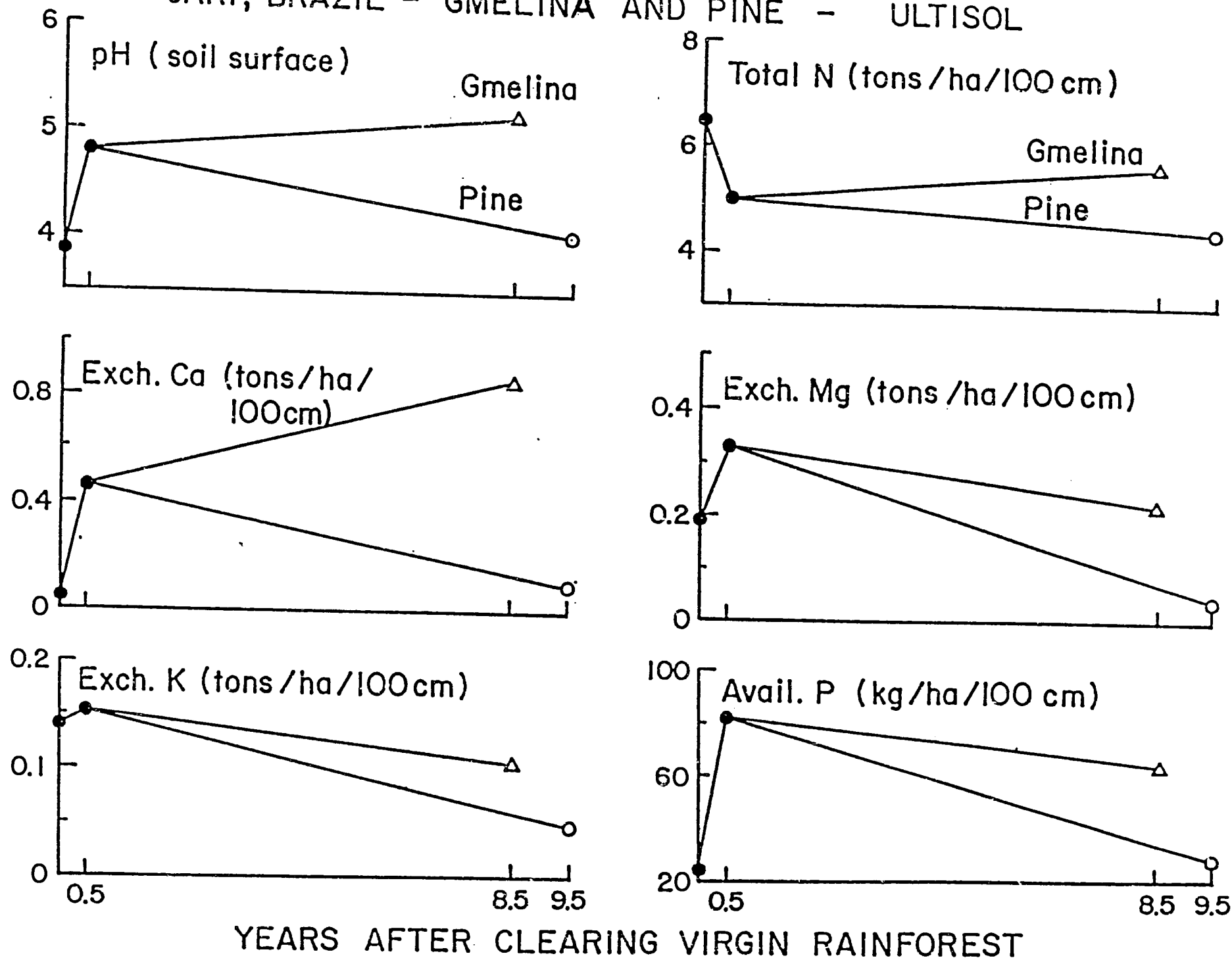


Figure 6. Effects of *Pinus caribaea* and *Gmelina arborea* plantings on surface soil pH and nutrient content of the top 1 m of a sandy Ultisol in Jarí, Brazil. Adapted from Russel (1983).