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DEFORESTATION IN THE AMAZON BASIN: MAGNITUDE, DYNAMICS
AND SOIL RESOURCE EFFECTS

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DEFORESTATION IN THE AMAZON BASIN:
MAGNITUDE, DYNAMICS AND SOIL RESOURCE EFFECTS

James Hecht

General Introduction

The Amazon Basin includes substantial areas of the national territories of Brazil, Colombia, Venezuela, Ecuador, Bolivia, Peru, Surinam, Guyana, and French Guiana. About 20% of the world's fresh water flows through the Basin. Important deposits of iron, aluminum, manganese, tin, copper, gold, uranium, and the world's largest timber reserves are found within the more than 5,000 km² of the Amazon drainage. It is also one of the least populated areas on the planet, and is the last real agricultural frontier.

The countries of the Amazon have varying physical, economic, and agricultural resources. These nations range from semi-industrialized countries like Brazil and Colombia, to those like Bolivia whose economy is almost completely based on agricultural and mineral exports. Several Amazon nations, like Venezuela, Ecuador and Peru are oil exporters. The diversity of these countries is reflected not only in their various economic bases, but in their extraordinarily complex cultural and historical experiences.

In spite of their differences, the Amazon countries share two basic problems. First, while they have been experiencing an increase in aggregate agricultural output, the production of basic foodstuffs has failed to keep pace with demand,

and virtually all Amazon countries are net food importers (World Bank 1980). Second, all Amazon nations have severe balance of payment deficits. Statistics on these problems are presented in Table 1.

All Amazon countries have developed agencies and programs (see Table 2) to relieve these two pressures, which originate outside the Basin itself. Amazonian regional development has thus been charged with a variety of goals: 1) to increase basic food production; 2) to expand exports; 3) to alleviate population and political pressure in non-Amazon regions of the countries; 4) to improve access to non-agricultural resources, such as timber, minerals, hydropower, etc; 5) to promote economic integration; 6) to secure national boundaries.

These programs have not been as successful in resolving the food production and international debt problems as expected, for two types of reasons. First, as many researchers in the region have noted, the policy goals and the means of their implementation are often contradictory (Smith 1976, Kleinpenning 1977, Schmink and Wood 1979, Bunker 1979, Schuurman 1979, Hebette and Acevedo-Marin 1977; 1979, Barbira-Scazzocchio 1980). Second, the programs failed to address to ecological economic, and political conditions in the region.

There are a variety of national pressures in the Amazon nations that have caused a diversity of actors to become involved in the Amazon development process. These groups include transnational corporations, traditional landed elites, industrial elites, land speculators, government sponsored colonists,

peasants and development agencies. The conflicting agendas of these groups have produced a highly charged situation, with bitter disagreements at the policy level, and violent conflict at the frontier.

All the Amazon countries have structural economic problems that are reflected in political tensions and inconsistent development strategies. All have high rates of population growth, inequitable distribution of resources and land, and high unemployment in both rural and urban areas. These structural difficulties are reflected in the crisis in food production caused by a decline in the access of small scale producers to land (Souza-Martins 1980, Schuurman 1979, Pompermeyer 1979 d'Arc 1980, Tavares 1978). Small producers are squeezed by changes in tenancy and other kinds of patron client relationships, which requires them to farm land that they do own more intensively, producing environmental degradation, and thus lower production. On the other hand, large estates are shifting to increasingly mechanized or low labor production of cash crops like sugar, soybeans, cattle, coffee and cacao for export, which is required by their nations balance of payment deficits and debt service costs.

All of these groups must operate in one of the most agronomically intractable environments, where agricultural expansion is hampered by serious technical and ecological difficulties. The agricultural systems that replace forest in the Amazon are often unstable. Land use instability

reflected in ephemeral, or low productivity, and land abandonment, thus has political, economic and social causes. The issues surrounding Amazonian deforestation therefore involve not just the proverbial environmental versus developer tradeoff^a, but questions about whether the nature of the development path itself is appropriate.

This paper reviews the magnitude of deforestation, outlines the major features of Amazonian ecosystems so that the environmental impact of the dominant land uses can be discussed. Factors affecting agricultural instability are also analysed. The paper focuses largely on the Brazilian Amazon, since that is the area with which the author is most familiar.

Space does not permit a treatment of the larger biological concerns associated with deforestation in the Amazon. This paper is mainly agronomic in focus. Readers interested in the conservation issues are referred to Goodland and Irwin 1975, Goodland 1980, Pires and Prance 1976, Myers 1980, Ayers and Best 1980, Salati et al. 1979, Schubart 1978, Gentry and Lopes -Parodi 1980, Schubart and Salati 1981.

Magnitude of Deforestation

How much of the Amazon forests have been replaced by other uses? This question has had a variety of responses ranging from 30% (Kerr cited by Cox 1978) 10% (Vega 1978)

to less than 1% (Lugo and Brown in press). The unreliability of much of the data base, definitional differences and the historical period encompassed all contribute to the confusing assertions about the rate and area cleared. Until relatively recently the inaccessibility of the area completed defied anything other than speculation about the magnitude of deforestation. The use of LANDSAT data has improved the situation enormously. In a very interesting study, Tardin, et al. (1977) presented useful results about clearing estimates and reality. In the Barra de Garças region of Mato Grosso, a major Amazonian ranching area, Tardin interviewed ranchers about how much land they thought they had cleared, and compared these with LANDSAT images. The tendency of the interviewees was to overestimate by about 25%. Some were as much as 68% off. LANDSAT data are not without their problems, especially given the high frequency of cloud cover in the Amazon, but it is certainly a vast improvement.

An important definitional question is whether secondary forested areas should be considered as forest or cleared area. Brown (1979) indicated that about 8% of the Basin is in secondary forests, presumably as a consequence of land abandonment following agriculture or cattle, yet the deforestation evaluations by Tardin, et al. (1979b) do not treat this question. Finally, LANDSAT imagery has only been in use during the 1970's and in many of the southern reaches of Amazonian forest, land clearing has been occurring for more than 20 years. Some Amazonian areas of Southern Goiás and

Mato Grosso were permanently converted from forest decades ago. These kinds of questions still remain to be publicly resolved, and are responsible for the diversity of clearing estimates.

The best data available for clearing in the Amazon are derived from LANDSAT photos, but only Brazil, at this time, has made the results easily available. This information, along with other estimates for the other Amazon countries, is presented in Table 3. It is emphasized that these are "ball park" numbers. As Table 3 suggests, the annual clearing rate in the Amazon at the close of the 1970's was over one million hectares per year. Published data from Colombia (Alarcon, et al. 1980) and Brazil (Tardin, et al. 1979) indicate that at least 14 million ha. have been cleared just in these two countries. The detailed data for the Brazilian Amazon is presented in Table 4, and shows that between 1976-1978 one million ha./year were cleared in the Brazilian Amazon alone. Tardin (1979b) has shown that in areas where clearing has been particularly pronounced, almost one third of the forest areas have been converted to other land uses, usually cattle ranching. It is ^{important to remember} emphasized that not all Amazonian countries ^{emphasize} ~~emphasize~~ Amazonian development to the same degree. Peru, Brazil, Ecuador, and Colombia have invested a great deal of political and financial effort toward Amazonian occupation. Venezuela at this time concentrates on more accessible areas of her territory (Benacchio 1981), but certainly has the capacity to convert

large areas quickly. Hamilton (1976) has shown that about one-third of Venezuela's forests were cleared for other land uses in 25 years. Bolivia's recent political crises argue against any major forays into the Amazon at this time.

Rates of deforestation are not linear, reflecting credit policies, subsidies, interest rates, colonization projects, peasant situations in other parts of the country, national and global investment patterns, and speculation. The environmental effects of the conversion of tropical forest to other land uses can only be understood in light of the Amazonian resource base, and the land uses that are implanted after forests are cleared.

The Amazonian Resource Base

Amazonian resources have been reviewed in several other volumes such as the RADAM volumes (1973-1978), Goodland and Irwin (1975), Skillings and Tcheyan (1980), and Hecht and Norez (1981). In this section Amazonian soils and forest resources are discussed in order to evaluate the effects of forest conversion.

Soils

A comprehensive analysis of Amazonian soil resources was recently prepared by Cochrane and Sanchez (1981) and this discussion relies heavily on these authors' results.

Table 5 shows the dominant soil types of the Amazon Basin, of which 75% fall into the relatively infertile Oxisol and Ultisol soil orders. Oxisols in general tend to

be soils of low fertility but with favorable physical properties. Amazonian Oxisols can be described for the most part as acid, P, K, Ca, and micronutrient deficient with often toxic levels of Al. Ultisols have similar chemical characteristics to Oxisols, but somewhat worse physical properties. Ultisols tend to be more vulnerable to erosions due to a sharp textural change between the sandy surface horizons and the clay horizons that underlie them.

Entisols, young soils with minimal horizon development, are the next most important soils, encompassing about 15% of the area. Most Amazonian Entisols are aquents or fluvents (alluvial soils), but some Entisols occur in the premontane regions or in zones of active erosion. Entisols strongly reflect the parent material from which they are formed. Many Amazonian alluvial soils receive annual additions of young Andean sediments, and these are among the richer soils of the Basin. Not all Entisols are fertile, however. Alluvial soils that occur in tributary watersheds draining the Guiana or Brazilian shield areas, or Blackwater regions develop on nutrient poor sediments. As a consequence, these soils are not particularly productive. Montane Entisols have good soil nutrient status, but their utility is limited by relief.

Alfisols account for about 4% of the Amazon soils. These are mature soils with good base supplying capacity. They are the most fertile upland soils (except for occasional pockets of Indian Black Earths) and are of great agronomic

importance where they occur. They are associated with basaltic extrusions in the southeastern part of the basin, and in many of the premontane areas in western Amazonia.

The other soil orders, as one can see from the table, account for only limited area and will not be discussed in this review.

Cochrane and Sanchez (1981) tabulated the major soil constraints in the Amazon and their results are presented in Table 6. As is clear from this data, P deficiency is of overwhelming importance, due to its widespread occurrence and correlation with productivity for pastures (Koster 1976, Serrão, et al. 1979), annual crops (Valverde and Bandy 1981) and tree crops (Alvim 1980). As more than 90% of Amazonian soils are deficient in this element, P management becomes critical for maintaining agricultural production.

According to the table, well over half the Amazon soils are low in K. K is a monovalent cation, usually stored in the vegetation in tropical ecosystems, that has very high rates of turnover and cycling (Golley, et al. 1976, Odum and Pigeon 1970, Herrera, et al. 1978). Low K tolerance is difficult to breed for in crop plants, and there is a limited array of techniques for compensating with low levels of K other than fertilization. Cochrane and Sanchez (1981) feel that K deficiencies are among the major agroeconomic constraints in the region.

About 87% of the soils in the Amazon have pHs lower than 5.3. These soils frequently have toxic levels of

aluminum saturation that can severely hamper crop production if Al tolerant cultivars are not used. Al levels in soils usually drop substantially after forests are burned, however. The large amounts of bases released from the biomass when forests are felled and burned effectively neutralizes much of the Al, at least temporarily.

Amazon soils as a group are also characterized by very low effective cation exchange capacities.^(C.E.C.) This means that the ability to hold nutrients once they are added to the soil is relatively low. The low ~~X~~CEC and high rainfall of the Amazon increases the likelihood of leaching cations such as K, Ca and Mg, and also increases the probability of nutrient imbalances.

The use of some Amazon soils is hindered by their physical attributes. About 23% of the Amazon soils are waterlogged for part of the year. Large areas of the Amazon also have pronounced dry seasons, resulting in soil moisture deficits. Relief and soil erodability mean that about 29% of the Amazon Basin is limited for agriculture by erosion hazards (Cochrane and Sanchez 1981). While laterite has often captured the media, the bulk of Amazonian Laterite is fossil, and is treated agronomically in the same manner as gravel. Only about 4% of the basin has laterite configurations, and most of these are fossil (Cochrane and Sanchez 1981).

Many of the constraints in Table 6 occur simultaneously. Only about 6% of the Amazon Basin shows no major

fertility constraints for agriculture (Cochrane and Sanchez 1981).

Management of the soil resources in the Amazon is exceptionally difficult, in spite of the well-known bumper crops that occur the first years after clearing. Continuous agriculture without inputs or a fallow cycle has led to serious productivity declines for all types and scales of agriculture in the Amazon. These yield declines are exacerbated not only by soil fertility changes, but also by pest invasion, and poor cultivar adaptation.

Soil dynamics are critical in the success or failure of various kinds of agriculture in the basin, but the biotic interactions between forest and soil, as well as the diversity of forest types can strongly influence the viability of the agricultural systems that follow forest.

Forest Resources

Amazon forests are among the most ecologically complex and least understood vegetation formations on the planet. Amazonia encompasses the largest reserve of tropical moist as well as seasonal forest (UNESCO 1978). The number of plant species contained in the Amazon is thought to lie between 250,000 and one million (Lovejoy and Schubart 1980). The extraordinary richness of Amazon forests has masked the low fertility of the soils on which they generally occur. The combination of biological exuberance and impoverished soils has made the development and occupation

of these regions fraught with difficulties.

At the broadest level, Amazonian forests are generally classified into floodplain (varzea) and upland (terra firme) forests. However, Amazonian vegetation is far more complex than just these as Table _ indicates. Vegetation and forest surveys have been carried out in the Amazon by FAO (Food and Agricultural Organization of the UN), IBDF ^{ONFRA (Oficina Nacional de Evaluación de Recursos Naturales)} (Brazilian Institute for Forestry Development), and RADAM ^{Inst. Geografico de Agustín Codazzi} (Radar Imagery of the Amazon), but detailed information on ^{Programa de Regiones} Amazonian forest dynamics remains spotty. Figure 1 gives some idea of the variability in terms of volume of marketable wood of several areas in the Amazon. This kind of information helps illustrate the fact that while 85% of the Amazon is covered by high biomass species rich forests (Prance 1978), these are more usefully perceived as mosaics of relatively analogous structure rather than a species diverse, but essentially uniform formation. Pest potential after conversion, resilience, and conservation value are also highly variable. The distribution of forest types in the Amazon is correlated with a complex of climatic edaphic and phytohistorical factors, the interrelationships of which are by no means clear.

Changes in biomass, species composition and to an extent morphology often correlate with climate. Cochrane and Sanchez (1981) have used the presence of a pronounced dry season to differentiate the moist forest of western Amazonia from the semi-deciduous forests of the eastern Basin.

Heinsdjick (1960), Glerum and Smith (1962) and Sombroek (1966) all report changes in species composition and biomass with climate.

Edaphic factors can also affect the variety of forest types. The classic example is the association of "Campina" (a scrub vegetation) with sandy, extremely impoverished tropical podzols (Klinge 1967, Anderson, et al. 1975). In less extreme situations, the relationship between soils and vegetation is unclear due to the lack of precise data on soil properties and plant distribution (Sombroek 1966). Of interest to agriculture is the recognition by local shifting cultivators of indicator species for Alfisols and Indian¹ Black Earth soils (Sombroek 1966, Moran 1977).

The existence of high biomass, ecologically complex forests on depauperate soils is primarily a function of nutrient cycling. Amazonian forest cycling pathways are reviewed elsewhere (Herrera 1978, Stark and Jordan 1979, Klinge 1973) but consist of structural, physiological and symbiont associations that recirculate and sequester nutrients in biomass and litter. Table 6 shows the relative amounts of nutrients stored in several different tropical forest systems. As is clear, most of the Ca, Mg and K are held in the living plants.

Soil Dynamics After Conversion

When forest lands are converted to other uses, the nutrients held in the biomass are largely shifted into soil

nutrient storage, crop and weed tissues, or are lost through leaching, erosion and exports of the products away from the site. Since high biomass forest systems (as much as 500 tons/ha.) are replaced by agroecosystems with biomass usually less than 20 tons/ha. one of the major questions in conversion concerns the fate of the nutrients when forests are cut and burned. First, as Silva (1979) has indicated, only about 20% of the forest is effectively burned, and even this value is variable. Leaves, small trunks and branches combust, but the larger tree boles are ^{often} gathered together and burned again (coivara) or simply left to rot. This means that it is possible to have a delayed release of nutrients as decomposition proceeds, and suggests that in many cases the soil nutrient increases (and later declines) may not necessarily be dramatic. In general, after cutting and burning, soil levels of organic carbon and nitrogen and possibly sulphur drop as a consequence of volatilization. Soil pH increases due to the addition of large amounts of Ca, K, Mg, and lesser amounts of P released from the forest with burning. The liming effect of the base rich ash serves to reduce much of the aluminum saturation common in Amazonian soils. P levels initially increase as a result of soil heating, ash additions, and with large pH increases, from "fixed" P in aluminum and iron sesquioxides. These changes reverse themselves with time. The rates and magnitude of change are affected by numerous factors including initial forest composition, clearing techniques, and land use

following conversion.

Tropical species, like those in the temperate zone, accumulate chemical elements differentially, both in the secondary and climax communities. Silva (1979) analyzed the ash from several known species in the Atlantic Rainforests of Bahia, and found a range in composition from .18 to 4.27 for Ca, .17 to 21.03 for Mg, 38.37 to 345.5 ppm for K and from .44 to 13.39 for P in the 25 species he examined. Differences in nutrient contents for Amazonian pasture weeds have also been documented by Hecht (1979). Kang (1977) has studied the influence of forest species on soil properties after clearing in Nigeria, but the effect of forest composition on soils after burning in the Amazon remains a fascinating research question.

Clearing Techniques

Land clearing methods in the Amazon involve manual techniques (men, chainsaws and axes) and various mechanical means including bulldozers, tree crushers, and D8 tractors with 24,000 kg. chains slung between them. In manual clearing a rancher acquires a labor force of several hundred men through a labor contractor (locally known as "Gatos"--cats) who usually obtains the workers from the destitute of the numerous boom towns in the region that are the temporary homes of the landless in the step wise migration to the larger cities (Hebette and Acevedo-Marin 1977, Pompermeyer 1979, Souza-Martins 1980). Mechanical clearing has gained

prominence on highly capitalized ranches because of the problems in controlling large numbers of men, disease outbreaks, and getting rid of the labor force once the work is done.

The effects of land clearing methods on soil properties has been studied by Seubert, et al. (1977) and by Toledo and Morales (1979) and is presented in Figure 1. These authors have shown that in spite of the greater efficiency of mechanical clearing (50 men/ha./day vs. 1.5 ha/hr.) it has clearly deleterious effects on soil properties. The rapid declines in productivity associated with mechanical clearing is due to the maldistribution of the ash, soil compaction and topsoil displacement. Mechanical clearing is also about three times as expensive as manual clearing (Toledo and Serrao 1981).

Different land uses vary in their effects on soil nutrient dynamics, and are discussed in the next section.

Land Uses in the Amazon and their Environmental Effects

Forestry

Forestry is the main export revenue earner in the Amazon Basin, but while important to the regional Amazonian economies, other, more accessible sites in the Amazon countries still dominate the wood markets. For example, the Brazilian Amazon only produces about 10% of Brazil's industrial timber (Mutoo 1978) of which most is still largely derived from the Amazonian floodplain forests where

extraction is far easier. The output of the varzea forests is derived from a 200 m strip along the waterways that generate about 5 to 10 m³ per hectare, mostly of Virola and Carapa. In spite of the vast wood volume on the terra firma, Mutoo (1978) estimates about 150 million cubic meters of wood are burned each year with clearing.

Other major forestry activities in the Amazon are associated with particular high value species (especially mahogany, Swietenia macrophylla) or selected one time extraction areas such as the Tucuruí dam. In the Brazilian Amazon, where the mahogany industry has been studied in some detail, information is available on the rate of exploitation. The main mahogany area occurs in the Araguaia region of Para and Mato Grosso. Godfrey (1979) cites an unpublished IBDF inventory that found a mahogany frequency there of about 1.2 trees/ha. at an average wood volume of 5 m³/ha. out of a standing volume composed of all species of about 55 m³. The mahogany forests are quite diverse, and in spite of 312 species of which 118 have commercial value, only Swietenia is usually extracted. Although some fairly resinous species such as Manilkara are used for local construction, most of the remaining timber is cut and burned as a prelude to pasture formation.

The IBGE (Brazilian Institute for Geography and Statistics) indicated in 1977 that some 200,000 m³ of mahogany were legally extracted in the Conceicao de Araguaia region (IBGE 1978), although a brisk illegal trade

in this wood also exists. Given a saleable cubic meterage of 3 m³ per tree, close to 67,000 trees were legally cut that year. With an average of 1.2 trees per ha., some 55,830 ha. were affected in 1977 alone (Godfrey 1979). The clearing and forest extraction in the Araguaia region are quite aggressive, and Godfrey (1979) indicates that the mahogany forests of the eastern Amazon will be logged out by the mid 1980's.

Selective logging is the major technique for timber extraction in the Amazon, except for projects like the Tucuruí dam. This manner of extraction, though certainly less deleterious than total clearing, is not without its environmental impacts on soil properties. Sanchez (1979) has indicated that the bulk of Amazonian erosion is due to civil engineering, i.e., roads, construction, etc. Studies on erosion elsewhere in the humid tropics suggest that erosion does increase with logging (Ewel and Condi 1978, Liew 1974). Falling trees compact the soil and heavy machinery disrupts the soil surface. Some areas are completely denuded for a time. All these contribute to an increase in sheet erosion.

Selective logging in the humid tropical forrests affects about one-third of the trees in a selectively logged forest (Suparto, et al. 1978). This is due to the close integration of canopies and the lianas that often bind several trees together.

Logging is usually preliminary to other land uses, and in the Amazon uplands selective extraction is usually followed by pasture. Habitat for forest regeneration is consequently lost. While many authors (Fox 1976, Palmer 1977) suggest that mahogany forests were capable of sustained yield and enrichment, wholesale conversion of these valuable forests to pasture have made mahogany a one time extraction.

The replacement of high value, potentially sustained yield forests by lower value, often ephemeral land uses is not unique to the mahogany forests. Valuable rubber forests in Acre, and Brazil nut forests near Santarem and Maraba have also been converted to grasslands.

The only attempt at commercial plantation forestry is Daniel Ludwig's Jari. More than 100,000 ha. of Pinus carribea and Gmelina arborea was planted largely in monoculture. Although the ecological disaster predicted (and probably hoped for) by many biologists did not materialize, the experiment should not generate unbridled optimism (Fearnside and Rankin 1980). It is likely that the pest outbreaks did not occur because of the high diversity within the plantations due to weed invasion, and the use of forest corridors between plantation quadrats, as well as assiduous monitoring of the plantation by its very expensive staff (Fearnside and Rankin 1980). While proving that it is possible to grow commercial forestry plantations in the Amazon if one is willing to invest 687 million dollars (Fortune 1981), Jari has yet to demonstrate its economic visability and is currently for

sale. Plantation forestry in the Amazon still remains questionable.

Forestry, in spite of its importance as a revenue earner and labor absorber, is only the first phase in a larger conversion process.

Agriculture

The conversion of forest for agriculture occurs in tandem with spontaneous or planned colonization. Prior to the 1960's, most of the Amazonian population lived along the varzeas (where the most fertile soils are located) or in the environs of the major Amazon cities. With the opening of the highways, people migrated to the upland areas in search of work and land. They primarily cultivate with slash and burn techniques, planting rice, manioc, corn and various beans. The fate of these migrants has been a research area of interest, since most of them have not become permanent settlers in the areas they initially colonized (Hebette and Marin Acevedo 1979, Smith 1976, Moran 1977, Fearnside 1978, Souza-Martins 1980, Schuurman 1979, Pompermeyer 1979). The instability of small scale agriculture is often explained as a consequence of yield declines due to soil nutrient changes (Sanchez 1979, Maxwell 1980). The ecological dynamic of annual crop production, as will be shown, is certainly an important factor in the unstable agriculture of the colonists since it increases their vulnerability to larger economic forces at the frontier. Stable small scale cultivators have, however, existed on the terra firma for decades, in areas

like the Araguaia and Western Maranhão (Ianni 1977). The subsequent instability in these areas, since the 1970's, reflects the land economics of the region at least as much as soil fertility.

Figure 2 shows the soil nutrient dynamics associated with continuous rice cultivation in Yurimaguas, Peru. When forests are converted to agriculture there is an initial nutrient flush that provides the necessary fertility elements for good rice yields. The first harvests produced about 1.2 tons per year, declining to about half that value by the fourth harvest. Subsequent yields at Yurimaguas were negligible (Seubert, et al. 1977).

The soil properties after conversion to annual rice cropping did not plummet to levels below those of forest at Yurimaguas, although other data from agricultural plots in Manaus did show a drastic decline (Brinkman and Nascimento 1973). Even so, various soil fertility difficulties for annual crop cultivation increase with time, as Table 8 indicates. Clearly the first year is the only relatively problem free year from the point of view of soil properties. Soil nutrient declines are not the only factor that hampers productivity for rice, however. Many small farmers cite weeds (and the labor involved in reducing them) as the major constraint to continuous production (Tendler 1981, Smith 1976, Fearnside 1978, Valverde and Bandy 1981). In spite of production obstacles, credit availability and titling are favored if the small scale cultivator plants to rice,

however, and it is certainly the most important peasant cash crop in the Amazon.

Given the difficulties, some authors have pointed out that more complex multicrop systems involving manioc, rice, corn, beans and tree crops may be more ecologically and economically tenable in the Amazon than rice cultivation, given the current erratic availability of inputs, equipment storage facilities, and marketing difficulties (Nelson 1975, Moran 1977, Bunker 1979, Smith 1978, Fearnside 1978, Schuurman 1979).

The yield declines, either as a consequence of soil fertility changes or weed invasion, the lack of inputs, the tenuous marketing systems and titling problems place small farmers at a distinct disadvantage in negotiating with banks and government entities for credit. Many small farmers cannot exit in the high state of indebtedness that credit systems ultimately exact, as their land, implements, and marketing all depend on their harvests (Schuurman 1979, Smith 1976, Bunker 1978). The weak bargaining position, coupled with the title insecurity characteristic of most of the Amazon (Santos 1979) place these farmers at the mercy of land grabbers (grileiros), higher capitalized small farmers, and ranchers, with the result, as a prominent Brazilian agronomist put it, that they must get big (an option not open to many) or get out. The migration and land turnover patterns in Amazonia reflect this process of continual disenfranchisement (Hebette and Acevedo Marin 1980, Schuurman

1979, Tendler 1981, Smith 1976, Pompermeyer 1979, Aragon 1978).

The pressure for land acquisition in the Amazon comes from several quarters. Increased mechanization and the decline of a variety of tenancy relationships in other agricultural zones, the closing of older frontier areas, as well as demographic increase, has served to create a huge landless population, who migrate to the Amazon to seek their fortunes. These become the squatters on government and unoccupied (though often owned) lands, and the labor force for large scale clearing.

At the same time, the increased importance of land in corporate portfolios, coupled with attractive credit lines for Amazonian investment, low capital gains taxes, and minimal control and monitoring of land acquisition have created a speculative search for land unparalleled in recent Amazonian history (Mahar 1979, Mueller 1980, Pompermeyer 1979, Schuurman 1979).

High potential profits (up to 100%/year according to Mahar 1979) produce an environment that favors the legal or illegal concentration of land into latifundia. While agro-nomic research oriented to enhancing small scale production systems is of major merit, the speculative nature of the Amazonian land economies, plus infrastructure, input and transport difficulties at this time favors larger holdings to the detriment of colonists. In Latin America (Parsons 1976)

) and particularly in Brazil (Furtado 1963) cattle have

historically played a major role in occupying contested land and continue to do so today. Various fiscal incentives and credit lines, ease of implantation, the possibility of discovering other valuable resources (gold, tourmalines, diamonds) and the speculative gains have fueled the transformation of agricultural land and forest into pasture.

Conversion of Agriculture to Pasture

When a cropping phase precedes pasture, several pathways for the transformation of the land use are possible. One important way, widely employed by the less capitalized ranchers is the "troca pela forma" or trade for pasture formation. Land is lent to the small cultivator to clear and cultivate for one year in exchange for which the farmer shares his crop and agrees to plant pasture. After the cropping cycle, he may relocate to another parcel on the ranch, or move away. The rancher then introduces his cattle. Another technique is simple appropriation. This may be done through legal or semi-legal means (contested titles or surveys) or by running the farmer off the land through violence or threat of violence (Souza-Martins 1980, Almeida 1980, Pompermeyer 1979). In lands that have been spontaneously settled by small farmers, who are then followed into the region by middle sized, mostly non-corporate ranches, this technique is not uncommon (Souza-Martins 1980, Almeida 1980). Land, of course, can also be bought.

Pasture

Pasture is the ultimate destiny of much of the land initially used for forestry or cleared for agriculture. Toledo and Serrão (1981) estimate that about 6 million ha. of the Amazon forest have been converted to pasture, and of this about 1 million ha. are degraded. This author ^{believes} ~~feels~~ that these figures underestimate both the area cleared and the magnitude of degradation. Alarcon, et al. (1980) indicate over 3 million ha. have been converted to pasture in the Colombian Amazon. This information coupled with the Brazilian data in Table 4 argues for an area in pasture of at least 10 million hectares, particularly if we consider that much of the Bolivian, Peruvian and Ecuadorian Amazon are also in ranching (Gazzo 1981, ↓ Pereira and Salinas 1981). Tardin (1979a) analyzing ranches in the Barra de Garças (de la Torre^{Wgl}) area of Mato Grosso, generally considered the most successful upland cattle region in the Brazilian Amazon, used LANDSAT imagery and ground truth testing to evaluate the level of pasture decline and weed invasion. He found that about half the pastures in the area he examined were degraded. The poor quality of pasture and extensive weed invasion in Paragominas Para, another major cattle development area, suggest a level of degradation exceeding 50%.

Only a few grass species are used in the Amazon for pasture formation. In the Brazilian Amazon, Panicum maximum, colonial guinea grass, is planted to about 85% of the area

(Serrão and Simão-Neto 1975, Toledo and Serrão 1981).

Brachiaria decumbens was also initially widely planted, but the attacks of spittle bug, Deois incompleta, has limited the use of this grass. In the Paragominas area, over one-third of the pastures planted to Brachiaria were destroyed by insect attack (Hecht 1981). Brachiaria humidicola, or Kikuyu da Amazonia, with its resistance to spittle bug and tolerance to low nutrient soil is gaining ascendance.

In the western Amazon, two species of Axonopus, A. micay and A. scoparius are the most important forage grasses. A grass of interest due to its high productivity on poor soils is Andropogon guyanus (Toledo and Serrao 1981). Most of the research on ranching has occurred in areas planted to Panicum, so a brief discussion of the major characteristics of this important forage is in order.

Panicum maximum is probably the most widely planted forage grass in Brazil (Martins 1963). The cultivation and the management of this is particularly well developed in southern Brasil, where it is the foundation of the beef fattening industry (Pardi and Caldas 1968, Santiago 1970, da Silva-Dias 1968). Based on the success of this Panicum based cattle production, and the relative success of the CONDEPE (Commission for the Development of Cattle Raising) projects in southern Mato Grosso and Goias, the Panicum production system was transferred in toto to the Amazon from the southern and central Brazilian ranching areas.

The source areas for Panicum in Africa are the savanna regions associated with volcanic and high base saturated soils, in areas that are further than 12 degrees south. These two factors, relatively high nutrient requirements, and adaptation to variable day length, are essential to understanding the poor performance of guinea grass in the Amazon. The grass is relatively nutrient demanding for P and N. In the impoverished soils of the Amazon, except for the few years right after clearing, the grass becomes stressed and cannot compete well with better adapted woody and weedy species. N, P, and K deficiencies have all been documented for guinea grass in the Amazon (Koster, et al. 1976).

Colonião (the Brazilian name for the grass) has low seed viability (about 27% according to Agrocere [1978] a major seed supplier) under the best conditions. Two factors in the Amazon Basin reduce seed viability even further. First, Panicum in optimal situations generally seeds twice a year, but in the Amazon continuous seeding occurs. This results in low quantities of seed at any given time, and lower germination since seed may fall during periods when the climate may not be favorable. The high humidity in the region also favors powdery mildew attack (Serrão and Simão-Neto 1975) that further reduces seed production and success.

Panicum plants become senescent within five years (Vincente-Chandler, et al. 1974) and productivity declines in the Amazon on experimental plots corroborate this trend (Simão-Neto, et al. 1973). Without continuous vigorous

establishment of new plants, the yield reductions are quite predictable, and are certainly compounded by the soil nutrient declines that also occur, particularly for phosphorous

The bunch grass morphology of Panicum results in relatively large areas of open ground between individual plants when pastures are grazed. This can produce erosion between plants, and soil compaction due to rainfall and trampling. Increased compaction further reduces the capacity of coloniao seedlings to establish themselves. The open area between the grass can also be colonized by weeds that, for a variety of reasons (Hecht 1979), can outcompete grasses. Another feature of the bunch grasses in the Amazon is their relatively shallow rooting depths. This may reflect increasing Al levels in the soil subsurface. The roots rarely reach below 30 cm. which limits plant ability to capture nutrients below this depth, and subjects the plants to dessication during the dry seasons.

While there are serious problems associated with coloniãõ, it is still considered to be one of the best fattening grasses by local ranchers. Seeds are readily available from several suppliers, and the establishment of the pasture is relatively simple: forests are cut, burned, and at the beginning of the rainy season the panicum is usually aeriaily seeded.

The effect of P. maximum pastures on soil properties has been examined by Falesi (1976), Fearnside (1978), Serrao, et al. (1979) based on Falesi's work, Toledo and

Morales (1979), and Hecht (1981).

Studies of the effects of conversion have focused on the Paragominas, the Southern Para Araguaia regions, and the municipios of Caceres and Barra de Garças in Mato Grosso. These are the areas where conversion has proceeded for the longest time and where investment has been most pronounced. The data on the effects of conversion is presented in Figures 3 through 8. It is important to look at these data with the sampling methodologies in mind: Falesi's and Serrão, et al.'s data is based on one composite sample of five sub-samples, hence we have no idea of the variability within those samples. Hecht's data are based on 20 random samples per age class of pasture. A more complete statistical analysis of this data is presented elsewhere (Hecht 1981), but the salient features of the effects of conversion are easily seen in the figures. As Silva (1979) and as the deviations from the mean indicate, there is great variability in the nutrient contents of the ash added to soil, so pronounced distortions can occur when the sample size is small.

pH

When forests are felled and burned an increase in the soil pH occurs as bases held in the biomass are transferred to soil storage (Nye and Greenland 1960, Sanchez 1976), regardless of the land use implemented. This liming effect is documented for annual crops and is presented for comparison in Figure 4. The pasture data indicate substantial

increases in pH for three of the four sites sampled, and in the first years after burning, high variability in the remaining site, reflecting the variation in the distribution and nutrient contents of the ash. In the larger data set, the range in the pH's included some samples that are comparable to the other Paragominas sites, but the overall mean increase was about half a pH unit (similar to Seubert, et al.'s data) while the other sites registered increases of 2 pH units.

One of the interesting aspects of the pH data is that the "liming" effect is maintained. Sanchez (1981) and Toledo and Serrao (1981) believe that the high cycling capacity of the grass is responsible for the persistence of the pH improvement. While Teitzel and Bruce ⁽¹⁹⁷²⁾ have shown that Panicum is a reasonably effective cyler of Ca, Mg, and K, there is an additional explanation that should also be considered. When forests are cut and burned for pasture, a great deal of slash remains on the ground. Since about 80% of the ecosystem Ca is stored in the boles and large branches of trees, their gradual decay could supply this element at a rate that could maintain the pH. This hypothesis does not, of course, exclude the possibility of nutrient cycling by the grasses.

Ca and Mg

Closely associated with the increase in pH are the additions of Ca and Mg in the soil. The augmented values are most pronounced in the years immediately after clearing (as

is the variability in this element) with the initial shift from biomass to soil storage when forests are burned. Since rainforests store close to a ton of Ca and Mg per hectare, and the ash additions add about 100 kg./ha. (Seubert, et al. 1977) the increases and the capacity to maintain them are not particularly surprising.

The increases in Ca and Mg (and the concomitant pH amelioration) have been used to assert that conversion of forest to pasture actually improves soil properties. It bears pointing out that the values of Ca and Mg for all sites are less than the soil values for these elements under unfertilized rice studied for four years in continuous cropping (Seubert, et al. 1977), for which no such claims are made. Further, even with the increases after burning, bole decay and cycling by the grasses, Ca and Mg levels oscillate around values that place them in the lower range of Ca and Mg contents of all Amazonian soils according to an analysis of fertility parameters by Cochrane and Sanchez (1981). The larger data set, as well as the Mato Grosso Oxisol and the Paragominas Ultisol show relatively modest absolute increases.

Potassium

K, as mentioned, is a monovalent cation stored largely in the vegetation that cycles relatively quickly and is considered quite vulnerable to leaching. Amounts of K in the vegetation are comparable to those of Ca. When forests

are cut and burned, K levels increase in soils, but the values are erratic throughout the pasture sequence reflecting periodic burning, levels of weed invasion, and other management. K values after conversion for both Paragominas sites are roughly similar, and correspond to the values of the Yurimaguas, Peru Ultisol examined by Seubert, et al. (1977). The higher Mato Grosso value may reflect higher initial soil K levels, as well as species composition. The Mato Grosso Forest near Suia Missu (the sample site) is relatively rich in palms (RADAM 1975), which Silva's (1979) and de las Salas' (1979) data show register high in K. The use of burnt ~~leaves~~ ^{palms} as a salt substitute is well-known and documented for many Indian groups in the Amazon. The palm Inaja (_____) is an important forest component and pasture weed in the Barra de Garças area of Mato Grosso and could contribute to the maintenance of these high values.

Phosphorous

Phosphorous is the most crucial element for pasture production in the Amazon (Koster, et al. 1976, Serrão, et al. 1979, Toledo and Serrão 1981), and 10 ppm is usually considered the minimum value for sustained production of pastures. After conversion, the P values increase dramatically, but by the fifth year they hover at about 5 ppm, and steadily decline thereafter.

The decline in P has been identified as the major reason for pasture instability in the Amazon (Serrao, et al.

1979). The high demand of Panicum for this element, coupled with losses due to erosion and animal export, and the competition the grass experiences from low P adapted weeds leads to drastic drops in pasture productivity, which often results in pasture abandonment. Serrao, et al. (1979) and Koster, et al. (1976) have shown Panicum's excellent response to P fertilization, but the high transport and application costs, coupled with the erratic availability of P fertilizers in much of the Amazon make widespread pasture fertilization rather uneconomic at this time.

Nitrogen

Soil nitrogen is a ^{balance} dynamic between N accumulating functions like N fixation, atmospheric additions, and organic matter decay; and N decreasing processes such as volatilization, denitrification, leaching, erosion and plant uptake. Many of these processes are mediated by the biota, and as the rates of loss and addition are also influenced by environmental factors (pH, temperature, soil moisture) this is an element that can vary strongly from site to site. The Paragominas Ultisol shows an initial slight increase after clearing and a subsequent equilibration suggesting that the differences between forest and pasture N storage is insignificant. In the clay loam Oxisol, soil N increased after conversion. Since these pastures were planted to the legume Pueraria phaseoloides it may be that the doubling in soil N reflects N fixation by this aggressive plant. The heavy clay

Oxisol from Paragominas and the Oxisol from Mato Grosso both show N declines, although the Paragominas clay is decidedly more erratic. The high N values at the year 13 in Paragominas Oxisol may reflect N fixation by native weedy legumes and other N fixing organisms. The Mato Grosso site shows a decline in N of 50% after conversion.

No N fertilizer is used on Amazonian pastures, and the introduction of legumes with forages is not widely practiced (Serrão and Neto 1975). Management factors that may have affected the variability in the sites include burning (volatilization and possible erosion losses), overgrazing, use of weed invasion as a temporary fallow (N possibly increasing) and the use of legumes (N increasing). Since the rangeland management for most of the sites is unknown, the N dynamics of Amazonian pastures remains a promising research area.

Organic Carbon

The percentage of organic carbon in Amazonian soils is quite variable, ranging in total storage from .92 to over 124 kg/m² (Zinke 1976). Carbon levels in pastures are affected by burning, grazing pressure, length of dry season, soil moisture regime, soil texture, species composition, and decomposition rates: in short, anything that influences organic productivity or decomposition. Not surprisingly, carbon levels are erratic over the time sequence, between sites, and within sites.

Soil carbon levels often drop with burning, but can increase if there is addition of fine charcoal, as probably occurred in the clay loam Oxisol. C levels can increase after burning as a consequence of slash decomposition and the high productivity of *Panicum* pastures before P becomes seriously deficient. Heavy weed invasion can also increase soil C values. The high carbon values in the clay loam Oxisol at year 11 and in the clayey Oxisol at years 11 and 13 reflect heavy weed infestation. Increases in soil organic matter by secondary vegetation to levels almost equal to those of virgin forest have been documented by Turenne (1977) and Zinke, et al. (1978) for reinvaded tropical agricultural sites. The Mato Grosso Oxisol and Paragominas Ultisol both show declines in soil carbon after clearing. The Mato Grosso site shows an initial decline that oscillates around a value that is less than 50% of the forest levels. The Suia Missu site (Mato Grosso) is in a zone that interdigitates with several transitional forest types and includes large areas of Cerrado (savanna) vegetation. Forests in this part of the Amazon are of lower biomass and productivity (RADAM 1976) than the Paragominas sites, as are the grasslands (Koster, et al. 1976). The climatic information (Falesi 1976) shows less soil moisture deficit, so that ^{de}composition can proceed without inhibition. The combination of low productivity and high decomposition rates probably act to produce the low C values observed.

The Paragomias Ultisol exhibits an initial drop, then increases and equilibrates around a value that approximates that of forest soil carbon levels.

Other Factors

While the soil changes after conversion are neither as catastrophic nor as beneficial as much of the literature suggests, there are other soil and vegetational effects that also influence pasture productivity. Figure __ shows the increase in soil bulk densities that double with increasing pasture age. ^{densidade de solo} High soil bulk density results in reduced infiltration (documented by Schubart 1976); that can affect the rate of sheet erosion. Erosion rates under young pastures have been studied by Macgregor (1980) in the Caqueta region of Colombia, where it was found that pastures have low erosion losses. The study did not include the grazing animal, or the influence of periodic soil exposure after burning, so the results must be extrapolated with caution.

Amazonian pastures are rapidly invaded with weeds, and these also act to reduce pasture productivity by competing with forage grasses for nutrients and water. Although many weed species are in fact browsed by animals (Hecht 1979) weed control is expensive, and absorbs about 20% of a ranch's operating costs. Ranches that do not receive fiscal incentives are squeezed between the declining productivities, escalating weed and infrastructure repair costs. Not surprisingly, when ranches pass the five-year mark, they are

frequently sold or repossessed. By 1978, about 85% of the ranches in Paragominas had failed, according to the director of the Para cattlemen's cooperative, Dr. Claudio Dias.

The productivity declines that follow the first years after conversion, coupled with the enormous speculative gains in land value in the Amazon (Mahar 1979), result in a situation that further exacerbates the instability of existing pastures while favoring the expansion of this land use. Speculative ranchers employ two basic strategies to maximize their returns over the short run: steer fattening operations and overgrazing.

Porcelos de angrida
Fattening operations involve buying young stock and fattening them and selling when the prices are good. Fat steers are relatively liquid assets, and can be sold or withheld in response to market conditions. Fattening animals require little more than a few cowboys and can be handled in large paddocks. This reduces labor and infrastructure costs (fences, handling corrals) substantially in comparison with the labor demands, high quality and smaller pastures, and high costs associated with managing cow-calf operations. Steers are robust, and can tolerate weedy pastures better than ^{breeding} cows with calves, without the risk of damaging expensive brood stock and excessive calf mortality. This tolerance also means that pastures do not need to be cleaned as often, further reducing labor requirements. Credit for fattening operations is relatively easy to obtain, because the banker can expect to see his money returned within three

years. When inflation rates are high (in Brazil they have been well over 40% since 1977), short-term notes are favored by financial establishments. Brood cow operations involve the initial purchase of fairly expensive animals (heifers and bulls) with a delayed return on the investment of at least five years (Serete 1972). In an attempt to break the fattening cycle, CONDEPE and SUDAM (Superintendency for the Amazon) developed preferential credit lines at low, subsidized interest rates to promote cow-calf production systems, but the credit, extension and fiscalization requirements are such that only the larger, well-capitalized corporate entities can afford to take advantage of them.

Given the high productivities of the first years, ranchers try to maximize their returns as quickly as possible, and they do this simply by overstocking. Pastures often experience stocking rates four times the "optimal" rate of .75 to 1.0 animal units per hectare. Overgrazing exacerbates the fertility decline (Toledo and Serrao 1981) and favors weed invasion, but with this practice the landowner is still likely to get a reasonable return on his initial animal and clearing investment. Since land values increase by about 100% per year in the active development areas, the rancher can pocket a tidy profit on the land itself, and begin a new cycle elsewhere. While clearly not all ranchers are as predatory as the situation just described, the speculative nature of Amazonian land economics makes this pattern a common one. As a consequence, the turnover

in land titles in the cattle and development areas of the Amazon has increased dramatically in the last 15 years (Santos 1980, Pompermeyer 1979, Hebette and Acevedo Marin 1979).

Land values increase both for pasture as well as virgin forest. Mahar (1979) points out that investors in Amazonian rural property consider it as a store of value rather than a factor in production. In the state of Para, for example, on farms of more than 1,000 ha. only about 26% of the land is cultivated. These establishments account for 84% of the land in private domain, but include only 8.4% of the farms. The area in use on farms of greater than 10,000 ha. drops to only 14% (INCRA 1978).

Small agriculturalists, on the other hand, cultivate an average of 66% of their claim, and this value can range up to 97%. The small scale farmer's acquisition of land, legally or through squatting, is for its use value, since the amount of land he owns and his labor expenditure rarely add up to grand speculative gains. He must have an annual rate of return on his production that is sufficient to support himself and his family.

In spite of the low rates of use, large groups have consistently captured land released from government tenure sold to the private sector. These lands, known as terras devolutas, often have been colonized by squatters. In areas where both large and small owners have claims on land, either by title or simple occupation, the process of land acquisition has been accompanied by bitter contention (Souza-Martins 1980, da Silva-Rodriguez and da Silva 1977). In the state of Para, well over 5300 titles were contested in the main colonizing

and ranching areas of Paragominas, Altamira, Marabá, and Conceição de Araguaia, and involved well over a million hectares. Because small farmers can neither afford the time or lawyers, they often lose these conflicts. As a consequence, there is a tendency toward land concentration. In the Paragominas area of the Belém-Brasília highway, the Gini coefficients increased from .60 to .77 between 1960 and 1970 (Santos 1980) indicating an increasingly regressive land tenure situation.

Conclusion

This paper has shown that a variety of ecological factors but particularly soils are linked to agricultural instability in the Amazon Basin. Nonetheless, to view them as the only causes of the ephemeral character of agricultural production in the region would be to ignore the catalysing effect of the economic structure of the region, and the social dynamic it creates.

In Brazil, for example

Although small farmers could cultivate in a manner to reduce the environmental impact of agriculture (and possibly their own economic vulnerability), most titling and agricultural credit is linked to rice production. Rice yield declines are almost inevitable, given current production technologies in the Amazon. These small holders with few assets are usually highly leveraged either to official organs, or informal money lenders (Punker 1979, Funnell 1979). Given decreasing yields, the small colonist must often relinquish his land to richer, medium sized farmers, grileiros, or ranchers when loans fall due, titles are contested, or power clashes occur.

Land holdings are concentrated due to consolidation of small holdings into larger ones. This sets into motion a social dynamic involving the expulsion of small farmers into other Amazonian areas, or to the major cities.

The large scale farmer or rancher has few incentives to produce for sustained yields. Livestock production also declines due to ecological changes, but since most of the land is not cultivated, but held for exchange rather than use value, the owner is less concerned with the annual rate of return on production than with the overall rate of return on the investment. The current economic climate in the Amazon basin actually encourages land resource degradation since speculative ranchers maximize short term gains by overgrazing and poor management of the land the do put to use. This leaves a degraded landscape in the wake of speculative waves.

At this time, the major question in Amazonian deforestation is perhaps not how much land has been cleared, but how it has been used and whether the current pattern of land occupation will really fulfill the potential of this important land resource to meet the pressing needs in the Amazon countries for food production, employment, income and social stability.

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Table 1. Some economic parameters of the Amazon countries.

Country	Population (millions)	Population growth rate (1970-1978)	Per Capita GNP (1975) (\$ US)	GNP Growth 1960-1975 %	Inflation rate 1960-70 1970-78) %	Current account Balance (1978) (millions \$ US)	Debt Service Interest 1978 (millions \$ US	
Bolivia	5.3	2.6	280.7	2.7	3.5	22.7	-301	83
Brazil	119.5	2.8	768	4.2	4.9	46.1	-5310	1725
Colombia	25.6	2.3	461.2	2.7	11.9	21.7	+305	172
Ecuador	7.8	3.3	594	3.9	---	14.6	-54	96
Peru	16.8	2.7	522	2.5	9.9	22.2	+119	17
Venezuela	14.0	3.3	1,486	2.2	1.3	11.1	-4973	394

	Debt Service % of exports	Ag. Production growth rate (1966-77)	Food Production growth rate (1966-77)	Trade in food commodities (1000 tons)			Rice x 75-77	Maize x 75-77		
				Beans x 65-67	Wheat x 75-77	Imports-Exports				
Bolivia	48.7	13.9	2.7	2.4	0.3	0.3	1	5	0	
Brazil	28.4	4.4	3.7	4.7	7.9	35.4	1	-136	-1327	
Colombia	9.8	2.3	3.1	3.8	2.4	-5.6	-63	-25	6.1	70.6
Ecuador	11.7	1.2	1.8	1.7	0.1	0.6	15	-8	0.1	0.6
Peru	31.7	1.1	0.1	-1.7	1.8	-0.6	59	53	8.4	233.5
Venezuela	6.9	1.4	4.2	4.6	32	45.4	-32	8	67.2	379

Compiled from World Bank (1980) World Development Report, 1980, and CIAT (1979) Latin America: Trend Highlights for CIAT commodities.

Table 2 . National area and development zones in the Amazon for different countries.

Country	Area in the 2 Amazonia (km ²)	% National Territory	Major Development Regions
Brazil	3,560,000	54 %	Highways: Belem-Brasilia TransAmazon Cuiaba- Santarem Manaus-Porto Velho Regions: Paragominas Araguaia Upper Xingu Western Maranhao Rondonia Carajas Manaus (SOEFAMA)
Peru	785,000	61 %	Tingo-Maria Apurimac Caballoche Jenaro Herrera Alto Maranon San Ignacio Pucallpa
Bolivia	510,000	47 %	Alto Beni Yapacani Chimore
Colombia	309,000	27 %	Caqueta Putomayo Vaupes Guania
Ecuador	138,760	48%	Shushufindi Payamino San Miguel Palora-Pastaza Morona
Venezuela	100,000	9 %	Minimal and mainly in the Caura and Caroni drainages

Table 3. Tropical lowland forests of the Amazon Basin: Approximate area of forest clearing rate, and dominant replacement land use(s).

Country	Amazon Forest Area (millions ha)	Current clearing [*] (ha/yr)	Dominant Land Use
Brazil	280	1,000,000 ¹	Cattle ranching (90%)
Peru	65	no data on rates but 10% thought to be cleared ²	Subsistence, cash crop cattle (15%)
Bolivia	51	3,000 ²	Cattle, citrus, cacao, coffee
Colombia	31	150,000+ ²	Cattle, rice
Guyana	13	10,000 ²	Subsistence
Surinam	13	3,000 ²	Subsistence, Forestry
Venezuela	13	no data on rates	Subsistence, cattle
Ecuador	10	no data on rates	Cattle (81%) ²
French Guiana	8	Negligible	Subsistence
	484	1,166,000	

Sources: 1) ~~INPE~~ IBDF, 1980; 2) Myers, 1980

^{*} Clearing here implies total replacement for and alternate land use. Selective logging etc. is not included. All these figures are at *best only approximations*.

Exhortação

Table 4. Deforestation in the Brazilian Amazon.

State	Area cleared in 1975 (ha)	Area cleared in 1976-1978 (ha)	Increase in clearing 1975 to 1978-1978 (%)	Total cleared as of 1978 (ha)	Cleared area 1980* (ha)
Mato Grosso	1,012,425	1,323,075	130	2,325,500	5,085,900
Pará	865,400	1,379,125	159	2,244,524	3,575,528
Pernambuco	294,075	433,225	149	733,400	1,032,763
Piauí	221,650	336,800	243	418,450	1,016,833
Acre	116,550	129,900	111	246,450	273,559
Amazonas	77,950	100,625	129	198,575	230,361
Roraima	5,500	3,375	161	14,375	23,000
Amapá	15,250	1,800	11	17,050	20,119
TOTAL	2,859,525	4,857,650		7,717,175	11,318,860

Source: INPE/IBDF, 1980

* Estimate calculated by multiplying the % increase in clearing with the deforested totals of 1978.

Table 6. Approximate areal extent of soil-related constraints in the acid infertile soil region. Total extension of each order in parenthesis. Question marks indicate insufficient information. (From Table 1)

Soil Constraint	Oxi- sols (512)	Ulti- sols (320)	Incep- tisol (119)	Enti- sols (88)	Histo- sols (4)	Total area (1043)	% of total
----- million ha. -----							

PHYSICAL:

Low water holding cap.	504	0	0	79	0	583	56
Water stress > 3 mo.	170	35	15	79	0	299	29
Erosion hazard	17	160	47	80	0	304	29
Compaction	0	160	0	9	0	169	16
Waterlogging	0	72	47	0	4	123	12
Laterite	48	71	0	0	0	119	11
Shallow depth	17	11	47	6	0	81	8
Vertic properties	0	0	0	0	0	0	0
Low temperatures	0	0	0	0	0	0	0

CHEMICAL:

P deficiency	512	320	83	83	4	1002	95
N deficiency	504	305	71	88	0	969	93
K deficiency	512	160	0	40	4	799	77
Al toxicity	409	255	18	73	0	755	72
S deficiency	512	160	0	73	0	745	71
Mg deficiency	490	224	0	7	4	731	70
Ca deficiency	504	224	0	0	4	732	70
P fixation	512	160	0	0	0	672	64
Zn deficiency	468	100	0	77	0	645	62
Low CEC	504	0	0	73	0	577	55
Cu deficiency	256	50	0	?	4	310	30
Salinity	0	0	0	0	0	0	0
Alkalinity	0	0	0	0	0	0	0
Fe deficiency	0	0	0	0	0	0	0
Cat clays	0	0	2	0	0	2	-
Mn toxicity	?	?	?	0	0	?	?
B deficiency	?	?	?	?	?	?	?
Mo deficiency	?	?	?	?	?	?	?

From: ~~Sanchez~~ Cochrane and Sanchez (1980)

Table 8. Time of appearance of fertility limitations in an upland rice-corn-soybean annual rotation after burning a secondary forest in an Ultisol in Yurimaguas, Peru.

Months After Clearing	Problem
1	Initial boost in pH, inorganic N, P, K, Ca, Mg, S, and micronutrients, decrease in Al saturation to below toxic levels. Effect of ash.
8	Inorganic N supply depleted. N deficiency symptoms appear. Exch. K below critical level of 0.2 meq/100 g. K deficiency symptoms appear.
10	Organic C decomposition to new equilibrium level completed. Al saturation increases, surpassing toxicity level of 60% for corn and soybeans. Available P below critical level (12 ppm P via Olsen method). Mg becomes critical at 0.2 meq Mg/100 g for soybeans and 0.4 for corn.
12	Liming to pH 5.5 and applications of 80-26-80 kg N, P, K/ha per crop except N for soybeans increases yields.
	K applications solve K deficiency but creates K/Mg imbalance when ratio < 1.2. Mg applications needed. B-deficiency evident.
	S, Cu, and Mo probably limiting (S became limiting immediately after clearing in bulldozed plots). Mo deficiency depends on Mo status in seed.
24	Nutrient removal by cropping depletes soil further. Rates of N, P, K and Mg have to increase.
48	Zn deficiency appears.

Source: Villachica, 1978, A. (from Sanchez (1979) and based on (in press).

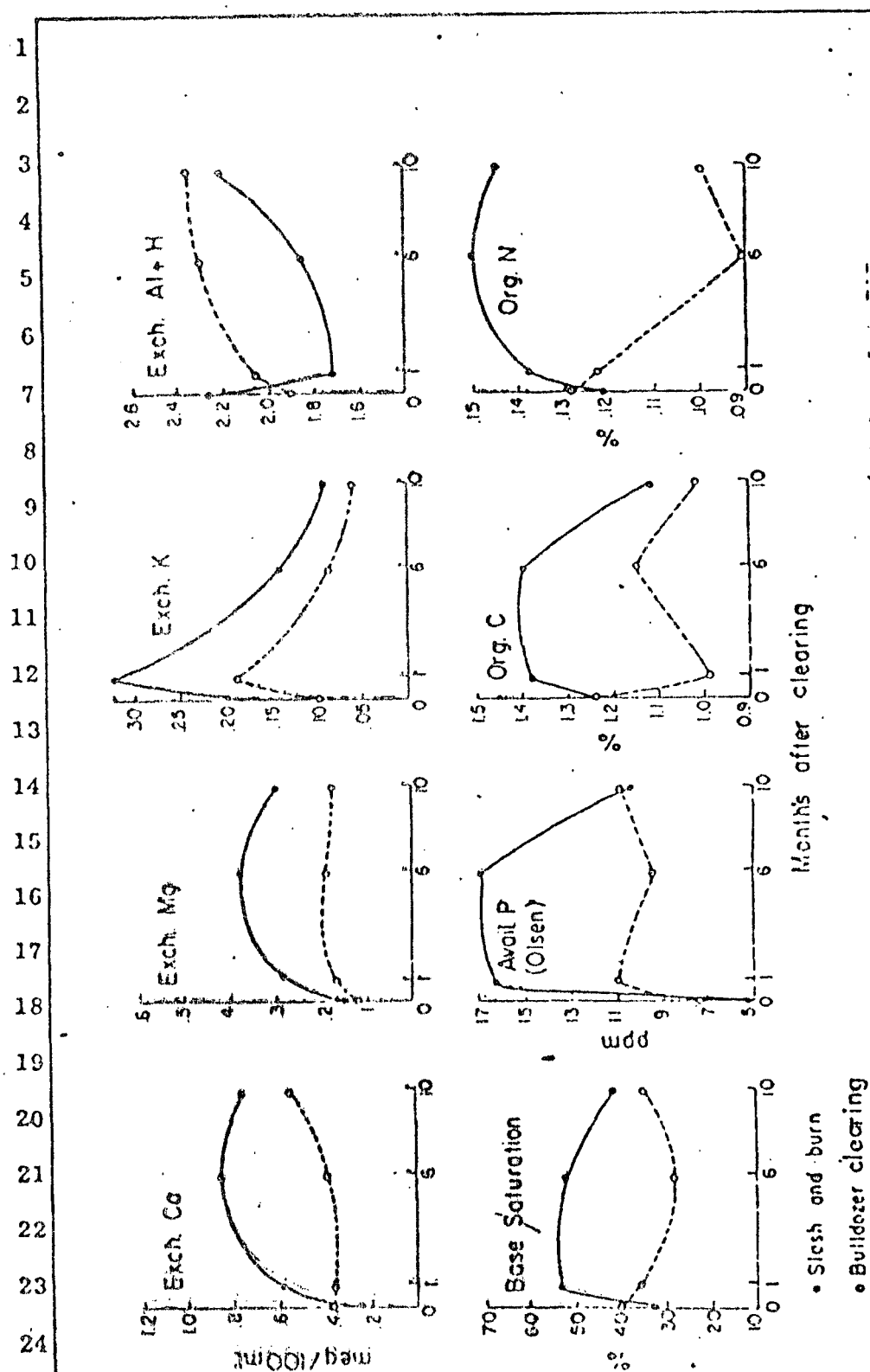


Figure 1. Effects of two land clearing methods on changes in topsoil (0-10 cm) properties in a Typic Paleudult of Yurimaguas, Peru.
Source: Seubert et al., 1977.

YURIMAGUAS ULTISOL (0-10 cm)

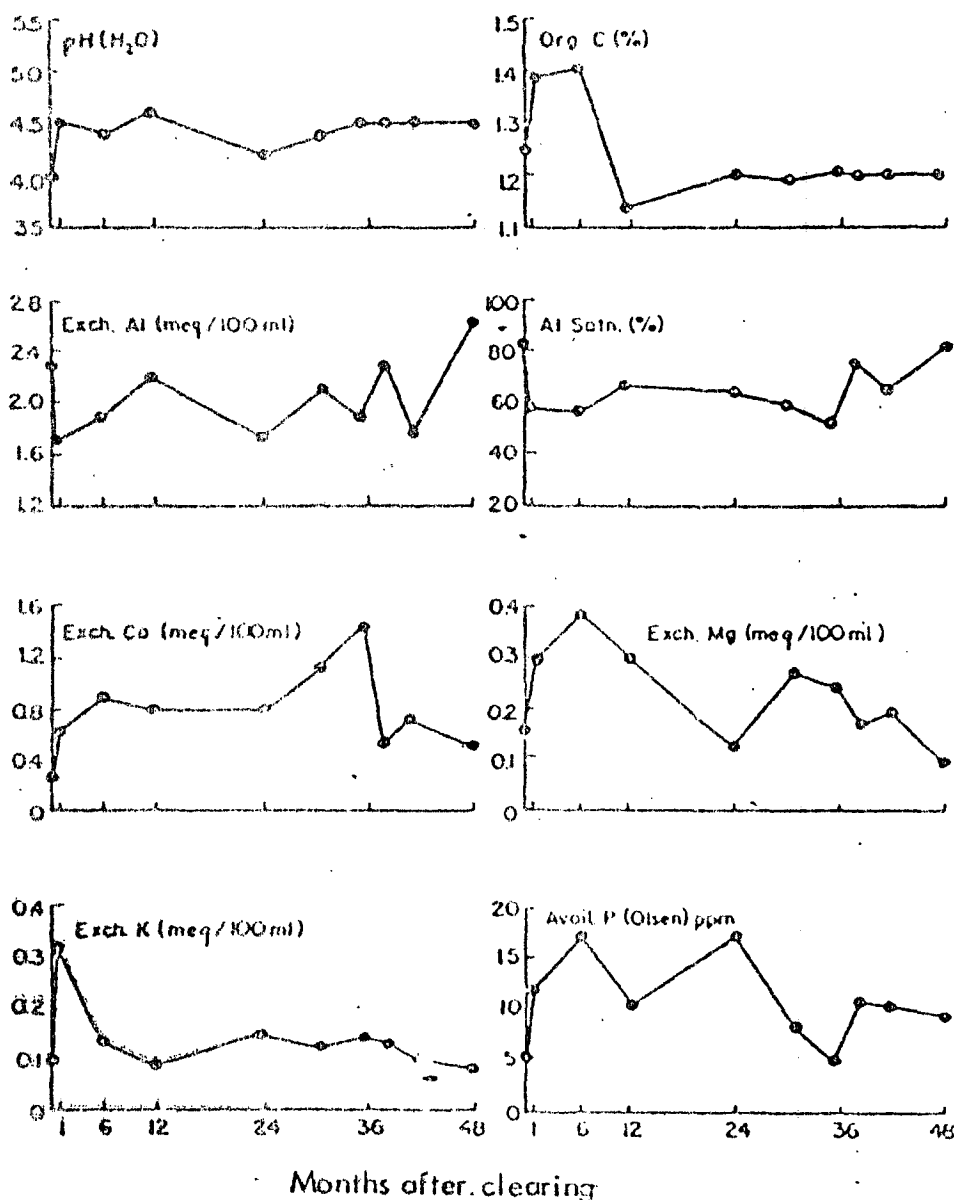
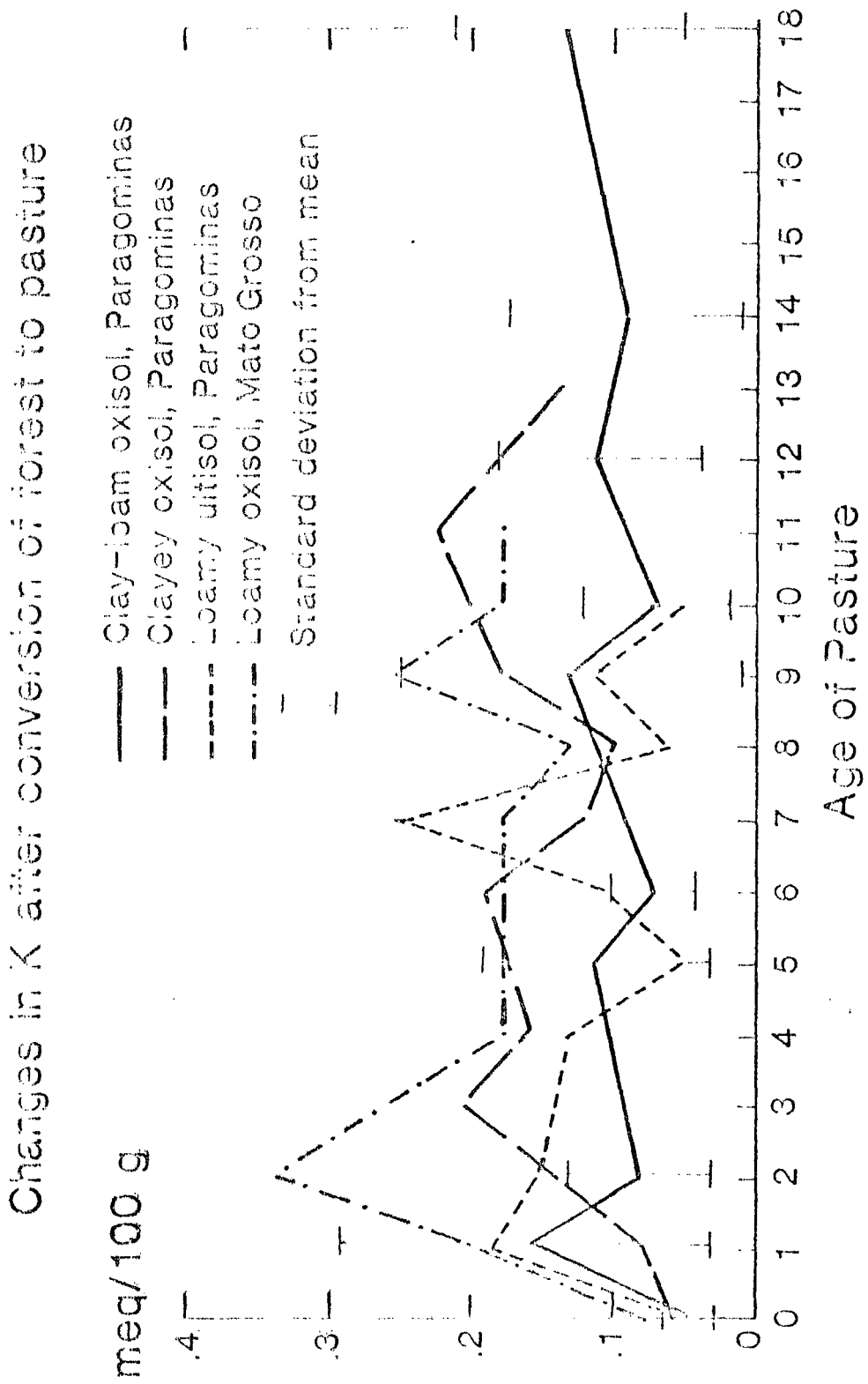
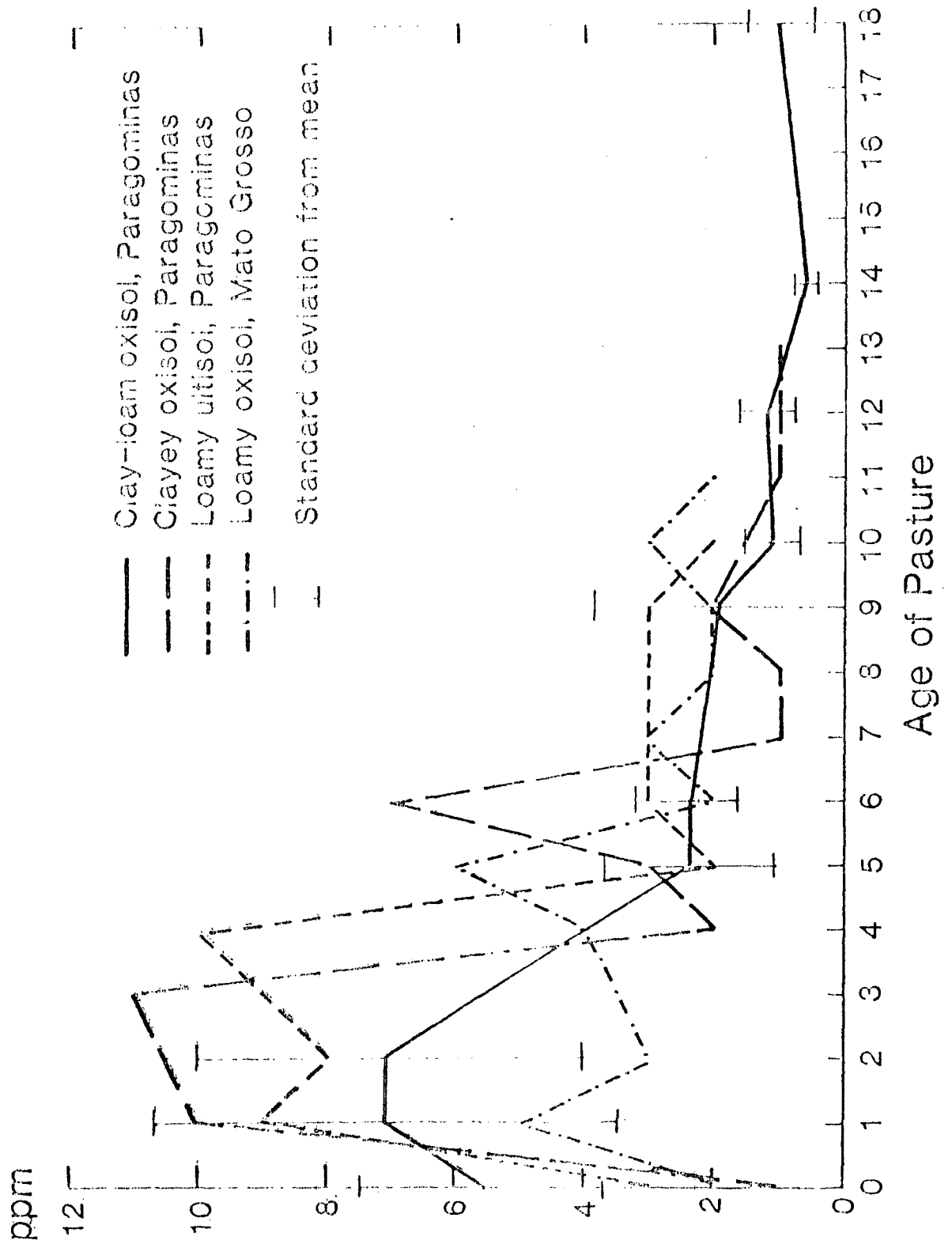
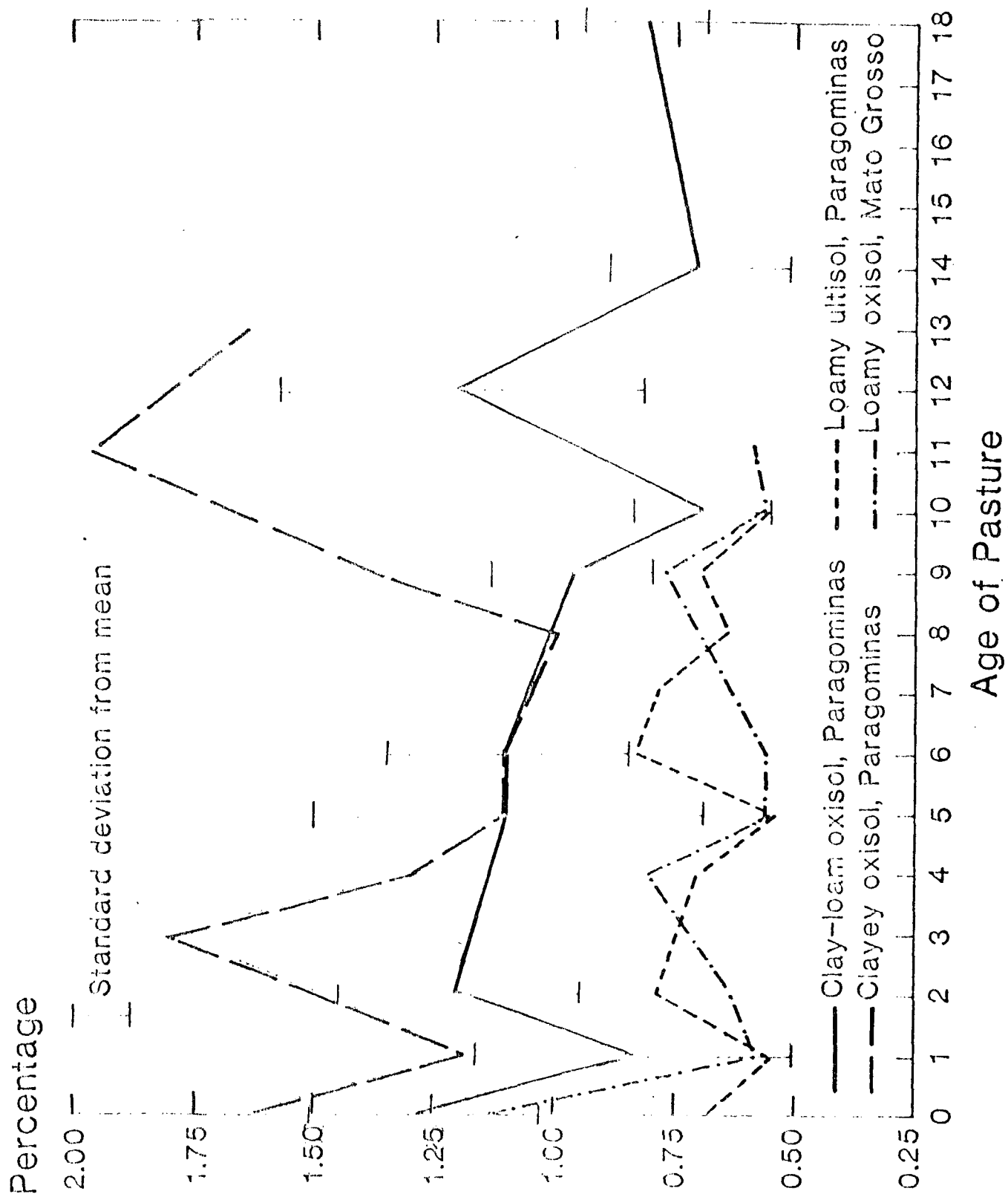


Figure 2. Changes in chemical properties of an Ultisol continuously cropped to upland rice (8 crops), without fertilization at Yurimaguas (1972-76).
 Source: Compiled from data by Seubert et al., 1977; and Villachica and Sánchez (in press).
 from Cochran and Sanchez (1981) from based on Seubert et al (1977)



Changes in P after conversion from forest to pasture





Changes in N after conversion from forest to pasture

