CEDI - P.I.B.
DATA 31/12/87
COD. 10D00643

CONTINUOUS CROPPING POTENTIAL
IN THE
AMAZON

J. J. Nicholaides, III, D. E. Bandy, P. A. Sanchez
and C. S. Valverde[1]

---

[1] Coordinator of Tropical Soils Research Program and Associate Professor of Soil Science, On-Site Leader and Visiting Assistant Professor of Soil Science, Coordinator of Tropical Soils Program and Professor of Soil Science, North Carolina State University, and Director of Planning and International Collaboration, National Institute for Agricultural Research and Promotion, Ministry of Agriculture, Peru. This work was supported by a Contract ta/C-1236 of the United States Agency for International Development.

CONTINUOUS CROPPING POTENTIAL IN THE AMAZON

J. J. Nicholaides, III, D. E. Bandy, P. A. Sanchez and C. S. Valverde

A. INTRODUCTION

There are realistic continuous cropping alternatives to the traditional shifting cultivation practiced in the Amazon Basin.

Denevan (1977) identified shifting cultivation as the primary cause for the clearing which some predict could result in the disappearance of the Amazon rainforest sometime between the turn of the century (Richards, 1970) and within less than 100 years (Denevan, 1973). Ecologists, geographers and other concerned individuals have decried this practice and have recommended trying to establish, for both forest preservation and agricultural development, "permanent field cultivation without first going through a sequence of increasingly shorter fallowing and associated environmental deterioriation" (Denevan, 1977).

Since 1971, North Carolina State University's Tropical Soils Research Program, under U. S. Agency for International Development funding and in collaboration with the Peruvian National Institute for Agricultural Research and Promotion under the Ministry of Agriculture, has been developing at Yurimaguas, Peru, continuous cropping systems for the acid, infertile soils of the Amazon Basin and other similar agroecological areas. The results of these research efforts which offer attractive alternatives for the Amazon Basin's shifting cultivators are presented herein following summaries of that area's climate, soil resources and current cropping systems, and prior to limitations, implications and potential.

B. CLIMATE AND SOIL RESOURCES

The geographical extent of the Amazon Basin has been estimated to vary from 557 million hectares (Moran, 1981) to 484 million hectares (Cochrane and Sanchez, 1982). The Cochrane and Sanchez estimates, within the confines of 4^{o}N and 12^{o}S and 48^{o}-78^{o}W, though eliminating some small portions of the Amazon Basin, will be used for this discussion as most of the climatic and soils data were derived from their study.

1. Climate

The agroecological zone known as the humid tropics encompasses the Amazon Basin. The humid tropics includes those areas with seven or more humid months, with at least 1500 mm precipitation annually, with no more than a four-month period where potential evapotranspiration exceeds precipitation with $\leq 5^{o}$C in mean monthly air temperatures between the three warmest and three coldest months.

a. Climatic-Vegetation Subregions. Three major climatic-vegetation subregions were identified in the Amazon as 1) tropical rainforest, 171 million hectares, 2) seasonal semi-evergreen forests, 274 million hectares, and 3) well-drained savannas, 39 million hectares (Cochrane and Jones, 1982). Thus, slightly more than 1/3 of the Amazon is in the tropical rainforest subregion and this occurs mainly in the western half of the Basin. The seasonal semi-evergreen forest occupies over 1/2 the Basin and is found primarily east of Manaus, Brazil. The well-drained savannas which are natural grasslands surrounded by forests are interspersed within the other subregions and include the savannas of Boa Vista, Rupununi, Amapa and Cachimbo, but neither the Llanos of Colombia nor Venezuela due to geographic limitations nor part of Cerrado of Brazil due to temperature limitations.

b. Meterological Variability over Subregions. The meterological data in Table 1 reflect, though not entirely, the climatic variability within the Amazon Basin by furnishing an example of a site in each of the three climatic-vegetation subregions.

Only small temperature differences (Table 1) in the subregions are noticed due to the moderating influence of rainfall and the relatively small variation in elevation across the Basin. Mean annual temperature at the equator at sea level is 26°C and theoretically decreases by 0.6°C for each 100 m increase in elevation. Soil temperatures at 5 cm depth (Table 1) in the tropical rainforest subregion are fairly constant during the year.

Precipitation in the Amazon Basin ranges from 1500 mm to nearly 4000 mm annually. Soil moisture regimes (Soil Survey Staff, 1975) of the Amazon Basin are primarily udic, though ustic regimes are also found. The udic soil moisture regime is in those areas where the rooting zone of the soil is dry for no more than 90 cumulative days during the year, whereas the ustic occurs when the soil's rooting zone is dry for more than 90 but less than 180 cumulative days or 90 consecutive days during the year. Generally, crop production in the Amazon Basin does not suffer from moisture limitations, but during periods of erratic rainfall, moisture stress can restrict plant growth--even in the udic areas. Usually rainfall exceeds potential evapotranspiration in the Amazon Basin, though the exception can also occur (Table 1). Rainfall in the Amazon Basin, therefore, can range from barely sufficient to excessive.

Solar radiation throughout the year is lower in the tropical rainforest subregion than in either of the other two subregions (Table 1). Theoretically, this lower solar radiation should somewhat inhibit crop yield potential in the tropical rainforest subregion compared to the other two, all other factors being equal.

The annual daylength variation ranges from zero to the equator to 2 hours and 15 minutes at the tropical limits of 23.5° latitude. As the Amazon Basin extends from 4^{o}N to 12^{o}S, daylength variation there ranges from 25 minutes to 1 hour and 10 minutes. As contrasted with the temperate region, daylength and solar radiation are not closely correlated in the Amazon Basin, or in any part of the tropics for that matter.

2. Soils

The primary influence on the geology of, and consequent soil development in, the Amazon Basin was the Guyana and Brazilian shields and the Andean uplights (Sanchez, 1976). The soils resulting from these geologic formations and actions are of two main orders, Oxisols and Ultisols (Fig. 1), both of which are extremely weathered, acid and infertile. Almost 75% of the Amazon Basin is occupied by these two orders (Table 2) according to the most recent and detailed survey of the land resources of the Amazon (Cochrane and Sanchez, 1982). Soil classification criteria (Soil Survey Staff, 1975), it must be recognized, are based on subsoil characteristics and may or may not reflect the surface soil characteristics. The Oxisols and Ultisols in other similarily based classification systems are known as Latosols, Red Yellow Podzols ("Podzolicos Vermelho Amarelo"), Ferralsols, Acrisols and often incorrectly as "lateritic soils" (Sanchez and Buol, 1975).

a. Resources. The most extensive soil order in the Amazon Basin is the Oxisol order occupying 45.5% of the area (Table 2). The Haplorthox (29%) and Acrorthox (14%) great groups are the most dominant. These Oxisols which originated from the Guyana and Brazilian shields are usually deep and well-drained, having uniform properties with deep, firm granular structure, low fertility, extreme acidity (Table 3) and red or yellow color. The Acrorthox differs from the Haplorthox only in lower cation exchange capacity of the clay. Cultivation almost immediately following rainfall is allowed in these soils by their excellent physical properties, as the granular soil structure permits rapid water infiltration and consequently low erosion hazard except during periods of intense rainfall. However, their available soil moisture contents are lower than what normally would be indicated by their high clay contents when compared with less weathered temperate soils. The Oxisols are found primarily north of Iquitos, Peru and eastward from Manaus, Brazil (Fig. 1).

Occupying 29.4% of the Amazon Basin are the Ultisols (Table 2), with the Tropudult (17.3%) and Paleudult (6.2%) great groups predominating. Although both Tropudults and Paleudults are well-drained, extensive areas of poorly drained Ultisols are also found. The Ultisols of the Amazon Basin were formed from Tertiary deposits from the shield areas and Andean uplights. These soils usually are deep, do not have uniform properties with depth, are low in weathereable minerals and base saturation and consequently have low fertility and extreme acidity (Table 3) and are red or yellow color. Ultisols have coarser textured surfaces and slower water permeability, hence worse physical properties than do Oxisols. The Tropudult and Paleudult great groups differ in depth of clay bulge in subsoil, but this is of little agronomic management importance. The Ultisols are found primarily south of Iquitos and and eastward to Manaus and then in a pocket southeast of Manaus (Fig. 1).

The poorly-drained alluvial soils (Aquents, 11.4%; Aquepts, 2.3%) account for 13.6% of the Amazon Basin soils (Table 2). These soils have little or no profile development. They presently are not important to agriculture in the region due to their poor drainage. These soils are found along the Amazon headwater flood plains. Selected soil test data of an Entisol representative of these soils are presented in Table 3.

Although the moderately fertile, well-drained soils comprise only 8.4% of the Amazon Basin (Table 2), they are perhaps the most important at present, since it is on these that the bulk of the Amazon Basin's food crops are produced. These soils include Alfisols ("Terra Roxa Estructurada"), Mollisols, Vertisols, Tropepts, Orthents and Fluvents. Soil test data from an Alfisol representative of these soils are shown in Table 3.

Only 3.3% (Table 2) of the Amazon Basin is covered by the extremely acid and infertile white sands (Spodosols, also known as Tropical Podzols, and Psamments), although these soils have received more attention (Klinge, 1975; Stark, 1978) than warranted by that small percentage. Presented in Table 3 are soil test data from a Spodosol representative of these soils.

One readily sees that the acid, infertile Oxisols and Ultisols (75%) predominate in the Amazon Basin with poorly-drained alluvial soils (13.6%), well-drained moderately fertile soils (8.4%) and very infertile, sandy soils (3.3%) comprising the remainder. However, these acid, infertile soils can be made productive once the constraints to crop production on them are recognized and overcome through proper management.

b. Constraints. Realistic estimates of constraints to crop production in the Amazon Basin were made possible by the Fertility Capability Classification (FCC) system (Buol *et al*., 1975; Buol and Couto, 1978; Buol and Nicholaides, 1980; Sanchez *et al*., 1982) and the Cochrane et al. (1979) use of this system via the FAO-UNESCO (1975) soil maps of South America, aerial surveys and on-site soil sampling. Major soil constraints to farming systems in tropical America and the Amazon Basin were identified by Sanchez and Cochrane (1980), Cochrane and Sanchez (1982) and Sanchez et al. (1982). Those data were further refined to develop the Table 4 estimates of the major soil constraints to crop production in the Amazon Basin. These estimates, though gross, tentative and subject to revision with new information, are considered to give a relatively accurate indication of soil constraints in that region.

Computer-based maps of Amazon Basin soil textures (to 50 cm) and of fertility constraints (condition modifier combinations) in the well-drained soils according to the FCC and as presented by Cochrane and Sanchez (1982) are given in Figs. 2 and 3. The most extensive topsoil textural class is loamy (18-35% clay), while in the subsoil loamy and clayey (>35% clay) predominate. Thus, 72% of the Amazon Basin soil textural classes are L and LC (Cochrane and Sanchez, 1982). The C class (>35% clay in both topsoil and subsoil) makes up 21% of the Amazon Basin. The CR and LR classes, which indicate physical barriers at 50 cm to root development, are found in only 0.4% of the Basin. Sandy soils only represent 4% of the soils of the Amazon Basin.

Nutritional constraints to crop production in the Amazon Basin are widespread (Fig. 3, Table 4). Nine of every ten hectares of the soils of the Amazon Basin are projected to be deficient in nitrogen and phosphorus for crop production (Table 4). Soils deficient in N are not necessarily deficient in P and vice versa, although there are overlaps. The severity of these deficiences depends on the crops grown. For instance, legumes such as peanuts, cowpeas, Phaseolus vulgaris and soybeans need no N amendments if the correct Rhizobia are present or added through inoculation. Some crop species and varieties are capable of producing reasonable yields on soils low in P, whereas others are not. Although 90% of the Amazon Basin soils are low in P, it is fortuitous that only 16% have the ability to transform large quantitites of P into relatively insoluble iron and aluminum phosphates. Consequently, the required P amendments will not be as high on most Amazon Basin soils as on the higher P fixing soils of the acid savannas such as in Brazil's Cerrado.

Nearly eight of every ten hectares of the Amazon Basin soils are estimated to have Al toxicity (79%) and potassium deficiency (78%) problems (Table 4). Some varieties within several crop species, such as rice and cowpeas, are more tolerant to higher levels of Al than are others. Given other desirable characteristics, these varieties could be used in cropping systems for the Amazon with less lime inputs than others require. Adequate K fertilization is a necessity for crop production on those K-deficient soils in the Amazon Basin.

Approximately six of every ten hectares of the soils in the Amazon Basin are projected to be deficient in calcium (62%), sulfur (58%) and magnesium (58%)(Table 4). Use of dolomitic lime in those areas where needed could help alleviate not only the Al toxicity problems, but also the Ca and Mg deficiencies. The S deficiency could be addressed by simple superphosphate applications in areas deficient in both P and S. Very few native areas of the Amazon Basin would be deficient in S without being deficient in P.

Zinc and copper deficiencies are estimated to be problems in 48% and 23% of the Amazon Basin soils, respectively (Table 4). Soil levels of these elements, as those of P, K, Ca, Mg and S must be monitored continually through soil testing during cropping to ascertain when, and in what quantity, amendments are necessary.

One immediately notes that the major constraints to crop production in the Amazon Basin are chemical and not physical; eleven of the first 12 major constraints in Table 4 are chemical. The only physical limitation to crop production in these first 12 constraints is poor drainage and flooding hazard (24%), which occurs in many of the flood plains and inland swamps of the region. The low cation exchange capacity (<4 meq/100 cc) of 15% of the Basin is a chemical limitation to crop production as it indicates low capability to retain nutrient cations such as K, Ca and Mg. Thus, leaching of these elements from well-drained low cation exchange capacity soils can occur following their addition. Imbalances of these elements can also trigger deficiences of one or the other.

Only 8% of the Amazon Basin soils are estimated to have high erosion hazard (Table 4). This is due in part to the fact that 82% of the Amazon has slopes from 0-8% and that the Oxisols and many Ultisols have favorable structures which permit rapid water infiltration, thereby reducing runoff. The key to erosion control is to not clear the highly erodible soils which are also on slopes greater than 30% and have an abrupt increase of clay with depth (6% of Amazon Basin). If these soils are cleared, they must be kept covered with protective vegetative canopies. The rest of the Amazon, which has gentle slopes and no abrupt clay increase with depth, will not have severe erosion hazards if properly managed.

The old "lateritic" myth that the Amazon Basin soils will turn to brick when cleared (McNeil, 1964; Goodland and Irwin, 1975; Friedman, 1977; Irion, 1978) is just that--a myth. Only 4% of the Amazon Basin soils possess a "lateritic" hazard (Table 4) and this is only when the subsoil is exposed. In the southeastern United States the percentage of similar soils is 7% (Sanchez and Buol, 1975); many of these have been farmed continuously for the past 150-200 years without problems. The key is to prevent the soft plinthite in the subsoil from being exposed by erosion of the topsoil. It is only then that the irreversible hardening takes place. As most of these plinthite soils (Plinthaquox, Plinthaquult, Plinthudult) occur only on flat, poorly-drained landscapes in the Amazon Basin, the erosion necessary for plinthite hardening is unlikely to occur (Sanchez _et al_., 1982). Several countries which share the Amazon Basin would like to find more plinthite as it is an excellent, low-cost material for road beds. Thus, laterite hazard is not a constraint to crop production, rather its limited quantities are constraints to road building in the Amazon Basin (Sanchez _et al_., 1982).

Only 7% of the Amazon Basin soils (32 million hectares) are estimated to have no major constraints to crop production. These soils are high in native fertility, well-drained and are classed primarily as Mollisols, Alfisols, Vertisols and some Inceptisols and Entisols. These are extremely important to crop production in the Amazon Basin. However, no soil can continually be "mined," no matter how fertile without being depleted of one or several nutrients. Therefore, nutrient amendments when needed and proper management of these soils are as necessary for their continued productivity as for that of the less-fertile ones.

Observed over 50 years ago by Marbut and Manifold, (1925), but realized by few people, other than soil scientists and agronomists, is the fact that the soils of the Amazon Basin are very similar in properties and management to those of the southeastern United States. The work reported herein confirms that observation. The most dominant Ultisols of the Amazon Basin, except for their location in the tropics and consequent temperature regime, are exactly the same as the most dominant and important agricultural soils in the Coastal Plain of the southeastern United States, for all management intents and purposes.

Therefore, soil nutritional constraints to crop production are the primary underlying cause for migratory agriculture or shifting cultivation being the almost exclusive current crop production system in the Amazon Basin. If these soil constraints to crop production can be overcome by proper management practices, then shifting cultivation will be replaced by continuous cultivation and the primary cause for clearing the Amazon forest will have been alleviated.

3. Crops

a. Resources. Although a wide array of crops are cultivated in the Amazon Basin, the most important economical annual food crops for small farmers in that area are rice, maize, peanuts, soybeans, cowpeas and cassava.

Quite obviously the acid, infertile conditions of the predominant Oxisols and Ultisols of the Amazon Basin are constraints to production of most of these species, except for some varieties of rice, cowpeas and cassava which are adapted to these conditions. However, there are also disease, insect and some climatic constraints which are just as important to be alleviated as are the soil constraints in order to produce sustained crop yields (Bandy and Sanchez, 1981). These follow.

b. Constraints. Rice (Oryza sativa). Blast (Pyricularia oryza) is the principal limiting factor to both upland and flooded rice production in Yurimaguas. Brown leaf spot (Helminthosporium oryza) also occurs, especially when potassium and/or water are limiting. Tall-satured varieties, such as the native Carolino, are susceptible to lodging under high rainfall conditions and especially if fertilized more than adequately with nitrogen.

Maize (Zea mays). Leaf blight (Helminthosporium sp.), kernel dry rot (Diplodia sp.) and European corn borer (Ostrinin nuvaladis) are the main disease and insect problems in the Yurimaguas area. Additionally, the relatively low solar radiation (Table 1), relatively short daylength of 11.5-12/5 hours and high night temperatures of >20°C contribute to low production, efficiency and distribution of photosynthate, thereby decreasing availability of carbohydrates for grain filling. Tall-statured varieties are susceptible to lodging under high rainfall conditions and especially if fertilized more than adequately with nitrogen.

Peanuts (Arachis hypogaea). Thrips, most likely Schtothrips dorsalis and Frankliniella schultzen, are carriers for virus which can cause serious problems. Peanut rust (Puccinia erachidis) and black spot (Cercospora sp.) can cause problems, but not usually, as many Peruvian cultivars are resistant. Cercospora incidence is noted more on soils low in potassium.

Soybeans (Glycine max.). Frog eye spot (Cercospora sojina), pod and stem blight (Diaporthe phaseolorum var. sojae) and purple stain (Cercospora kikuchii) have been noted to reduce yields and/or seed quality considerably when cloudy, humid conditions occur during pod filling stage. Seed viability in this humid climate is also a problem.

Cowpeas (Vigna unguiculata). Fungal infestation of the pods by Choanephora curcurbitaricum and others can be a major problem if excessive rainfall occurs during pod filling stage.

Cassava (Manihot esculenta). Super elongation due to the disease Sphaceloma manihoticola is the only potentially serious problem of cassava in the Yurimaguas region of the Amazon Basin.

These disease, insect and climatic constraints to crop production on the predominant soils of the Amazon Basin must be addressed as in any agricultural system, for that system to become productive. The small farmers of the region currently are facing these problems. Some are doing so successfully, others not successfully. However, it should be emphasized again that once the constraints to crop production, whatever they may be, are addressed and alleviated by proper management practices, then shifting cultivation will be replaced by continuous cultivation and the primary cause for clearing the Amazon forest will be no more.

C. CURRENT CROPPING SYSTEM--SHIFTING CULTIVATION

The term shifting cultivation encompasses the many variations practiced around the world and includes any system under which the soil remains fallow for a longer period of time than it is cropped. Shifting cultivation has been discussed in numerous publications, among those being Moran (1981), Nicholaides (1979), Sanchez (1977), Ruthenberg (1976), Sanchez (1976), Grigg (1974), Manshard (1974), Sanchez (1973), National Academy of Science (1972) and Nye and Greenland (1960).

1. Clearing

Most shifting cultivators in the Amazon Basin employ the "slash-and-burn" technique in which the larger trees and shrubs are cut by ax and machete or chainsaws during period of low rainfall, allowed to dry for up to 10-14 days, and burned either in place or in piles of smaller trees and shrubs. Others, such as those in the rainforests on Colombia'a Pacific coast, broadcast crop seed in the forest, cut the undergrowth and use that vegetation as a mulch, instead of burning.

Not all land clearing in the Amazon Basin, however, is by the shifting cultivators. Heavy equipment such as bulldozers, tree crushers and D8 tractors with large chains between them. Mechanical clearing by the larger farmers and ranchers who have access to capital is noted by Hecht[2/] to be increasing in prominence. However, as we shall see, its increased popularity is not necessarily equated with increased crop yields.

2. Cropping and Fallow

The most common cropping system practiced by shifting cultivators involves planting some combination of rice, beans, maize, cassava, sweet potatoes and plantains among the ashed debris using a "tacarpo," "coa" or stick to make a hole into which seed or vegetative portions of the crops are placed. Moran (1981) states that cassava and bananas are often planted before rice and that cassava is planted to 90% of the cultivated fields in the Amazon. In the Yurimaguas region of the Peruvian Amazon, small farmers usually plant rice in monoculture following slash-and-burn clearing. Then an intercrop of maize, cassava, plantains and sometimes pineapple is grown (Bandy and Sanchez, 1981). The common intercropping practice reduces, but does not eliminate, the

---

[2/] Hecht, S. 1981. Unpublished report. Univ. Calif-Berkeley.

need for manually weeding the crops.

However, after only one or two harvests, especially on the acid, infertile soils, crop yields decline drastically due to soil fertility depletion and consequent greater weed competition. Consequently, the land is abandoned to forest regrowth for a 17 to 20 year fallow period, during which time the fertility of the soil is rejuvenated by the nutrient cycling of the forest growth and litter. Then the land is cleared once again, cropped and returned to fallow.

Although this traditional form of shifting cultivation is ecologically sound (Nye and Greenland, 1960; Moran, 1981) and functional, it has been described as guaranteeing perennial poverty for those who practice it (Alvim, 1978). What has happened in several parts of the Amazon in recent years with the opening of the Transamazon Highway and other roads (Moran, 1981), is a consequent increased population pressure, shortening of both the forest fallow period and the soil fertility regeneration process, and a subsequent conversion of an ecologically-sound cropping system into an unstable, unproductive one which causes ecological damage (Sanchez et al., 1982). The effect of shortening of the fallow period is especially pronounced on the more infertile soils, the Ultisols and Oxisols, of the Amazon Basin. When one notes that these soils comprise 75% of the Amazon, the true perspective of the situation is realized.

Therefore, it becomes immediately evident that some alternate cropping system(s) must be made available to and accepted by the current shifting cultivators on both the more and less fertile soils of the Amazon Basin, if there is to be any chance of producing more food for the Amazon Basin's people while at the same time helping to preserve the ecological integrity of much of the yet undisturbed Amazon forest.

D. IMPROVED CROPPING SYSTEMS--CONTINUOUS CULTIVATION

Certainly included in these alternate cropping systems for the Amazon Basin must be those developed by North Carolina State University's (NCSU) Tropical Soils Research Program in cooperation with Peru's Instituto Nacional de Investigacion y Promocion Agraria (INIPA) in Yurimaguas, Peru since 1971. These continuous cropping systems resulted as NCSU and INIPA addressed the question whether continuous cropping of basic food crops would be agronomically possible and economically feasible on the acid, infertile soils of the Amazon Basin.

The primary research site selected, Yurimaguas, is representative in both climate and soil properties of much of the tropical rainforest subregion of the Amazon Basin. Its mean annual temperature is 26°C, well-distributed mean annual rainfall exceeds 2100 mm with three months averaging about 100 mm each and the rest around 200 mm (Table 1). The properties of the flat, well-drained Ultisol at the Yurimaguas Agricultural Experiment Station (Table 3) reflect a sandy loam surface over a clay loam subsoil, both of which have toxic levels of Al, are deficient in P, K and most other nutrients and have a low cation exchange capacity.

Yurimaguas is experiencing a large population influx as it is the westernmost large fluvial port of the Amazon headwaters. Its present population of 35,000 is expected to triple by 1990. This population influx creates extra pressure on the land, shortens the fallow duration and consequently breaks the soil fertility rejuvenation process. Similar population and land pressures are found in many other areas of the Amazon Basin.

1. Land Clearing

The choice of the land clearing method is the first step, and certainly one of the most important, affecting cropping productivity of soils of the Amazon Basin. Crop yields on soil cleared by the traditional slash-and-burn were found superior to those on the same soil cleared by bulldozer (Seubert et al., 1977). The reasons were 1) fertilizer value of the ash, 2) no soil compaction or 3) no topsoil displacement as caused by bulldozer.

Nutrient content of the ash and partially-burned material produced by slashing and burning a 17-year old forest fallow on an Ultisol of Yurimaguas contributed the equivalent of 145 kg/ha of urea, 67 kg/ha of simple superphosphate, 50 kg/ha of potassium chloride, 1/4 ton/ha of dolomitic limestone, fairly large quantities of iron and manganese, and some zinc and copper (Table 5). Variability in the nutrient content of the ash of various slash-and-burn clearings is certainly present due to different clearing techniques, soils, vegetation and portion of biomass burned. Da Silva (1979) estimated that only 20% of the forest biomass was ashed when a virgin forest on an Ultisol in southern Bahia, Brazil was burned and found extremely wide ranges of nutrient contents when the ash of various tree species was analyzed. This could indicate that certain species might be accumulators of certain nutrients (Cochrane and Sanchez, 1982). In more fertile soils, the fertilizer value of the ash for crop production might be of less importance, as Cordero (1964) found no concomitant increase in crop yields with increases of phosphorus and potassium produced by burning vegetation on an Entisol which was already high in those elements.

Soil compaction produced by bulldozed clearing of the sandy loam

Ultisols of Yurimaguas increased mechanical impedance and decreased water infiltration rates substantially (North Carolina State University, 1978-1979). Similar data have been noted for other locations in the Amazon Basin (Table 6). Infiltration rates on the bulldozer-cleared plots in Yurimaguas after six years of cropping had increased only from 0.5 to 4.1 cm/hr, while those of the slash-and-burn cleared plots remained at 10 cm/hr, almost 250% better (Table 6). The subsoil hardpan produced by bulldozer clearing was broken by chisel plowing or subsoiling with consequent increase in crop yields (Alegre _et al_., 1981). Thus, it is possible to reclaim land compacted by bulldozer clearing. Obviously, it would be more desirable to prevent the compaction problems from occurring in the first place.

Topsoil displacement caused by the bulldozer dragging uprooted trees and logs into the topsoil has not been quantitatively defined in the Amazon Basin. However, even the most inexperienced observer notes scraping in high spots and deposition in low spots following bulldozer clearing. Sanchez (1976) suggested that the better jungle regrowth near windrows of felled vegetation might indicate yield reductions due to topsoil removal in adjacent areas. When half of the top 2.5 cm of an Alfisol was removed, corn yields were found to decrease in Nigeria (Lal _et al_., 1975).

The land clearing method used very much affects crop yields. Never did rice, maize, soybean or cassava yields on bulldozed land at Yurimaguas exceed those on land cleared by slash-and-burn (Table 7). Without fertilizer and lime, the mean relative yields of eight croppings on bulldozer-cleared land was only 30% of that on slashed-and-burned land. Lime was especially critical as mean relative yields only increased to 43% when NPK were applied, but went to 80% when NPK and lime were applied. However, effects of topsoil removal and subsoil compaction are apparent as even with the proper nutrient amendments, yields on bulldozer-cleared land never were greater than 80% of those on slashed-and-burned land.

Many farmers and development organizations in the Amazon Basin recognize the negative effects of bulldozer land clearing. Since 1978 Brazilian government credits for large scale mechanized land clearing operations have been sharply reduced (Cochrane and Sanchez, 1982). Many farmers and development organizations are beginning to question the practice of complete destruction of the forest versus its partial harvest prior to burning. By removing the marketable trees prior to cutting and burning the remainder, da Silva (1979) made use of the advantages of slash-and-burn for soil fertility, and increased income from the cleared area. That there were no significant differences between da Silva's method and traditional slash-and-burn is probably due to the relatively small portion of the biomass actually burned.

Offering certain advantages and disadvantages are other alternate methods of land clearing, such as using two bulldozers dragging a heavy chain between them (Toledo and Morales, 1979), large tree crushers, bulldozer with KG shear blade with and without burn (North Carolina State University, 1980-1981).

Unquestionably, the traditional slash-and-burn clearing system is the best for most farmers of the Amazon Basin, unless they can add additional fertilizer, lime and tillage operations to compensate for the soil fertility limitations and compaction disadvantages of bulldozer clearing. The crucial question now revolves around how to keep these slash-and-burn clearings continually productive with a consequent reduction in migratory agriculture.

2. Continuous Cropping

The NCSU/INIPA program turned its attention to developing continuous crop production systems for these slashed and burned areas of the acid, infertile soils of the Amazon Basin, once the advantageous nature of the traditional slash-and-burn clearing system had been established. Components included determing the most important crops, their best cropping sequences, their nutritional needs and changes in soil properties with time of cultivation (North Carolina State University, 1972-1981; Bandy, 1977; Bandy and Benites, 1977; Sanchez, 1977a, b, c, d; Villachica, 1978; Wade, 1978; Valverde et al., 1979; Nicholaides, 1979). Crops grown and studied included rice, maize, cassava, peanuts, cowpeas, soybeans, sweet potatoes and plantains in various rotations and combinations. As mentioned earlier, the most important economical annual food crops for the Amazon Basin are rice, maize, peanuts, soybeans, cowpeas and cassava.

The production of three crops per year without any overlapping relay cropping is permitted by the climate and rainfall pattern of the Yurimaguas area. Recommended planting dates for the main annual crops in Yurimaguas are shown in Fig. 4. Five crops per year were possible with intercropped combinations (Wade, 1978), but as the farmers of the area are turning to rotational monocultures, only the most promising monoculture rotations obtained to date will be presented. These are the rotations of upland rice-maize-soybeans and upland rice-peanuts-soybeans, which keep the soil covered during most of the year. Monocultures without rotations did not produce sustained yields because of a build-up of many of the diseases and insects previously detailed.

Twenty-one consecutive crops of the upland rice-maize soybean rotation have been harvested from the same field since it was slash-and-burn cleared in October, 1972. Without fertilization and lime, yields declined to zero with the third consecutive crop (Fig. 5). The average long-term yield of the "complete" fertilization treatment of this rice-maize-soybeans rotation, replicated over three fields, was 7.8 tons grain/ha/yr. Twenty-one consecutive crops of the upland rice-peanut-soybean rotation also have been harvested with equally high yields. In fact, peanuts with higher yield potential, may be more appropriate for the area due to the climatic constraints on corn. These results indicate that with adequate fertilization (Table 8), subtained moderately high yields of these annual crops under continuous production can be achieved on some of the most infertile soils of the Amazon Basin.

Not only are these systems agronomically feasible, but they are economically productive as well. A net return of U.S. $2.91 per U.S. $1.00 invested in fertilizer and lime at 1977 Yurimaguas prices, including transportation, was realized for the rice-peanuts-soybeans rotation (Bandy, 1977).

3. Soil Fertility Dynamics: The Key Factor

The understanding of soil fertility dynamics was the key to the development of the successful "Yurimaguas technology." The nutritional needs of the crops in the Amazon Basin, as with crop production anywhere, could be determined only by continual monitoring of soil fertility dynamics through soil and plant sampling and testing. Only then could the most judicious use of lime and fertilizers for crop production be ascertained.

Soil fertility dynamics were monitored by sampling soils after each harvest and analyzing for pH, organic C, total N, exchangeable K, Ca, Mg and Al, effective cation exchange capacity and available P, Zn, Cu, Fe and Mn (Fig. 6). Determined periodically by plant analysis were S, B and Mo. Of special interest is the "check," which never received fertilizer or lime, and the "complete," which received what NCSU's Tropical Soils Research Program considered the best fertilization and liming practices according to soil tests and accumulating experience.

Time of appearance and intensities of fertility limitation varied among various clearings even though they were near each other, on the same soil mapping unit, landscape position, and had the same pre-clearing vegetation. Burn intensity was considered a factor contributing to this variability. A generalized summary of the soil fertility dynamics follows.

A temporary increase in soil fertility produced by ash from the burn was reflected by increases in pH, total N, available P, exchangeable K, Ca, Mg and some micronutrients, with a concomitant decrease in exchangeable Al to below-toxic levels. Similar changes have been noted in other locations in the Amazon (Table 9). As a result, upland rice, the first crop planted in Yurimaguas, did not suffer from fertility limitations.

At about eight months after clearing, the N and K levels were reduced such that their deficiency symptoms appeared along with occasional ones of S, Cu and B. Organic matter contents, as reflected by organic C in the topsoil decreased sharply during the first year at an annual decomposition rate of 25%, but reached a new equilibrium level beginning with the second year. The rapid organic matter decomposition released many H^+ ions that acidified the soil and increased exchangeable Al to toxic levels, thereby reversing the liming effect of the ash.

During the second year, P and Mg became deficient, as did Ca within the first 30 months and Zn during the fourth year. Manganese deficiency was suspected after the eighth year. Deficiences of Mo were detected occasionally in grain legumes, particularly when seed produced in acid soils of the Amazon were used, but not when seed came from more fertile soils of the Peruvian coast. Therefore, after eight years of continuous cultivation, crops grown on this Ultisol have exhibited deficiencies of all essential soil nutrients but Fe and Cl.

Fertilizers and lime were added according to soil test recommendations in the "complete" treatment. However, during the third year yields declined rapidly in those treatments (Fig. 5). Soil analysis identified the two factors responsible for this decline: 1) a shorter than expected residual effect of the lime applied and 2) a triggering of Mg deficiency induced by K applications and a consequent K/Mg imbalance (Villachica, 1978). Crop yields stabilized (Fig. 5) after correction of these factors. It is apparent that a monitoring of the soil fertility dynamics during the period when the soil was undergoing transition from forest to cropland provided the key for continuous cultivation of these Amazon Basin soils.

It is appropriate to emphasize here the value of long-term field research. Second and third generation problems do not appear in the first years of continuous cultivation. Had the research been branded a success and ended after one or two years, the answers to longer-term continuous cultivation of annual crops on these soils would not now be available for the farmers desiring to implement it.

The fertilizer needs for intensive continuous cropping on these soils (Table 8) are no more than those required for crop production in Ultisols in other parts of the world. In fact, fertilizer rates for continuous production of corn, soybeans and peanuts on Ultisols in the Amazon Basin do not differ substantially from these crops grown in Ultisols of southeastern United States. On an annual basis, the total amounts are somewhat higher in the Amazon Basin because three crops a year are grown instead of one. After the first crop, which does not normally require fertilization, chemical inputs, whether inorganic or organic, are required to produce and sustain moderately high yields.

These fertilizer recommendations, as with any sound ones, are site-specific and thus only applicable to the soils and cropping systems in question. In other soils and cropping systems recommendations should be based on local soil analysis. Nevertheless, Table 8, developed after some 8 years of continuous cropping, gives an indication of the inputs and their rates required for continuous crop production on Ultisols of the Amazon Basin.

4. Effects of Soil Properties

A common concern in the literature is that of soil degradation with cultivation in the humid tropics (McNeil, 1964). However, the results of NCSU's Tropical Soils Research Program indicate just the contrary; i.e., with intensively managed, appropriately fertilized, continuous crop production systems, soil properties improved (Table 10).

After 20 consecutive crop harvests, the topsoil pH had increased from a very acid 4.0 before clearing to a favorable level of 5.7. Organic matter contents decreased by 27%, most of which occurred during the first year. Exchangeable Al was decreased by liming from very high levels to negligible amounts, decreasing Al saturation on the exchange sites from a toxic level of 82% to a negligible 1%. Exchangeable Ca levels increased nearly twenty-fold as a consequence of liming applications. Exchangeable Mg levels doubled, although this figure fluctuated over time. Exchangeable K levels did not increase in spite of large quantities of K fertilizer applied, suggesting rapid utilization by crops and perhaps leaching to the subsoil. Effective CEC, a measure of the soil's capability to retain cations against leaching, doubled with time, a significantly important increase; this was probably a consequence of the pH-dependent charge characteristics of the kaolinite clay and iron oxides. Fertilization also increased available P levels from below the critical level of 10 ppm P to substantially above it. The same trend occurred with Zn and Cu, as both elements were applied as fertilizers. However, as no Mn fertilizer was applied the available Mn levels decreased to less than the critical level of 5 ppm, suggesting the possibility of Mn deficiency. Available Fe levels remained considerably above the critical range of 20-40 ppm. On the whole, these soil fertility changes are indicative of improvement in the topsoils' chemical properties.

No unfavorable changes in soil physical properties have been detected thus far (North Carolina State University, 1978-1979) because of the protection that three well-fertilized crops per year provide against the impact of rain on the soil. Although crop residues are left in the field until the experimental plots are tilled again in preparation for the next planting, the soil is exposed for a period of up to 30 days until the crop canopy is established. Occasionally following heavy rains, runoff losses on sloping land have been observed; but areas larger than one hectare have not been tested. However, severe surface soil compaction was rampant in the continuously cultivated plots that received no fertilization because crops never developed a complete canopy.

Frequently acting as chemical barriers to root development are the acid subsoils of Oxisols and Ultisols. Crop roots are unable to enter a subsoil with high Al saturation and low exchangeable Ca (Bandy, 1976; Gonzalez et al., 1979; Ritchey et al., 1980). Consequently produced are shallow root systems which often result in plants suffering from drought stress during rainless periods while the subsoil has available water. Deep lime placement compared with normal or shallow lime placement resulted in corn roots being able to grow into the subsoil (Fig. 7) and consequently to use the subsoil moisture to reduce plant water stress. The deep liming treatment showed a more even distribution of soil water use by the corn plant throughout the 45 cm profile and resulted in a minimum of 8 mm more soil water used by the plants on the deep lime plots (North Carolina State University, 1978-1979); that amount equals 2-3 days of evapotranspiration from corn plants.

With time following lime and fertilizer application, these chemical subsoil constraints have been observed to be alleviated. Significant increases in Ca, Mg and effective CEC and a decrease in Al saturation were found in subsoil layers of 15-45 cm depth after 92 months of continuous cultivation of this acid, infertile Ultisol at Yurimaguas. The downward movement of these basic cations was promoted by the lime and fertilization scheme which resulted in a more favorable environment for root development than before clearing. Appropriate fertilization and continuous cultivation, therefore, improved rather than degraded this

Ultisol of the Amazon Basin.

5. Farmer Acceptance

The true test of any improved technology for continuous cropping in the Amazon Basin is its acceptance and utilization by the target group--the shifting cultivators. Thus, in 1978, the NCSU and INIPA team felt that results from formal experiments appeared to have sufficient practical application to test at the farm level. Established in shifting cultivators' slashed-and-burned fields within an 80 km radius of Yurimaguas were a series of demonstration plots.

The small farmers themselves, with NCSU/INIPA support, planted and managed several technological systems using several three crop per year rotations (Mesia et al., 1979). The systems were 1) their traditional system, 2) improved agronomic practices without lime and fertilizer and 3) improved agronomic practices with moderate rates of lime (1 ton $CaCO_3$ -equivalent/ha/yr) and fertilizer (60 kg N/ha for rice and corn only, 35 kg P/ha/crop, 66 kg K/ha/crop and 22 kg Mg/ha/crop). System 3 is the improved "Yurimaguas technology" and was considered equivalent to the "complete" treatments developed at the Yurimaguas Agricultural Experiment Station. The three crop per year rotational systems were planted on a 1-10 year forest fallow slashed-and-burned clearings in soils similar to (Typic and Aquic Paleudults and Tropudults) and more fertile than (Typic Tropudults and Vertic Eutropepts) those of the Yurimaguas Agricultural Experiment Station.

The annual cumulative grain yields produced by the improved System III ranged from 7.5 to 11.4 tons/ha, while those from the traditional System I were 3.5-5.3 tons/ha (Table 10). These yields are similar to those obtained at the experiment station. They compare very favorably with the traditional yields of 1 to 1.5 tons grain/ha usually produced on the shifting cultivators' farms in the Amazon Basin (Smith, 1981).

Soil analysis revealed soil fertility depletion due to crop removal and loss of ash-liming effect after three consecutive crops. In all locations, the soils had become deficient in P, more acidic with exchangeable Al increasing and Ca and Mg decreasing; organic C also decreased. This soil fertility depletion was reflected in declining yields of corn and soybeans in the respective corn-peanuts-corn and soybeans-rice-soybeans rotation (Table 10). As soil fertility depletion became more severe in the second year of the trials, yields declined even further in the traditional system.

The System III corn-peanuts-corn rotation was revealed by economic analysis using no limit on labor and capital resources to give the highest net revenue per hectare (923,771 Peruvian soles) and the consistently highest marginal rate of return, exceeding 450% in all three systems (North Carolina State University, 1978-1979).

The limited resource economic analysis restricted capital, labor and even work output by nutritional intake of the small farmer family to all possible levels and combinations. This analysis revealed that the System III corn-peanuts-corn rotation on a 1.45 hectare farm using 50,000 Peruvian soles as owned capital, another 50,000 soles as borrowed capital (at 64% APR), and a model seven-member small farm family as the sole labor pool could realize a net farm income of 1,555,132 Peruvian soles (North Carolina State University, 1978-1979). This net income is equivalent to U.S. $3,055 at the current exchange rate and compares extremely favorably with the current net farm income in the Yurimaguas area of U.S. $750 and the $1,500 annual net income of the top 25% of the families in Lima's slums (Hernández and Coutu, 1981).

Thus, the small farmers in the region have the continuous cropping alternative to enable them to permanently and economically farm their land normally subjected to shifting cultivation. After the first year, all 11 of the initial farmers in the project adopted use of the improved seed and insecticides, 10 adopted the improved plant spacing techniques, six adopted the use of weeding at critical times, five adopted the use of fertilizer, but none adopted the use of lime. As many of the farmers' plots were on higher base-status soils, the need for lime was not exhibited as rapidly as it would have been on the more acid soils. As the 11 farmers selected to participate in the initial demonstration project are the respected farm leaders in their communities, their neighbors are now learning from them.

Although the initial plans were for only three consecutive crops on the initial 11 farmers' land, three wanted to continue and did so for a second year and one continued into the third year stopping only after he had grown seven consecutive crops on a parcel of land that could not produce more than two under the traditional system. That farmer, Sr. Luiz Gonzalez, is one of the true salespersons for the workability of the "Yurimaguas technology" on small farms. He and several other small farmers are now pioneering the continuous cropping technology on areas greater than one hectare. In the 1979-1980 and 1980-1981 growing seasons, five and 19 more small farmers, respectively, entered into the same demonstration arrangement as had the initial 11.

A pilot project with 27 rural schools in the Yurimaguas region was initiated also in the 1980-1981 period in order to reach more small farmers and their families. Collaboration among INIPA (under the Ministry of Agriculture), the Ministry of Education and NCSU set up the same type demonstration projects but this time with rural school students, their families and teachers planting and managing the trials using the three systems. After only one year, over 50% of the 626 small farm families involved in the project are interested enough to want to use at least some of the "Yurimaguas technology" on their own lands.[3/] Given the favorable Peruvian government response to the "Yurimaguas technology," the local availability of fertilizer and credit has increased and marketing facilities have improved in Yurimaguas. Clearly, this is only a beginning, but it is a solid one which is permeating the Yurimaguas region and has the potential to be of benefit to small farmers throughout the Amazon Basin.

6. Continued and New Research

As important as are the findings that there are available agronomically and economically feasible continuous cropping systems to at least some small farmers on the acid, infertile soils of the Amazon Basin, not all the answers have been obtained for changing the region's predominant agricultural practice from shifting to permanent cultivation. Several complementary options for sustained agriculture in the Amazon Basin are being investigated by the NCSU/INIPA team and others. These include the following research thrusts.

Alternate land clearing methods. New research in Yurimaguas is directed to determine whether any of several combinations of the traditional slash-and-burn clearing with some type of small- or large-scale

---

[3/] Benites, J. 1981. Unpublished report. North Carolina State Univ.

mechanization might be advantageous in both clearing and subsequent crop yields for the small farmers of the region. One of the most promising involves use of bulldozer with KG shear blade to cut the trees at soil surface, thereby minimizing topsoil removal, and removing the larger trees prior to burning the vegetation for fertilizer value of the ash[4/]. Longer term research is needed in this area.

Lower input systems. To develop alternate systems requiring lower inputs for the small farmers of the region, emphasis is given to this area of research in Yurimaguas. One approach is evaluation of crop varieties for tolerance to soil Al. As soil acidity is a main limiting factor to crop production on the Ultisols and Oxisols of the Amazon Basin, determining tolerant varieties would result in lessening costly, though economical, lime inputs. Evaluation of varieties of rice, peanuts, cowpeas, soybeans and sweet potatoes has identified promising varieties of rice and cowpeas (Piha and Nicholaides, 1981). These efforts are continuing.

Increase of efficiencies of N and K fertilizers and evaluation of use of rock phosphate compared with the more costly phosphate fertilizers on these acid soils (in collaboration with IFDC and CIAT) are other components of the low input approach. Research in these areas, though promising, will require more years.

Use of organic inputs to replace or supplement the costly, though economical inorganic inputs, has included mulching crops with residues from the previous crop or with Panicum maximum. This research has produced non-conclusive results with generally detrimental results for

---

[4/] Cassel, D. K. and J. C. Alegre. 1981. Unpublished data. North Carolina State University.

upland rice, some positive yield increase in corn and little effect on soybeans and peanuts after more than 20 experiments (Valverde and Bandy, 1982). Use of kudzu (Pueraria phaseoloides) as a green manure has provided positive results, often attaining crop yields similar to complete fertilization (Wade, 1978). The labor involved in hand-harvesting, transporting and incorporating kudzu into the soil has made this an unattractive alternative to the small farmers. Making compost out of crop residues appears to have some promise. For the first four consecutive crops, replacing complete fertilization with compost produced from crop residues resulted in only a 20% yield reduction (Bandy and Nicholaides, 1979). In order to maintain this rate, it was found to be necessary to apply K fertilizer with the compost. However, the potential use of this practice also is restricted by the high labor requirements of compost making.

There is current research on use of managed kudzu fallows as an intermediate stage between shifting and continuous cultivation.. Kudzu can establish itself on the acid, infertile soils and quickly develop a lush green canopy underlain by an abundance of N-fixing nodules in its roots. Kudzu can be killed by slashing with a machete and burning after one or two years of fallow. Reasonable crop yields have been obtained by rotating 2 crops with 1 to 2 years of fallow (Bandy and Sanchez, 1981). During the second rotation, K was again needed to obtain moderate crop yields. Additional research is needed.

Legume-based, low input pasture production technology is being developed, primarily for the sloping areas of Ultisols, using acid-tolerant grass and legume species selected by CIAT's Tropical Pastures Program (Toledo and Serrao, 1981). Promising germplasm has been tested for adaptation in an Ultisol of pH 4.0 and 80% Al saturation with only 11 kg P/ha application as simple superphosphate. Results thus far reveal the grasses Andropogon gayanus, Brachiaria humidicola and B. decumbens plus the legumes Desmodium ovalifolium, Pueraria phaseoloides, and Centrosema pubescens to be well adapted to the soil, climate, pest and disease constraints of the region. Grass-legume pastures are now being tested under grazing pressure (Ara et al., 1981), although conclusive results are not yet possible.

Also considered vital to development efforts in the Amazon Basin is the use of indigenous and imported tree species. Agroforestry is consequently an important new research component at Yurimaguas. Being initiated is research to combine crop production systems at various input levels with promising tree species that can produce food, oil or pulpwood. These include the peach palm (Guilielma gasipaes), oil palm (Elaeis guianensis) and pulp producing Gmelina arborea and Pinus caribea.

The Amazon Basin's relatively fertile alluvial soils which are not subject to flooding have great food production potential. Application of research on improved rice varieties and spacing (Sanchez and Nurena, 1972) resulted in doubling rice yields without eliminatng shifting cultivation. Stressing their importance is their inherent native fertility and proximity to natural transportation systems. Current research at Yurimaguas is developing the most suitable paddy rice production technology with river irrigation and using rotations of corn, soybeans and cowpeas when the soils are not flooded. Other innovative farming systems for similar soils are being developed by UEPAE/EMBRAPA near Manaus (UEPAE/EMBRAPA, 1979-1981).

E. CONCLUSIONS

Increasing demand for food and fiber within the countries sharing the common heritage of the Amazon Basin will continue, through both spontaneous and government-directed colonization, to increase the clearing of the Amazon Basin forests, in spite of the objections of well-meaning individuals and organizations. The data presented herein show clearly that attempts to produce food (and pasture) crops without the correct technology for the acid, infertile soils which comprise 75% of the Amazon Basin are likely to fail and to produce widespread ecological damage. The key is the development, extension and use of the correct technology for these soils so that sustained continuous cultivation can occur on the cleared lands, with a consequent preservation of the ecological integrity of those portions of the Amazon Basin which are yet uncleared.

1. Limitations

An incorrect inference would be that continuous production technologies described herein are directly applicable to all the Oxisols and Ultisols in the Amazon Basin. The NCSU/INIPA research has concentrated on nearly level soils (<5% slope), thereby avoiding the erosion hazards of cultivating the undulating lands. Adaptation of the "Yurimaguas technology" to undulating lands would be needed, perhaps including terracing as practiced in areas of humid tropical Asia. Other options for the undulating lands to be cleared could be legume-based pastures or agroforestry. Better yet would be to leave the undulating Amazon Basin forests in their pristine state and to concentrate food production efforts on the 205 million hectares of well-drained Oxisols and Ultisols with less than 8% slope (Sanchez et al., 1982).

Socio-economic conditions provide another limitation to the widespread adaptation of the "Yurimaguas technology." The Yurimaguas area, though not a privileged region of the Amazon, has an unpaved road to Lima and several rivers which link it with the rest of the country and therefore with markets. The data show that present socio-economic conditions indicate clear economic feasibility for the "Yurimaguas technology." However, different cost:price ratios, an inelastic demand for products, various government policies and many other time- and location-specific factors could make the same technology economically unattractive. For example, attempts at continuous cultivation in isolated areas with little market accessability could be counterproductive. Necessary for any region considering adopting the "Yurimaguas technology" are site-specific economic interpretations based on local and national factors.

Also, agronomic conditions could be different within and among regions. Therefore, prior to widespread implementation attempts, the "Yurimaguas technology" must be tested through adaptive research trials to local situations. Modifications could include different fertilizer rates, different crop species, varieties and rotations. Vital to these adaptive research trials for fertilizer rates will be some type of soil fertility evaluation and improvement service to assist farmers changing from shifting to continuous cultivation.

2. Potential

Once the limitations are realized and addressed successfully, the potential of the"Yurimaguas technology" is that settlers and governments in the Amazon Basin will have available the means to increase food production while sparing many hectares of forest. Farmers do not clear the Amazon forest because they like to do so. Slash-and-burn clearing is excruciatingly hard work. Farmers clear the rainforest because they need to grow food and fiber. If they can produce more food more economically with less work, as are those involved with the NCSU/INIPA project, they will do so without hesitation. If they cannot, then the Amazon Basin forest will continue to fall under the shifting cultivators' axes. The "Yurimaguas technology" offers one agronomically-, economically-, and ecologically-sound alternative to that scenario.

7. LITERATURE CITED

Alegre, J. C., D. K. Cassel, and D. E. Bandy. 1981. Effects of tillage practies on reclaiming a severely compacted Ultisol in Yurimaguas, Peru. p. 38. In Agron. Abstrs., Amer. Soc. of Agron. 1981 Ann. Mtgs. Madison, Wis.

Alvim, P. T. 1978. Perspectivas de produção agricola na região amazõnica. Interciencia 3(4): 243-249.

Ara, M., P. A. Sanchez, D. E. Bandy and J. M. Toledo. 1981. Adaptation of acid-tolerant grass and legume pasture ecotypes in the Upper Amazon Basin. p. 38. In Agron. Abstrs. Amer. Soc. Agron. 1981 Ann. Mtgs. Madison, Wis.

Bandy, D. F. 1976. Soil-plant-water relationships as influenced by various soil and plant management practices on Campo Cerrado soils in the Central Plateau of Brazil. Ph.D. thesis. Cornell Univ. Ithaca, N.Y. 236 pp.

Bandy, D. E. 1977. Manejo de suelos y cultivos en sistemas de agricultura permanente en la selva amazõnica del Peru. In P. Arens (ed.) FAO/SIDA: Reuniõn-Taller sobre Manejo y Conservacion de Suelos. Lima, Peru.

Bandy, D. E. and J. Benites. 1977. Proyecto internacional de suelos tropicales, Yurimaguas. Ministerio de Alimentaciõn, Lima, Perũ. 32 pp.

Bandy, D. E. and J. J. Nicholaides, III. 1979. Use of composts for crop production on Ultisols of the Amazon jungle. p. 42. In Agron. Abstrs. Amer. Soc. of Agron. 1979 Ann. Mtgs. Madison, Wis.

Bandy, D. E. and P. A. Sanchez. 1981. Continuous crop cultivation in acid soils of the Amazon Basin of Peru. Unpublished manuscript presented at the Workshop on the Management of Low Fertility Acid Soils of the American Humid Tropics held at the University of Surinam, Faculty of Natural Resources, Panamaribo, Surinam and sponsored by IICA. November 23-26, 1981.

Buol, S. W. and W. Couto. 1978. Fertility management interpretations and soil surveys of the tropics. Chapter 5. pp. 65-75. In Drosdoff, M., R. B. Daniels and J. J. Nicholaides, III (eds.) *Diversity of Soils in the Tropics*. Amer. Soc. Agron. Spec. Publ. No. 34. Madison, Wis.

Buol, S. W. and J. J. Nicholaides, III. 1980. Constraints to soil fertility evaluation and extrapolation of research results. pp. 425-438. In: IRRI/Cornell Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics. IRRI. Los Baños, Laguna, Philippines.

Buol, S. W., P. A. Sanchez, R. B. Cate, Jr. and M. A. Granger. 1975. Soil fertility capability classification. pp. 126-141. In E. Bornemisza and A. Alvarado (eds.). Soil Management in Tropical America. North Carolina State Univ., Raleigh, N.C.

Cochrane, T. T. and P. G. Jones. 1982 (in press). Clima e vegetação na America do Sul Tropical. Um estudo computarizado dos recursos das terras. In Anais do XXXI Congresso Nacional de Botânica. Ilheus/Itabuna, Brazil.

Cochrane, T. T. and P. A. Sanchez. 1982 (in press). Land resources, soil properties and their management in the Amazon region: A state of knowledge report. In Amazon Agricultural Land Use Conference. CIAT, Cali, Colombia.

Cochrane, T. T., J.A. Porras, L. Azevedo, P. G. Jones and L. F. Sanchez. 1979. An explanatory manual for CIAT's computerized land resource study of tropical America. 131 pp. CIAT. Cali, Colombia.

Cordero, A. 1964. The effect of land clearing on soil fertility in the tropical region of Santa Cruz, Bolivia. M.S. thesis. Univ. of Florida, Gainesville, Florida.

da Silva, L. F. 1979. Influência do manejo de um ecossistema nas propiedades edéficas dos Oxisols de "Tabuleiro," Resumenes de Ponencias X Reunión ALCA, Acapulco, Mexico. Centro de Pesquisas do Cacau, CEPLAC, Itabuna, Bahia, Brazil.

Denevan, W. M. 1973. Development and the imminent demise of the Amazon rainforest. The Professional Geographer 25(2):130-135.

Denevan, W. M. 1977. The causes and consequences of shifting cultivation in relation to tropical forest survival. Presented at the Congreso Internacional de Geografos Latinoamericanistas, Paipa, Colombia, August 3-9.

FAO-UNESCO. 1975. Soil Map of the World. Vol. IV-South America. UNESCO, Paris.

Friedman, I. 1977. The Amazon basin, another Sahel? Sci. 197:7-

Gonzalez, E., E. J. Kamprath, G. C. Naderman, and W. V. Soares. 1979. Effect of depth of lime incorporation on the growth of corn on an Oxisol of central Brazil. Soil Sci. Soc. Amer. J. 43:1155-1158.

Goodland, R. J. A. and H. S. Irwin. 1975. Amazon Jungle: Green Hell to Red Desert? Elsevier. Amsterdam.

Grigg, D. B. 1974. The Agricultural Systems of the World: An Evolutionary Approach. Cambridge Univ. Press. London.

Hancock, J. R., R. W. Hill and G. H. Hargreaves. 1979. Potential evapotranspiration and precipitation deficits for tropical America. 398 pp. CIAT. Cali, Colombia.

Hernandez, D. and A. J. Coutu. 1981. Economic evaluation of slash/burn cultivation options in Yurimaguas, Peru. p. 42. In Agron. Abstrs. Amer. Soc. of Agron. 1981 Ann. Mtgs. Madison, Wis.

Irion, G. 1978. Soil infertility in the Amazon rainforest. Natwuvissenchaften 65:515-519.

Klinge, H. 1975. Root mass estimation in lowland tropical rainforests of central Amazonia, Brazil. III. Nutrients in five roots from giant humus Podsols. Trop. Ecol. 16:28-39.

Lal, R., B. T. Kang, F. R. Moormann, A. S. R. Juo and J. C. Moomaw. 1975. Soil management problems and possible solutions in Western Nigeria. pp. 372-408. In E. Bornemiza and A. Alvarado (eds.): Soil Management in Tropical America. North Carolina State Univ., Raleigh, N.C.

Manshard, W. 1974. Tropical Agriculture: A Geographical Introduction and Appraisal. Longman Group Ltd., London.

Marbut, C. F. and C. B. Manifold. 1926. The soils of the Amazon basin in relation to agricultural possibilities. Geogr. Rev. 16:414-442.

McNeil, M. 1964. Lateritic soils. Sci. Amer. 211(5):96-102.

Mesia, R., D. E. Bandy and J. J. Nicholaides. Transfer of agronomic practices to the small farmer of the Amazon jungle. p. 46. In Agron. Abstrs. Amer. Soc. of Agron. 1979 Ann. Mtgs. Madison, Wis.

Moran, E. F. 1981. Developing the Amazon. Indiana Univ. Press. 292 pp. Bloomington, Indiana.

National Academy of Sciences. 1972. Soils of the Humid Tropics. National Research Council of National Academy of Sciences. Washington, D.C.

Nicholaides, J. J., III. 1979. Crop production systems on acid soils in humid tropical America. Chpt. 16. pp. 243-277. In: D. W. Thorne and M. D. Thorne (eds.) Soil, Water and Crop Production. AVI Publ. Co. Westport, Conn.

North Carolina State University. Tropical Soils Research Program Annual Reports. 1972, 1973, 1974, 1975, 1976-1977, 1978-1979, 1980-1981. Raleigh, N.C.

Nye, P. H. and D. J. Greenland. 1960. The soil under shifting cultivation. Comm. Agr. Bur. Tech. Comm. 51. Harpenden, U.K.

Piha, M. and J. J. Nicholaides, III. 1981. Field evaluation of legume, sweet potato and rice varieties for tolerance to soil acidity. p. 45. *In* Agron. Abstrs. Amer. Soc. of Agron. 1981 Ann. Mtgs. Madison, Wis.

Richards, P. W. 1970. *The Life of the Jungle*. McGraw-Hill. 194 pp. New York, New York.

Ritchey, K. D., M. G. Diadma, E. Lobato, and O. Correa. 1980. Calcium leaching to increase rooting depth in a Brazilian Savannah Oxisol. Agron. J. 72:40-44.

Ruthenberg, H. 1976. *Farming Systems in the Tropics*. Clarendon Press, Oxford.

Sanchez, P. A. (ed.). 1973. *A Review of Soils Research in Tropical Latin America*. Bull. 219. Soil Sci. Dept. North Carolina State Univ. Raleigh, N.C.

Sanchez, P. A. 1976. *Properties and Management of Soils in the Tropics.* 618 pp. John Wiley and Sons Publ. New York.

Sanchez, P. A. 1977a. Alternativas al sistema de agricultura migratoria en América Latina. *In* P. Arens (ed.) FAO/SIDA: Reunión Talles sobre Manejo y Conservación de Suelos. Lima, Peru.

Sanchez, P. A. 1977b. Advances in the management of Oxisols and Ultisols in tropical South America. pp. 535-566. *In Proceedings of International Seminar on Soil Environment and Fertility Management in Intensive Agriculture*. Soc. Soil Sci. and Manure. Tokyo, Japan.

Sanchez, P. A. 1977c. Manejo de suelos tropicales en la Amazonía suramericana. Suelos Ecuatoriales 8:1-11.

Sanchez, P. A. 1977d. Manejo de solos de Amazonia para produção agropecuária intensiva. Bol. Inf. Soc. Bras. Ciência Solo 2(3): 60-63.

Sanchez, P. A. and M. A. Nureña. 1972. Upland rice improvement under shifting cultivation in the Amazon Basin of Peru. North Carol. Agr. Exp. Sta. Tech. Bull. 210.

Sanchez, P. A. and S. W. Buol. 1975. Soils of the tropics and the world food crises. Sci. 180:598-603.

Sanchez, P. A. and T. T. Cochrane. 1980. Soil constraints in relation to major farming systems of tropical America. pp. 101-139. *In IRRI/Cornell Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics*. IRRI. Los Banos, Laguna, Philippines.

Sanchez, P. A., D. E. Bandy, J. H. Villachica and J. J. Nicholaides. 1982 (in press). Soils of the Amazon basin and their management for continuous crop production. Sci.

Sanchez, P. A., W. Couto and S. W. Buol. 1982 (in press). The fertility capability classification system: Interpretation, applicability and modification. Geoderma.

Schubart, H. O. R. 1977. Criterios ecológicos para o desenvolvemento agrícola das terras firmes da Amazônia. Acta Amazônica 7(4): 559-567.

Smith, J. H. 1981. Colonization lessons from a tropical forest. Science 214/755-761.

Soil Survey Staff. 1975. Soil Taxonomy. SCS/USDA: Washington, D.C.

Stark, N. 1978. Man, tropical forests and the biological life of a soil. Biotropica 10:1-10.

Toledo, J. M. and V. A. Morales. 1979. Establishment and management of improved pastures in the Peruvian Amazon. pp. 177-194. In P. A. Sanchez and L. E. Tergas (eds.) Pasture Production in Acid Soils of the Tropics. CIAT. Cali, Colômbia.

Toledo, J. M. and E. A. S. Serrao. 1982 (in press). Pastures and animal production in Amazonia. In S. B. Hecht (ed.): Amazon Agricultural Land Use. CIAT. Cali, Colômbia.

UEPAE/EMBRAPA. 1979-1981. Relatorio tecnico anual 1978, 1979, 1980. Manaus, Amazonas, Brazil.

Valverde, C. S. and D. E. Bandy. 1982 (in press). Production of annual food crops in the Amazon. In S. B. Hecht (ed.) Amazon Agricultural Land Use. CIAT. Cali, Colômbia.

Valverde, C. S., D. E. Bandy, P. A. Sanchez and J. J. Nicholaides. 1979. Algunos resultados del Proyecto Yurimaguas en la Zona Amazônica. INIA. Lima, Peru. 26 pp.

Villachica, J. H. 1978. Maintenance of soil fertility under continuous cropping in an Ultisol of the Amazon jungle of Peru. Ph.D. thesis. North Carolina State Univ. Raleigh, N.C. 269 pp.

Wade, M. K. 1978. Soil management practices for increasing crop production for small farmers in the Amazon jungle of Peru. Ph.D. thesis. North Carolina State Univ. Raleigh, N.C. 243 pp.

Table 1. Selected meterological data from one site in each of the three climatic-vegetative subregions of the Amazon

A. Tropical Rainforest: Yurimaguas, Loreto, Peru. 5°56'S, 76°5'W, 184 m.*	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Air Temp. Mean, °C	26.6	26.7	26.5	26.2	26.3	25.2	24.8	25.2	26.0	26.4	26.3	25.9	26.2
Rainfall, mm	261	83	312	265	192	117	98	135	151	285	257	203	2218
Evaporation, mm	109	87	64	77	78	84	87	94	113	110	[illegible]	78	1061
Solar Rad., lang./day	357	331	309	317	322	314	335	376	411	392	351	346	347
Rel. Humid. Mean, %	85	81	83	90	87	87	77	77	78	81	81	83	82
Wind Vel., m/sec/day	6.0	4.9	5.0	5.7	4.8	5.4	4.8	5.5	5.9	6.6	6.1	6.4	5.6
Soil Temp, °C at 5 cm	33.5	32.5	30.5	31.5	32.0	31.5	32.0	33.0	33.5	33.0	33.0	31.0	32.3
B. Seasonal Semi-evergreen Forest: Manaus, Amazonas, Brazil. 3°8'S, 60°1'W, 48 m.*													
Air Temp. Mean, °C	25.9	25.8	25.8	25.8	26.4	26.6	26.9	27.5	27.9	27.7	27.3	26.7	26.6
Rainfall, mm	276	277	301	287	193	99	61	41	62	112	165	228	2102
Evaporation, mm	132	118	131	123	135	136	149	172	173	167	155	142	1732
Solar Rad. lang./day	420	415	418	404	426	441	462	525	541	509	491	443	458
Rel. Humid. Mean, %	88	89	89	88	81	74	71	63	67	76	78	85	79
C. Well-drained Savannas: Conceicao de Araguaia, Parana, Brazil. 8°15'S, 49°12'W, 90 m.**													
Air Temp. Mean, °C	25.1	24.9	25.2	25.6	25.6	25.1	24.9	26.0	26.7	25.8	25.6	25.2	25.5
Rainfall, mm	253	252	263	163	60	8	7	15	64	163	196	227	1671
Evaporation, mm	135	119	132	137	147	146	156	167	162	150	144	132	1727
Solar Rad. lang./day	437	431	428	453	470	448	510	530	521	479	477	427	471
Rel. Humid. Mean, %	88	89	88	79	65	48	44	54	70	83	83	89	73

* Yurimaguas data are derived from NCSU Tropical Soils Research Program Annual Reports for 1976-77, 1978-79. All data are averages of those from 1976, 1978 and 1979, except for evaporation and soil temperature which are averages of 1978 and 1979 data and relative humidity which is from 1976 alone.

** Manaus and Conceicao de Araguai data are from Hancock et al. (1979) as presented by Cochrane and Sanchez (1982).

Table 2. General distribution of major soil types in the Amazon basin.*

General soil grouping**	Million hectares	% of Amazon
1. Acid, infertile soils (Oxisols and Ultisols)	361.6	74.7
2. Poorly-drained alluvial soils (Aquents, Aquepts).	66.0	13.6
3. Moderately fertile, well-drained soils (Alfisols, Mollisols, Vertisols, Tropepts, Orthents, Fluvents)	40.5	8.4
4. Very infertile, sandy soils (Spodosols, Psamments)	16.0	3.3
Total	484.1	100.0

* Adapted from Sanchez et al. (1982) and Cochrane and Sanchez (1982).

**Soil Taxonomy (1975) terminology in parenthesis.

Table 3. Selected soil test data representative of general groups of the acid, infertile soils, the poorly-drained alluvial soils, the moderately fertile, well-drained soils, and the very infertile, sandy soils of the Amazon basin.*

Horizon depth	Clay	Sand	Org. C	pH	Exchangeable Al	Ca	Mg	K	Effective CEC	Al Sat'n
cm	--------- %	--------		(H_2O)	----------------		meq/100 g	------------------		%
1. ACID, INFERTILE SOILS (74.7% of Amazon Basin)										
A. OXISOL: e.g., Haplic Acrorthox (Latosol Amarelo muito pesado); FCC: Caek, UEPAE-EMBRAPA Station, Manaus, Brazil.										
0-8	76	15	2.9	4.6	1.10	1.70	0.30	0.19	3.29	33
8-22	80	12	0.9	4.4	1.10	0.2		0.09	1.39	79
22-50	84	8	0.7	4.3	1.20	0.2		0.07	1.47	82
50-125	88	7	0.3	4.6	1.00	0.2		0.04	1.24	81
125-365	89	5	0.2	4.9	0.20	0.2		0.11	0.51	39
B. ULTISOL: e.g., Typic Paleudult (Yurimaguas series); FCC: LCeak. Yurimaguas Agr. Exp. Station, Peru.										
0-5	6	80	1.3	3.8	2.05	0.84	0.37	0.20	3.49	59
5-13	10	70	0.8	3.7	2.63	0.05	0.03	0.04	2.76	95
13-43	15	61	0.4	3.9	3.11	0.05	0.03	0.03	3.24	96
43-77	17	57	0.3	4.0	3.12	0.03	0.01	0.02	3.20	98
77-140	25	51	0.2	4.1	4.48	0.03	0.01	0.03	4.58	98
140-200	24	54	0.2	4.4	3.80	0.06	0.03	0.04	3.94	96
2. POORLY-DRAINED ALLUVIAL SOILS (13.6% of Amazon Basin)										
ENTISOL: e.g., Fluvaquent (Gley Pouco Humico); FCC: Cgh. Flood plain Rio Cupixi, Amapa, Brazil.										
0-20	41	30	1.2	4.8	1.50	0.70	0.90	0.20	2.67	57
20-70	38	38	0.5	4.9	0.90	0.60	0.70	0.10	2.30	39
70-130	66	31	0.5	5.1	0.20	1.00	1.40	0.30	2.63	76

Table 3. (Continued)

Horizon depth	Clay	Sand	Org. C	pH	Exchangeable Al	Ca	Mg	K	Effective CEC	Al Sat'n
cm	--------- %		--------		--------------		meq/100 g		------------------	%
3. MODERATELY FERTILE, WELL-DRAINED SOILS (8.4% of Amazon Basin)										
ALFISOL: e.g., Orthoxic Rhodic Paleustalf (Terra Roxa Estruturada Eutrófica); FCC: Cd. Km 218 of Transamazonic Highway near Altamira, Brazil.										
0-20	48	34	1.5	5.9	0.0	5.59	1.20	0.16	6.95	0
20-40	57	24	1.1	5.8	0.0	4.40	0.62	0.06	5.00	0
40-60	69	19	0.6	6.0	0.0	2.62	0.58	0.04	3.24	0
60-80	62	16	0.5	5.9	0.0	2.30	0.82	0.04	3.16	0
80-100	71	15	0.4	6.1	0.0	2.18	1.06	0.04	3.28	0
4. VERY INFERTILE, SANDY SOILS (3.3% of Amazon Basin)										
SPODOSOL: e.g., Arenic Tropaquod (Podzol Alico); FCC: Sgeak. Km 4.5 of BR-174 SUFRAMA, Brazil.										
0-3	2	89	6.3	3.8	5.4	0.30		0.16	5.86	92
3-25	2	95	0.5	4.4	0.7	0.10		0.04	0.84	83
25-50	2	94	0.1	5.0	0.1	0.10		0.02	0.12	83
50-90	1	98	0.0	5.1	-	0.10		0.01	-	-
90-105	5	93	1.1	3.7	3.0	0.10		0.04	3.14	96
105-125	9	91	2.2	4.7	2.9	0.10		0.03	3.03	96
125-165	16	76	0.8	5.6	0.4	0.10		0.03	0.53	75

*Adapted from Cochrane and Sanchez (1982) and Sanchez et al. (1982).

Table 4. Gross estimates of major soil constraints to crop production in the Amazon Basin.*

Soil constraint**	Million hectares	% of Amazon
Nitrogen deficiency	437	90
Phosphorus deficiency	436	90
Aluminum toxicity	383	79
Potassium deficiency	378	78
Calcium deficiency	302	62
Sulfur deficiency	280	58
Magnesium deficiency	279	58
Zinc deficiency	234	48
Poor drainage and flooding hazard	116	24
Copper deficiency	113	23
High phosphorus fixation	77	16
Low cation exchange capacity	71	15
High erosion hazard	39	8
Steep slopes (> 30%)	30	6
Laterite hazard if subsoil exposed	21	4
Shallow soils (< 50 cm deep)	3	<1

*Adapted from Sanchez and Cochrane (1980), Cochrane and Sanchez (1982) and Sanchez _et al_. (1982).

**Nutritional deficiencies of boron and molybedenum also have been noted in some Amazon basin soils, but are not quantitatively estimable due to paucity of data.

Table 5. Nutrient content of ash and partially burned material produced by slashing and burning a 17-year old forest fallow on an Ultisol in Yurimaguas, Peru.*

Element	Content	
	% or ppm	kg/ha
Nitrogen (N)	1.72	67.0
Phosphorus (P)	0.14	6.0
Potassium (K)	0.97	38.0
Calcium (Ca)	1.92	75.0
Magnesium (Mg)	0.41	16.0
Iron (Fe)	0.19	7.6
Manganese (Mn)	0.19	7.3
Zinc (Zn)	132	0.3
Copper (Cu)	79	0.3

* Adapted from Seubert *et al.* (1977)

Table 6. Effects of land clearing method on infiltration rates in Ultisols in Yurimaguas, Peru, Manaus (Amazonas) and Belmonte (Bahia), Brazil.*

Location	Infiltration rate at Yurimaguas	 Manaus	 Belmonte
	----------------	cm/hr	-------------
Virgin forest	117.0	15.0	24.0
15-year old forest fallow	81.0	-	-
Path through virgin forest	5.2	-	-
Slashed-and-burned clearing (after 1 year of cropping)	10.0	-	20.0
Bulldozed clearing (after 1 year of cropping)	0.5	-	3.0
Slashed-and-burned clearing (after 6 years of cropping)	10.0	-	-
Bulldozed clearing (after 6 years of cropping)	4.1	-	-
Bulldozed clearing (after 5 years in pasture)	-	0.4	-

* Adapted from Seubert _et al_. (1977), Schubart (1977), Silva (1977) and North Carolina State University (1978-1979).

Table 7. Effect of land clearing method on crop yield at Yurimaguas, Peru.*

		Crop Yield		
		Clearing		
Crop (number of harvests)	Fertility Treatment**	Slash and Burn	Bulldozer	Bulldozer / Slash and Burn
		------ t/ha --------		----- % ------
Rice, upland (3)	0	1.33	0.70	53
	NPK	3.00	1.47	49
	NPK Lime	2.90	2.33	80
Maize (1)	0	0.10	0.00	0
	NPK	0.44	0.04	10
	NPK Lime	3.11	2.36	76
Soybeans (2)	0	0.70	0.15	24
	NPK	0.95	0.30	34
	NPK Lime	2.65	1.80	67
Cassava (2)	0	15.40	6.40	42
	NPK	18.90	14.90	78
	NPK Lime	25.60	24.80	97
Mean Realtive Yields	0			30
	NPK			43
	NPK Lime			80

---

* Adapted from Seubert *et al.* (1977).

** Applied were N, P, K at 50, 172 and 42 kg/ha, respectively and $Ca(OH)_2$ at 4 t $CaCO_2$-equivalent/ha.

Table 8. Lime and fertilizer requirements for continuous cropping of a three crop/year rotation of rice-maize-soybeans or rice-peanuts-soybeans on an Ultisol of Yurimaguas, Peru.*

Input**	Rate	Frequency
Lime	3 tons $CaCo_3$-equivalent/ha	Once/3 years
Nitrogen	80-100 kg N/ha	Rice and maize only
Phosphorus	25 kg P/ha	Each crop
Potassium	100 kg K/ha	Each crop, split applied
Magnesium	25 kg Mg/ha	Each crop, unless dolomitic lime is used
Copper	1 kg Cu/ha	Once/year or two years
Zinc	1 kg Zn/ha	Once/year or two years
Boron	1 kg B/ha	Once/year
Mo	20 g Mo/ha	Mixed with legume seed during inoculation

* Adapted from Sanchez et al. (1982).

** Calcium and sulfur requirements are satisfied by lime, simple superphosphate and Mg, Cu and Zn carriers.

Table 9. Changes in topsoil chemical properties and before and shortly after burning tropical forests in Ultisols and Oxisols of the Amazon.*

Soil property	Time in relation to burn	Yurimaguas (2 sites)		Manaus ($\underline{X}$ 7 sites)	Belem ($\underline{X}$ 60 sites)	Belmonte (1 site)
		I	II			
Months after burning:		1	3	1/2	12	1
pH	Before	4.0	4.0	3.8	4.8	4.6
	After	4.5	4.8	4.5	4.9	5.2
Exch. Ca+Mg (meq/100 g)	Before	0.41	1.46	0.35	1.03	1.40
	After	0.88	4.08	1.25	1.97	4.40
Exch. K (meq/100 g)	Before	0.10	0.33	0.07	0.12	0.07
	After	0.32	0.24	0.22	0.12	0.16
Exch. Al (meq/100 g)	Before	2.27	2.15	1.73	1.62	0.75
	After	1.70	0.65	0.70	0.90	0.28
Al sat'n. (%)	Before	81	52	80	58	34
	After	59	12	32	30	5
Avail. P (ppm) (mod. Olsen in Peru) ($HCl-H_2SO_4$ in Brazil)	Before	5	15	-	6.3	1.5
	After	16	23	-	7.5	8.5

* Adapted from Cochrane and Sanchez (1982).

Table 10. Changes in topsoil (0-15 cm) chemical properties after 7 3/4 years of continuous production of 20 crops of upland rice, corn and soybeans with complete fertilization in Yurimaguas, Peru.*

Time	pH	Org. matter	Exchangeable Al	Ca	Mg	K	Eff. CEC	Al Sat'n.	Available P	Zn	Cu	Mn	Fe
		%	meq/100 cc					%	ppm				
Before clearing	4.0	2.13	2.27	0.26	0.15	0.10	2.78	82	5	1.5**	0.9**	5.3**	650**
90 months after clearing	5.7	1.55	0.06	4.98	0.35	0.11	5.51	1	39	3.5	5.2	1.5	389

* Adapted from North Carolina State University (1978-1979).

** 30 months after clearing.

Table 11. Average yields of 11 small farmer-managed continuous cropping demonstration trials from July 1978-June 1979 in an 80 km radius from Yurimaguas, Peru.*

Production system	Crop Rotation											
	Corn-Peanuts-Corn			Total	Peanuts-Rice**-Soybeans			Total	Soybeans-Rice+-Soybeans			Total
	average grain yields, tons/ha											
I. Traditional	2.44	1.10	1.77	5.31	0.97	1.91	1.34	3.53	1.43	1.91	1.15	4.49
II. Improved, no lime or fertilizer	3.81	1.36	2.73	7.90	1.22	3.56	1.98	6.76	2.09	2.25	1.89	6.23
III. Improved, with lime and fertilizer	5.12	1.62	4.66	11.40	1.49	4.53	2.75	8.77	2.73	2.53	2.22	7.48

* Adapted from North Carolina State University (1978-1979).

** Rice in System I is the traditional Carolina variety, in Systems II and II the improved IR 4-2 variety.

\+ Rice in all systems is the traditional Carolina variety.

LIST OF FIGURES

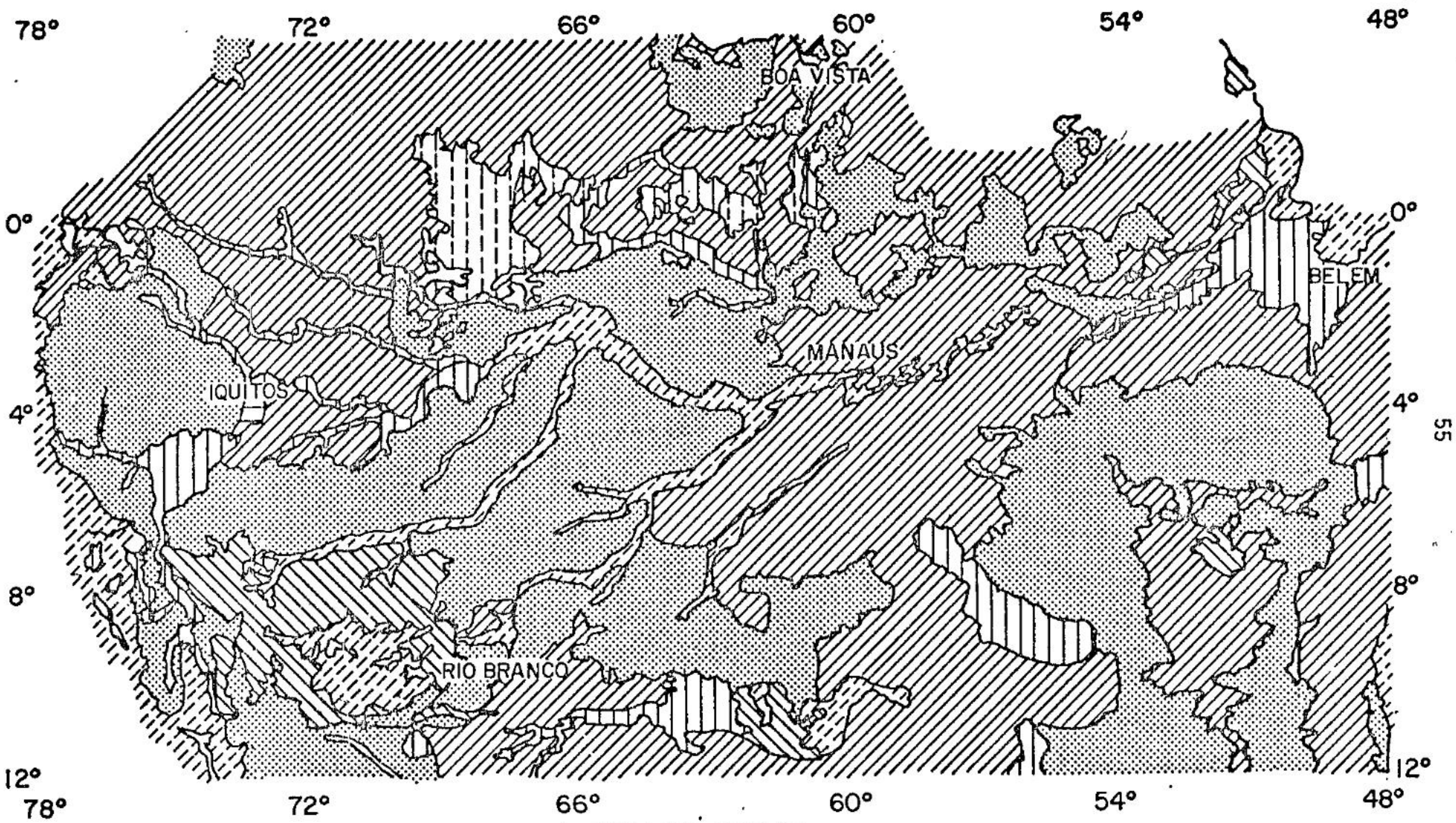

Fig. 1. SOIL ORDER MAP OF THE AMAZON BASIN

▧ Alfisols
▨ Inceptisols
▨ Oxisols
▒ Ultisols
▥ Entisols
▤ Mollisols
▥ Spodosols

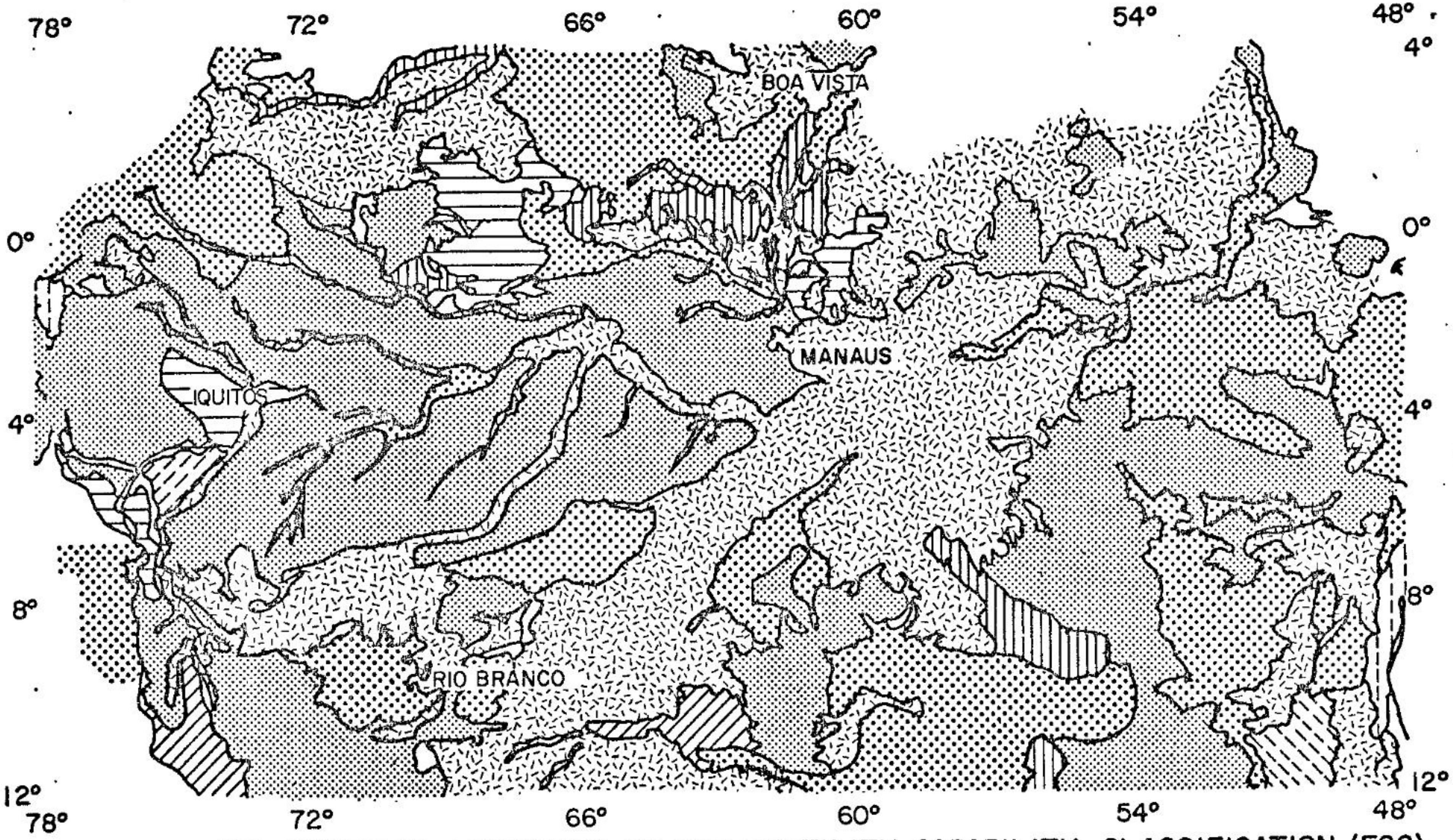

Fig. 2. SOIL TEXTURE ACCORDING TO THE FERTILITY CAPABILITY CLASSIFICATION (FCC) SYSTEM OVER THE AMAZON BASIN

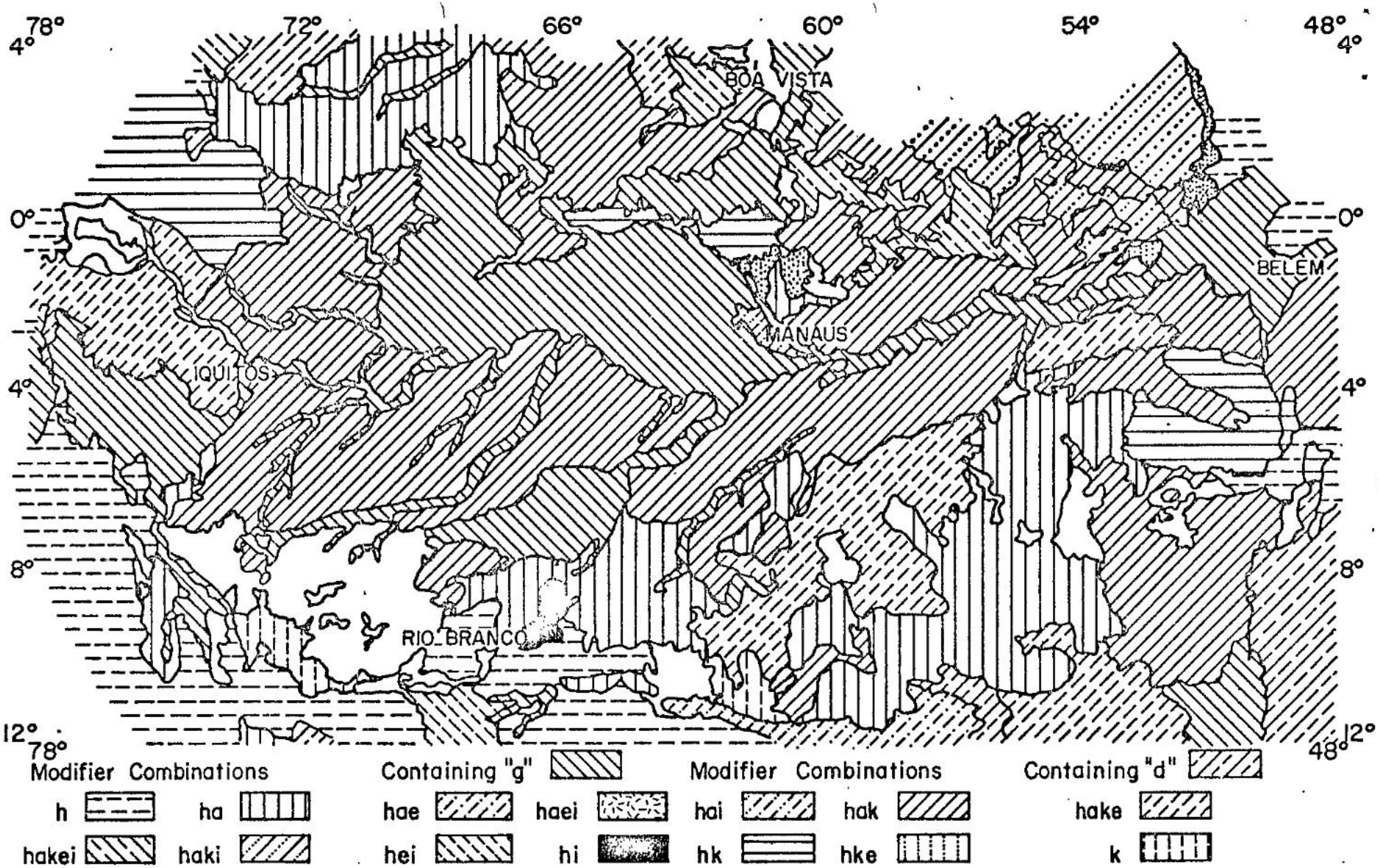
78°
72°
66°
60°
54°
48°
4°
0°
4°
8°
12°
BOA VISTA
BELEM
MANAUS
IQUITOS
RIO BRANCO
Modifier Combinations
Containing "g"
Modifier Combinations
Containing "d"
h
ha
hae
haei
hai
hak
hake
hakei
haki
hei
hi
hk
hke
k

Fig. 3.

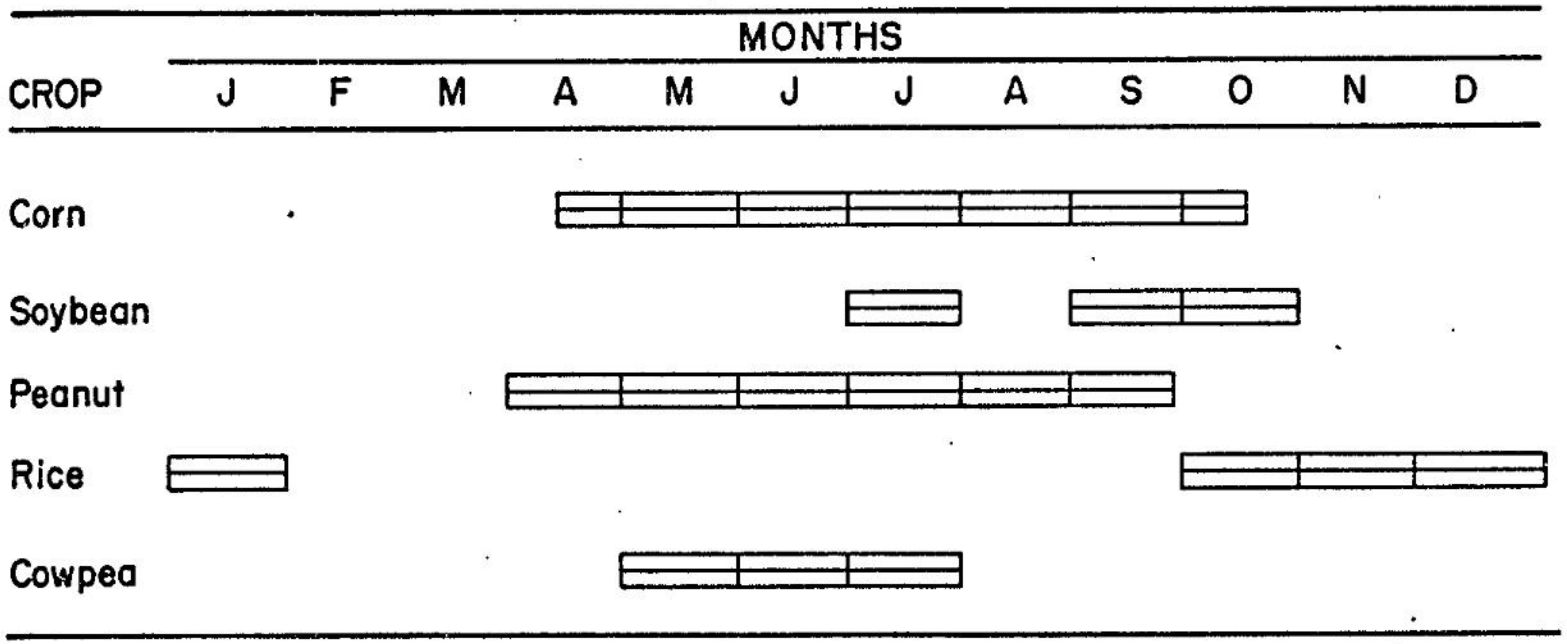

Fig. 4.

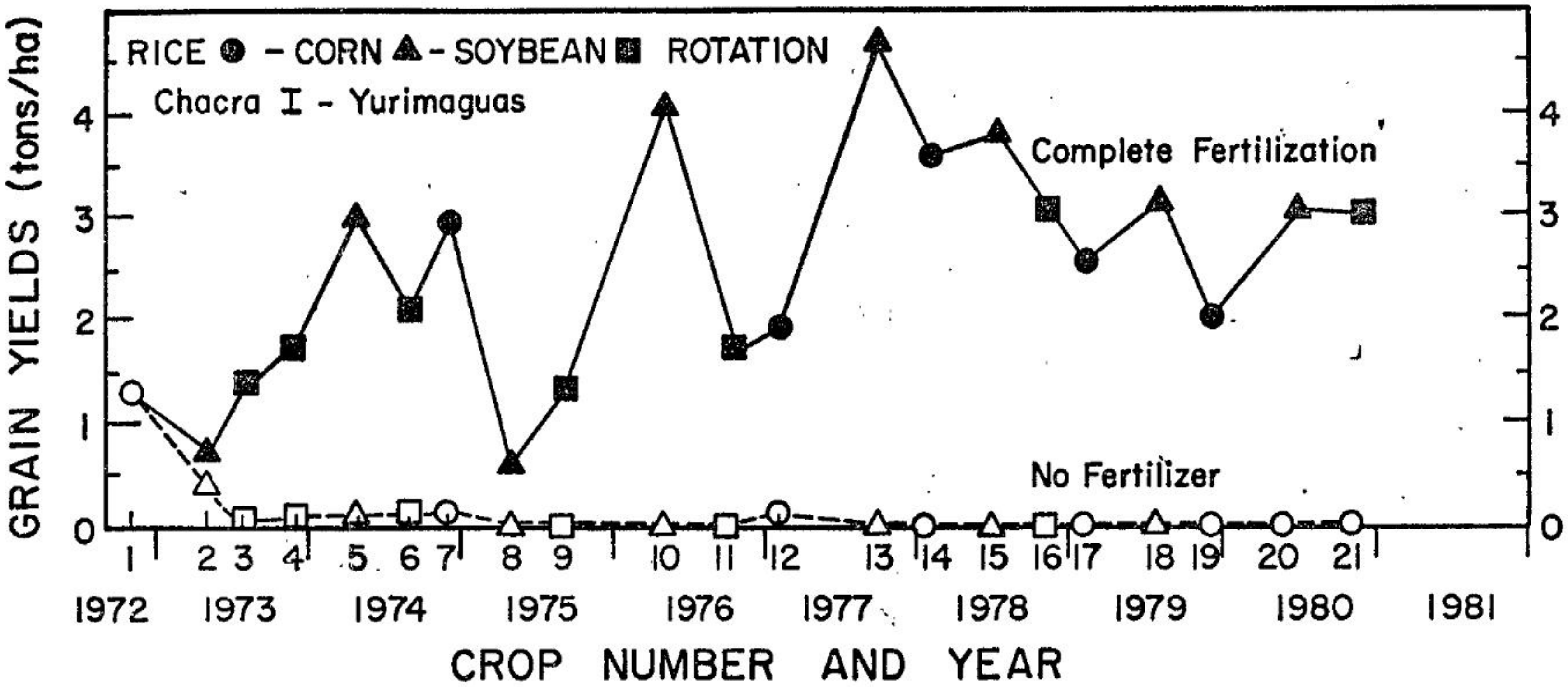
RICE ● - CORN ▲ - SOYBEAN ■ ROTATION
Chacra I - Yurimaguas
GRAIN YIELDS (tons/ha)
0
1
2
3
4
Complete Fertilization
No Fertilizer
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
CROP NUMBER AND YEAR

Fig. 5.

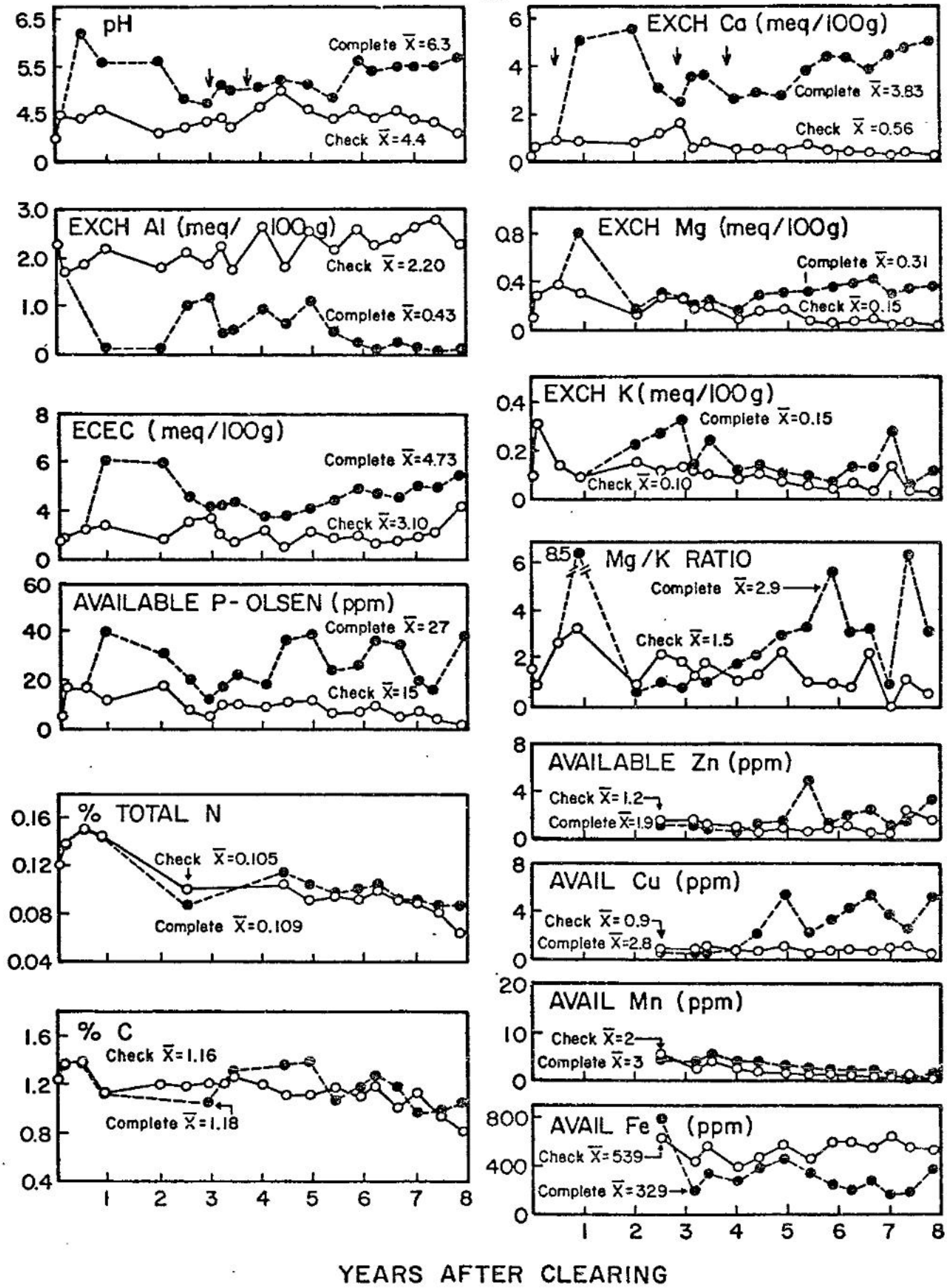
pH
Complete X̄=6.3
Check X̄=4.4
EXCH Ca (meq/100g)
Complete X̄=3.83
Check X̄=0.56
EXCH Al (meq/100g)
Check X̄=2.20
Complete X̄=0.43
EXCH Mg (meq/100g)
Complete X̄=0.31
Check X̄=0.15
EXCH K (meq/100g)
Complete X̄=0.15
Check X̄=0.10
ECEC (meq/100g)
Complete X̄=4.73
Check X̄=3.10
Mg/K RATIO
8.5
Complete X̄=2.9
Check X̄=1.5
AVAILABLE P-OLSEN (ppm)
Complete X̄=27
Check X̄=15
AVAILABLE Zn (ppm)
Check X̄=1.2
Complete X̄=1.9
% TOTAL N
Check X̄=0.105
Complete X̄=0.109
AVAIL Cu (ppm)
Check X̄=0.9
Complete X̄=2.8
AVAIL Mn (ppm)
Check X̄=2
Complete X̄=3
% C
Check X̄=1.16
Complete X̄=1.18
AVAIL Fe (ppm)
Check X̄=539
Complete X̄=329
YEARS AFTER CLEARING
1 2 3 4 5 6 7 8

Fig. 6.

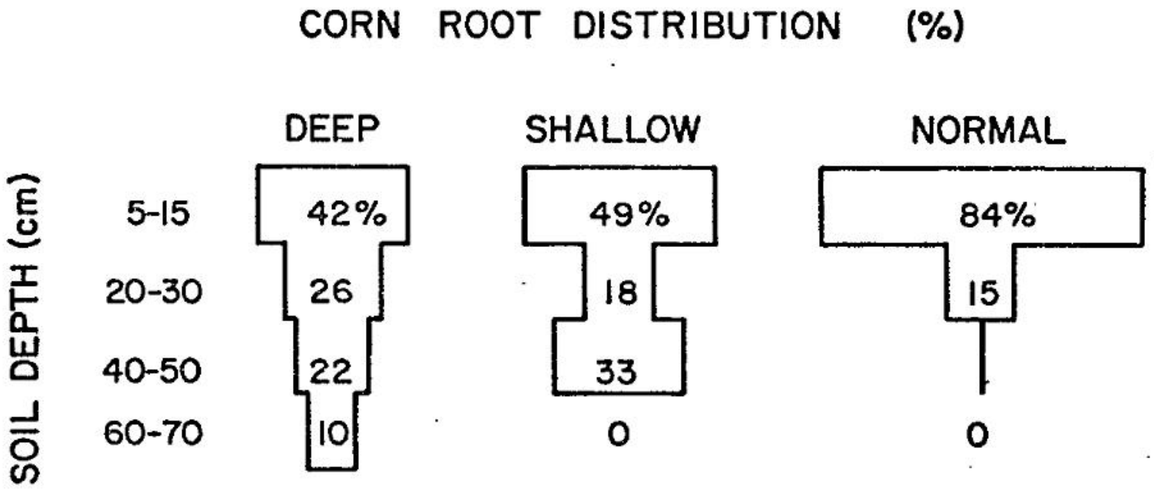
CORN ROOT DISTRIBUTION (%)
DEEP
SHALLOW
NORMAL
SOIL DEPTH (cm)
5-15
20-30
40-50
60-70
42%
26
22
10
49%
18
33
0
84%
15
0

Fig. 7.

CHACRA I - COMPLETE FERTILIZATION
EFFECTS ON SUBSOIL PROPERTIES

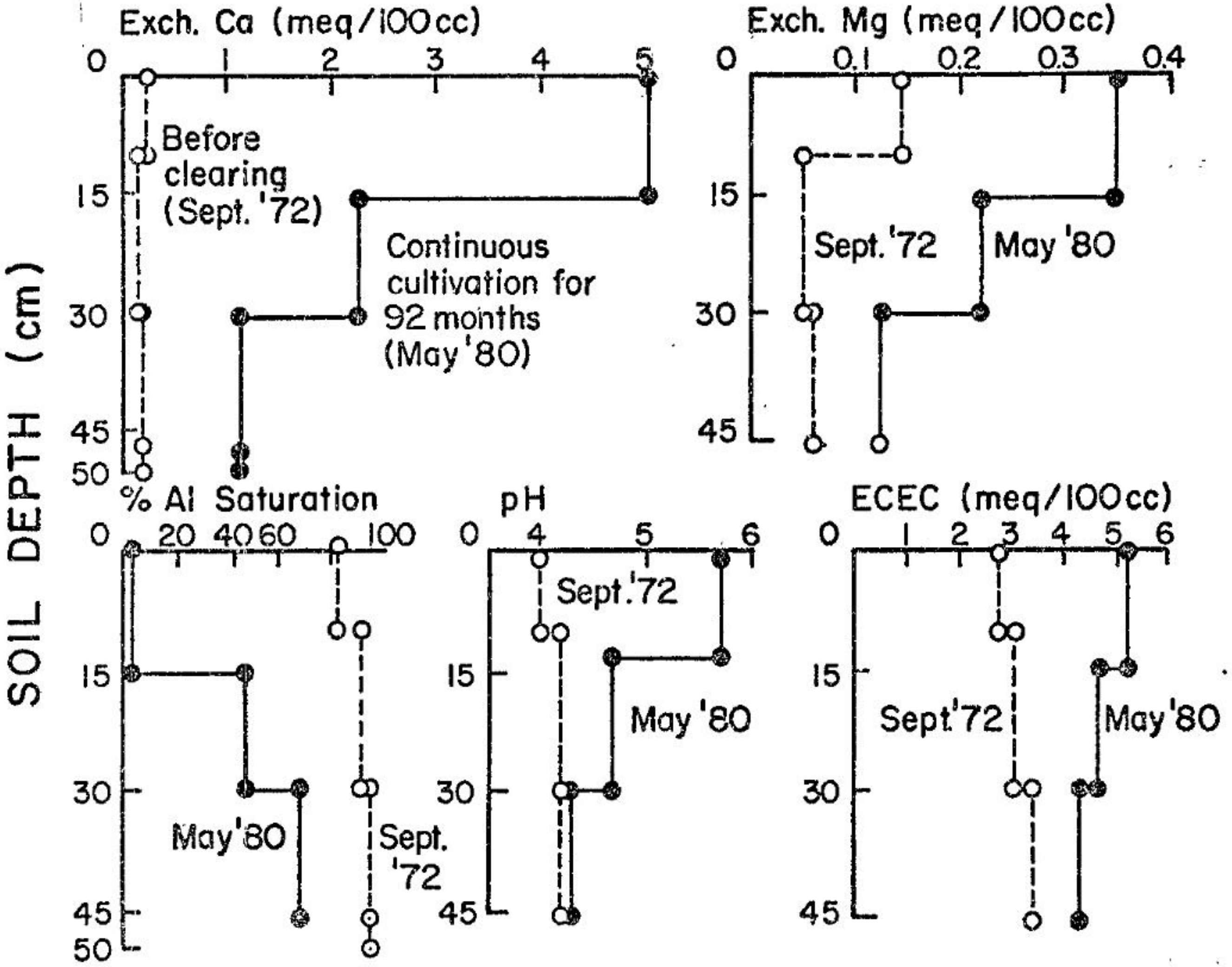

Fig. 8