A LEGUME-BASED, PASTURE PRODUCTION STRATEGY FOR ACID INFERTILE SOILS OF TROPICAL AMERICA

by

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INTRODUCTION

Tropical America (from 23°N to 23°S of latitude) can be divided into two broad soil regions at the highest level of generalization. Region A, with predominant high base status soils of the orders Alfisols, Inceptisols, Mollisols, Entisols, Vertisols and Aridisols, covers about 30% of tropical America, commonly with dense rural populations. Region B, with predominant acid infertile soils (Oxisols, Ultisols, acid Inceptisols and acid sandy Entisols) covers the remaining 70% (1043 million ha), and has mainly low population densities (Sanchez and Cochrane, 1980).

Two main strategies for increasing food production exist in the tropical portions of this hemisphere: 1) Increase yields in presently cultivated areas, mainly high base status soils, and 2) expand the agricultural frontier in the vast areas of acid infertile soils mostly under savanna or forest vegetation. Sanchez and Cochrane's analysis suggests that these two strategies are complementary rather than competitive, and

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[1/] This paper represents to a large extent the existing position and strategy of CIAT's endeavor to bring marginal lands in Latin America into economic production. It draws heavily on the research carried out by many investigators within the Tropical Pastures Program (formerly Beef Program) and associated special projects of CIAT. The paper largely reflects the experience of the Program, synthetized by the author, who was Program Coordinator from January 1977 to May 1979.

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that the interaction between them is already playing a major role in the overall agricultural development of many Latin American countries. A third strategy, increasing irrigation is very limited in areal extent, although locally very important.

The countries of tropical America have a combined population of 378 million inhabitants as of 1980, and are growing at an annual rate of 2.7%, which doubles the population every 24 years. To maintain the present and largely inadequate level of per capita human nutrition, food supplies must also double every 24 years. FAO (1979) estimates that 55% of food production increases will come from opening new lands in Latin America and 45% from increasing production on land presently under cultivation. The vast majority of the rural population is located in Region A, mainly in coastal or highland areas. Increases in population density cause the size of traditional farms to decrease. Farmers then attempt to cultivate marginal land beyond its limits of slope, causing severe soil erosion. This, in turn, forces large scale migration of farmers to the slums of major cities. Tropical America at present has two cities with over 10 million people, three others with over 5 million, and 18 others with over 1 million people each (Sanchez and Cochrane, 1980). Displaced rural populations add major unemployment and welfare problems to these cities.

An alternative for these displaced people is to settle in the acid infertile soil regions, and in certain cases this is a viable alternative. However, lack of sufficient knowledge on how to manage these soils, plus limited infrastructure, credit, and accessibility to markets has caused many settlement efforts to fail.

It is not possible to quantify the consequences of soil erosion in tropical America at this time; some generalizations, however, can be made. Visual evidence of gully and sheet erosion are most prevalent in ustic, densely populated, high base status soils, mainly on hillsides along the Andes and other steeplands in Central America and the Caribbean. The presence of a strong dry season is crucial because the soil is left unprotected by a crop canopy at the beginning of the rainy season, when the danger of water erosion is highest. The situation is worse in semi-arid or arid climates.

In udic soil moisture regimes, where there is no significant dry season, soil erosion is less of a problem, since there is usually a plant cover protecting the soil throughout the year. This is the case in much of the Amazon where secondary forest regrowth covers the soil when crops are not growing. Visual sheet or gully erosion in udic areas of the Amazon and other similar regions is mostly caused by civil engineering rather than agronomic mismanagement, along the roads, farm pathways, and as a consequence of improperly designed drainage and sewage outlets.

These observations do not imply that erosion is unimportant in udic regions, but that it is more extensive and critical in ustic and aridic regions. Erosion hazard is very important when the soil surface is exposed by conventional plowing in udic regions. This is seldom done by traditional cultivators, but newcomers to rainforest areas often cause severe soil erosion in steep mountain hillsides while planting food crops (Watters, 1971). The same occurs when pastures are overgrazed, or when land in permanent crops or pastures is converted to annual crop production.

POSSIBLE SOLUTIONS

The best methods of erosion control are good soil and crop management practices, particularly those that minimize water runoff and improve water infiltration (Lal, 1980). The adaptation of this fundamental concept to tropical America involves both the stabilization of erosion-prone areas under dense populations, and the development of productive, economically and ecologically sound management systems for the acid infertile soil regions, the latter in order to provide a viable alternative to urban migration.

The purpose of this paper is to describe the development of one strategy for the Oxisol-Ultisol regions, the use of low input, legume-based pastures. Not all the components of this strategy are yet in place; therefore, several gaps are recognized in this paper. There are other viable strategies for Oxisol-Ultisol regions such as changing from annual to permanent crops like rubber, oil palm or forestry (Alvim, 1977). These crops keep the soil protected by a plant canopy the year around. Another one is the continuous cultivation of annual crops under moderate to high fertilizer inputs to correct acid soil infertility, where economics and infrastructure considerations make it feasible (Sanchez, 1977). By growing three crops per year, the soil is protected by a plant canopy most of the time. There is no question that most Oxisols and Ultisols with no serious physical limitations can be continuously and profitably managed for intensive food production in tropical America, provided the price ratios of chemical inputs to farm products are sufficiently attractive (Vicente-Chandler *et al.*, 1974; Sanchez, 1977; Valverde et al., 1979).

In the majority of the savanna and rainforest areas however, the economics of high input use are seldom attractive, mainly because of a poorly developed transportation and marketing infrastructure, credit, and the increasing cost of energy. Thus, an alternative is presented here, at least in its initial stages.

Legume-based pastures are a promising strategy for new land areas because the low cost per unit area involved in producing beef with the animals harvesting the pasture, storing the product in their bodies and transporting themselves away from the farm, if necessary. Beef is one of the basic staple foods in tropical America. Studies show that families of lowest income strata spend from 8 to 18% of their total income buying beef (CIAT, 1979). Much of tropical America's beef is produced in high base status soils, where unfortunately it competes with intensive crop or milk production. Consequently, a gradual displacement towards the acid infertile soils where beef has the comparative advantage, could provide alternative uses for the better soils located closer to markets.

The importance of legume-based pastures in this strategy deserves emphasis. Several million hectares of Amazon rainforests have been cleared within the last 15 years and planted to pasture grass species such as *Panicum maximum* without legumes or fertilization. This species is not well adapted to severe soil constraints found in the Amazon and such pastures disappear after a few years, causing widespread bankruptcies and a spreading belief that successful pasture-based beef production is impossible in the Amazon (Hecht, 1979).

COMPONENTS OF A LEGUME-BASED PASTURE PRODUCTION SOIL MANAGEMENT STRATEGY

A low input soil management strategy designed to take advantage of acid soil infertility for pasture production is emerging as a result of multidisciplinary teamwork by various research institutions in tropical America: CIAT's* Tropical Pastures Program; EMBRAPA's Cerrado Research Center (CPAC), the UEPAE Station at Manaus, and the Humid Tropical Center (CPATU) at Belém in Brazil; ICA's Carimagua Station in the Colombian Llanos; INIA's Yurimaguas Station and IVITA's Pucallpa Station in the Amazon of Peru, and North Carolina State University's Tropical Soils Program. Nine main components of the strategy are described in the following pages.

1. Land Resource Evaluation for Site Selection

The first step is to select the appropriate soils, avoiding certain groups of fertile, high base status soils that are best used for food crop production, poorly drained soils that are seasonally flooded, and soils with severe physical limitations or with extreme infertility such as Spodosols. The acid infertile soil regions of tropical America are mainly under rainforest or savanna vegetation. The total area of rainforest is on the order of 700 million ha and the savanna areas about 300 million ha. Lead calculations from the FAO-UNESCO (1971) world soil map, modified by the author's observations (Sanchez, 1979) plus the recent completion of the RADAM soil survey of the Amazon (Ministerio das Minas e Energía, 1973-1979) provide some estimates of soil distribution

*See list of acronyms used at the end of the paper.

in the rainforest areas of South America. Well drained, high base status soils cover about 60 million ha or 8% of the Amazon. Although many of them can support grass/legume pastures, their higher native fertility gives the comparative advantage to intensive annual food crop production or to export crops such as cacao. In addition, the Amazon has about 42 million ha of poorly drained soils either as flood plains or swamps, accounting for 6% of the total. Many of the flood plain areas are already under intense use, such as many "várzeas" in Brazil and many "restingas" in Peru and Ecuador.

Also to be avoided, but for different reasons are acid infertile soils with severe physical limitations such as shallow depth or steep slopes, and coarse sandy soils classified as Psamments or Spodosols with extremely low native fertility, severe leaching and erosion hazards, often called "Tropical Podzols." These two groups cover about 33 million ha or 5% of the Amazon. Unfortunately a sizeable proportion of the data gathered by ecologists to warn about the extreme fragility of the Amazonian environment has been gathered from these Psamments or Spodosols, which represents the worst combination of physical and chemical soil constraints.

The total area to which the proposed strategy may apply is therefore, on the order of 560 million ha or 81% of the Amazon, mainly Oxisols and Ultisols. Extremely steep slopes within these areas should also be avoided.

In the savanna regions it is less difficult to identify the soils to be avoided, but the criteria remain the same. Many of the islands of high fertility soils are already under intensive production such as in

the Eastern Llanos of Venezuela. Steep and shallow soils are readily recognized in the landscape. Large areas of seasonally flooded plains such as parts of the Western Llanos of Venezuela and its extension into Colombia, and parts of the Beni of Bolivia will require a different management strategy.

Although the above generalizations provide an overall picture, actual selection is very site specific. Soil parameters per se are not sufficient for appropriate site selection. Land classification therefore, is a more useful tool because it also considers climate, landscape, native vegetation and infrastructure. The land systems approach used in CIAT's Land Resource Study of Tropical America (CIAT, 1978, 1979) appears to be an appropriate method for evaluating the potential of these vast areas. Using a scale of 1:1 million, about 500 land systems have been identified so far, each representing a recurring pattern of climate, soil, landscape and vegetation (Cochrane, 1979). Soils and climate are classified according to technical systems such as the moisture stress probabilities (Hargreaves, 1977; Hancock et al., 1979) and the Fertility Capability Soil Classification system (Buol et al., 1975) and assembled in computer tapes (Cochrane et al., 1979). Users of these tapes can produce computer-made maps of specific regions pinpointing one or several parameters, such as shallow soils, or soil with more than 60% aluminum saturation at a specific depth.

A fundamental modification of the USDA Land Use Capability Classification System has been developed in Brazil to take into account the realities of the tropical environment. Ramalho et al., (1978) defined six groups, including three management levels for crops, (low, moderate

and high input). Input use is interpreted in terms of fertilizer and mechanization, but not irrigation, limiting the system to rainfed agriculture. The highest categories of this system are illustrated in Table 1. Only land classified in groups 3 and 4 should be used for improved pastures. Groups 1 and 2 although suited, may be best used for crop production.

2. Appropriate Land Clearing Methods

Land clearing is not a major problem in savanna regions where trees are generally small and widely spaced. Clearing rainforests however, is a crucial step which strongly influences the future productivity of the soil. The traditional slash-and-burn method is superior to mechanical clearing with bulldozers, because it provides a sharp but temporary increase in soil fertility due to the nutrient content of the ash, avoids soil compaction and topsoil displacement commonly caused by bulldozing operations (Seubert et al., 1977; Sanchez, 1979). The establishment and initial growth of grass and legume species is significantly retarded by mechanical land clearing, giving rise to more intense weed and jungle regrowth problems. The tangled mass of partially burned logs and tree stumps left by the slash-and-burn method provides an important degree of protection against erosion to the soil while the pasture is being established. These effects have been demonstrated at the experimental scale in Yurimaguas, Peru (Table 2) and on a commercial scale in Manaus, Brazil (EMBRAPA, 1979).

There are many cases where lack of labor forces mechanized land clearing. In such cases, the method used should strive to minimize

compaction and topsoil carryover and to include burning in order to take advantage of the free fertilizer value of the ash. Toledo and Morales (1979) based on their work in Pucallpa, Peru, recommend initial clearing with tree crushers, followed by burning and overseeding pasture species.

3. Selection of Adapted Species Tolerant to Acid Soil Stresses

The basic principle of this component is to use plants adapted to the soil and climatic limitations rather than change the soil to meet the plant's nutritional requirements (Spain *et al.*, 1975). The use of such plants reduces the rates of fertilizer needed, but does not eliminate the need to fertilize. Research has identified several species and ecotypes that are remarkably tolerant to the main stresses present in Oxisol-Ultisol regions: Aluminum toxicity, low phosphorus availability, water stress, insect and disease attacks, and occasional fires. In addition, grass and legume species must be compatible with each other and must persist in mixtures under reasonable grazing pressures.

Aluminum tolerance. A wide range of CIAT's forage germplasm bank is tolerant to high levels of exchangeable aluminum simply because much of it has been collected from acid infertile soil regions of tropical America. An example of differential tolerance to aluminum of four common tropical grasses is shown in Figure 1 from a culture solution study of Spain (1979). *Brachiaria decumbens* shows even a slight positive response to the first increment of aluminum, and no growth reduction at high concentrations. *Panicum maximum* exhibits strong tolerance up to half the aluminum concentration as *Brachiaria decumbens*. In contrast, *Cenchrus ciliaris*, one of the most widespread tropical grasses in ustic but not

acid areas of Australia, is severely affected by aluminum. This excellent grass is well adapted to non-acid soils, but to grow well in Oxisol-Ultisol regions it is necessary to completely neutralize the exchangeable aluminum by liming.

Figure 2 also adapted from Spain (1979) shows actual responses to lime applications in an Oxisol of Carimagua, Colombia with pH 4.5 and 90% aluminum saturation before liming. Very tolerant grasses such as *Andropogon gayanus*, *Brachiaria decumbens* and *Panicum maximum* and the legumes *Stylosanthes capitata* and *Zornia latifolia* produced maximum growth either at 0 or 0.5 ton/ha of lime. The 0.5 ton/ha rate did not alter soil pH or aluminum saturation, but provided calcium and magnesium to the plants. Other legumes, particularly *Desmodium ovalifolium* and *Pueraria phaseoloides* appear to require either more calcium and magnesium or a lower level of aluminum saturation than the previous group. Yet, their performance is clearly superior to aluminum-sensitive species such as grain sorghum and *Centrosema plumieri*, a legume clearly not adapted to acid soils. It is also relevant to point out that some species are aluminum tolerant but do not grow vigorously in acid soils. This is the case of Pangola grass (*Digitaria decumbens*), shown in Figure 2.

Low levels of available soil phosphorus. Phosphorus is the single most expensive input needed in improved pastures in Oxisol-Ultisol savannas. It is not, however, the only nutrient that is deficient in these soils, but its correction is certainly the most expensive one. No improved pastures can be established or maintained without phosphorus fertilization. In order to maximize the efficiency of phosphorus fertilization, it is possible to select plants that have a lower requirement

of phosphorus for maximum growth than those commonly used. Fortunately, aluminum tolerance and "low phosphorus tolerance" often occur jointly because the latter seems associated with the plant's ability to absorb and translocate phosphorus from the root to the shoot in the presence of high levels of aluminum in the soil solution and in root tissue (Salinas, 1978).

Table 3 shows examples of promising grass and legume species that require a fraction of the available soil test phosphorus levels required by annual crops and much less than other pasture species. The general soil test critical level used for crops in Colombia is 15 ppm P by the Bray II method (Marín, 1977). Promising, aluminum-tolerant ecotypes of Stylosanthes capitata, Zornia latifolia and Andropogon gayanus require 1/3 to 1/5 of that amount to attain maximum yields. Other forage species require considerably higher levels of phosphorus, such as Desmodium leonii and Macroptilium sp. 535. They are not recommended for low input systems.

It should be noted that adapted grasses such as Andropogon gayanus and Brachiaria decumbens require higher levels of available soil phosphorus than adapted legumes like Stylosanthes capitata and Zornia latifolia. The commonly held view that fertilization of grass-legume mixtures should be based on the legume's higher nutritional requirement does not apply to these species. This has been proven in the field by Spain (1979), who in addition to phosphorus, observed a higher need for potassium in the grasses than in the legumes.

Field responses during the establishment year show significant differences in optimum levels of phosphorus fertilization at Carimagua in

an Oxisol with about 1 ppm available P prior to treatment applications (Figure 3). Andropogon gayanus required 50 kg P_2O_5/ha to reach maximum yields, while Panicum maximum required 100 kg P_2O_5/ha and Hyparrhenia rufa required 200 or perhaps more. The latter species, very widespread in Latin America, performs poorly in Oxisol-Ultisol regions because of a generally higher requirement of phosphorus and potassium and a lower tolerance to aluminum than the other two (Spain, 1979). These differences are quite significant at the animal production level. At levels of inputs where other grasses produce good cattle liveweight gains, Hyparrhenia rufa produced serious liveweight losses at Carimagua (Paladines and Leal, 1979).

It may be argued that the use of species that require less phosphorus may provide insufficient phosphorus for animal nutrition. There is no evidence in the CIAT work that this is so (CIAT, 1978, 1979) but, if it were it is probably cheaper to apply to the soil the quantities required for maximum plant growth and supplement the rest directly to the animals via salt licks.

Water stress. The ability to grow and survive the strong dry seasons of ustic environments under grazing pressure is necessary for these grass and legumes, as irrigating pastures is prohibitively expensive in most of the Oxisol-Ultisol regions. Because of their aluminum tolerance, roots of adapted forage species are able to penetrate deeply into extremely acid subsoils and exploit the residual moisture available. This is in sharp contrast with aluminum sensitive crops that suffer severely from water stress even during short dry spells because their roots are confined to the limed topsoil (Gonzalez et al., 1976).

Adapted legume species are generally more tolerant to drought stress than the grasses, and also maintain a higher nutritive value during the dry season. For example, Zornia latifolia 728 contained 23.6% protein in its leaves at the height of the Carimagua dry season (CIAT, 1979). Among the adapted grasses, Andropogon gayanus is more tolerant to drought stress than Brachiaria decumbens or Panicum maximum (CIAT, 1979). Its pubescent leaves also permit dew drops to remain on the leaves longer than in B. decumbens or P. maximum. It is common to get one's pant legs wet while walking through an Andropogon pasture at about 10 a.m. in the Llanos of the Amazon, when swards of the other two species are already dry.

Insect and disease attacks. Most of the adapted legume species have their center of origin in Latin America and therefore, have many natural enemies. Anthracnose caused by Collectotrichum gloeosporoides is a most devastating disease of legumes (CIAT, 1977, 1978, 1979). Stemborers of the genus Caloptilia also destroy several Stylosanthes species (CIAT, 1979). Spittlebug attacks caused by Deois incompleta and other species have destroyed thousands of hectares of Brachiaria decumbens pastures in udic regions of Brazil. The solution to these problems is varietal resistance since applications of insecticides or fungicides to these pastures are likely to be uneconomical. Screening for tolerance to these and other pathogens has provided ecotypes that combine the adaptation to adverse soil conditions with pathogen resistance. Examples of these to date are several ecotypes of Andropogon gayanus, Stylosanthes capitata and Desmodium ovalifolium. Several promising ecotypes of Stylosanthes guianensis, a legume extremely well adapted to the soil limitations,

unfortunately have succumbed to insect and disease attacks (CIAT, 1978, 1979). As in other plant improvement programs, the search for new ecotypes that combine tolerance to pathogens with other desirable characteristics is a continuing activity.

It is interesting to note that plant protection problems increase in importance after the soil constraints are solved by plant selection, breeding or management in these Oxisol-Ultisol regions. This may be a consequence of eliminating a previously limiting factor or of a pathogen buildup as new plants are grown on many hectares for the first time in a new environment. The same is the case with crops. Tolerance to disease and insect attacks, however, vary with ecological conditions and therefore, the degree of tolerance of each promising ecotype must be validated locally.

Tolerance to burning. Accidental burning is common in savanna regions and intentional burning may be a necessary management practice in cases where grasses grow too fast and lose their nutritive value. Consequently, the adapted species must be able to regrow after burning. Studies by Jones (CIAT, 1979) show that *Andropogon gayanus*, *Panicum maximum*, *Brachiaria decumbens* and *Brachiaria humidicola* regrow rapidly after burning.

4. Supply Nitrogen with Acid-Tolerant Rhizobia

Nitrogen deficiency is a widespread limiting factor in most Oxisol-Ultisol regions, except during the first year or two after land clearing. In most of these regions the price of nitrogen fertilizer is very high relative to the price of beef. Nitrogen fertilization for pasture-based beef production is seldom profitable (O. Paladines, personal

communication). Consequently, the majority of these pastures must rely on symbiotic nitrogen fixation by legumes for their nitrogen supply.

Until recently it has been assumed that most tropical pasture legumes growing on acid soils develop effective symbiosis with native "cowpea-type" strains of Rhizobium, and therefore, the selection of specific strains for individual legume species or cultivars is the exception rather than the rule (Norris, 1972). Recent work by Halliday (1979) and collaborators clearly shows that this is no longer the case. A five-stage screening and matching procedure involving laboratory, greenhouse and field stages has shown a high degree of strain specificity for obtaining effective symbiosis in the most promising legume ecotypes. Recent recommendations including inoculation technology are available (CIAT, 1979).

Long-term field experiments however, show that the response to inoculation with selected Rhizobium strains generally decreases with time. Protecting the inoculant strain with lime or rock phosphate pelleting permits an effective infection in an acid soil. The critical point however, is reached two to three months afterwards when the primary nodule population decomposes. Then the Rhizobia must fend for themselves in an acid soil environment in order to reinfect the plant roots (CIAT, 1979). The selection of effective acid-tolerant strains is therefore, highly desirable. Date and Halliday (1979) developed a simple laboratory technique to screen for acid tolerance at the early stages of strain selection, using an agar medium buffered at pH 4.2. Rhizobium strains tolerant to acidity grow in such a media while those susceptible die.

Acid soil tolerance of the Rhizobia, therefore, is probably as important as acid soil tolerance of the pasture species.

Differences in aluminum tolerance of Rhizobium strains for cowpea have also been identified (Keyser et al., 1979) suggesting that similar relationships may take place in aluminum-tolerant annual crops.

The potential of associative symbiosis by nitrogen-fixing bacteria such as Spirillum lipoferum in the rhizosphere of tropical grasses created expectations about possible important contribution of nitrogen fixation by grasses (National Academy of Sciences, 1977). Unfortunately, evidence to date indicates that the practical exploitation of such symbiosis appears to be minimal (Hubbell, 1979). This is an example of a low input component that did not work.

5. Use Low Cost, Low Reactivity Rock Phosphates

As previously mentioned, phosphorus is the single most expensive purchased input used in establishing and improving pastures in Oxisol savannas, particularly since many of these soils have a high phosphorus fixation capacity. The use of grass and legume species requiring lower levels of available soil phosphorus decreases phosphorus application rates appreciably. Still greater efficiency can be attained if the cost per unit of fertilizer phosphorus can be decreased by direct application of rock phosphates. This is possible in tropical South America which is blessed with large rock phosphate deposits, shown in Figure 4.

All these deposits, except for Bayovar in Peru, are classified as low reactivity materials which are considered unsuitable for direct application (Lehr and McClellan, 1972). Low reactivity rock phosphates

need to react with acids in order for their solubility to increase, which is done in superphosphate manufacturing.

If the soil is acid, the same process occurs naturally, but few crop plants can tolerate the high levels of exchangeable aluminum present at such low pH values. When aluminum-tolerant plant species are grown, however, these low reactivity rock phosphates can be as effective as superphosphates. Table 4 shows the effect of various rock phosphate sources and placement methods on pasture production in an Oxisol of Carimagua, with a pH of 4.8 and about 85% aluminum saturation. The acid-tolerant grass used, Brachiaria decumbens is well adapted to these conditions. Rock phosphate from all tropical South America sources performed in a fashion similar to triple superphosphate, regardless of reactivity rating. Apparently the chemistry of acid soils can effectively replace a superphosphate factory when acid-tolerant plants are grown. Since the cost per kilo of phosphorus as rock phosphate costs 1/3 to 1/5 as much as superphosphate, considerable savings can be made. Thus, low reactivity rock phosphates are suitable for direct application under these conditions. High reactivity rock phosphates are also suitable, but are less common in tropical America.

Since phosphorus is particularly critical during the establishment phase, it is important that these rock phosphates react quickly with the soil and provide the needed boost to get the pasture established. This occurred with the high (Bayovar) and medium (Huila) reactivity rock phosphate at the recommended rate of 50 kg P_2O_5/ha in the Carimagua experiment shown in Table 4. The dry matter production of Brachiaria decumbens during the first cut (three months after planting) with these

two sources was equivalent to that with superphosphate. Similar results with the high reactivity Bayovar rock phosphate on an acid, unlimed Ultisol from the Amazon of Peru have been reported by North Carolina State University (1975). The pasture growth pattern with the low reactivity Pesca rock in the Carimagua experiment, at the same rate (50 kg/ha of P_2O_5), was slower during the first year than with Bayovar and Huila but it caught up with the others within the first year (CIAT, 1978). Results with another low reactivity rock, Araxā, on Oxisols of Brasília, Brazil show that it took about two years to produce the same dry matter yields of Brachiaria decumbens as high reactivity rock phosphate (Sanchez, 1977). A combination of low reactivity rock phosphate with banded superphosphate applications may be desirable in some instances.

6. Correct Other Nutrient Deficiencies

Oxisols and Ultisols are often deficient in calcium, magnesium, potassium, sulfur and several micronutrients particularly zinc, copper, boron and molybdenum. Unfortunately, very little is known about the geographical occurrence of these deficiencies, particularly sulfur and micronutrients, in terms of critical levels in the soil and the requirements of the promising grass and legume species. There are no known ways to overcome these deficiencies except by conventional fertilization. Hutton (1979) attributed most of the lack of legume persistence in mixed pastures of Latin America to uncorrected nutrient deficiencies. Many ranchers in tropical America feel that applying triple superphosphate is sufficient for grass/legume pastures. This fertilizer source provides only phosphorus and some calcium. In tropical Australia molybdenized

simple superphosphate is widely used as the only fertilizer in Alfisols very deficient in nitrogen, phosphorus, sulfur and molybdenum. This source corrects phosphorus, sulfur and molybdenum deficiencies, allowing the legume to provide nitrogen to the mixture. Given the fundamental differences in soil acidity between soils of tropical Australia where improved pastures are grown (mainly Alfisols) and the Oxisol-Ultisol region of tropical America, it is not possible to extrapolate the Australian fertilization practices directly (Sanchez and Isbell, 1979). Surveys of the nutritional status of Oxisol-Ultisol regions such as the one Lopes and Cox (1977) did in the Cerrado of Brazil, plus on-site field experiments on the nutrients such as those conducted in Carimagua, Colombia (CIAT, 1977, 1978, 1979, Spain, 1979) and in Yurimaguas, Peru (Villachica, 1978) contribute significantly to identifying which nutrients are deficient and which are the best practices to correct them, including possible nutrient imbalances which may be induced by fertilization. These studies, however, show that nutrient deficiencies other than phosphorus are in the Oxisol-Ultisol regions. Therefore, site-specific identification is necessary. These efforts must be related to the nutritional requirements of the main grass and legume cultivars, of which very little is known about the species mentioned in this paper.

Insufficient knowledge of nutrient deficiencies is the weakest component in this strategy. This gap can be corrected by systematic determinations of critical nutrient levels in the soil and in the plants. Fortunately, the relatively long-term residual effect of calcium, magnesium, zinc and copper fertilization may reduce application costs. Also, maintenance of suitable levels of these nutrients plus potassium

and sulfur is also favored by a degree of recycling via animal excreta. Nevertheless, it should remain clear that deficiencies of these nutrients must be identified and corrected in order for the improved pastures to persist.

7. Use Low Cost Pasture Establishment Methods

Conventional pasture establishment methods in savanna regions commonly consist of one or two passes with a disk harrow, followed by seeding with a grain drill equipped with a fertilizer attachment. These are relatively easy to do during the rainy season but the cost is high, on the order of U.S.$133/ha in the Llanos of Colombia (Spain 1979, CIAT, 1979). Low establishment costs are possible by two mechanisms, one applicable to Oxisol savannas, and another applicable to most Oxisol-Ultisol regions.

In Oxisol savannas, weed growth after land preparation is very slow due to the extremely low native soil fertility, as long as the soil is not limed or fertilized. Taking advantage of this situation, Spain (1979) developed a low density planting system where considerable savings can be accomplished in terms of seed costs and initial fertilizer applications. After the land is prepared with one or two passes with an offset disk harrowing, grass and/or legume seeds are planted in holes spaced at about 3.16 m giving a population of 1000 plants/ha during the rainy season. The plants receive a localized high rate of phosphorus and potassium, but on a per hectare basis the highest rates used were 9 kg P_2O_5/ha and 1.5 kg K_2O/ha. One man equipped only with a shovel can plant and fertilize one hectare in one day (Spain, 1979).

These plants grow vigorously during the rainy season due to their high soil fertility status and absence of competition from weeds or plants of their own species. Stoloniferous species cover the ground within eight months, at the beginning of the next rainy season (CIAT, 1979). Tussock-type grasses such as Andropogon gayanus and Panicum maximum produce seed at the end of the rainy season. At Carimagua, these seeds aligned themselves in the furrows left by the disk harrow and germinated with the first rainy season showers, starting ahead of the weeds. The new seedlings have to be fertilized shortly after emergence or they will die because of phosphorus and potassium deficiencies. With such a system, pastures were ready for grazing within nine months after planting, which is about three months later than with conventional land preparation. The details are explained more thoroughly in reports by Spain (1979) and CIAT (1978, 1979). Although this system does not reduce the fertilizer requirements relative to conventional plantings, the seed costs are reduced from U.S.$34 to $3/ha (CIAT, 1979). Since seed of improved pasture species is generally scarce, an additional advantage is that vegetative propagation can be used.

This low density planting system is not likely to be successful in savanna areas that have been previously fertilized or in recently cleared rainforest areas where vigorous weed and jungle regrowth takes place. In many of these areas a feasible alternative is to grow crops as precursors of pasture establishment, with the land preparation and fertilization practices required by the crops but interplanting pasture species so when crops are harvested, the pasture is established (Shelton and

Humphreys, 1975; Kornelius *et al.*, 1979; Toledo and Morales, 1979). In effect, pasture establishment costs are largely paid for by the cash crop.

Recent results with a Colombian Ultisol, shown in Table 5, describe some of the relationships involved. When cassava (*Manihot esculenta*) and *Stylosanthes guianensis* were planted simultaneously, cassava yields were decreased somewhat and stylo production halved, but a stylo pasture was ready for grazing after the cassava harvest. When cassava was interplanted with a mixture of *Brachiaria decumbens* and *S. guianensis*, crop yields were adversely affected by the vigorous grass growth. Although the sum of relative yields is identical to the previous case, this combination seriously decreases cassava yields.

When a crop with short growth duration is used, the results are different. Table 5 also shows the same two pasture species planted at the same time with *Phaseolus vulgaris*. Bean yields were not affected by the presence of either the legume alone or the grass-legume mixture, although pasture growth was retarded by the presence of the bean crop. Nevertheless, a pasture was established after the bean harvest.

Intercropping between pastures and crops is extremely site specific and weather dependent. The actual systems to be used must be validated locally, particularly in terms of relative planting rates, row spacing, crop varieties and fertility. On the same location in Colombia, the first upland rice-pasture experiment failed because rice growth was so vigorous that the pastures could not compete with it. A second trial in which relative planting dates and spacings were studied showed excellent associations of short-statured upland rice with a mixture of *Brachiaria decumbens* and *Desmodium ovalifolium* (CIAT, 1979).

It is likely that pastures established in such a manner would enjoy a higher soil fertility level if fertilized with the recommended rates for the crops, which would provide a beneficial residual effect to the pastures. If managed in conjunction with other conventionally established pastures, they could serve as a source of protein or energy for the herds.

8. Use Low Cost Pasture Reclamation Techniques

After the pasture is established, management is aimed at maintaining its initial productivity and botanical composition by manipulating stocking rates, grazing pressure, fertilization and weed control. Unfortunately, most of the existing data is related to stocking rates and grazing pressure, with extremely limited knowledge of maintenance fertilization and weed control in Oxisol-Ultisol regions. It is generally believed that maintenance fertilization rates should be less than half of the established rates of all nutrients applied. Soil tests and plant analysis could quantify which are the most economical rates and what their frequency of application should be, either every year or every two years. Also these techniques would identify nutritional deficiencies or imbalances that arise with time.

Pasture degradation in the Amazon Jungle has received considerable attention. According to Hecht (1979) most of the *Panicum maximum* pastures in the Brazilian Amazon are in some stage of degradation. In the Paragominas area of the State of Pará, Hecht reports that about 70% of the cattle ranches went out of business because of degraded pastures. The main causes of degradation are the use of a grass species with high nutritional requirements, no fertilization, no legumes and often excessively high stocking rates. The costs of controlling jungle regrowth

becomes too high when the Panicum maximum population decreases, and the fields are gradually transformed into a secondary forest.

Serrão and coworkers (1979) have found that phosphorus deficiency is the factor that sets this process in motion. Phosphorus availability is high right after burning the forest, remains above the critical level up to four years, and then declines. The correction of this problem is remarkably simple and of low cost. Serrão et al., (1979) recommend to cut the jungle regrowth with a machete and burn the field, then broadcast 50 kg P_2O_5/ha half as simple superphosphate and half as rock phosphate. Under these conditions, the Panicum maximum population increased from about 25 to 90%. Broadcasting legume seeds has also been incorporated into the system.

9. Strategic Use of Improved Pastures

The combination of some of these components in actual grazing trials is providing promising results. Legume-based pastures on Carimagua Oxisol savannas, planted conventionally, with an initial fertilization rate of 50 kg P_2O_5/ha, 25 kg K_2O/ha, 20 kg S/ha and 20 kg Mg/ha and an annual maintenance rate of half that amount are expected to produce an average liveweight gain of steers on the order of 400 to 500 g/day, with a carrying capacity of about 2 animal units/ha during the rainy season and 1 animal/ha during the dry season. Total beef production per hectare in fattening operations is expected to be on the order of 200 to 300 kg/ha/year (Nores and Estrada, 1979). Actual grazing trial data at Carimagua have exceeded these estimated (CIAT, unpublished). This figure is approximately twice the production with improved Brachiaria decumbens pastures without legumes, and about 10 times as much as the productivity of

the native savanna. Although such liveweight gain levels have been obtained during the first or second year in Oxisol regions (CIAT, 1978; Rolón and Primo, 1979), they have to be validated for persistence for a period of time. Under Colombian Llanos conditions, a minimum persistence of six years is necessary according to economic analyses (CIAT, 1979).

If these legume-based pastures are indeed persistent as they appear to be at the time of this writing, the increases in production per unit of land are so large that several cost cutting alternatives become feasible. In areas relatively close to the markets where cattle can be fattened, most of the grazing area could be put into such improved pastures. In the case of the Colombian Llanos this could double the rate of return on investment (Nores and Estrada, 1979).

In udic rainforest areas, the productivity of well managed grass-legume pastures is even higher than in the savannas because of the absence of a strong dry season. Toledo and Morales (1979) report an annual liveweight gain of 450 kg/ha with a mixture of Hyparrhenia rufa and Stylosanthes guianensis fertilized with single superphosphate for a three-year period in an Ultisol from Pucallpa, Peru. This is three times the amount obtained with the pure grass without fertilization.

In areas devoted to cow-calf operations and far away from the markets, putting about 10% of the grazing area in improved legume-based pastures appears to be a promising alternative. Such an area would be strategically grazed in relation to the 90% left as unimproved native savanna. Strategic grazing consists of placing the animals with higher nutritional requirements such as lactating cows and recently weaned calves on the improved pastures while other animals graze the native

savanna. Also, intense grazing periods by much of the herd are done when the pasture seems to be growing too fast and is in danger of decreasing its nutritional value.

A breeding herd experiment was established in Carimagua in 1977 to test this hypothesis. Three identical herds with 54 cows each were subjected to native savanna plus the best animal management and health practices including ad libitum mineral supplementation. Three other identical herds were given the same treatment except that 10% of their grazing area had Brachiaria decumbens and Stylosanthes guianensis grown in separate paddocks. At the end of the first full year, the strategic use of improved pastures in 10% of the area increased the annual liveweight output by 250 percent (CIAT, 1979).

Although these results need more time for validation, they show the promise of strategic use of improved pastures, either as energy or protein banks or both. The concept could also apply to rainforest areas with degraded pastures such as those described by Serrão et al., (1979). In cases where it is not feasible to have a pasture regeneration program for the entire farm, complete regeneration of part of it could have a similar effect as that observed in the savannas.

EFFECTS OF IMPROVED LEGUME-BASED PASTURES ON SOIL PROPERTIES

Most of the present improved pastures in Oxisol-Ultisol regions of tropical America are inherently unstable because they lack one or more of the key components described in this paper. The principal limitations are the use of a poorly adapted grass species, lack of fertilization, the

absence of persistent legumes or sufficient seed supplies. The proposed strategy, if successful, should have the opposite effect. Persistent, legume-based pastures can provide continuous cover to protect against soil erosion, as long as they are not overgrazed. Such well managed pastures have maintained the organic matter contents of an Ultisol from northern Australia for 16 years at the same levels as before clearing the rainforest, as shown in Figure 5. In the eastern Amazon of Brazil, an additional advantage in the maintenance of soil chemical properties has been recorded. Serrão et al., (1979) sampled soils in unfertilized *Panicum maximum* pastures of known ages in two areas of Brazil. The results summarized in Figure 6 indicate that soil pH increased from about 4.5 to between 6 and 7 right after burning, and remained constant up to 13 years. Aluminum toxicity was completely eliminated and calcium and magnesium levels were maintained at fairly high levels, as well as organic matter and nitrogen. Potassium values remained close to the critical level while available phosphorus decreased below the critical level rather quickly. These results are from samples of different fields of known age after clearing taken at the same time; therefore, they confound time and space variability. Nevertheless, it seems clear that many of the chemical properties of these Oxisols were definitely improved when cleared and grazed. These soil dynamics are in sharp contrast with the rapid fertility decline observed after clearing rainforests and growing annual crops in udic areas of Peru and Brazil (Sanchez, 1977, 1979). The reasons for these differences are not clearly understood and deserve more thorough study. Some factors favoring a less marked decline in eastern Amazonia may be an ustic soil moisture regime which

allows for a more thorough burn and more ash and possibly upwards movement of cations and anions during the dry season. Also, the periodic burning every few years practiced in these areas and some degree of nutrient recycling by the grazing animal may contribute to the effects shown in Figure 6. Whatever the reasons are, the improvement in the chemical properties of acid infertile Oxisols is remarkable, and shows promise for better managed grass-legume pastures in the Amazon region.

SUMMARY

Results from a multidisciplinary effort by CIAT's Tropical Pastures Program and collaborators in Colombia, Brazil and Peru suggest the emergence of a low input soil management strategy designed to take advantage of acid soil infertility rather than overcoming it by large applications of lime and fertilizers. Legume-based pastures for beef production have comparative advantages for expanding the agricultural frontier of tropical America into its vast Oxisol-Ultisol regions. This may provide an alternative for alleviating population pressures from erosion-prone, high base status soil regions. Although not all the components of this strategy are sufficiently well known, the main ones are: 1) Use of land resource evaluation studies to select soils suitable for crop-pastures systems, avoiding those with severe physical constraints; 2) use of appropriate land clearing systems in forested areas that prevent soil compaction and include burning to take advantage of the free fertilizer value of the ash; 3) selection and/or breeding of productive, persistent and compatible pasture grass and legume cultivars tolerant to high levels of Al saturation, low levels of available soil P, major disease and

insect attacks, drought stress, and burning; 4) supply nitrogen to the system by inoculating legumes with effective, acid-tolerant Rhizobium strains; 5) use low cost, low reactivity rock phosphates which become readily available when the soil is kept acid and Al-tolerant plants are grown; 6) correct other nutritional deficiencies, particularly potassium, sulfur and micronutrients; 7) use low cost pasture establishment methods such as low density seedings or interplanting with crops; 8) use low cost pasture reclamation techniques; 9) for extensive cow-calf operations place about 10% of the grazing area in improved pastures.

Preliminary results show that this strategy is very promising. Well managed pastures provide a continuous protective cover against soil erosion, promote nutrient recycling and improve certain soil chemical properties.

LIST OF ACRONYMS OF RESEARCH INSTITUTIONS MENTIONED IN THIS PAPER

CIAT = Centro Internacional de Agricultura Tropical

CPAC = Centro de Pesquisa Agropecuária dos Cerrados

CPATU = Centro de Pesquisa Agropecuaria do Trópico Úmido

EMBRAPA = Empresa Brasileira de Pesquisa Agropecuaria

ICA = Instituto Colombiano Agropecuario

INIA = Instituto Nacional de Investigación Agraria

IVITA = Instituto Veterinario de Investigación del Trópico y de Altura

UEPAE = Unidad de Execução de Pesquisa no Ámbito Estadual

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Table 1. Land use capability groups used in Brazil for rainfed agriculture (from Ramalho *et al.*, 1978).

Land capability group	Crops			Improved Pastures	Forestry and/or Natural Grasslands	Biological Reserve
	H	M	L[1/]	M	M	O
1	X	X	X	X	X	X
2		X	X	X	X	X
3			X	X	X	X
4				X	X	X
5					X	X
6						X

[1/] Management levels:

H = High input use: fertilizer, new technology, largely mechanized

M = Moderate input use: limited fertilizer, technology and mechanization

L = Low input use: primarily manual labor, few purchased inputs

O = Zero use.

Table 2. Effects of land clearing methods on pasture dry matter production within the first 10 months and soil properties (0-10 cm depth) in Yurimaguas, Peru

Parameter	Slash and Burn	Bulldozer Clearing
Dry Matter Production (ton/ha):		
P. maximum	7.8	3.2
P. maximum - *P. phaseoloides*	6.3	3.5
P. maximum + N P K + lime	32.2	24.2
Soil Properties:		
Infiltration rates (cm/hr):	11.7	0.5
Exch. Al (meq/100 g)	1.70	2.07
Exch. Ca + Mg (meq/100 g)	0.88	0.55
Exch. K (meq/100 g)	0.32	0.19
Avail. P (Olsen-ppm)	16.5	11.0
% Al saturation	59	73

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

Table 3. Difference in requirements of available soil phosphorus for maximum growth of various grass and legume species growing on an Oxisol of Colombia in relation to general soil test recommendation for crops.

Species or Ecotype	Critical Bray II soil test level
	ppm
Gen. crop recommendation (Colombia)	15.0
Desmodium leonii 3001	11.4
Macroptilium sp 545	9.5
Brachiaria decumbens 606	7.0
Desmodium ovalifolium 350	6.6
Andropogon gayanus 621	5.2
Zornia latifolia 883	3.4
Stylosanthes capitata 1019	3.1
Stylosanthes capitata 1078	2.5

Source: CIAT (1978, 1979).

Table 4. Relative agronomic effectiveness, expressed as percent yields with superphosphate of various rock phosphate sources in relation to the cumulative dry matter yield of *Brachiaria decumbens* in an Oxisol of Carimagua, Colombia (sum of cuttings over 28 months after planting).

P Source	P applied (kg P_2O_5/ha)				
	25	50	100	400	$\bar{x}$
	% Relative Agronomic Efficiency				
Triple superphosphate	100	100	100	100	100
Gafsa R. P. (high reactivity)	110	75	108	99	98
Bayovar R. P. (high reactivity)	125	90	87	98	100
Huila R. P. (med. reactivity)	90	110	96	109	103
Pesca R. P. (low reactivity)	111	81	101	104	99
Tenn. R. P. (low reactivity)	112	78	88	106	96

Source: CIAT (1979).

Table 5. Crop and pasture production in row intercropped systems planted simultaneously on an Ultisol from Quilichao, Colombia fertilized with 0.5 ton/ha of dolomitic lime and 100 kg P_2O_5/ha of triple superphosphate.

Species		Crop Yields			Pasture (Dry Matter)			Sum of RY
Crop	Pasture* (# cuts)	Mono-culture	Inter-cropped	RY**	Mono-culture	Inter-cropped	RY	
		----- ton/ha -----		%	----- ton/ha -----		%	%
Cassava (roots)	S.g. (3)	45.6	38.2	84	2.1	1.0	48	132
"	B.d. + S.g. (3)	42.4	17.0	40	7.0	6.4	92	130
Beans (grain)	S.g. (1)	1.08	1.08	100	0.80	0.37	40	146
"	B.d. + S.g. (1)	1.22	1.24	102	1.70	0.93	55	157

Adapted from CIAT (1979).

*S.g. = *Stylosanthes guianensis* 136; B.d. = *Brachiaria decumbens*.

**RY = Relative Yields = $\frac{\text{Intercropped}}{\text{Monoculture}} \times 100$

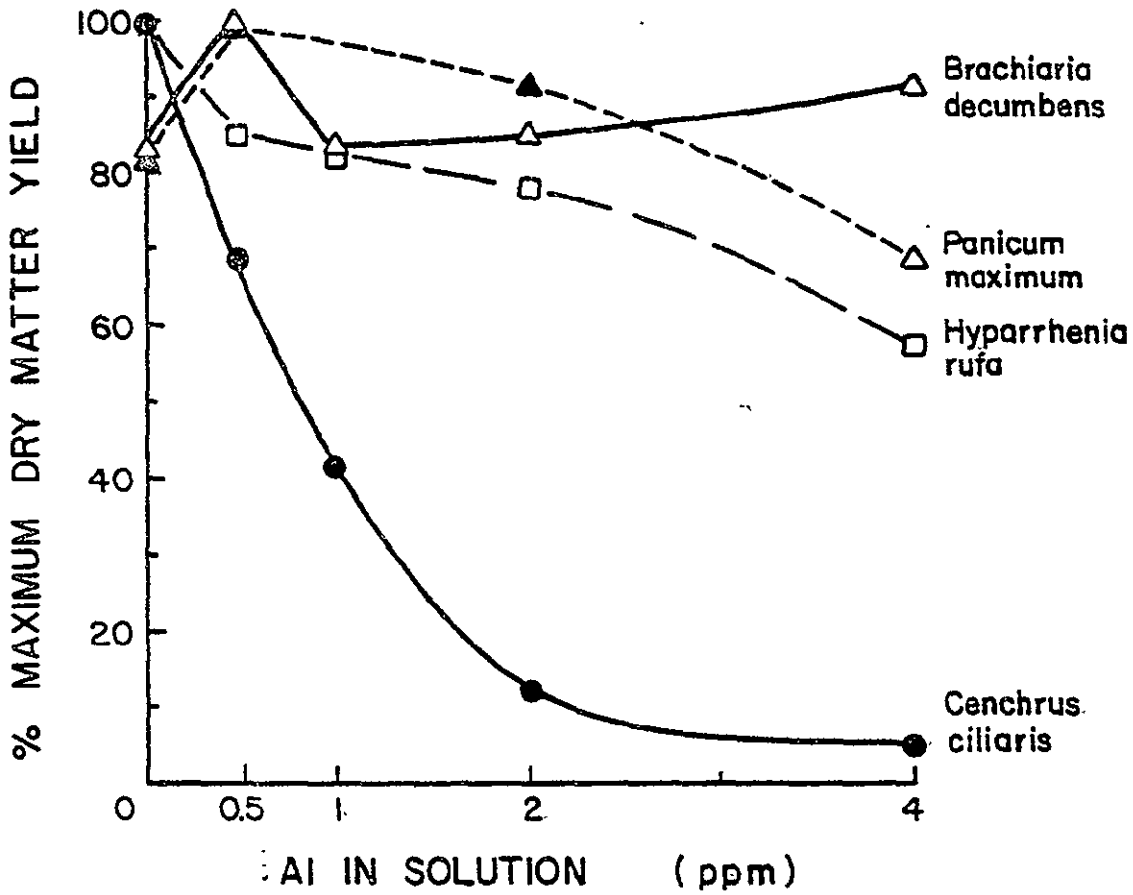

Figure 1. Differential tolerance to aluminum in culture solution by four tropical grasses. Source: Spain (1979).

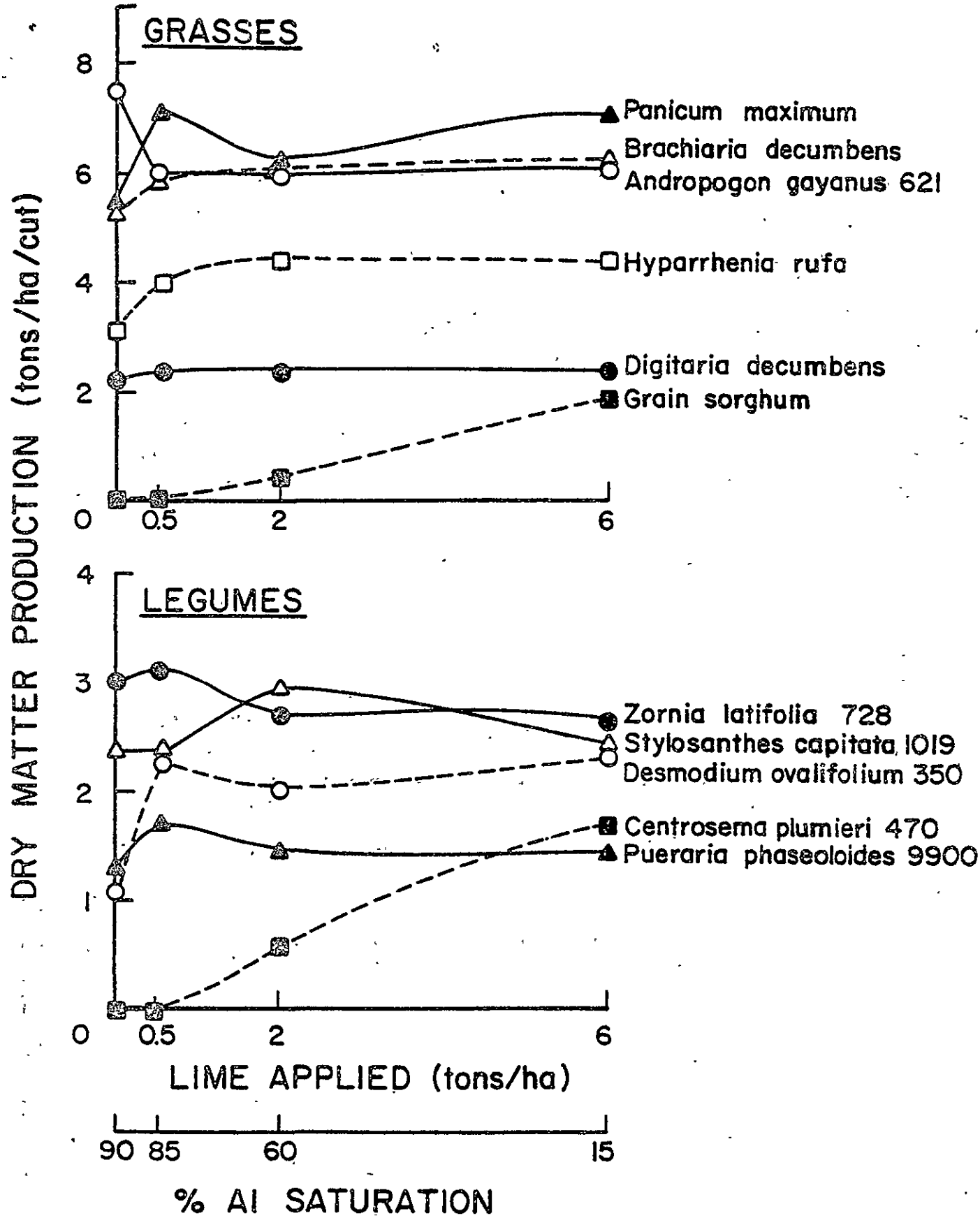

Figure 2. Field response to lime applications by several grass and legume forage species in an Oxisol of Carimagua, Colombia. Mean of 4-5 cuts for the grasses and first cut for legumes. Adapted from Spain (1979).

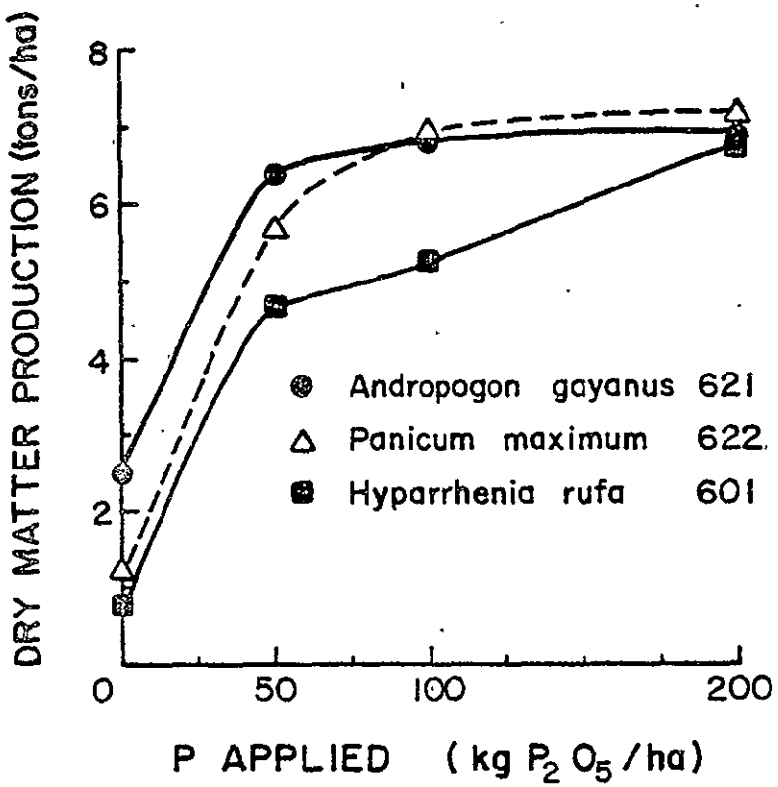

Figure 3. Differential response to phosphorus fertilization of three grass species during the establishment year in an Oxisol of Carimagua, Colombia. Sum of 3 wet season cuts. All treatments received 400 kg N/ha. Source: Jones (CIAT 1979).

Figure 4. Rock phosphate deposits in tropical South America, 1977.
Source: Fenster and León (1979).

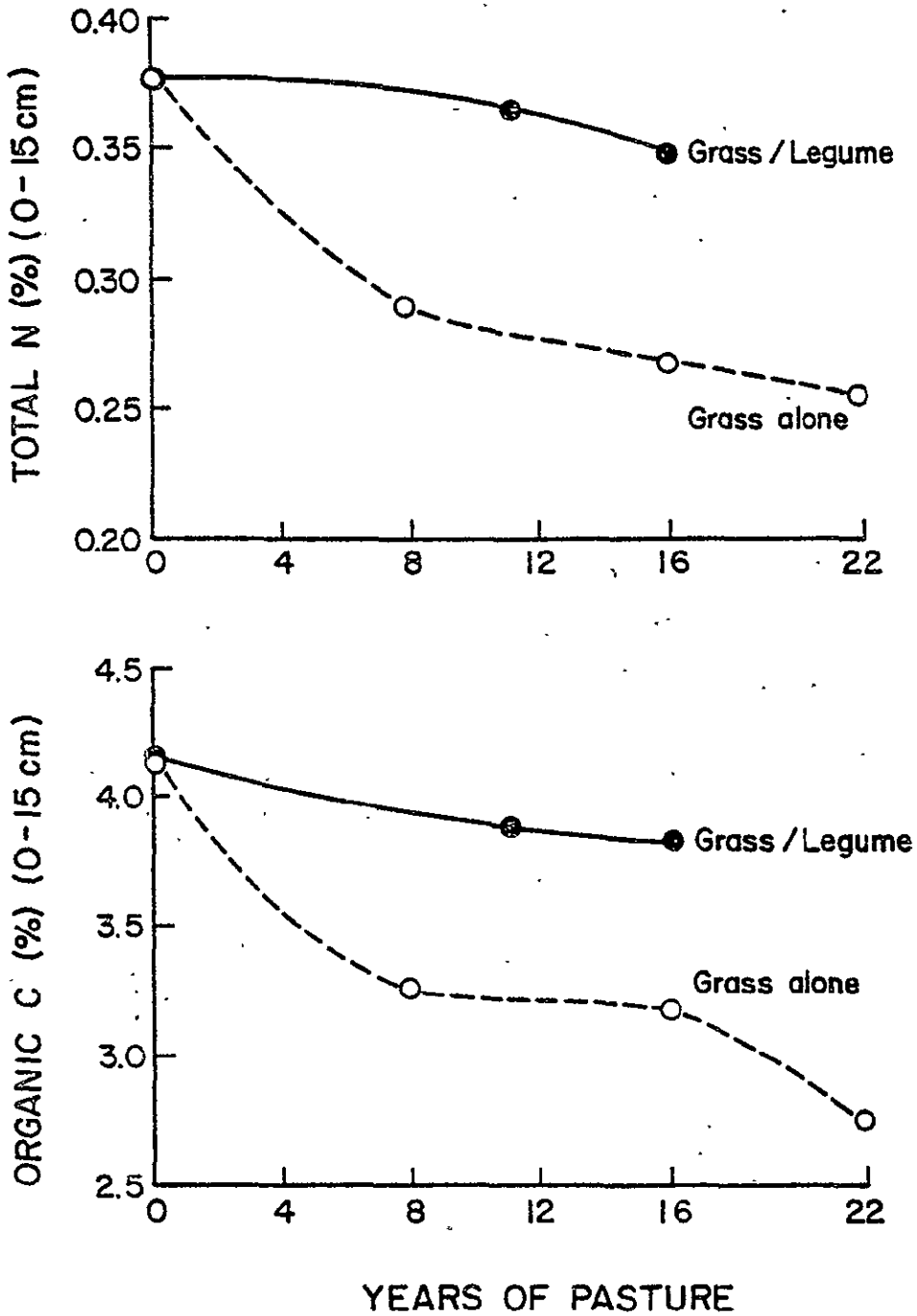

Figure 5. Long-term effects of unfertilized guinea grass (Panicum maximum) pastures, with and without Centrosema pubescens, on the topsoil organic matter after clearing a rainforest in South Johnstone, Australia. Source: Adapted from Bruce (1965).

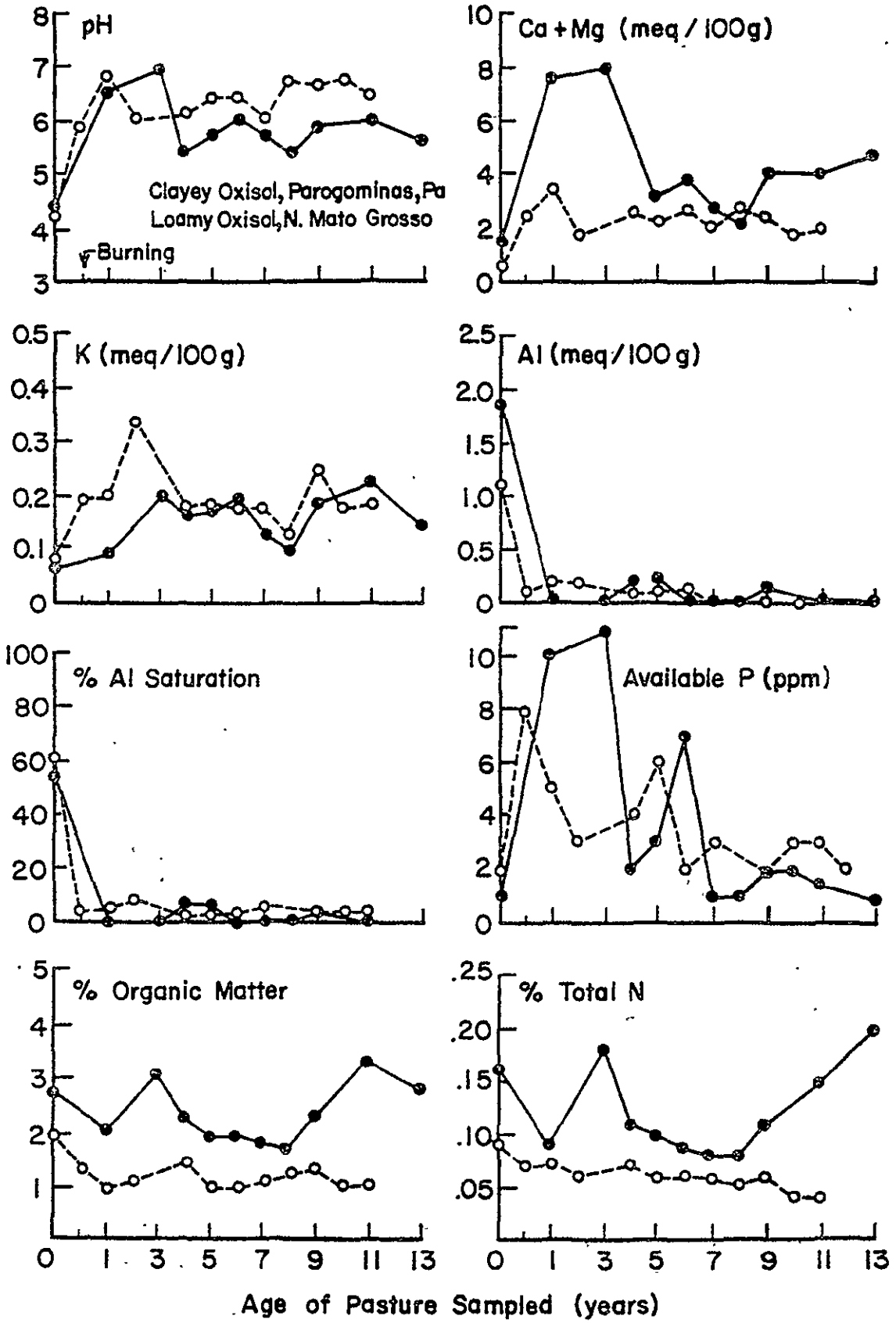

Figure 6. Changes in topsoil properties of Pancium maximum pastures of known age in eastern Amazonia (sampled at the same time). Adapted from: Serrão et al., (1979).