Sustainable Utilization of Poor Acid Soils of Tropical America

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ABSTRACT

Tropical America's 800 million hectares of savannas and forests are characterized by the predominance of acid Oxisols and Ultisols with low fertility. These frontier lands are being incorporated into the region's agricultural production area. Land-clearing and intensification of areas close to infrastructure cause the degradation of natural resources. There is thus a need to develop higher-yielding sustainable production systems. CIAT strategies to reduce pressures for land-clearing in fragile environments include the development of sustainable agropastoral production systems for less fragile savanna environments and the reclamation of already degraded forest lands by the replacement of extensive ranching and shifting cultivation with sustainable agrosivilvopastoral systems. To achieve these specific strategies, it is necessary to promote efficient input use based on adapted components; low-cost management to maximize outputs and effectively use natural and purchased inputs in minimizing negative environmental effects; and maximizing nutrient cycling. New, adapted grass-legume pastures, upland rice, maize, sorghum, soybeans and cassava cultivars are becoming available. Crops can pay for upgrading soil fertility to establish pastures and tree components. Grass-legume pastures with deep and profuse roots can reduce erosion and improve the physical chemical and biological soil conditions for subsequent cropping. To realize the potential of these sustainable integrated systems on poor acid soils, technologies must be based on commercially valuable, ecologically compatible, adapted components.

Background

Tropical America has 800 million hectares of savannas and forests. In more than 50% of the tropical savannas (about 100 million hectares), the topography and soil physical properties are favourable for intensified land use. Some 15% of the forest areas (80–100 million hectares) also have a potential for cropping and livestock production; however, they are at high environmental risk given the indiscriminating land use, current pratices and available technology. Fifty-one percent of tropical American soil consist of acid Oxisols and Ultisols with a low fertility (Table 1).

The main ecosystems of tropical American lowlands were classified and mapped by Cochrane *et al.* (1985). A summary of the chemical properties classified by topographic conditions for the South American savanna and semi-evergreen seasonal forest areas is presented in Table 2. Tropical American savannas and rainforest areas are being subjected to land-clearing and intensification of land use as a result of socio-economic pressures.

The tropical American process of frontier expansion includes population migration:

1) To the savannas, where mostly well-do-to ranchers occupied or purchased land and established extensive cow-calf ranching systems. With the development of infrastructure,

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Table 1 Distribution and percentage of total area of Oxisols and Ultisols in tropical America

Region/country	Million hectares	% of the region/country
Tropical America	848	51
Brazil	573	68
Colombia	67	57
Peru	56	44
Venezuela	52	58
Bolivia	40	57
Guyana	12	62
Suriname	11	62
Paraguay	10	24
Ecuador	9	23
French Guiana	9	94

Source: Cochrane, 1979.

Table 2 Area (million hectares) of topsoil (0-20cm) chemical properties classified by topographic conditions in the seasonal forests and tropical savannas of South American lowlands

Parameter range	Semi-evergreen seasonal forest			Poorly drained flat	Tropical savannas	
	Poorly drained flat	Well-drained			Well-drained	
		<8% slope	>8% slope		<8% slope	>8% slope
pH: >7.3	0.1	-	-	-	-	-
5.3-7.3	30.0	15.9	7.3	10.7	20.5	14.0
<5.3	28.5	143.3	77.4	24.9	66.8	33.5
% Al saturation:						
<70	14.3	94.0	53.1	4.1	34.9	20.5
40-70	3.3	36.8	16.8	7.7	12.7	13.1
10-40	14.0	14.2	9.0	13.5	24.0	4.1
<10	26.8	14.2	6.8	10.3	15.6	9.8
% OM:						
>4.5	22.8	18.3	4.2	20.0	12.6	10.6
1.5-4.5	31.0	124.1	54.3	16.4	66.5	32.3
<1.5	4.8	16.8	26.1	0.3	8.3	4.5
CEC (meq/100g)						
>8	36.2	20.8	6.8	16.4	8.2	5.8
4-8	18.4	66.8	24.4	9.5	21.7	13.2
<4	3.9	71.5	53.4	10.6	57.3	28.4
Total area	58.5	159.2	85.7	35.6	87.2	47.7

Source: Cochrane et al., 1986.

higher land prices occur together with subdivision and intensification. Improved pastures and crop production replace native savanna grasslands. Fattening and dual-purpose (beef-milk) cattle production systems together with crop expansion are replacing traditional extensive ranching systems in Brazil, Venezuela and Colombia.

2) To the forest, where two contrasting situations coexist. In the Brazilian Amazon, highway development and national policies providing economic incentives and subsidies for development and occupation of the region during the 1960s and 1970s have led to massive deforestation and the establishment of large cattle ranches and plantations (rubber, cacao, pawpaw, guarná, castanha do pará, etc.). In contrast, in the Andean Amazon, migration and

colonization of the region are the result of socio-economic pressures rather than direct national policies. Landless rural peasants migrate into the forest after roads are opened for the exploitation of timber or oil. Settlers establish shifting cultivation systems (*chacras*) to grow subsistence crops such as rice, maize, cassava and plantains. Part of this production is sold in local markets, to obtain some income for other needs but seldom for savings and investment. The most successful settlers buy neighbors' degraded lands and consolidate the area in cattle pastures.

A parallel phenomenon, is land-use redistribution due to expansion of crop production on prime lands, shiftig cattle production systems into marginal and frontier lands of savannas and forest with lower opportunity cost. Figure 1 shows the shift of cattle population in Brazil and Colombia during the last 35 years. Migration of population and cattle together with the expansion of crop production in areas close to infrastructure is promoting intensification of land use and degradation in these poor-acid-soil lands. There is a clear need to develop highly productive sustainable land use systems to facilitate economic development and preserve tropical savanna and forest natural resources.

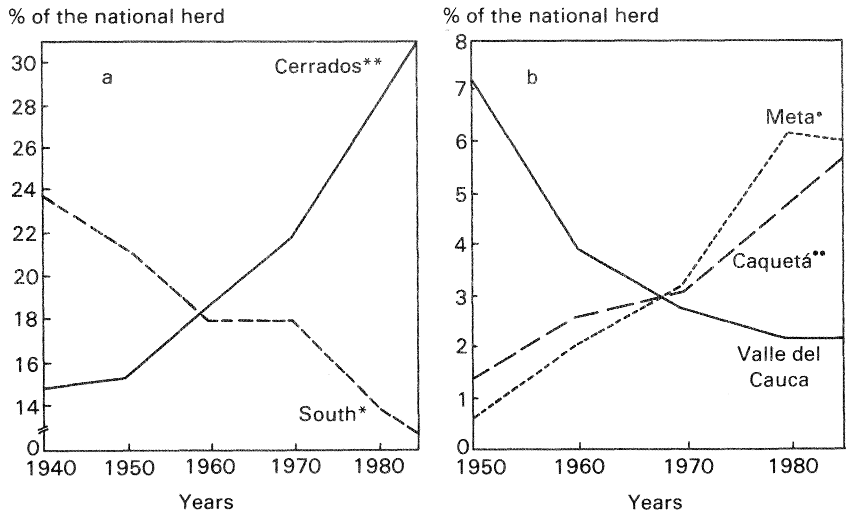

Fig. 1 Regional shift of cattle industry : a) Brazil (*Rio Grande do Sul and Sta. Catarina ; **Goias and Mato Grossso), b) Colombia (• Savannas, ••rainforest areas).

Constraints on sustainable land use

Biophysical constraints

The predominant Oxisols and Ultisols are chemically poor, with low cation exchange capacity (CEC$<$5meq/100g), low pH ($<$5) and toxic levels of aluminum saturation ($>$70%). These characteristics prevent continuous production of crops such as maize, rice, soybeans, wheat and others. The same can be said for non-adapted cultivars of tropical grasses and legumes such as *Digitaria decumbens* cv. Pangola, *Panicum maximum* cv. Mckueni, *Glycine wightii* and others. Heavy mechanization, liming and fertilization are only a partial solution. Mechanization and chemical inputs will only change the topsoil, without removing negative soil conditions beyond 20-30cm. Roots of non-adapted plants will suffer under short drought stresses and will be limited in their capacity to use the scarce native soil fertility, since root development is limited to the modified topsoil layer.

High biotic pressures that occur in these savanna and rainforest ecosystems, with contrasting wet and dry seasons, are also an important constraint on crops and pastures. Examples are the spittlebug on *Brachiaria* spp. pastures, anthracnose of *Stylosanthes* spp. and rice blast (Piricularia). Large pesticide use is only an expensive short-term solution and may pose a threat to the environment's biological equilibrium.

Intensification of these lands requires the development of new crop and pasture cultivars adapted to soil, climate and biotic conditions of these areas.

Socio-economic constraints

Weakened Latin American economies with high international debts and high inflation rates, favor the short-term perspective in natural resource use and exploitation. The long-term perspective required for natural resource conservation and sustainability of production systems is of minimal or no priority for politicians and decision-makers. Additionally, farmers often have only limited access to capital (credit and/or subsidies) for investing in high-input technologies or conservation practices.

Consequently, if new technologies to increase land productivity with crops, pastures, and trees in a sustainable manner are to be adopted, they must be economically attractive and based on efficient use of purchased inputs.

Strategies

CIAT has adopted two levels of strategies to develop sustainable production systems in poor acid soils of tropical America. On the one hand, pressures for land-clearing and utilization of fragile environments should be reduced; on the other hand, environmentally fitted components and technologies should be developed.

For the first level, CIAT's two-pronged strategies aim at the;

1) Development of highly productive agropatsoral sustainable production systems in the less fragile zones of the tropical savannas, thus helping to reduce market pressure for land-clearing and deforestation in more fragile environments (i. e. steep savanna or forest lands). In other words, if economically attractive technologies can be developed for less fragile environments, commercial enterprises and wealthy farmers will less likely invest in development of more fragile areas.

2) To reclaim already degraded forest lands, replacing extensive ranching, low-productivity shifting cultivation, and degraded plantations with highly productive and land use efficient sustainable agrosilvopastoral systems. Since further infrastructure development is not expected under Amazonian countries' economies, sound ecological and economical intensification of these degraded lands will effectively help to reduce socio-economic pressures on further deforestation.

These strategies at the ecosystem level require a detailed land use potential classification and their discrimination for development, reclamation or protection.

The strategies at the second level, to facilitate the intensification with sustainable production systems, in both savannas and forests, will require: 1) efficient use of inputs; 2) low-cost management; and 3) maximizing nutrient cycling to improve the low natural soil fertility and the conservation of natural resources.

Efficient use of inputs

Inputs should be used to correct soil deficiencies limiting plant growth. To achieve this objective, it is essential to genetically improve and select cultivars of crops, trees, and pastures adapted to prevailing soil, climate and biotic constraints.

Extensive root development, association with microbes (i. e., mycorrhiza), tolerance of exclusion of toxic elements (Al and Fe), and N fixation through legume-rhizobium symbiosis are essential parts of the strategy.

Low-cost management

Improved, environmentally adapted plants are not a panacea ; management of crops, pastures and tree components should maximize the utilization of available natural resources (fertility, positive biotic elements and water) and purchased inputs (mechanization, amendments, fertilizers and agrochemicals), as well as minimize loss of soil and nutrients from the system. Management techniques should also minimize negative environmental (physical, chemical and biotic) impact.

Maximizing nutrient cycling

The working hypothesis is that the integration of crops, trees, and pastures in agropastoral and agrosilvopastoral systems, will contribute to the sustainability of intensified production systems on poor acid toils.

Crops (rice, maize, sorghum, cowpea, cassava, soybeans, etc.) are expected to reduce the cost of pasture/tree development by paying for land preparation and fertilizers required to initially upgrade soils' physical and chemical status. In turn, effective recycling under well-managed adapted grass-legume pastures will improve over time (5-10 years) the soil structure and organic matter status for subsequent cropping cycles, within sustainable agropastoral systems. In agrosilvopastoral systems, trees will additionally contribute to nutrient cycling and income generation, preventing erosion on steep hillsides.

Work in progress

Development of new, adapted components

Over the last 15 years, CIAT has developed compatible components for integration of crop-pasture systems for sustainable production on poor acid soils. CIAT also hosts the main efforts of CIMMYT to develop aluminum-tolerant maize cultivars and INTSORMIL's effort to develop sorghum for acid soils.

1) New pastures

CIAT's Tropical Pastures Program increased the world's acid soil forage grass and legume collection from 4,000 accessions in 1978 to more than 22,000 accessions today.

Through decentralized screening for adaptation to soil, climate and biotic pressures, in cooperation with the RIEPT (International Tropical Pastures Evaluation Network) (Toledo, 1982), several key species are being identified for their adaptation and promise in savannas and degraded forest areas of tropical American lowlands. New cultivars of the grasses *Andropogon gayanus, Brachiaria brizantha, B. decumbens, B, dictyoneura, B. humidicola* and *Panicum maximum* ; and the legumes *Arachis pintoi, Centrosema acutifolium, C. brasilianum, C. macrocarpum, C. pubescens, Desmodium ovalifolium, Stylosanthes capitata* and *Stylosanthes guianensis* are now being released by national programs.

Combining adapted grasses with nitrogen-fixing legumes reduces the need to apply expensive nitrogen fertilizers for pasture maintenance. New pasture technology based on adapted grass and legume cultivars is achieving striking levels of productivity in savanna ecosystems. Figure 2 shows the magnitude of productivity increases of *Andropogon gayanus* alone and in association with the commercially released legume *Stylosanthes capitata* cv. Capica, as well as productivity of *Brachiaria dictyoneura* cv. Llanero and *Centrosema acutifolium* cv. Vichada pasture. This association's productivity is twice that of native grassland in terms of liveweight gains per animal and about 15-fold in terms of liveweight gains per hectare.

Farmer adoption is under way. It is estimated that about 15,000 ha of these pastures are planted in the Llanos of Colombia. The main factor limiting further adoption there has been

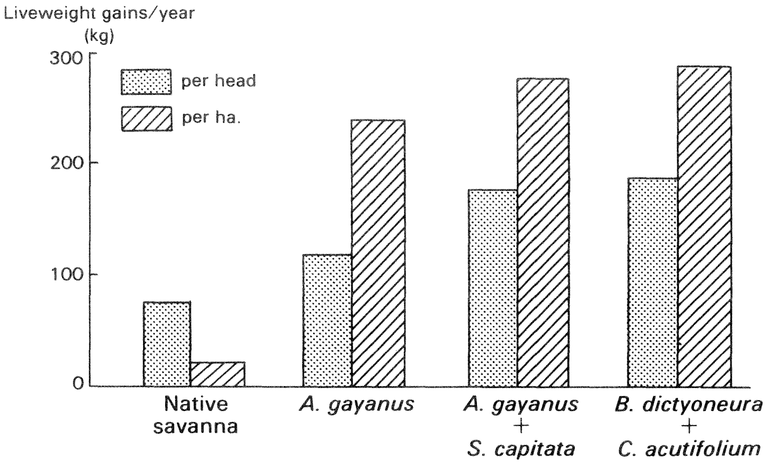

Fig. 2 Productivity of best managed native savanna and new pastures in Oxisol of the Colombian Llanos (Cited from CIAT, 1988).

seed availability of the new cultivars. In the Brazilian Cerrados, where an aggressive commercial seed sector exists, more than 600,000 ha have been planted with *Andropogon gayanus* due to its insect tolerance and better dry-season performance (Sáez and Andrade, 1990).

New grass-legume pastures, that effectively capture and recycle limited soil nutrients and purchased inputs, are emerging for reclamation of degraded lands and intensification of production on already cleared forest areas. Table 3 shows experimental results from different areas of the region, documenting the possibility of obtaining annual liveweight gains of over 600 kg/ha, especially when legumes are present in the pasture.

Legumes contribute directly and indirectly to high protein levels in the diet, especially

Table 3 Liveweight gains from several pastures after degraded rainforest lands

Pastures	No. of years	Stocking rate (head/ha)	Liveweight gains/ha /year
Native grasslands :			
Homolepis sturensis ("Guaduilla")[a]	1	1.5	110
Paspalum notatum ("Trenza")[b]	1	3.1	204
Improved grass pastures :			
Brachiaria humidicola (CIAT 679)[c]	2	2.5	351
Andropogon gayanus (CIAT 621)[c]	2	2.1	340
Improved grass-legume pastures :			
A. gayanus +			
C. macrocarpum (CIAT 5452)[d]	5	4.4	660
Aci. *gayanus* +			
S. guianensis (CIAT 184)[e]	2	3.5	650
B. decumbens (CIAT 606) +			
D. ovalifolium (CIAT 350)[e]	5	5.5	897
B. dictyoneura (CIAT 6133) +			
D. ovalifolium (CIAT 350)[d]	4	5.0	803

Sources : a/ Caqueta, Colombia (Maldonado, 1990). b/ Cauca, Colombia (Escobar *et al.*, 1971). c/Paragominas, Brazil (EMBRAPA, 1988). d/ Quilichao, Colombia (CIAT, 1988). e/ Yurimaguas, Peru (Dextre *et al.*, 1987).

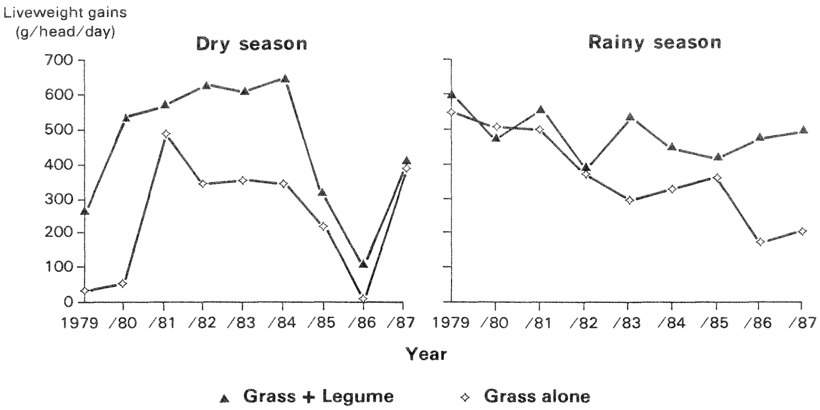

Fig. 3 Liveweight gains of steers on *B. decumbens* and *B. decumbens* + *P. phaseoloides* pastures at Carimagua, Colombian Llanos (Cited from : Lascano and Estrada, 1989).

when grass availability drops in the dry season (particularly in savannas), by inputting nitrogen, critical for plant production sustainability and soil improvement.

Figure 3 shows dry and rainy season productivity over time of a single grass (*Brachiaria decumbens*) pasture and a grass-legume (*Brachiaria decumbens*+*Pueraria phaseoloides*) pasture in the Colombian Llanos. Legume contribution to pastures is not only reflected in additional liveweight gains through the seasons but also in improving sward production stability, better expressed during the rainy season, when water is not limiting plant growth.

2) Upland rice for poor acid soils

The main constraints for developing high-yielding upland rice for acid soil savannas is tolerance to rice blast (Piricularia), tolerance to soil acidity and grain quality for Latin American consumers. Several selected upland lines, from IITA (International Institute of Tropical Agriculture), IRRI (International Rice Research Institute), and EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) have been used as parents by CIAU's rice breeding program to develop new semi-dwarf lines highly tolerant to Al and Fe toxicity, with profuse root systems to effectively use soil nutrients and water. Table 4 presents the yield of several advanced upland rice lines and a local check at three different acid soil savanna sites of the Colombian Llanos. These materials have performed well in other parts of the

Table 4 Upland rice yields (kg/ha) of advanced lines compared with local check at three sites of the Colombian Llanos

Cultivar	Sites*		
	Corocoras	Matazul	Piamonte
CT 6947-7-1-1-1-7M	2945	2121	2265
CT 6196-33-11-1-3	2663	1548	1651
CT 6261-5-7-2P-5	2578	1496	2085
P 5589-1-1-3P-5-2P	2525	1604	1620
CT 6196-33-10-4-15	2481	1872	2247
CT 6196-33-10-4-9	2360	1664	1989
Check : Orizica-2	754	1193	1173

* Al saturation 89-93% ; fertilized with 300kg/ha of Dolomitic lime ; 80kg/ha N ; 50kg/ha P ; and 24kg/ha K.
Source : CIAT, 1989.

Table 5 Yield (kg/ha) of selected and rejected maize families for adaptation to acid-soil sites

Site*	Maize yield Selected (56)	Maize yield Rejected (557)	Significance of differences
Carimagua, Colombia	3980	2080	* * *
Yurimaguas, Peru	3510	1650	* * *
Mindanao, Philippines	1800	860	* * *

* Soils limed to 60% Al saturation and fertilized with 120kg/ha N, and 80kg/hn P_2O_5.
* * * $P<0.001$
Source : Haag and Pandey, 1988.

tropical American savannas.

The new lines of acid-soil-tolerant upland rice have a potential for mechanizable Oxisols and Ultisols of the well-drained savannas and degraded forest lands.

3) Maize for acid soils

CIMMYT's recent efforts to develop germplasm for stress environments in Latin America included the compositon of acid-soil-tolerant populations (two yellow, two white) to be improved through recurrent selection. Table 5 presents data on the performance of 613 yellow families tested under 60% Al saturation at several acid soil sites. The 56 selected families singificantly outyielded the rejected ones by 1 metric ton per ha. These results are very encouraging given the importance of maize as a subsistence and cash crop in farming systems of savannas and cleared forest lands.

4) Sorghum for acid soils

The new, adapted sorghum lines being developed by INTSORMIL yield 2 t/ha up to 60% Al saturation in the savannas of the Colombian Llanos. During 1990, ICA will commercially release two cultivars for the Colombian Llanos Oxisols.

5) Soybeans for acid soils

Following EMBRAPA's work, yields of 2t/ha are obtained with the new acid-soil-tolerant cultivars : BR-4, IAS-5, "Diamantina" and others. Today, more than 3.5 million hectares Brazilian Cerrados are being planted to soybeans, and the rate of their expansion in cultiveted area has been 30% per year over the last three years.

Similar work is being done by ICA for the Colombian Llanos Oxisols. First, commercial farmer plantings of the cultivar Soyica-Ariare are considered a promising alternative for land use intensification in mechanizable areas of this ecosystem.

6) Cassava

Traditionally, cassava is a farmer subsistence crop in savannas and forest. Its expansion as a commercial crop has been limited mainly by the lack of a fresh cassava market and susceptibility to biotic pressures (mites, thrips, mealybugs, superelongation fungus and cassava becterial blight).

CIAT, in cooperation with national programs, has developed new, resistant cultivars. Two of them have been recently released by ICA for the Llanos, under the names of "Catumare" and "Cebucan." Simultaneously, technologies for sun-drying and utilization of dry cassava chips as an energy source for feed have been developed.

The availability of acid-soil-tolerant upland rice, maize, sorghum, cassava and soybeans, will greatly contribute to the intensification of land use in the savanna and degraded forest lands.

Integration of agropastoral and silvopastoral systems

Integrated systems are now feasible following the development of new, environmentally adapted cultivars of crops and pastures. The agropastoral and agrosilvopastoral systems can increase productivity and sustainability based on the ecological and economic complementarity of the adapted components.

1) Agropastoral systems

During 1989, CIAT initiated research activities on the integration of agropastoral systems for savannas. The acid-soil-tolerant upland rice lines and new grasses (*A. gayanus* and *B. dictyoneura*) and legumes (*S. capitata* and *C. acutifolium*) developed for these savanna Oxisols were studied in associations.

The first approach was to use the crops as pioneer components to establish pastures after native savanna grassland. Results showed that pasture establishment simultaneously or 30 days after rice had no detrimental effect on rice yields, which indicated that the competition between pasture plants and rice was minimal. Both legume and grass pasture components were initially suppressed by shading of rice plants. However, they recovered rapidly after the rice harvest. Commercial pastures after savanna in the Llanos are commonly established with only 20 kg of P+20 kg of K+200 kg of dolomitic lime, and one year may elapse before the pasture is ready for grazing. After the 80 kg of N, 50 kg of P, 24 kg of K, and 300 kg of dolomitic lime are applied to upland rice, the resulting pastures are ready for inital grazing by the end of the rains, 7-8 months after establishment. Cropping and pasture establishment costs are equivalent to these for 1.25t/ha of rice, while yields are 2t/ha. These new upland rice materials will contribute greatly to the decrease of the rice production costs in the region, and will also provide a tremendous impetus to the rapid adoption of the new grass-legume pastures (CIAT, 1989).

The pasture-rice sequence was also studied at Carimagua. The maximum rice yield after savanna was only 2 tons with the highest levels of N (80 kg/ha) and P (50 kg/ha) fertilization (Fig. 4). However, after improved grass alone, more than 3 t/ha were obtained with a clear retponse to N fertilization; also, more than 3 t/ha of rice were produced after a 10-year grass-legume pasture, but with no response to either nitrogen or phosphorus. These are striking results that document the soil improvement capacity of pastures in general, and particularly of grass-legume pastures. The additional yield of 1 t/ha of rice after improved pastures cannot be explained solely on the basis of improved N availability.

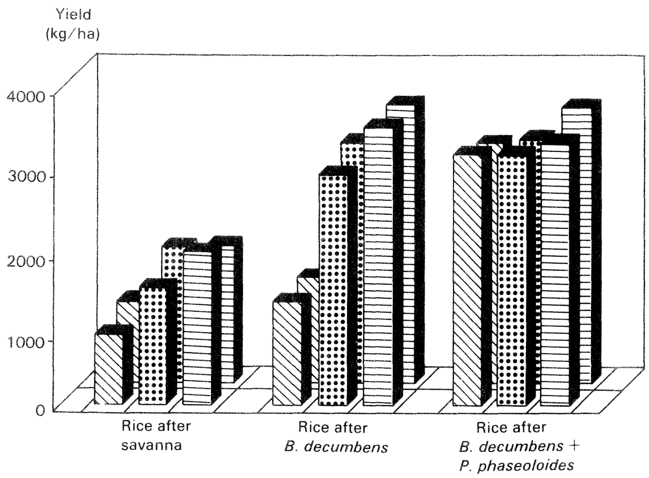

Fig. 4 Rie yields after native savanna grassland and improved pastures at 25 kg P/ha (columns in background), and at 50 kg P/ha (columnsins in foreground) and at three levels of N (⊟=80 kg N/ha, ⸬=40 kg N/ha; ⧅=no N) (Cited from CIAT, 1989).

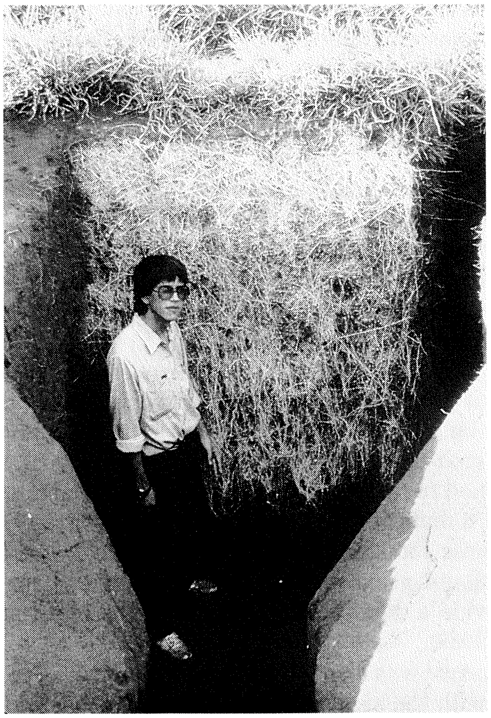

Photo 1. ***Andropogon gayanus*** **with deep and profuse root system in an Oxisol of the Brazilian Cerrados.**

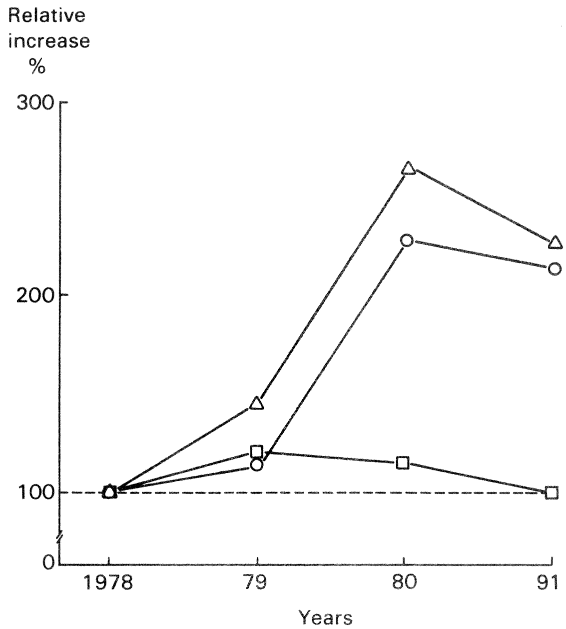

Fig. 5 Relative increases of Ca. (△) Mg (○) and K (□) under an A. gayanus + ***P. phaseoloides*** **pasture at Carimagua, Colombia** (Cited from CIAT, 1984).

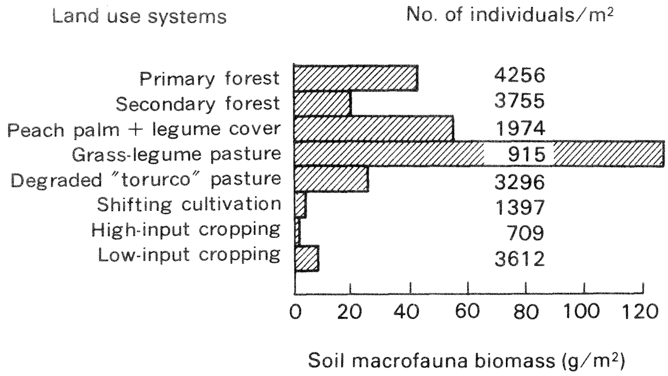

Fig. 6 Macrofauna biomass and number of individuals in top 10 cm soil under different land-use systems at Yurimaguas, Perú (Adapted from Pashanasi and Lavelle, 1989).

The deep and profuse root systems of adapted pastures will greatly contribute to soil stucture improvement (Photo 1), which in turn will improve the crop's soil-water-plant relations. Strong root systems, together with high turnover of pasture biomass (through trampling and animal intake/faeces+urine) under grazing, will result in the accumulation of organic matter (OM) and nutrients in topsoil. Figure 5 shows Ca, K, and Mg dynamics in a Colombian Llanos Oxisol under an *A. gazanus*+*P. phaseoloides* pasture.

The high turnover rates, accumulation of OM, and minimal extraction of mineral nutrients in grazed pastures (Spain and Salinas, 1984), together with the pasture microclimate environment in the topsoil layer and surface, are conducive to greater micro- and macrobiological activity. The inoculum potential of VA mycorrhiza normally increases at the onset of rains in the savannas. However, the number of spores in the soil increases much faster under improved pastures than under native grassland vegetation (CIAT, 1982). Recent data (Pashanasi and Lavelle, 1988) document the beneficial effect of grass-legume pastures and trees+legume cover systems in increasing the biomass of the macrofauna (earthworms and insects) in the topsoil compared with primary and secondary forest (Fig. 6). In contrast, low-input and high-input cropping, as well as shifting cultivation, drastically reduce the macrofauna in the topsoil biomass.

2) Agrosilvopastoral systems

The introduction of trees in integrated production systems should contribute to the alleviation of the global greenhouse effect by capturing CO_2 from the air. In addition, adapted trees should enhance soil conservation and improvement through profuse and deep root systems, also contributing to income generation. Plantation trees such as mangoes, cashew nut, oil palm, rubber, peach palm, coconut, tropical fruits and timber trees are available for introduction. However, tolerant N-fixing trees for living fences, forage, and shade are still lacking for the very poor acid soils of tropical America. Trees such as *Leucaena* spp., *Gliricidia* spp. and *Erithrina* spp. are not adapted to Oxisols and Ultisols (Toledo and Torres, 1990). CIAT's forage legume collection contains about 1,000 shrub and tree entries, and initial screening for tolerance to soil acidity is under way. Institutions such as the Nitrogen Fixing Trees Association in Hawaii (USA), CATIE in Costa Rica, as well as ILCA and IITA in Africa, are also working toward the development of multipurpose trees.

Grasses, and legumes must have some degree of shade tolerance for their introduction under trees. CIAT preliminary work has selected *Axonopus compressus, Paspalum conjugatum* and *Stenotaphrum secundatum* as grass sepcies that perform well under shade (Toledo *et al.*, 1989). Similarly, legumes such as *Arachis pintoi, Centrosema macrocarpum* and

C. acutifolium tolerate shade (CIAT, 1988).

CIAT's strategies for the 1990s include the expansion of its work in land use classification, and the integration of agropastoral and agrosilvopastoral systems in tropical American Oxisols and Ultisols. Ultimately, CIAT will develop principles for sound land use and the better assembly and management of integrated system components, as well as develop understanding of soil-crop-tree-pasture-management interactions to maximize sustainability and economic output.

Final remaks

The success or failure of any technological innovation in agriculture depends on the fit between the proposed technology and specific conditions at the farm, regional, and ecosystem level. Crops, pastures, livestock, and/or trees must efficiently convert soil energy, water, and soil resources into valuable commercial products. Management possibilities also depend on fitness of system components, since it will be impossible to manage economically non-adapted components.

Farmer access to capital and the existence of positive market forms are important factors affecting the efficiency of production systems. The success of perishable or novel crops having limited demand such as fresh cassava, tropical fruits and unknown timber will largely depend on market development.

Agropastoral and agrosilvopastoral systems based on commercially valuable, environmentally adapted components offer great potential for the development of ecologically and economically sound sustainable land use systems fro tropical savanna ecosystems and currently degraded forest, and hill-side agroecosystems.

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Discussion

Kanwar, S. S. (India): I wonder whether pigeonpea and pearl millet have been tried in these acid soils. Indeed, cooperative work coordinated by ICRISAT showed that both crops are well suited to soils with low pH, high aluminum level and low phosphorus level. Pearl millet can give a yield as high as 4 t/ha under such conditions.

Answer: We have tried *Cajanus cajan* (pigeonpea) and found that this crop is well adapted to the acid poor Oxisols and Ultisols. Market demand may be a problem for its utilization in Latin America and a feed market should be developed. Thank you for your information on pearl millet adaptation to acid soils. We will test this crop.