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LEGUME CONTRIBUTION TO PASTURE PRODUCTIVITY AND  
IMPROVEMENT OF ACID SOILS

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ABSTRACT

Tropical pasture production is limited by the supplies of N and even though the application of N fertilizer can be effective in improving pasture productivity, it is an uneconomical practice in most cattle production systems. Therefore, the role of legumes in the improvement of animal productivity and the fertility of acid soils through enhanced nitrogen fixation and nutrient cycling is being studied in Oxisols and Ultisols. Results indicate that legume-based pastures can contribute significantly to improve animal production both in terms of liveweight gain and milk production. In addition, N<sub>2</sub> fixing legumes in association with grasses have high potential to improve soil fertility for subsequent crops, most likely due to increased N levels and biological activity of the soils.

INTRODUCTION

Tropical pasture production is limited by supplies of N even though there may be relatively large stores of N in the soil organic matter. This is because the rate at which soil N becomes available for plant uptake via mineralization is a limiting factor for plant growth. Only 1% or less of the N in the rooting profile is mineralized to forms available for uptake by plants (Henzell, 1968). Therefore, it is necessary to improve the supply of available N and/or increase the efficiency of its use.

The application of N fertilizers to grass pastures can be a very effective means of improving pasture productivity (Vicente-Chandler, et al., 1983). However, for most pastures and cattle producers in the tropics fertilizers are unavailable or are uneconomic. Therefore N input from through legumes is the only viable option.

This paper discusses the role of legumes in the improvement of animal productivity and the fertility of acid soils through enhanced N fixation and nutrient cycling of grass-legume pastures.

## ROLES OF LEGUMES IN PASTURE SYSTEMS

### The cycling of N and the role of the legume.

In grazed pastures, unlike cropping systems, most of the nutrients in herbage are returned to the soil/plant system via animal excreta and plant litter. The balance between these two recycling processes and the rate of decomposition and mineralization of soil organic matter determine the net gain or loss of plant available N within the pasture (Hoglund, 1985). As pasture utilization increases more N passes through the animal excreta pathway. This pathway is subject to large losses of N (as much as 80%) via volatilization, denitrification and leaching of N from urine patches (Ball and Ryden, 1985). On the other hand, when utilization is low more N passes through the plant pathways of internal remobilization and litter returns. However, if the plant litter has a high C:N ratio, N can be immobilized and will be unavailable to plants (Robbins et al., 1989).

The relative importance of these pathways as a function of pasture utilization is illustrated in Table 1, which shows the estimated fluxes of N in a pasture producing 100 kg herbage N/ha/yr for a period of about 1-5 years. At utilization levels typical of tropical pastures (10-40%) it can be seen that the N available for plant uptake from excreta is small compared with internal remobilization and litter decomposition. Also shown are the amounts of N needed to balance the N cycle of a pasture that produces 100 kg N/ha every year. These increase from 34 to 60 kg N/ha as the utilization of the pasture increases. In the absence of a  $N_2$ -fixing legume this N must come from reserves in the soil or from fertilizer inputs.

### The role of the legume in improving N availability.

The relationship between the amounts of N needed to balance the N cycle and pasture utilization shown in Table 1, is independent of the total biomass and the amounts required can be expressed as a % of the biomass-N, e.g. at 10% utilization an amount of N equal to 34% of total biomass-N is required and at 70% utilization 60% is required. This N can be supplied by legume  $N_2$  fixation. Thus, if we take a range of tropical pasture production of 3-22 t DM/ha/yr (Helyar, 1985) with an average N content of 1.5% and a utilization range of 10-40%, then using the data in Table 1, column I, we can estimate that a N input from the legume of 15-155 kg N/ha/yr would be required to balance the N cycle. This range is similar to that reported for forage legumes of 24-155 kg N/ha/4 months (Cadisch et al., 1989) in the Llanos of Colombia. Thus forage legumes have the potential to supply pasture with enough N to maintain productivity without requiring N fertilizer or depleting the reserves of N in the soil. Further, if we assume that legumes fix about 90% of their N requirements and on average, have an N

Table 1. Fluxes of N through the major recycling pathways of the N cycle of a pasture producing 100 kg herbage N/ha/yr with differing levels.

kg N/ha/yr										
A	B	C	D	E	F	G	H	I		
Utilization % of herbage eaten	Intake by animals ( $\times 100$ kg N)	Excretion 90% of animal intake ( $B \times 0.9$ )	Plant available excreta-N 30% of excreta ( $C \times 0.3$ )	Internal cycling plant N (50% herb.) age N uneaten ( $(100-B)/2$ )	Plant available litter-N 40% litter-N ( $(100-A)/2 \times 0.4$ )	Litter-N entering stable OM (100-A)/ 2 $\times 0.6$	Sum of recycled N (D+E+F) (100 - H)	Amount of N needed to produce another 100 kg herbage N		
10	10	9	2.7	45	18	27	65.7	34.3		
20	20	18	5.4	40	16	24	61.4	38.6		
30	30	27	8.1	35	14	21	57.1	42.9		
40	40	36	10.8	30	12	18	52.8	47.2		
50	50	45	13.5	25	10	15	48.5	51.5		
60	60	54	16.2	20	8	12	44.2	55.8		
70	70	63	18.9	15	6	9	39.9	60.1		

Notes:

- C - Henzell and Ross, 1973.
- D - Steele and Vallis, 1988.
- E - Robson and Deacon, 1978; Milford and Haydock, 1965.
- F - Vallis, 1983.
- G - by difference, compared with column F.

content of 2.5% compared with 1% for the grass component, the range of legume N requirement of 34 to 47% needed for a pasture utilization range of 10-40% (Table 1), converts to a range of 20-31% on a DM basis. This should be the target level of legume content for tropical pastures if the assumptions made in Table 1 are valid.

#### The role of the legume in long term soil improvement.

The amounts of N entering stable pools of soil organic matter (i.e., N that is relatively unavailable to plants over short periods of 1-5 years) is shown in Table 1, column G. For tropical pastures values of 18-27% of the plant biomass-N can be expected to enter the stable organic matter. This represents the potential of the pasture to accumulate soil organic-N. This N will be mineralized at slow rates unless the soil is disturbed (e.g. Sylvester-Bradley et al., 1988). Generally, legumes have greater N contents than grasses and will therefore add more N to the organic matter. In addition to increased quantities there may also be differences in quality of the organic matter and subsequent effects on N availability. An example of this is given in Figures 5 and 6, where rice yields were increased when sown in a grass-legume pasture compared with a grass only pasture. In these soils there were no apparent differences in total organic matter or N. In addition to N, legumes can improve other chemical and physical properties of soil via the increased additions of organic matter (Whiteman, 1980).

#### The role of the legume in animal nutrition.

Production of beef and milk in tropical areas in pure grass pastures is limited by low digestible energy intake (Elliot et al., 1961; Hamilton et al., 1970; Alvarez and Lascano, 1987; Schneichel et al., 1988). In addition to low energy intake, protein may also be deficient in the dry season and part of the rainy season which further limits voluntary intake (Minson and Milford, 1967).

Legumes in association with grasses contribute to increase the protein level of the ingested forage in the dry season and also to increase the protein level of the grass during the rainy season (Gardener, 1980; Bohnert et al., 1986; Lascano and Thomas, 1989). In addition, legumes generally contain higher concentrations of calcium, sulphur and phosphorus than grasses (Whiteman, 1980). As a result, legume consumption by grazing animals is expected to increase liveweight gains (Lascano et al., 1989) and milk production (Stobbs, 1976) in tropical pastures.

The nutritional mechanisms by which legumes contribute to increase animal production are not well understood. For example, a nutritional balance in milking cows of medium genetic potential (8-10 liters/day) grazing tropical pastures, would

indicate that the protein requirement in the diet should be in the order of 12% (Glover and Dougall, 1961; Hardison, 1966). However, there have been cases in which cows grazing a grass alone pasture with 15% protein, have produced more milk when supplemented with a legume like Leucaena leucocephala (Florez et al., 1979). This positive response to legumes has been related to the low solubility or degradability of the protein in L. leucocephala, thus indicating a certain degree of by-pass protein. Other studies have also shown responses in milk production in cows grazing nitrogen fertilized grasses, supplemented with Glycine wightii (Cribeiro and Ruiz, 1976). It follows, that it would be important to characterize tropical legumes in mixtures with grasses, not only in terms of total protein content, of the forage ingested, but also in terms of the degree to which this protein is supplying nitrogen for rumen bacterial activity (i.e., fermentable nitrogen) and amino acids to the lower gastrointestinal tract (i.e., by pass-protein).

#### RESULTS IN ACID POOR SOILS

The Tropical Pastures Program of CIAT in cooperation with IRIEPT (International Tropical Pastures Evaluation Network) are developing a new generation of grasses and legumes for the low fertility acid soils of the savannas and degraded forest land of tropical American lowlands (Toledo and Nores, 1986). Grasses such as Andropogon gyanus, Brachiaria decumbens, B. brizantha and B. dictyoneura are now available for farmers use. Similarly, legumes such as Arachis pintoi, Centrosema acutifolium, C. brasilianum, C. macrocarpum, Stylosanthes capitata, S. guianensis, S. macrocephala are also becoming available to farmers in the region. These are plants tolerant to prevailing pests and diseases, and adapted to the high aluminum saturation and soil acidity typical of Oxisols and Ultisols.

Grasses are readily adopted by farmers in the tropics; however legumes are at a disadvantage due to poor experiences with previously non-adapted commercial cultivars selected elsewhere and their novelty nature for farmers in the region (Ferguson et al., 1989).

The potential contribution of adapted legumes to the improvement of animal productivity and soil fertility in acid soils is being documented. At Carimagua in the Colombian Llanos, grass-legume pasture have more than doubled liveweight gains per head and shown a ten fold increase in productivity per hectare in contrast with well managed native savanna (Figure 1). These grass-legume pastures also produce a 50% increases in liveweight gain per head and 20 to 30% increase in gain per hectare, when compared with grass monocultures.

Experimental results from different degraded lands in the humid forest, indicate that it is possible to obtain annual liveweight gains of over 600 kg/ha when legumes are present in

Liveweight gains/year  
(kg)

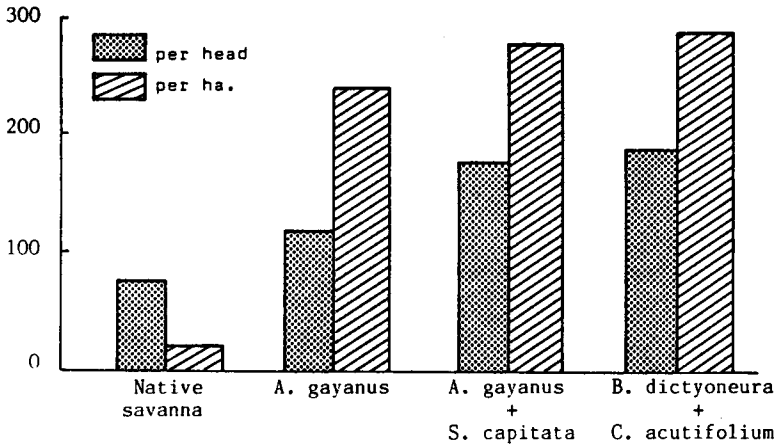


Figure 1. Productivity of best managed native savanna and new pastures in Oxisol of the Colombian Llanos. (Taken from CIAT, 1988).



the pasture (Table 2). This represents a three-fold increase over native degraded grasslands and two-fold increases over improved grass alone pastures.

The potential contribution of legumes to increase milk production is being studied at the CIAT/FES Quilichao Station on an Ultisol in the Cauca Valley of Colombia. Preliminary results show a 20% increase in productivity when legumes such as C. macrocarpum and C. acutifolium are associated with the grass B. dictyoneura (Figure 2).

The contribution of the legume to long-term pasture productivity and stability has been documented in the Llanos of Colombia (Lascano et al., 1989). In this study, the grass-legume pasture always resulted in higher gains than the grass monoculture in the dry season, with the relative advantage depending on the severity of the dry season (Figure 3). However, during the rainy season, when water does not restrict plant growth, a high and stable trend of productivity was observed in the grass-legume pasture contrasting with the declining productivity trend observed in the grass monoculture (Figure 3).

The role of pastures in improving soil N has been documented by Russell (1980). The loss of N availability in the soil after continuous wheat cropping in temperate Australia is shown in Figure 4. No increases in soil N were observed when wheat was rotated with fallow. In contrast, N levels in the soil increased under permanent pasture, while the rotation wheat-pasture gave stable levels of soil N.

First results of planting a crop of upland rice after different pastures in an Oxisol at Carimagua, document the potential of pastures to improve soil fertility for subsequent crops. More than 3 t/ha of rice were obtained after a ten-year-old legume-grass pasture with no significant responses to N (Figure 5). After the grass alone the rice yields were also more than 3 t/ha but with the application of 80 kg of N/ha. In contrast, the maximum yields of rice obtained after native savanna grassland were less than 2 t/ha.

The additional 1 t/ha of rice obtained after improved pastures at the highest level of N fertilization can be explained by factors other than N in the soil. Deep and profuse root systems of the adapted pasture plants should have important effects on improving soil structure, facilitating access of the rice roots to deeper water and making available higher concentrations of nutrients in the top soil as a result of effective turnover. Furthermore, mycorrhiza inoculum potential at the onset of the rains increases at a faster rate in improved pastures than in the native savanna (CIAT, 1982), which may have an important effect on P uptake by the rice plants. Similarly, Pashanasi and Lavelle (1988) found that macrofauna (insects and earthworms) biomass in the top 10 cm layer of an Ultisol under

Table 2. Liveweight gains from several pastures after degraded rainforest lands.

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

Sources: a/ Caquetá, 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).

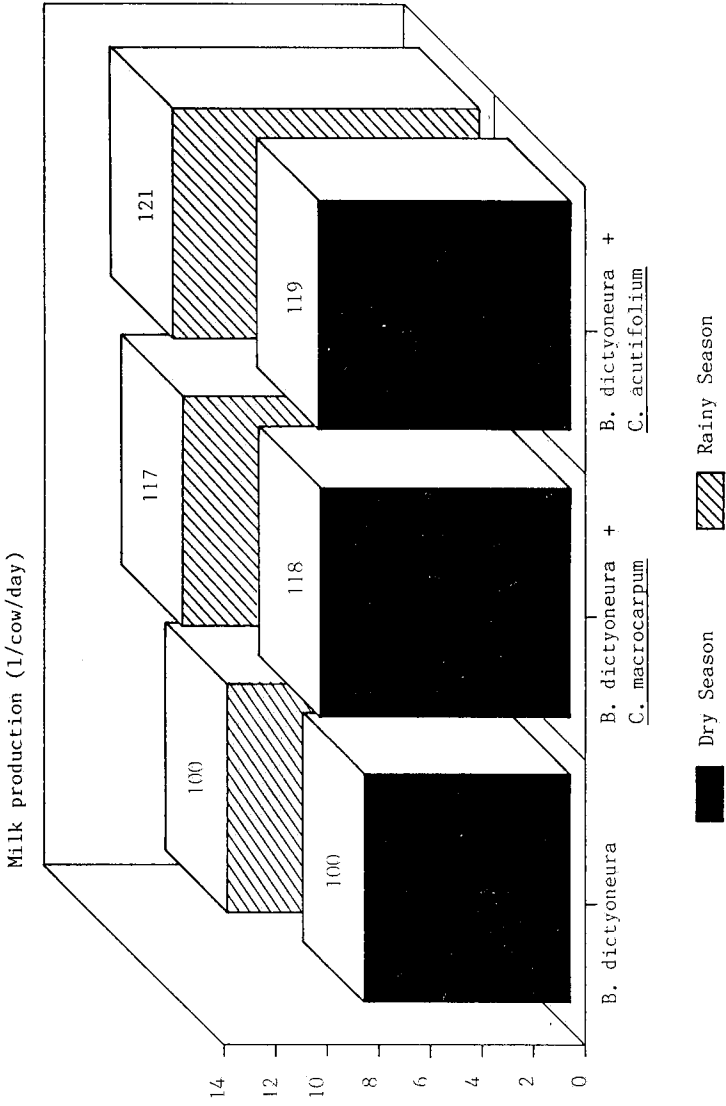


Figure 2. Milk production from different pastures at Quilichao station (from CIAT, 1990).

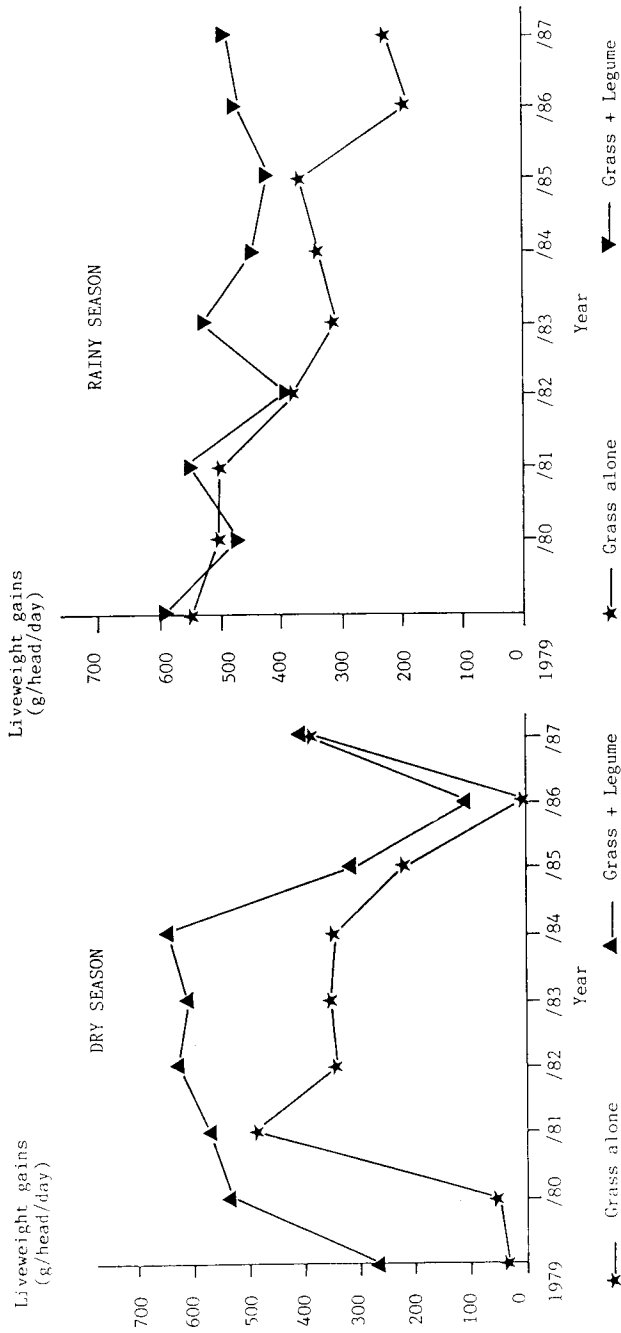


Figure 3. Liveweight gains of steers on B. decumbens and P. phaseoloides pastures at Carimagua, Colombian Llanos. (From: Lascano and Estrada, 1989)

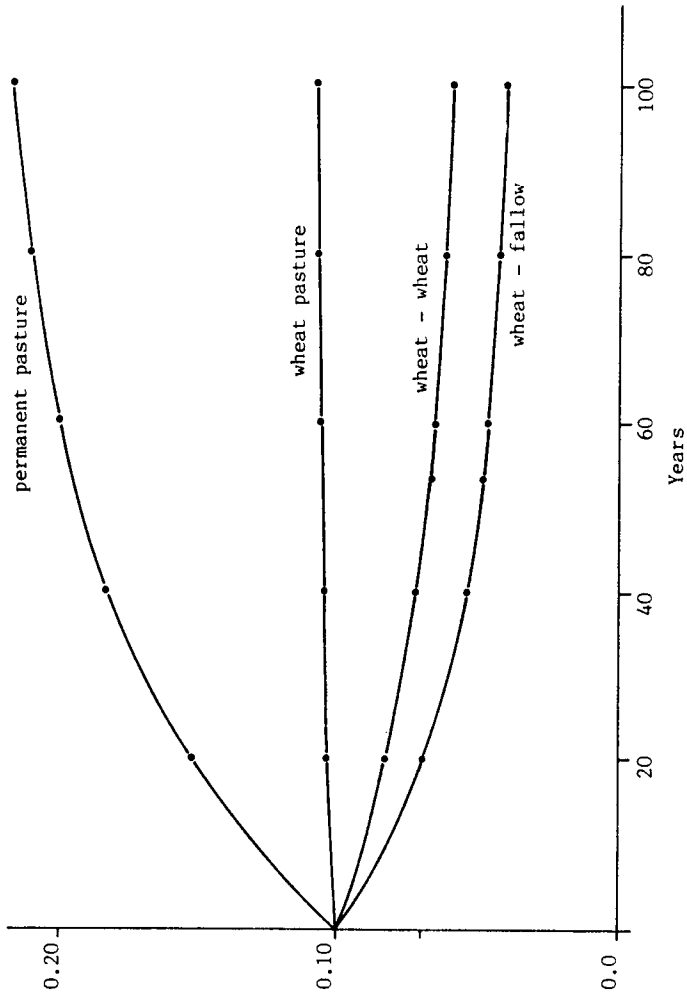


Figure 4. Soil N changes under different land use systems at Waite Agricultural Research Institute (From Russell, 1980).

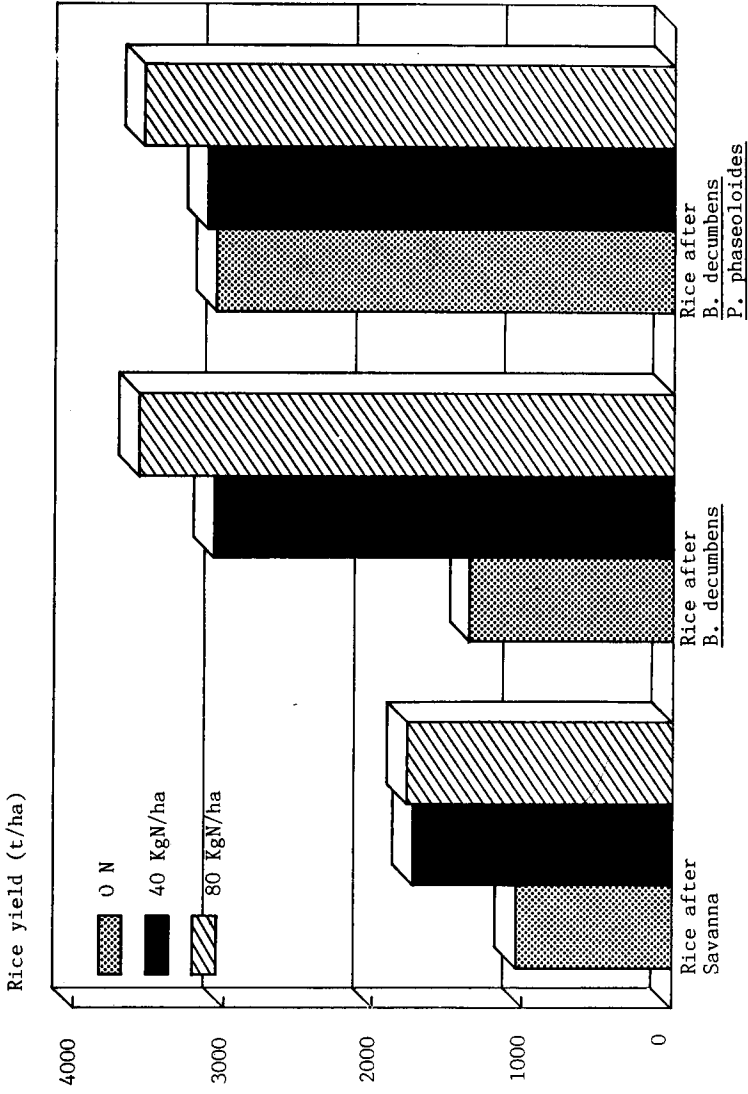


Figure 5. Rice yields after 10 years of improved pastures and savanna in response to different levels of N and 25 kgP/ha fertilization (from CIAT, 1990).

grass-legume pastures at Yurimaguas, Peru was more than twice that encountered under primary forest and about 15 times greater than the macrofauna biomass under cropping. It would seem that the N levels and the biological activity of the soils which have N<sub>2</sub> fixing legume-grass pastures are clearly superior to those found in grass alone pastures in Oxisols and Ultisols of the tropics.

#### FINAL REMARKS

Despite the difficulties for the adoption of legume based pastures in tropical America, their potential contribution to improve animal production, soil fertility and soil biological activity seems to be so significant that every possible research effort should be made to select a wider range of legumes adapted to biotic and edaphic constraints prevailing in areas with acid soils. In addition, to demonstrate the ecological and economical soundness of grass-legume pastures and to facilitate adoption by farmers, aggressive seed production projects are required on a regional basis.

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