ISSN 0120-2383
CIAT Series No. 02ETP1-79
August 1980

1979
Tropical Pastures Program
Annual Report

Centro Internacional de Agricultura Tropical
Apartado Aéreo 67-13
Cali, Colombia

Table 34. Current inoculation recommendations developed for several promising forage legumes.

Species	Accession CIAT No.	Rhizobium strain CIAT No.	Technology
Category 4			
Desmodium ovalifolium	350	299	Rock phosphate pellet
Zornia latifolia	728	71	Rock phosphate pellet
Stylosanthes capitata	1019, 1315	71 + 1238	Rock phosphate pellet
Pueraria phaseoloides	9900	79	Rock phosphate pellet
Category 3			
Stylosanthes capitata	1318, 1323, 1325, 1342, 1405, 1728, 1943	71 + 1238	Rock phosphate pellet
Zornia spp.	9179, 9220, 9245, 9258, 9260, 9270, 9286, 9295, 9648	71	Rock phosphate pellet
Aeschynomene brasiliana	9681, 9684	71	Rock phosphate pellet
A. histrix		71	Rock phosphate pellet
Desmodium heterophyllum	349	31	Rock phosphate pellet
Stylosanthes hamata	147	71	Rock phosphate pellet
Codariocalyx gyroides	3001	299	Rock phosphate pellet

The acid medium was slightly modified and two carbon sources (arabinose and glycerol) were tested for ability to support rhizobial growth without a change in the pH. Bromocresol green, a pH indicator with an equivalence point in the acid range (pH = 4.5), was also tested for possible adverse effects on rhizobial growth. Preliminary results indicated that both media permitted rhizobial growth, while final reaction was dependent on the strain (Table 33). Glycerol was chosen as a suitable, yet less expensive C-source (US$461.90/kg and $9.55/kg for arabinose and glycerol, respectively).

Strains have been isolated from nodules collected from *Z. latifolia* 728 and *S. capitata* 1315 grown under greenhouse conditions in a non-inoculated Carimagua soil. The cultures were obtained by streaking rich and acidified rhizobial media with the cell suspension from a single nodule. The paired isolates' efficiencies will be compared under defined conditions in Leonard jars. This study will be periodically repeated to determine if there are adverse effects of storage on either media over time.

Inoculant Recommendations

The inoculant recommendations for promising legume accessions are given in Table 34. During 1979, 63 kg of peat-based inoculum were produced, 36 kg were used by CIAT and the Instituto Colombiano Agropecuario (ICA), while 12 and 8 kg were sent to national and international agencies, respectively, and 7 kg to private entities.

SOIL FERTILITY AND PLANT NUTRITION

The overall objective of the Soil Fertility and Plant Nutrition Section is to identify and correct mineral deficiencies and toxicities during the pasture establishment period on the acid soils with low native fertility of the Tropical Pastures Program target area. The research strategy takes into account the soil-plant relationship as an important criteria to define the critical nutrient requirements and tolerance to certain mineral stresses. The specific objectives of this section are: (1) to select germplasm for tolerance to Al and Mn toxicity, and low available P in the soil; (2) to determine the nutrient requirements of promising germplasm during the establishment period; and (3) to identify the nutritional status of soils and forage plants in representative regional trial sites of the Tropical Pastures Program.

Attention was focused this year on: (1) germplasm selection for tolerance to Al toxicity and low available P in the soil; (2) systematic estimation of the nutrient requirements of promising grass and legume accessions; and (3) evaluation of the soil fertility-plant nutrition status in regional trials.

Tolerance to Al Toxicity and Low Available P

There is clear evidence that most of the acid Oxisols and Ultisols of the target area have high Al levels in the soil profile that adversely affect the productivity of forage species. One of the most striking effects of high Al saturation in the soil is a reduction of root penetration inhibiting the use of subsoil nutrients and moisture. In addition, these soils require a certain amount of P fertilizer to counteract their high P fixation capacity and satisfy the plant's needs for adequate yield. Al toxicity and P deficiency frequently occur simultaneously in these soils. It is difficult to separate these two problems because of the tendency of Al to react chemically with P.

When taking into consideration the present high cost of P fertilizers and the strong evidence of differential responses of forage species in tolerating high Al levels and low P levels in the soil, it appears that the selection and use of forage species and/or accessions tolerant to both situations must be considered as an integral part of the solution to the problems challenging the Tropical Pastures Program.

A preliminary selection for tolerance to high soil Al was carried out for the large number of forage germplasm introduced to the Program's collection. The technique used was simple and rapid and is based on a visual estimation of the stainability of the root system of young seedlings and is calibrated with controls of known Al tolerance. This method uses a hematoxilian solution (0.2%) which has a high affinity for Al and permits distinguishing between tolerant and less tolerant plants. All forage accessions were grown in three Al treatments (0, 5, and 10 ppm Al with 0.5 ppm P) in a 1/10 Arnon and Hoagland solution. The differentiation of meristem tissues between tolerant and sensitive accessions to Al toxicity was readily determined as the concentration of Al in the seedling root increased in relation to the reduction in root elongation.

The results showed that genera *Stylosanthes* and *Zornia* had the largest number of accessions tolerant to Al and *Centrosema* and *Macroptilium* the largest number of sensitive accessions (Table 35). Although Al tolerance varied widely at the genera level, it also varied markedly among accessions within genera. Since the grass and legume germplasm has been previously classified in categories based on qualitative field evaluations in Carimagua, the results from the hematoxilin tests were related to field performances. This relationship is presented in Table 36 which includes germplasm in categories II, III and IV. The comparison between the hematoxilin tests and the field results shows a close relationship. Consequently, screening of forage accessions for Al tolerance using the hematoxilin test meets the requirements of simplicity, quickness, high-volume screening, and accuracy.

Morphological and Physiological Effects of Al Toxicity

Due to the close relationship between the hematoxilin test and field data, a better understanding of the morphological and physiological changes that occur in the forage legumes from Al toxicity was necessary. Accordingly, a study was designed to determine the effect of Al on the growth of three *Stylosanthes* species and to identify, through the hematoxilin test, anatomical and morphological changes in roots resulting from Al toxicity. The results of this study are shown in Figure 20. Al damage to tops and roots of these *Stylosanthes* species varied markedly. In general, however, *S. capitata* and *S. guianensis* were less affected than *S. sympodialos,* an Al sensitive species. A 69% reduction in root length was observed for *S. sympodialos,* while only 13 and 19% reductions for *S. capitata* and *S. guianensis,* respectively. Dry matter of tops and roots decreased in a similar manner.

From a nutrient standpoint, increasing Al resulted in a decreased P, Ca and Mg content in the tissues

Table 35. Evaluation of forage legume germplasm for aluminum tolerance by the hematoxilin test.

Genera	No. of accessions evaluated	Tolerant		Sensitive	
		5 ppm Al	10 ppm Al	5 ppm Al	10 ppm Al
Stylosanthes	296	197	182	99	114
Zornia	156	112	93	44	63
Centrosema	151	23	15	128	136
Macroptilium	104	19	19	85	85
Vigna	69	10	10	59	59
Phaseolus	9	1	1	8	8
Aeschynomene	93	42	32	51	61
Calopogonium	55	0	0	55	55
Galactia	81	30	30	51	51
Pueraria	1	1	0	0	1
Leucaena	1	0	0	1	1
Desmodium	2	1	1	1	1
Total	1018	436	383	582	635

(Figures 21 and 22). The P content in *S. sympodialos* decreased significantly in tops as Al concentrations increased. Similar results were obtained with the Ca content in tops and roots as well as Mg in roots. Al levels, however, appeared to have little or no effect on the K contents (Figure 22).

Increasing Al in the nutrient solution appeared to cause the accumulation of P in the roots and restricted its translocation to the tops in all *Stylosanthes* species (Table 37). *S. capitata*, however, was less affected than the other two species. By contrast, the strong reduction of total Ca and Mg uptake by increasing Al did not appear to affect the translocation of these nutrients to the tops. This would indicate that the Ca and Mg transport indices cannot be used to identify Al tolerant species. The practical implication of these results is that Ca and Mg deficiencies in the presence of Al in a forage crop is a result of the reduced uptake of Ca and Mg rather than their translocation to the upper parts.

From a morphological standpoint, the elongation of the primary root axis of *S. sympodialos* was inhibited soon after the plants were transferred to the Al solutions. In addition, the root color changed from white to brown and lateral roots exhibited a disintegration and disorganization of cells. These observations were significantly less evident in the other two species. By longitudinal sectioning of the roots after hematoxilin straining, it was possible to differentiate Al accumulation zones. In the case of an Al tolerant species, such as *S. capitata*, Al accumulation did not cause cell destruction in the outermost cortical region of the primary root. In contrast with *S. sympodialos*, an Al sensitive species, the red staining hematoxilin showed a flow of Al into the central part of the primary root which coincided with disintegration of cells.

In another experiment related to the above-mentioned ones, forage grass and legume accessions were subjected to Al and P stress under field conditions. This experiment was established in 1977 during the rainy

Table 36. Comparative performance of legume germplasm for tolerance to high Al saturation and P stress under field conditions and using the hematoxilin test.

Species	Accession CIAT No.	Category of promise	Relative yield under field conditions	Hematoxilin test[1]	
			86% Al sat. 2.6 ppm P	5 ppm Al	10 ppm Al
				0.5 ppm P	
Desmodium ovalifolium	350	IV	79	T	T
Zornia latifolia	728	IV	82	T	T
Stylosanthes capitata	1019	IV	60	T	S
Stylosanthes capitata	1315	IV	80	T	T
Pueraria phaseoloides	9900	IV	70	T	S
Stylosanthes capitata	1318	III	85	T	T
Stylosanthes capitata	1323	III	48	S	S
Stylosanthes capitata	1325	III	22	S	S
Stylosanthes capitata	1342	III	16	S	S
Stylosanthes capitata	1405	III	55	T	T
Stylosanthes capitata	1693	III	-	-	-
Stylosanthes capitata	1728	III	-	T	T
Stylosanthes capitata	1943	III	-	T	T
Zornia latifolia	9179	III	-	T	T
Zornia sp.	9220	III	-	T	T
Zornia sp.	9245	III	-	T	T
Zornia latifolia	9258	III	-	T	T
Zornia sp.	9260	III	-	T	T
Zornia sp.	9270	III	-	T	T
Zornia sp.	9286	III	-	T	T
Zornia sp.	9295	III	-	T	T
Zornia sp.	9648	III	-	T	T
Aeschynomene brasiliana	9681	III	50	T	T
Aeschynomene brasiliana	9684	III	24	S	S
Aeschynomene histrix	9666	III	33	S	S
Aeschynomene histrix	9690	III	66	T	T
Stylosanthes hamata	147	III			
Desmodium heterophyllum	349	III	20	S	S
Desmodium gyroides	3001	III	-	-	-
Zornia sp.	813	II	-	T	T
Zornia sp.	935	II	-	T	T
Zornia sp.	7041	II	-	-	-
Zornia sp.	7214	II	-	T	T
Zornia sp.	7373	II	-	-	-
Zornia sp.	7376	II	-	-	-
Zornia sp.	7377	II	-	-	-
Zornia sp.	7465	II	-	-	-
Zornia sp.	7475	II	-	-	-
Zornia latifolia	9151	II	83	T	T
Zornia latifolia	9199	II	-	T	T
Zornia latifolia	9215	II	-	T	T
Zornia latifolia	9225	II	-	T	T
Zornia latifolia	9226	II	-	T	T
Zornia latifolia	9265	II	48	T	T
Zornia latifolia	9267	II	12	S	S
Zornia latifolia	9282	II	83	T	T
Zornia sp.	9284	II	89	T	T
Zornia sp.	9292	II	17	S	S
Zornia sp.	9472	II	-	-	-
Zornia sp.	9473	II	-	-	-
Zornia sp.	9589	II	-	T	T

Table 36 (cont.)

			Relative yield under field conditions	Hematoxilin test[1]	
Species	Accession CIAT No.	Category of promise	86% Al sat. 2.6 ppm P	5 ppm Al 0.5 ppm P	10 ppm Al 0.5 ppm P
Zornia sp.	9600	II	15	S	S
Zornia sp.	9616	II	9	S	S
Zornia sp.	9771	II	51	T	S
Zornia sp.	9896	II	8	S	S
Stylosanthes capitata	1007	II	-	S	S
Stylosanthes capitata	1191	II	-	T	T
Stylosanthes capitata	1298	II	-	S	S
Stylosanthes capitata	1319	II	-	T	T
Stylosanthes capitata	1321	II	-	S	S
Stylosanthes capitata	1322	II	-	S	S
Stylosanthes capitata	1324	II	-	S	S
Stylosanthes capitata	1328	II	-	S	S
Stylosanthes capitata	1332	II	-	T	T
Stylosanthes capitata	1333	II	-	S	S
Stylosanthes capitata	1334	II	-	S	S
Stylosanthes capitata	1338	II	-	T	T
Stylosanthes capitata	1339	II	-	S	S
Stylosanthes capitata	1340	II	-	S	S
Stylosanthes capitata	1343	II	-	S	S
Stylosanthes capitata	1414	II	78	T	T
Stylosanthes capitata	1419	II	52	T	T
Stylosanthes capitata	1441	II	69	T	T
Stylosanthes capitata	1495	II	-	T	T
Stylosanthes capitata	1497	II	100	T	T
Stylosanthes capitata	1499	II	-	T	S
Stylosanthes capitata	1504	II	36	S	S
Stylosanthes capitata	1516	II	-	S	S
Stylosanthes capitata	1519	II	-	T	T
Stylosanthes capitata	1520	II	67	T	T
Stylosanthes capitata	1535	II	-	T	T
Stylosanthes capitata	1642	II	-	T	T
Stylosanthes capitata	1686	II	-	T	T
Stylosanthes capitata	1781	II	-	T	T
Stylosanthes capitata	1899	II	65	T	T
Stylosanthes bracteata	1906	II	-	S	S
Stylosanthes bracteata	1281	II	83	T	T
Stylosanthes bracteata	1582	II	57	T	T
Stylosanthes bracteata	1643	II	20	S	S
Stylosanthes humilis	1222	II	37	-	-
Stylosanthes humilis	1303	II	12	S	S
Centrosema spp.	5062	II	-	S	S
Centrosema spp.	5064	II	-	T	T
Centrosema spp.	5065	II	-	T	T
Centrosema spp.	5066	II	-	S	S
Centrosema spp.	5126	II	-	S	S
Centrosema spp.	5127	II	-	T	T
Centrosema spp.	5189	II	-	S	S
Vigna adenantha	4016	II	51	T	T
Stylosanthes guianensis	136	RT	-	T	T
Stylosanthes guianensis	184	RT	90	T	T
Stylosanthes capitata	1078	RT	79	T	T

Table 36 (cont.)

Species	Accession CIAT No.	Category of promise	Relative yield under field conditions 86% Al sat. 2.6 ppm P	Hematoxilin test[1] 5 ppm Al 0.5 ppm P	 10 ppm Al
Stylosanthes capitata	1097	RT	-	-	-
Macroptilium sp.	535	RT	-	S	S
Centrosema hybrid	438	RT	55	T	S
Leucaena leucocephala	734	Negative control	30	S	S
Medicago sativa	Alfalfa	Negative control	0	S	S

1 T = tolerant; S = susceptible.

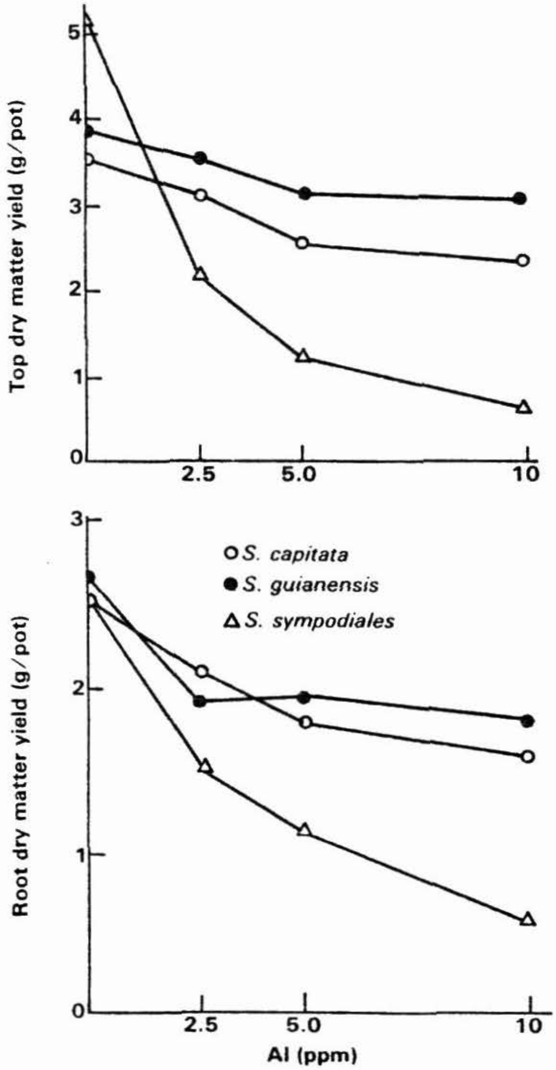

Figure 20. Effect of Al on root and top dry matter production of three *Stylosanthes* species grown in nutrient solutions.

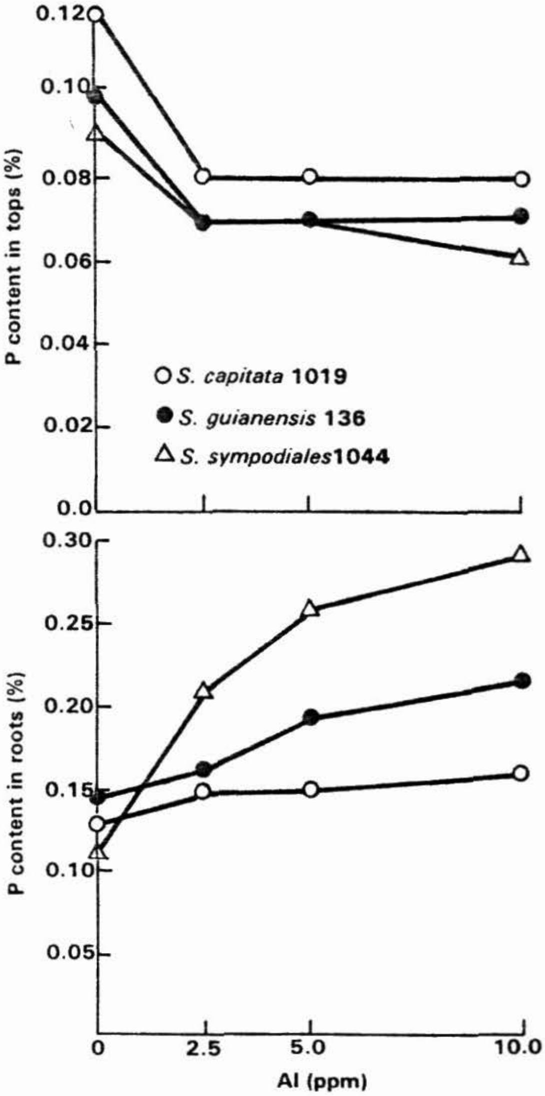

Figure 21. Effect of Al on the P content in tops and roots of three *Stylosanthes* species grown in nutrient solutions.

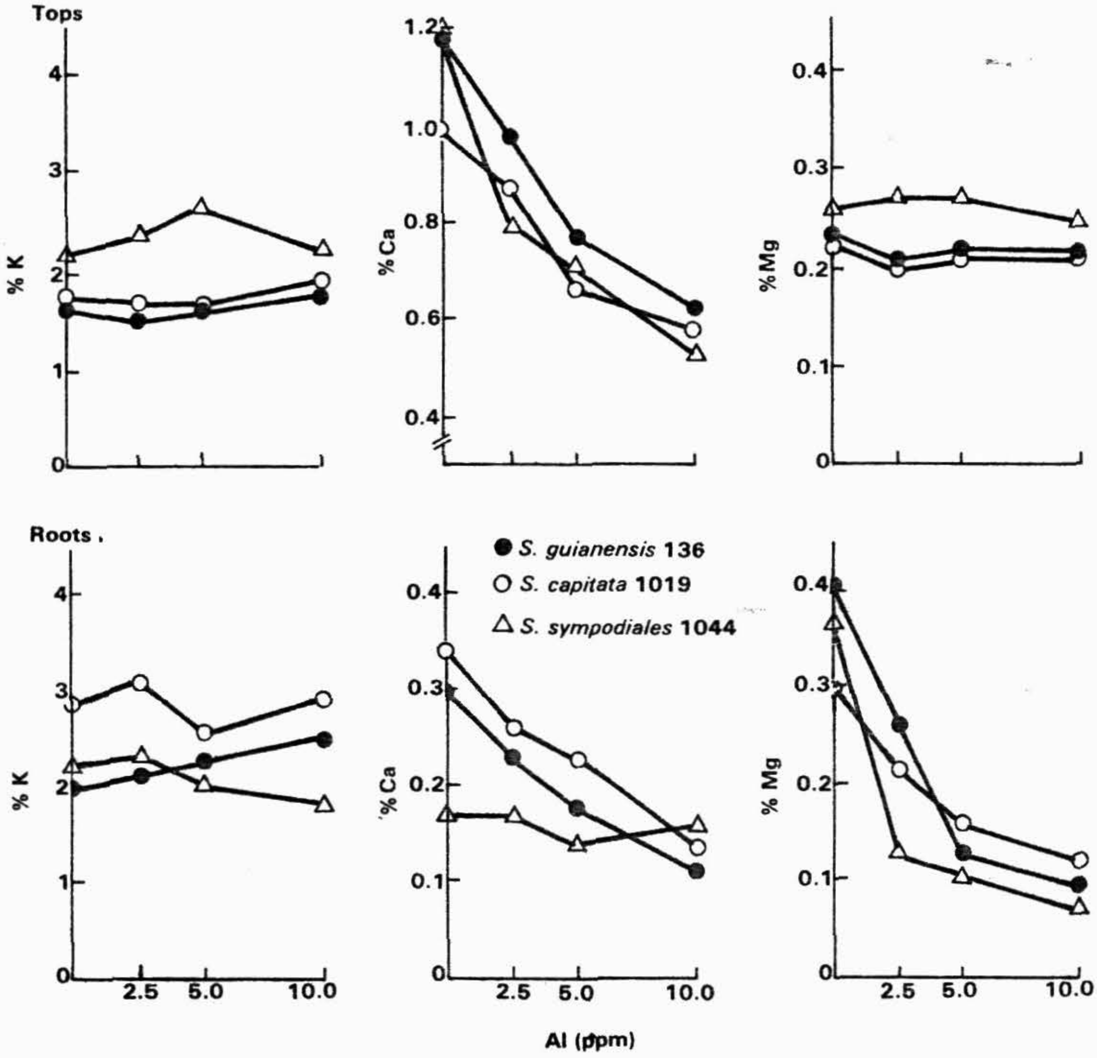

Figure 22. Effect of Al on the content of K, Ca, and Mg in roots and tops of three *Stylosanthes* species grown in nutrient solutions.

season in Carimagua with four lime levels (to provide 90, 85, 75 and less than 20% Al saturation) and four P levels (to provide 1.5, 3, 9 and 30 ppm available in soil P-Bray II). Lime levels applied were 0, 0.5, 1.0 and 5 t/ha and the P rates were 0, 17, 117 and 277 kg P/ha. Both lime and P (as triple superphosphate, TSP) were broadcast and incorporated to a 20 cm depth.

The relative yield seems to be the most useful criterion for comparing the tolerance of different forage species and/or accessions to Al or P stress. Thus, survival of a plant under Al and/or P stress was defined as having a dry matter production level not exceeding 50% of its maximum yield. On the other hand, a producing plant under Al or P stress was defined as having the relative yield between 50 and 80% of its maximum. The upper limit was fixed at 80% due to the inflection point observed in many forage ecotypes. A relative yield of over 80% was considered excellent.

The performance of eight tropical grasses is illustrated in Figure 23. When no lime and no P were applied (93% Al saturation and 1.7 ppm P) all grasses showed marked differences under both P and Al stress. *Brachiaria humidicola* 682 and *Andropogon gayanus* 621 produced more than 50% of their maximum yield while the rest of the grasses had 40% or less of their maximum yields. The 93% Al saturation histogram shows the ranking of the grasses illustrating wide differences to Al and P stresses between them. As the P level was increased, with Al saturation kept constant, all grasses increased their relative yields.

Table 37. Effects of Al on the uptake and translocation of P, Ca, Mg and K by three *Stylosanthes* species grown in nutrient solution.

Al treatment (ppm)	*Stylosanthes capitata*				*Stylosanthes guianensis*				*Stylosanthes sympodiales*			
	Uptake (mg/g dry wt.)			Transport index[1] (%)	Uptake (mg/g dry wt.)			Transport index (%)	Uptake (mg/g dry wt.)			Transport index (%)
	Tops	Roots	Total		Tops	Roots	Total		Tops	Roots	Total	
					Phosphorus							
0.0	1.2	1.3	2.5	48	1.0	1.4	2.4	42	0.9	1.2	2.1	43
2.5	0.8	1.5	2.3	35	0.7	1.6	2.3	30	0.7	2.1	2.8	25
5.0	0.8	1.5	2.3	35	0.7	2.0	2.7	26	0.7	2.6	3.3	21
10.0	0.8	1.7	2.5	32	0.7	2.2	2.9	24	0.6	2.9	3.5	17
					Calcium							
0.0	9.9	3.4	13.3	74	11.8	3.0	14.8	80	12.7	1.7	14.4	88
2.5	8.3	2.6	10.9	76	8.9	2.3	11.2	79	7.6	1.6	9.2	83
5.0	6.8	2.3	9.1	75	6.7	1.8	8.5	79	7.0	1.4	8.4	83
10.0	6.0	1.4	7.4	81	5.5	1.2	6.7	82	5.7	1.5	7.2	89
					Magnesium							
0.0	2.3	3.0	5.3	43	2.3	4.2	6.5	35	2.6	3.7	6.3	41
2.5	2.0	2.3	4.3	47	2.2	2.7	4.9	45	2.7	1.3	4.0	68
5.0	2.2	1.7	3.9	56	2.2	1.3	3.5	63	2.7	1.2	3.9	69
10.0	2.2	1.3	3.5	63	2.2	0.9	3.1	71	2.5	0.7	3.2	78
					Potassium							
0.0	18.3	20.2	38.5	48	18.0	29.5	47.5	38	21.8	22.1	43.9	50
2.5	15.9	22.0	37.9	42	15.2	30.8	46.0	33	23.2	22.6	45.8	51
5.0	15.8	22.2	38.0	42	16.4	26.0	42.0	39	25.7	21.0	46.7	55
10.0	16.7	25.0	41.7	40	17.6	28.5	46.1	38	22.5	18.9	41.4	54

[1] Transport index = (top mineral uptake/total mineral uptake) x 100.

With the addition of 0.5 and 1.0 t lime/ha most of the species showed an increase in dry matter production. This indicates that the response of grasses tolerant to Al is mainly related to Ca and Mg requirements rather than to the effect of liming. When Al toxicity was eliminated by applying 5 t lime/ha all grasses showed more than 50% of their relative yields at the two lowest P levels. However, when P was increased most of the grasses showed a sharp yield decrease which is probably related to some nutritional imbalance due to the high lime and P applications.

Results with forage legumes are given in Figure 24. Although there were marked variations between species in response to the P and lime applications, in general the results were similar to those obtained for grasses.

Nutritional Requirements of Grass and Legume Forages

The research strategy developed by the Soil/Plant Nutrition Section for determining the mineral requirements of promising forage species has taken into account: (1) the need for standardized analytical methods for acid soils and plant tissues; (2) the description of visual foliar symptoms caused by mineral disorders; and (3) the determination of responses of promising forage species to a given

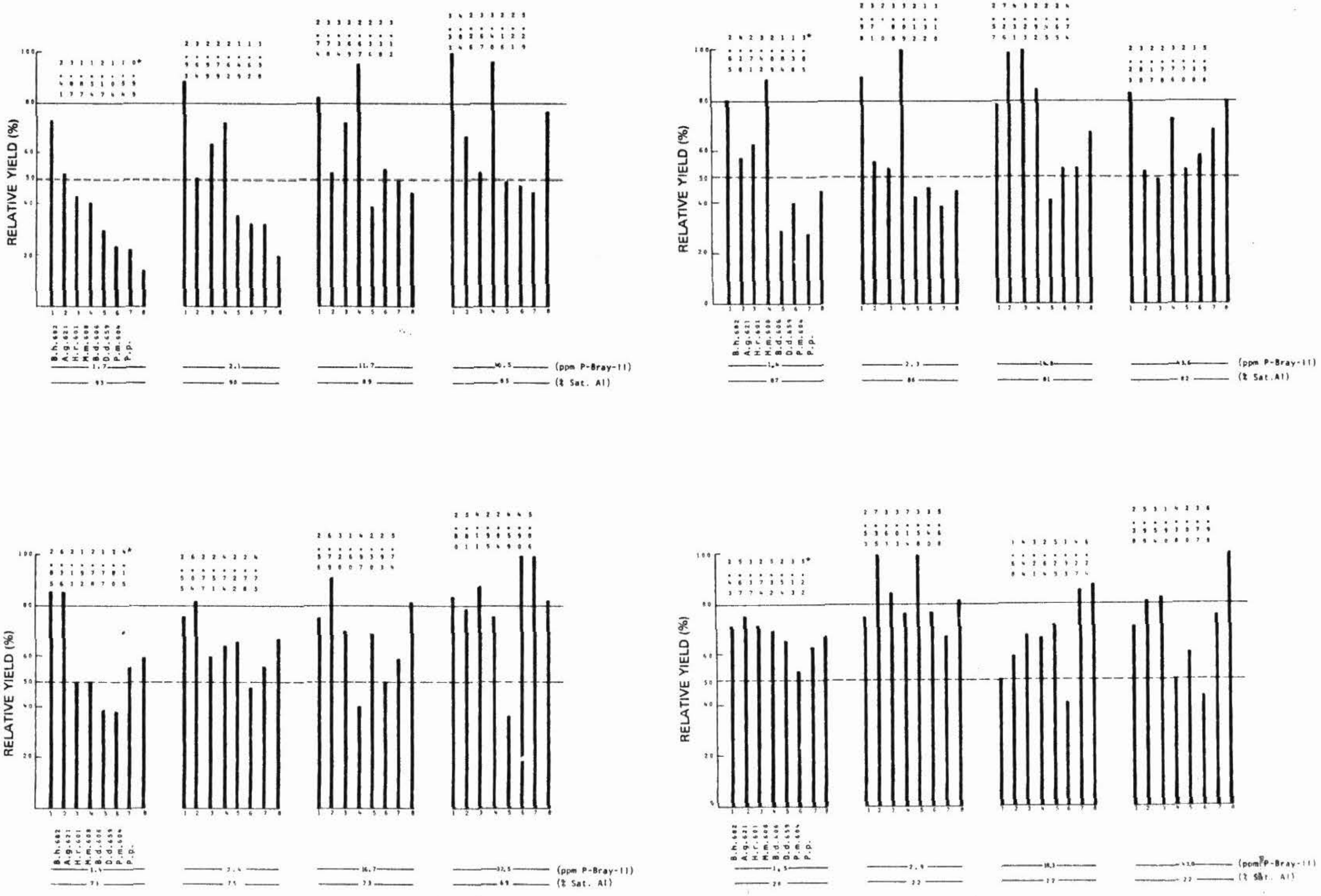

Figure 23. Differential response of eight tropical grasses at different P levels and 92, 86, 77 and 27% Al saturation (0, 0.5, 1, and 5 t lime applied/ha) under field conditions at Carimagua. 1 = *Brachiaria humidicola* 682; 2 = *Andropogon gayanus* 621; 3 = *Hyparrhenia rufa* 601; 4 = *Melinis minutiflora* 608; 5 = *Brachiaria decumbens* 606; 6 = *Digitaria decumbens* 659; 7 = *Panicum maximum* 604; 8 = *Pennisetum purpureum*.

(Figures on bars are dry matter yield beans in t/ha.)

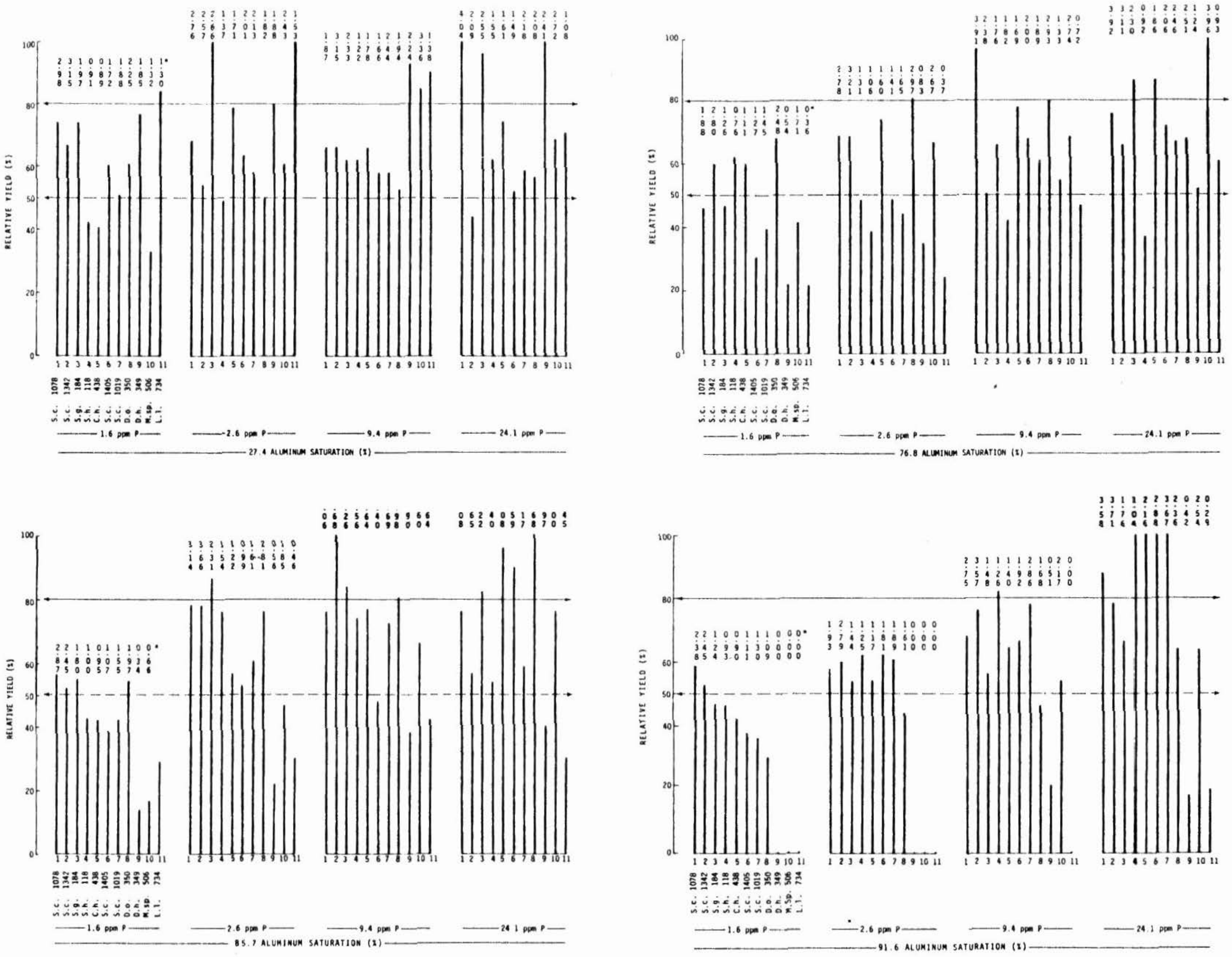

Figure 24. Differential response of 11 forage legumes at different P levels and under 92, 86, 77, and 27% Al saturation (0, 0.5, 1, and 5 t lime applied/ha) under field conditions at Carimagua. 1 = *Stylosanthes capitata* 1078; 2 = *Stylosanthes capitata* 1342; 3 = *Stylosanthes guianensis* 184; 4 = *Stylosanthes humilis* 438; 5 = *Centrosema hybrid* 438; 6 = *Stylosanthes capitata* 1405; 7 = *Stylosanthes capitata* 1019; 8 = *Desmodium ovalifolium* 350; 9 = *Desmodium heterophyllum* 349; 10 = *Macroptilium* sp. 506; 11 = *Leucaena leucocephala* 734. (Figures on bars are dry matter yield means in t/ha.)

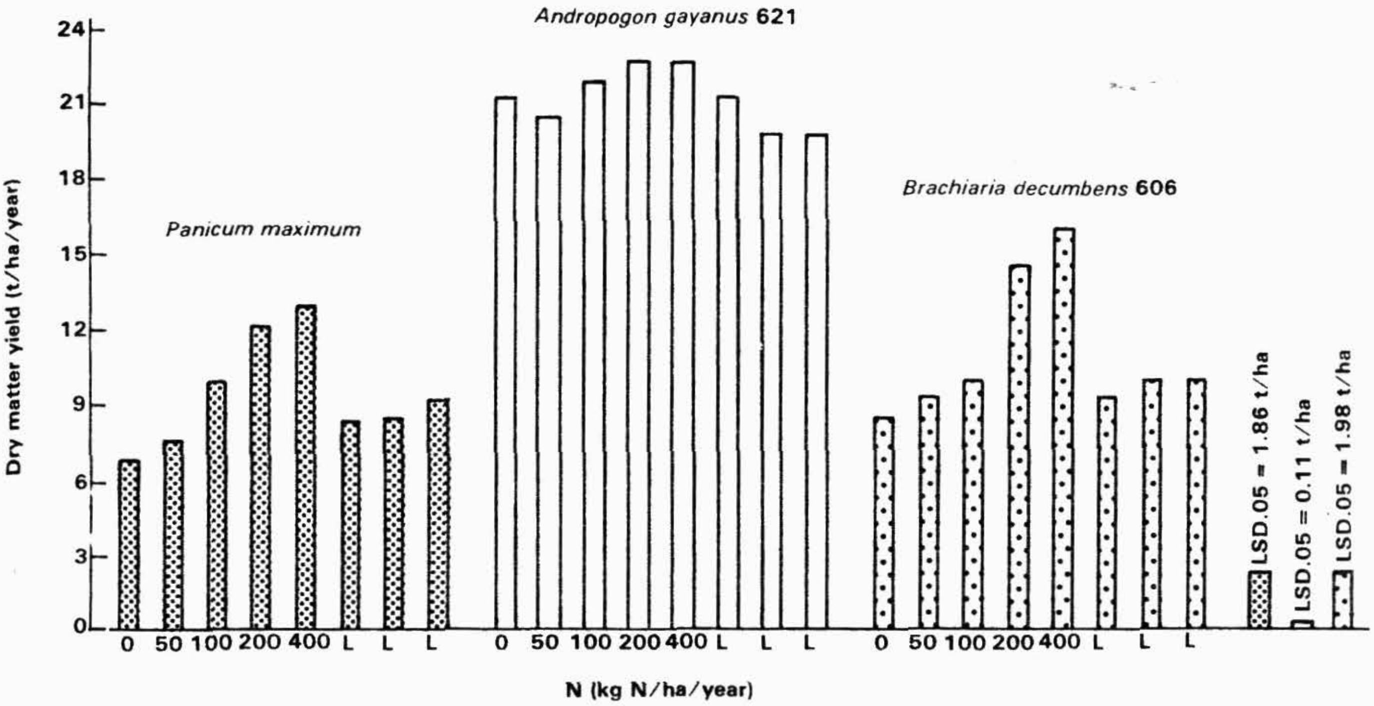

Figure 25. Effect of varying rates of nitrogen (applied as urea) on yield of three forage grasses compared to their mixtures with three legumes (L_1 = *Stylosanthes guianensis* 136, L_2 = *S. guianensis* 184, and L_3 = *Centrosema* hybrid 438) under field conditions at CIAT-Quilichao.

nutrient and its effect on the mineral composition of the plant.

Standardized analytical methods for acid soils and plant tissues

During 1979, a considerable effort was devoted to preparing a handbook describing analytical methods and procedures for running soil and plant analyses in the acid infertile soils of the Tropical Pastures Program target area. Since soils from other countries cannot be brought into Colombia it is essential that standardized methods and Orocedures be used by collaborating laboratories. To date six national laboratories have been identified, located near the regional trials sites. Soil and plant samples have been distributed to these laboratories to verify uniformity of results from the proposed methods and procedures.

Visual foliar symptoms of mineral disorders

A series of greenhouse experiments was conducted to develop mineral deficiency and toxicity symptoms. The study included N, P, K, Ca, Mg and S deficiencies among the micronutrients group, and Al and Mn toxicities. Photographs of these deficiencies and toxicities were taken on the various grass and legume forage accessions; these, along with a detailed description will be incorporated into a handbook for practical use by researchers involved in forage evaluation in regional trials.

Fertilizer requirements during pasture establishment

Attention was focused on estimating fertilizer requirements during the establishment stage of promising forage species. Results reported here are for N, P, K, and S fertilization in soils from CIAT-Quilichao and Carimagua.

N requirements of forage grasses

Although N fertilization of forage grasses is not considered feasible for the target area, it is important to have an understanding of the N demand of promising forage grasses. In any given pasture situation it is assumed that the N will be supplied by the legume in the mixtures. Figure 25 shows the response of three forage grasses *(Panicum maximum, Andropogon gayanus* 621 and *Brachiaria decumbens* 606) to N fertilization at CIAT-Quilichao during the second year of evaluation compared to their mixtures with three forage legumes *(Stylosanthes guianensis* 136 and 184 and *Centrosema pubescens* hybrid 438). All three grasses showed a positive response to N, although *A. gayanus* 621 showed a significant response only up to 200 kg N/ha/year; *P. maximum* and *B. decumbens* 606 showed linear responses up to 400 kg N/ha/year. On the other hand, it was observed that *A. gayanus* 621 also had a much higher yield potential than the other two grasses at all N rates; in this regard, it is interesting to note that the percentage recovery of the applied N was much lower for *A. gayanus* (Table 38). However, because of the higher yield potential, *A. gayanus* still proved to be a more efficient user of the N applied.

In this same study the N:S ratios of the three grasses was also considered. It is generally assumed that a critical S level of 0.1% is required for tropical forage grasses. This apparently is not the case with *A. gayanus*, however, as in almost every instance the S content in the tissue was below the considered minimum (Figure 26). These results suggest that the critical S requirement for *A. gayanus* 621 is less than that required by *P. maximum* and *B. decumbens* 606, however, it must be kept in mind that the S content in the tissue of *A. gayanus* probably does not satisfy the S requirement of the animal.

Positive responses to N fertilization of the grasses were also observed in Carimagua (Figure 27). *A. gayanus* 621, *B. decumbens* 606 and *M. minutiflora* gave significant responses from 75 to 225 kg N/ha during the 1979 rainy season. However, the efficiency of N utilization is expected to be better in *A. gayanus* 621 than in *B. decumbens* 606 based on the percent N recovery observed at CIAT-Quilichao. Further studies are being carried out to confirm this.

P and K requirements of forage grasses

Calibration of soil P tests. To date several different extractants have been used to determine available soil P. It was necessary to compare these tests to see how well they correlated with one another.

Accordingly, four different methods were evaluated for available P in a Carimagua Oxisol. Regression and correlation analysis between percentage yield of *P. maximum* and P extracted by the four methods (Bray I,

Table 38. Plant nitrogen content, protein equivalent, nitrogen uptake, and nitrogen recovery for three forage grasses under a cutting regime at CIAT-Quilichao.

Grass species	N applied (kg N/ha/year)	N (%)	Protein (%)	N uptake (kg N/ha/year)	N recovery[1] (%)
Andropogon gayanus 621	0	1.27	7.94	197	-
	50	1.24	7.75	188	0
	100	1.31	8.19	218	21
	200	1.32	8.25	226	15
	400	1.48	9.25	248	13
Panicum maximum	0	1.29	8.06	84	-
	50	1.30	8.13	94	20
	100	1.38	8.63	132	48
	200	1.53	9.56	178	47
	400	1.90	11.87	234	38
Brachiaria decumbens 606	0	1.06	6.62	83	-
	50	1.12	7.00	94	20
	100	1.16	7.25	113	30
	200	1.38	8.62	193	55
	400	1.78	11.12	269	46

[1] $$\%\ \text{N recovery} = \frac{\text{N uptake at applied rate} - \text{N uptake without added N}}{\text{N rate}} \times 100$$

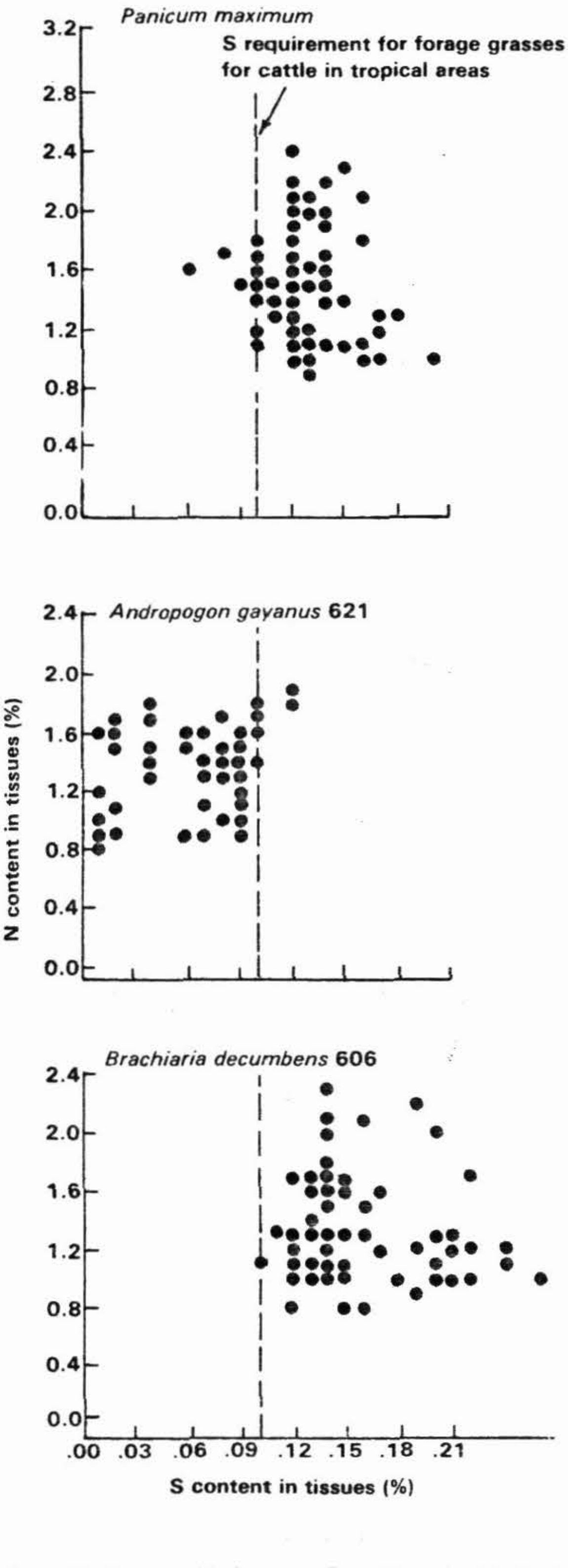

Figure 26. Relationship between S and N content in the tissue of three grass species at CIAT-Quilichao.

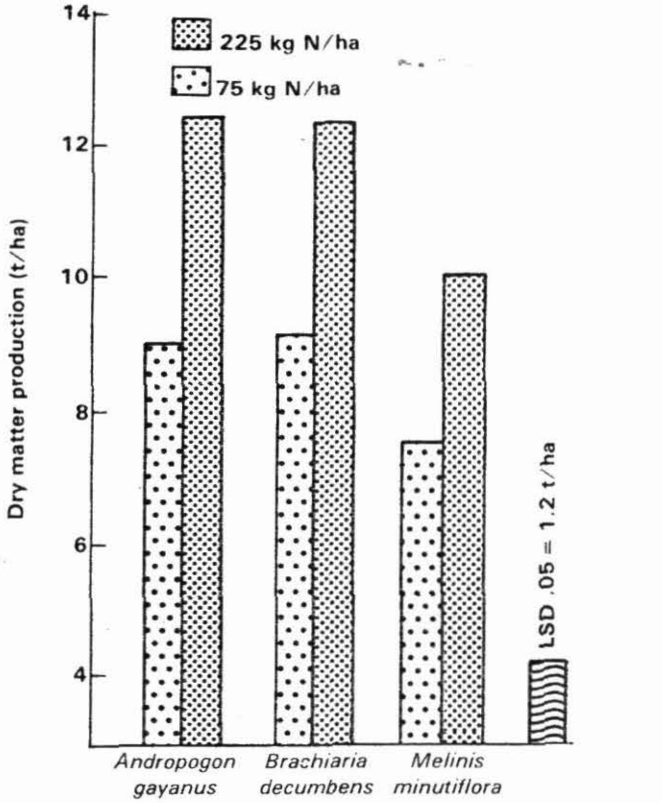

Figure 27. Response of three tropical grasses to nitrogen fertilization under field conditions in the Carimagua Oxisol. (Sum of four cuts during rainy season.)

Bray II, North Carolina 1:4 soil-extractant ratio, and North Carolina 1:10 soil-extractant ratio) showed that the amounts of P extracted were in direct relation to the amount of P fertilizer applied (Figure 28). However, the amount of P extracted by Bray I, Bray II and the modified North Carolina method (1:10 ratio) were much higher and with a wider range in available P than the traditional North Carolina method (1:4 ratio). Correlation coefficients relating P extracted by the four methods to *P. maximum* yields are shown in Table 39. Although the methods are well correlated, the Bray II extractant gave the best correlation with percentage yield (r = 0.90) but with no significant differences compared with Bray I and North Carolina 1:10 methods. A low correlation coefficient (r = 0.66) for North Carolina 1:4 methods vs. percentage yield was found. The results of this study have shown that the Bray II method as well as the Bray I and the modified double acid North Carolina methods provide good indices of P available to plants in the Carimagua Oxisol.

Effects of P sources on forage grasses. A long-term field experiment with *A. gayanus* 621 and *P. maximum*

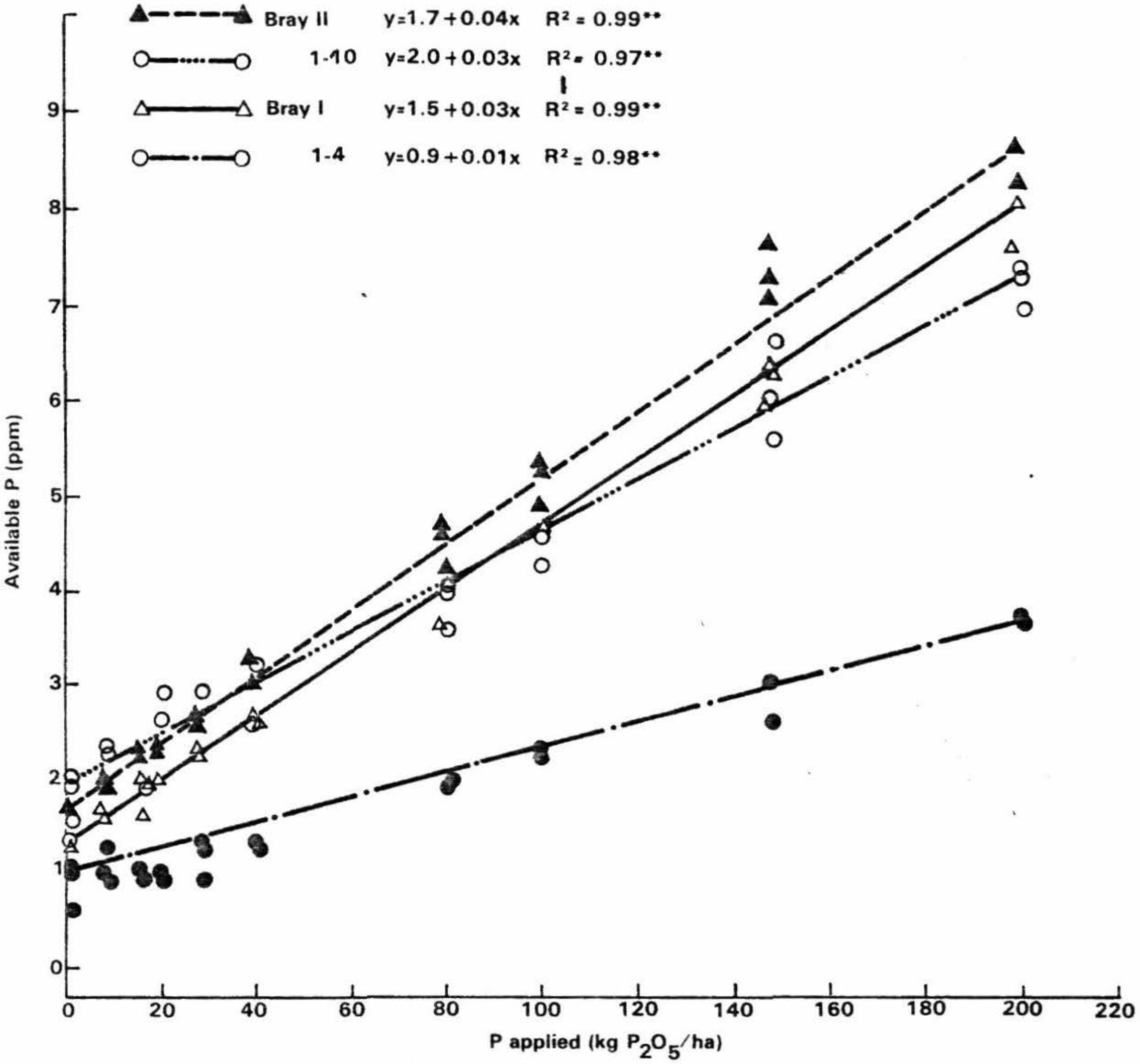

Figure 28. Soil available P in the Carimagua Oxisol, determined by extractant solutions Bray I, Bray II, North Carolina (NC) 1:10 soil extractant ratio, and NC 1:4 soil extractant ratio.

Table 39. Simple correlation coefficients (r) relating four soil tests for available P and yield of *Panicum maximum* for the Carimagua Oxisol.

Soil test	Extractant	Bray I	Bray II	NC-1:10	NC-1:4	Yield
Bray I	0.03N NH_4F + 0.025N HCl	1.00	-	-	-	0.87**
Bray II	0.03N NH_4F + 0.1N HCl	0.99**	1.00	-	-	0.90**
NC-1:10	0.025N H_2SO_4 + 0.05N HCl	0.98**	0.98**	1.00	-	0.85**
NC-1:4	0.025N H_2SO_4 + 0.05N HCl	0.97**	0.97**	0.96**	1.00	0.66*

* Probability at the 0.05 level.
** Probability at the 0.01 level.

was established early in 1978 at CIAT-Quilichao to evaluate the effects of cheaper P sources and the differential P requirements of forage grasses in order to decrease the cost of fertilizer applications. Three phosphate rocks (Pesca, Gafsa, and Huila) and triple superphosphate (TSP) were broadcast applied at rates from 0 to 1600 kg P_2O_5/ha, incorporated into the topsoil. To date the results have shown no significant differences between P sources so only the TSP results will be given.

Figure 29 shows yields of the two forage grasses. *A. gayanus* 621 showed a significant response only at the 800 kg P_2O_5/ha rate compared with the check plot. It must be kept in mind, however, that control yields were very high. A significant increase in yield of *P. maximum* was obtained with only 60 kg P_2O_5/ha; a linear response continued reaching a peak up to 100 kg

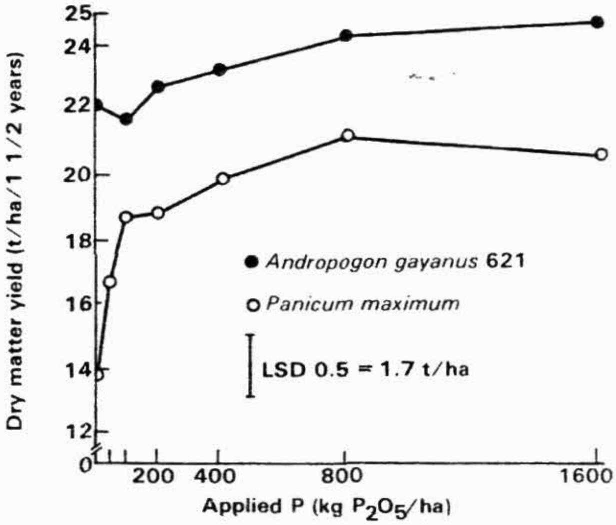

Figure 29. Effect of phosphorus fertilization on the dry matter yield of two tropical grasses grown at CIAT-Quilichao.

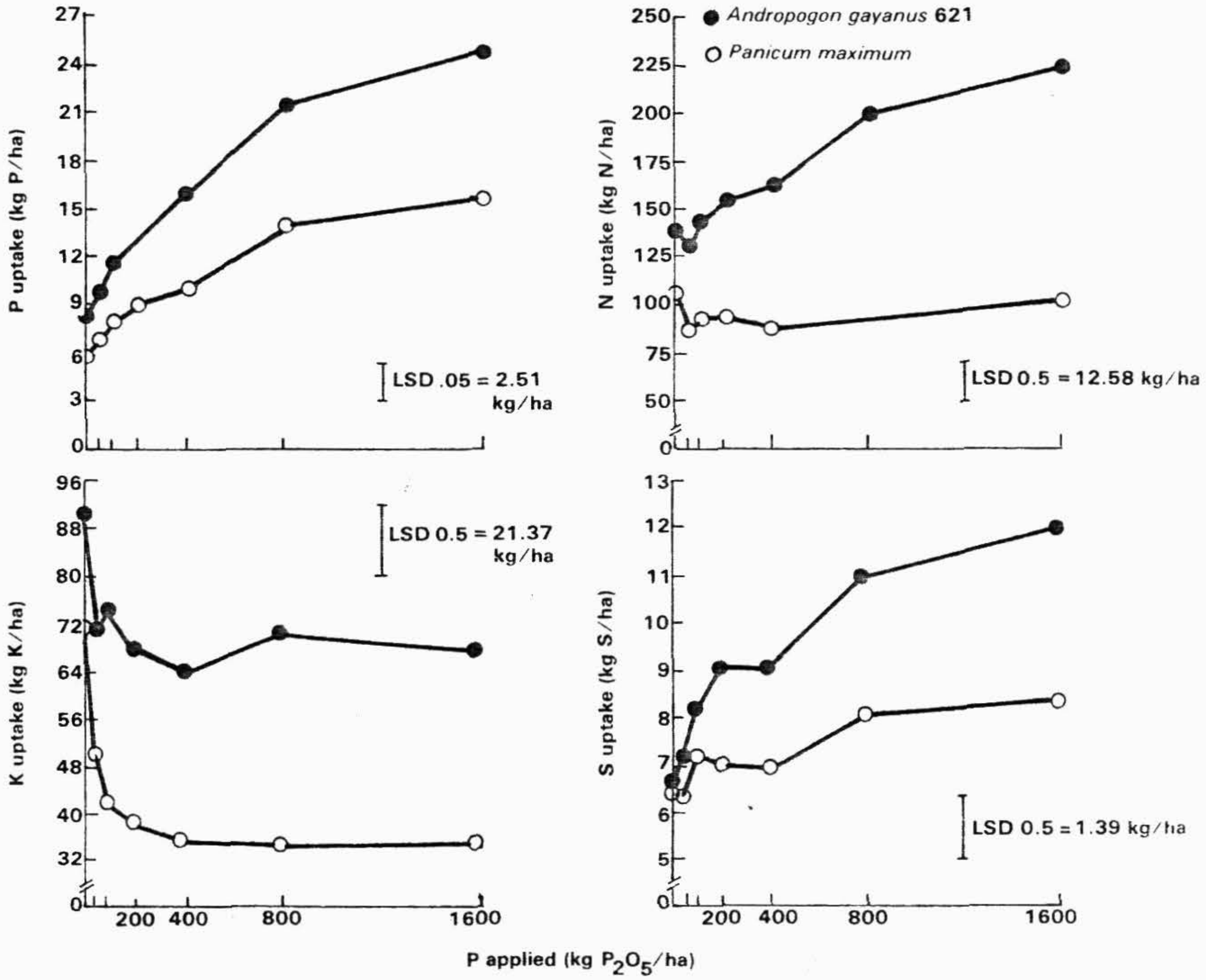

Figure 30. Effects of P fertilization on the P, N, K and S uptake by two tropical grasses.

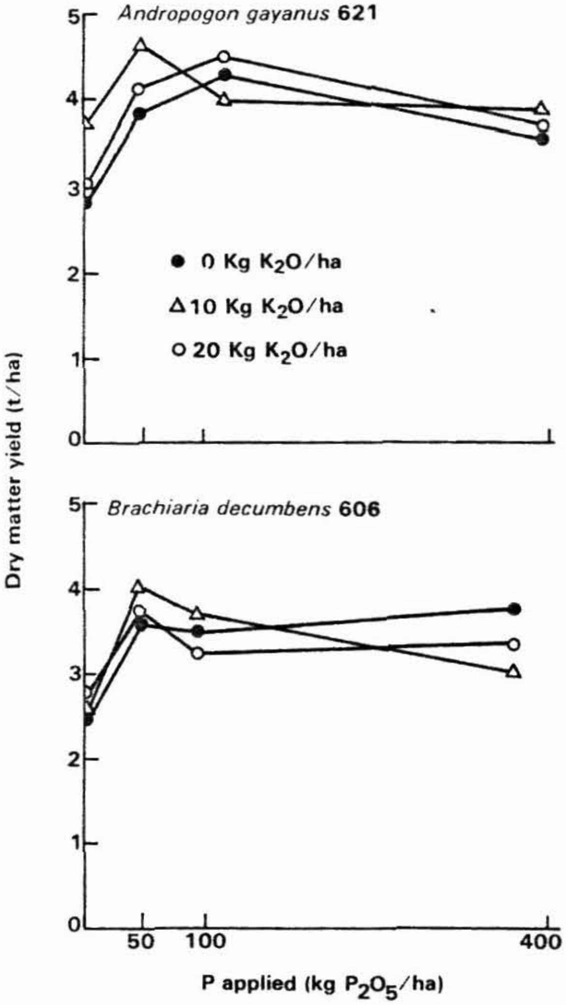

Figure 31. Effects of phosphorus and potassium on dry matter production of *Andropogon gayanus* and *Brachiaria decumbens* grown in an Oxisol from Carimagua. (Sum of the two first cuts, 1979)

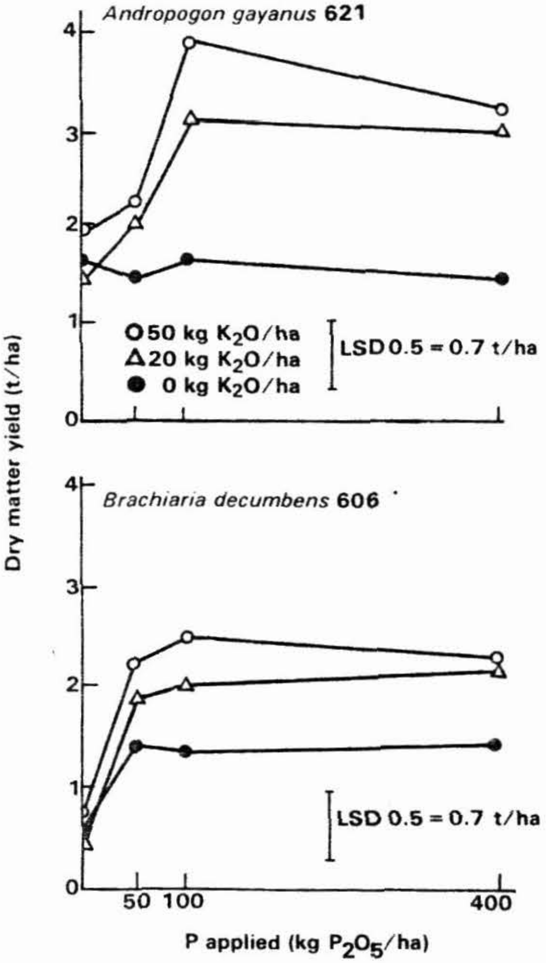

Figure 32. Effects of phosphorus and potassium on dry matter production of *Andropogon gayanus* and *Brachiaria decumbens* grown in an Oxisol from Carimagua. (Third cut during the rainy season, 1979.)

P_2O_5/ha after which it leveled off. The results suggest that *A. gayanus* 621 has a lower P requirement for high yields than *P. maximum*. Figure 30 illustrates the effect of P fertilization on P, N, K and S uptake by the two grasses.

P x K fertilization. *A. gayanus* 621 and *B. decumbens* 606 are also being evaluated for P and K responses in Carimagua. After two cutting periods, both grasses showed a response to P at the 50 kg P_2O_5/ha rate but no response to K (Figure 31). After the second cut, K fertilization was increased to 20 and 50 kg K_2O/ha, respectively. Figure 32 illustrates the results of the third cut showing a significant interaction with K and P. With very low K application rates *A. gayanus* 621 did not respond to P applications; however, when K was applied at the rate of 20 kg K_2O/ha it showed a large response to P up to 100 kg P_2O_5/ha. With the addition of 50 kg K_2O/ha, dry matter yield was increased. *B. decumbens* showed a similar type of response to K application, it was only responsive up to a level of 50 kg P_2O_5/ha. These preliminary results suggest that, in order to determine the critical percentage of a nutrient, other nutrients must not be limiting.

S fertilization of forage legumes

A greenhouse experiment was conducted in CIAT-Quilichao and Carimagua soils to determine the effects of S on the yield of *Zornia latifolia* 728, *Stylosanthes capitata* 1019, and *Desmodium ovalifolium* 350.

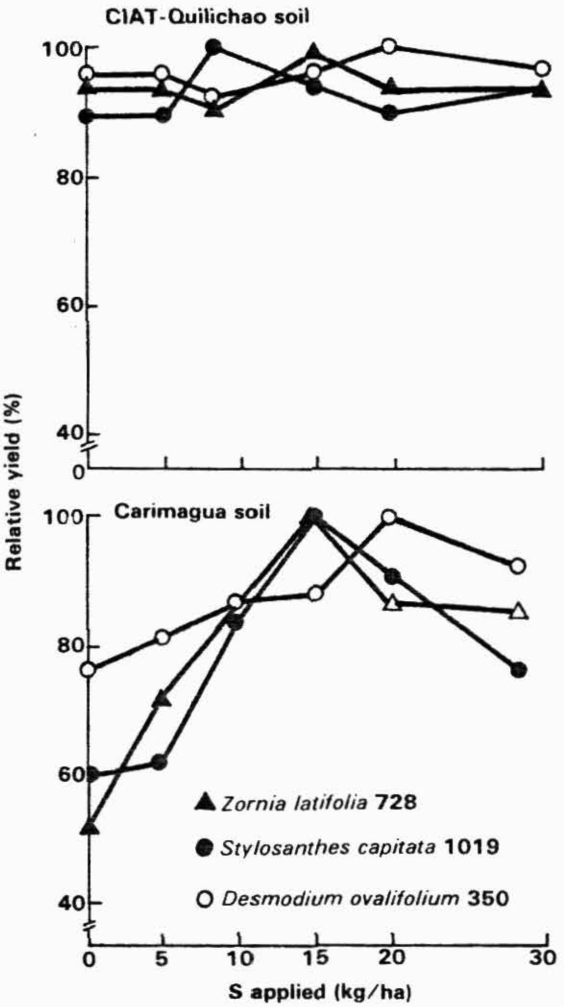

Figure 33. Relative yields of three tropical forage legumes grown under greenhouse conditions in soils from CIAT-Quilichao and Carimagua in response to fertilization with sulphur.

Table 40. Sulphur contents and forms in the top layer (0-20 cm) of soils from CIAT-Quilichao and Carimagua.

	S contents (ppm)	
S forms	CIAT-Quilichao	Carimagua
Total S	1013	420
Organic S	633	231
Inorganic S	380	189
Available S $[Ca(H_2PO_4)]$	29	10

Relative dry matter yields are shown for both soils in Figure 33. There was no response to S application in the CIAT-,quilichao soil, but all three legumes gave significantly higher relative yields in the Carimagua soil. *S. capitata* 1019 and *Z. latifolia* 728 showed a linear response to S applications and then attained maximum yields at the rate of 15 kg S/ha. *D. ovalifolium* 350 also showed a positive response to S with maximum yields at 20 kg S/ha. Dry matter yields were depressed at the highest S treatment which is probably due to a nutritional imbalance between N and S.

The lack of response to S application at CIAT-Quilichao may be explained by the fact that the native S supply is considerably higher due to the high organic matter content in the topsoil. Table 40 shows the S contents and forms in the top layer of both soils.

PASTURE DEVELOPMENT IN THE HYPERTHERMIC SAVANNAS (CARIMAGUA)

The objectives of the Pasture Development section in Carimagua continue to be the development of simplified, low-cost establishment methods and efficient maintenance practices. New trials were initiated during the year and long term trials were continued.

Several new legume/grass associations were established. It is recommended that the grass and legume be seeded simultaneously and in rows spaced 0.50-1.00 m using a 1:1 or 2:2 legume/grass planting pattern. Row planting combined with band fertilization favors the establishment of a vigorous population of seedlings with minimum fertilizer and both species have sufficient time and space to become well established with minimum weed competition. The 1:1 planting pattern may present a problem with bunch type grasses as the grazing animal moves between the grass rows, trampling the legume planted in that space.

The importance of firming the seed bed in the row at the time of planting was reconfirmed in a seed