Soil Fertility and Plant Nutrition

The research strategy on soil fertility and plant nutrition of the Tropical Pastures Program is based on a low-input soil management technology. Its general objective is to make the most efficient use of scarce fertilizer inputs by establishing pasture species and ecotypes that are most tolerant to existing soil constraints, thus decreasing the rates of fertilizer applications while attaining reasonable, but not necessarily maximum quality and yield. The specific objectives of this strategy are the management of soil acidity (Al and Mn toxicities, Ca and Mg deficiencies) and management of low native soil fertility (macro and micro-nutrient deficiencies, except nitrogen) for the establishment and maintenance of tropical pastures.

Management of Soil Acidity

The main soil acidity constraints are identified as aluminum and/or manganese toxicities, calcium and magnesium deficiencies, which need to be alleviated in order to obtain successful pasture establishment. Selection of productive pasture species and ecotypes that are tolerant to Al and/or Mn toxicities is the main component in soil acidity management. In addition, the aluminum-tolerant species and ecotypes of tropical pastures do not need a decreased aluminum saturation level of the soil by liming, but in most cases the plants require fertilization with calcium and magnesium.

Tolerance to aluminum toxicity

Although the hematoxylin test is a very useful technique to separate the germplasm into two broad groups according to tolerance to Al toxicity, it was found that the evaluation in many cases was very qualitative. In order to avoid this situation and in addition to the visual estimation of the stainability of the root system by the hematoxylin, the relative root length was introduced as a quantitative measurement. Figure 1 shows the relationship between regression coefficients of the relative root length and the relative dry matter yields of 47 ecotypes of *Stylosanthes macrocephala* grown under three levels of Al stress. This figure shows the distribution of the ecotypes according to their Al tolerance. Comparing with the hematoxylin test and the Al-susceptible control (*Stylosanthes sympodialis* 1044), the Al-susceptible ecotypes of *S. macrocephala* fall within the group defined as susceptible by the hematoxylin test. There are several ecotypes that were grouped as Al-tolerant by the hematoxylin test but that were identified as susceptible by their low regression coefficients of relative root length. These results may be explained in the sense that the ecotypes identified as Al-tolerant by the visual-hematoxylin test were healthy plants although their root growth was reduced under Al stress. In fact, the relative dry matter yields of most of the ecotypes were over 50% of maximum yield obtained with no Al stress. It appears that not only the reduction in root growth but also the top growth has to be considered in this screening process. However, for practical use the selection of the most Al tolerant ecotypes by any of the two tests is enough considering the high number of ecotypes.

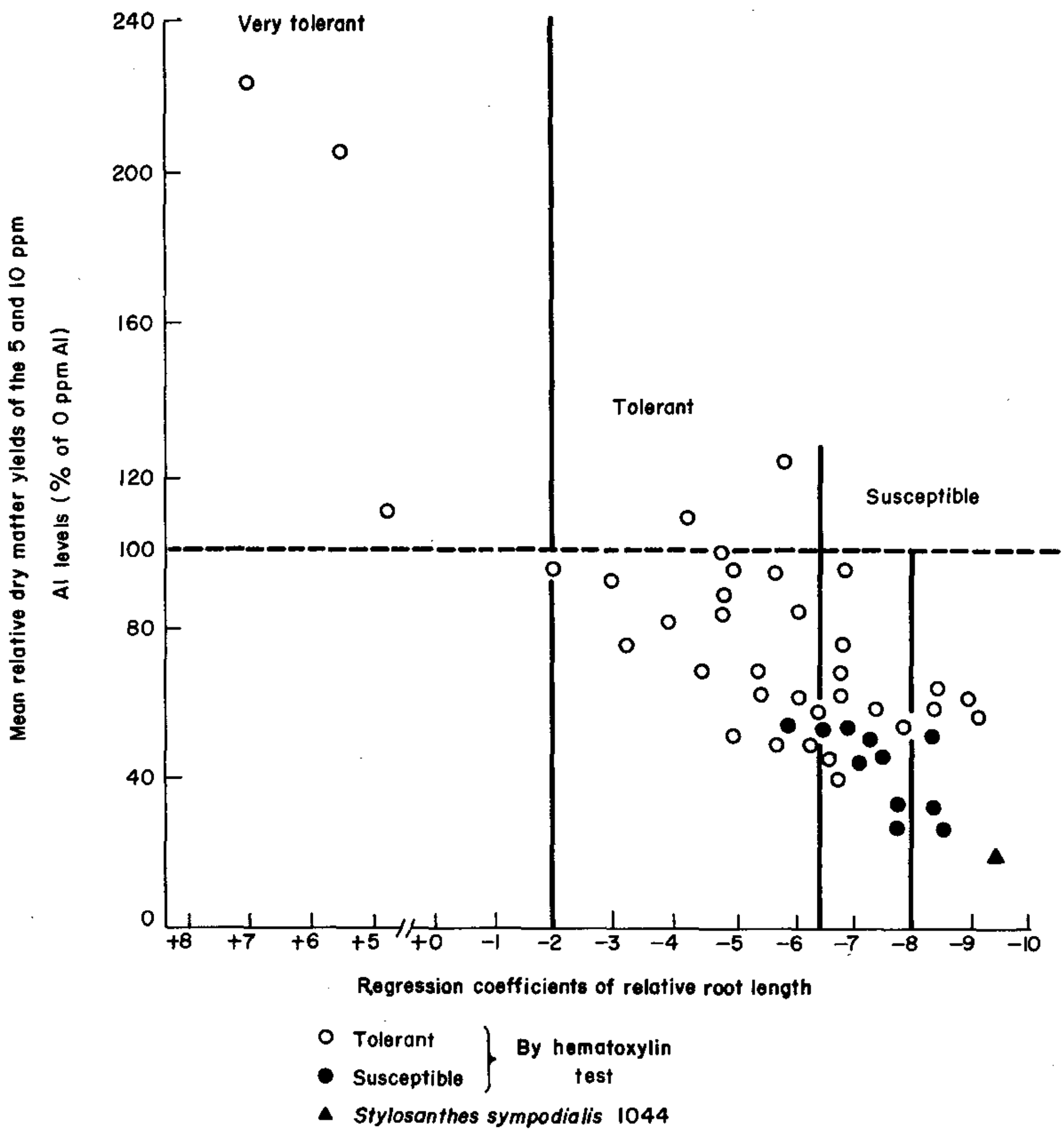

Figure 1. Relationship between regression coefficients of the relative root length and the mean relative dry matter yields of 5 and 10 ppm Al of 47 ecotypes of Stylosanthes macrocephala and their comparisons with the hematoxylin test.

Tolerance to manganese toxicity

Managenese toxicity is another constraint in certain acid soils but its geographical extent is not known. During the soil characterizations for the pasture regional trials, however, several soils were identified with available soil manganese above the toxic level for tropical pastures (>50 ppm Mn). Using the natural distribution of the soil manganese from low (0-20 ppm Mn) to high (> 50 ppm Mn) at Quilichao, a field experiment was established to study the differential tolerance of several species and ecotypes of tropical pasture grasses and legumes.

The results are shown in Tables 1 and 2. The idea that legumes are more susceptible to manganese toxicity than the grasses appears not to be true since among pasture species and ecotypes within species in both grasses and legumes there is a differential tolerance to Mn toxicity. Among the pasture grasses the differential tolerance is better appreciated among ecotypes than at species level. On the other hand, the most tolerant ecotypes had higher dry matter production at high Mn stress than at low Mn stress which would indicate a beneficial rather than a detrimental effect. Some ecotypes within a species judged on the basis of the relative index as Mn-susceptible (Relative Index less than 0.5) had a dry matter production similar to the most Mn-tolerant ecotypes. This fact can be related to the high inherent potential of these ecotypes for biomass production which in many cases may be enough for animal feeding. This is the case of *Brachiaria humidicola* 679, *Brachiaria eminii* 6241 and *Andropogon gayanus* 6200.

Table 2 shows the dry matter yield and differential tolerance of several tropical legume species and ecotypes to Mn toxicity in the soil. The performance of these pasture legumes follows a similar trend to that of grasses. In general, the manganese toxicity symptoms included marginal chlorosis, induced iron deficiency, distortion of young leaves, and localized spots where manganese accumulates.

Calcium requirements by tropical pastures

The diagnosis of aluminum toxicity in acid soils of tropical America has been based on exchangeable aluminum extracted by 1N KCl. Liming recommendations are commonly derived from the level at which this exchangeable aluminum is almost neutralized and the soil pH is raised to the range 5.2-5.5. However, liming requirements based only on exchangeable aluminum may overestimate the lime rates because of varying degrees of plant tolerance to aluminum toxicity. In addition, initial results (Tropical Pastures Program, Annual Report, 1980) provided the information that the response of the Al-tolerant pasture grasses and legumes was mainly related to calcium requirements rather than to liming. Thus a field experiment was established on an Oxisol of Carimagua to determine the calcium requirements of several tropical pasture grasses and legumes. Four calcium rates (50, 100, 200 and 400 kg Ca/ha) plus a control (no Ca applied) were used and calcitic lime was the calcium source. Table 3 shows the external and internal critical calcium requirements associated with about 80% of maximum yield during the rainy season and dry seasons of several tropical pastures species and ecotypes.

Table 1. Dry matter production and differential tolerance of several species and ecotypes of tropical pasture grasses to manganese toxicity under field conditions.

Species	Ecotype	Dry matter yield Low Mn (10 ppm Mn)	Dry matter yield High Mn (86 ppm Mn)	Relative Index (High Mn/Low Mn)
		-----t ha^{-1}	$year^{-1}$------	
Brachiaria ruziziensis	654	2.88	3.00	1.04
	655	4.86	3.10	0.64
	660	3.53	1.83	0.52
	656	3.30	1.48	0.45
Brachiaria decumbens	606	5.52	6.69	1.21
	6130	3.37	3.19	0.95
	6131	2.82	1.93	0.68
	6132	3.14	1.28	0.40
Brachiaria humidicola	675	2.66	2.63	0.98
	6013	3.76	3.00	0.80
	679	5.73	2.78	0.48
Brachiaria brizantha	665	5.74	6.05	1.05
	667	5.44	3.29	0.60
	6016	1.47	0.86	0.58
Brachiaria radicans	6020	1.30	1.87	1.43
Brachairia dictyoneura	6133	2.42	1.86	0.77
Brachiaria eminii	6241	4.70	2.20	0.47
Andropogon gayanus	6054	3.40	4.06	1.19
	621	3.70	4.01	1.08
	6053	6.81	6.78	0.99
	6200	6.07	4.39	0.72
Panicum maximum	661	3.14	4.45	1.42
	673	4.30	4.54	1.05
	697	4.78	4.85	1.01
	684	2.28	1.95	0.85
Pennisetum purpureum	658	10.0	8.73	0.87
	672	13.1	10.39	0.79
Setaria anceps	6187	6.25	7.13	1.14
	6188	3.13	1.16	0.37

Among the grasses, Brachiaria humidicola 679 had the least external calcium requirement (50 kg Ca/ha equivalent to only 125 kg calcitic lime/ha) and also the least internal calcium requirement (0.22% Ca) as compared with the other grasses which required twice the amount of external calcium to have more or less the same dry matter production. However, all these grasses have a low Ca requirement since the small amount of calcium applied to the soil practically did not change the soil pH or the Al saturation percentage at all.

Table 2. Dry matter yield and differential tolerance of several species and ecotypes of tropical pasture legumes to manganese toxicity under field conditions.

Species	Ecotype	Dry matter yield		
		Low Mn (10 ppm Mn)	High Mn (86 ppm Mn)	Relative index (High Mn/Low Mn)
		-----t/ha^{-1}	year^{-1}------	
Stylosanthes capitata	1405	1.93	2.59	1.34
	1315	2.14	2.31	1.07
	1019	1.95	2.01	1.03
	1097	3.23	3.32	1.02
Stylosanthes guianensis	136	4.82	6.21	1.29
	184	5.39	5.80	1.07
Stylosanthes hamata	147	4.78	5.05	1.05
Centrosema macrocarpum	5065	3.11	2.72	0.87
	5462	2.95	2.36	0.80
Centrosema brasilianum	5237	2.10	2.52	1.20
	5180	1.61	1.44	0.89
Centrosema pubescens	5118	1.26	1.95	1.54
	5053	1.88	2.20	1.17
	5112	3.03	3.23	1.06
	5189	2.27	2.27	1.00
	5126	3.23	2.80	0.87
	438	3.16	2.55	0.80
	Common	2.47	1.89	0.76
Desmodium ovalifolium	350	3.95	4.52	1.14
Desmodium heterophyllum	349	2.80	2.36	0.84
Desmodium heterocarpon	365	2.34	1.15	0.49
Codariocalyx gyroides	3001	3.37	2.20	0.65
Calopogonium mucunoides	7367	2.27	2.41	1.06
	Common	4.09	3.72	0.90
	9161	2.79	1.68	0.60
Pueraria phaseoloides	9900	4.79	5.79	1.20
Zornia latifolia	9286	1.93	1.65	0.85
	728	1.54	1.27	0.82

Results with pasture legumes also show marked variations in their calcium requirements not only among species but also among ecotypes within species. Although the external calcium requirements were in many cases the same as with the grasses, the internal calcium requirements for legumes were higher than those of the grasses at both rainy and dry seasons. These observations have implications for competitive effects with respect to calcium in grass-legume mixtures and especially for those with the same external Ca requirement. Under these conditions pasture legumes may compete with grasses since when the immediate supply of calcium falls below the combined demands of the plants, competition begins.

The equivalent amount of calcium to that applied with the calcitic lime would be also applied with the basic slag (Calfos) or rock phosphates to meet the external calcium requirements avoiding in this way the use of lime.

Table 3. External and internal critical calcium requirements* and critical dry matter yields for the rainy and dry seasons of various tropical pasture species for the establishment period.

Species	Ecotype	External critical Ca level (kg/ha^{-1})	Dry matter yield (t/ha^{-1}) Rainy (3 cuts)	Dry (2 cuts)	Internal critical Ca level (%) Rainy	Dry
Grasses						
Brachiaria humidicola	CIAT-679	50	6.7	2.0	0.22	0.25
Andropogon gayanus	CIAT-621	100	6.7	2.6	0.23	0.21
B. decumbens	CIAT-606	100	7.6	2.1	0.37	0.30
B. brizantha	CIAT-665	100	7.3	1.8	0.37	0.32
Legumes						
Stylosanthes capitata	CIAT-1315	50	6.0	1.1	0.73	0.53
S. capitata	CIAT-1693	50	5.5	1.4	0.82	0.56
S. capitata	CIAT-1691	50	5.6	1.2	0.70	0.54
S. capitata	CIAT-1318	100	6.5	1.1	1.16	0.71
S. capitata	CIAT-1019	100	5.6	0.7	0.93	0.74
S. capitata	CIAT-1441	200	5.5	1.0	1.15	0.88
S. capitata	CIAT-1405	200	5.1	1.0	0.96	0.72
S. capitata	CIAT-1342	200	5.1	0.9	1.30	0.89
S. macrocephala	CIAT-1643	50	5.5	1.4	0.78	0.49
Desmodium ovalifolium	CIAT-350	100	4.9	1.3	0.74	0.64
Pueraria phaseoloides	CIAT-9900	100	4.4	0.9	1.04	0.57
Centrosema macrocarpum	CIAT-5065	100	2.5	0.7	0.72	0.57
Desmodium gyroides	CIAT-3001	100	3.0	0.5	0.66	0.48
Zornia sp.	CIAT-9600	100	2.9	0.3	0.53	0.50
Z. latifolia	CIAT-728	200	3.5	0.8	0.82	0.66
Z. latifolia	CIAT-9286	400	2.7	0.9	0.95	0.76
C. pubescens	CIAT-5053	400	2.0	0.6	0.98	0.74

*Critical requirements associated with about 80% of maximum yield.

Management of Low Native Soil Fertility

The main low-input technology required to manage low native soil fertility centers on increasing the efficiency of fertilization. This may be possible through the identification and correction of soil nutrient deficiencies and use of pasture species and ecotypes that are more efficient users of low fertilizer inputs. In addition, the promotion of nutrient recycling in pasture production systems needs substantial investigation.

Phosphorus and potassium requirements of tropical pastures

Following the methodology for regional trials but with three fertilization levels of P and K, a field experiment was established with the germplasm identified for the isohyperthermic well-drained savannas such as Carimagua. The results are presented in Tables 4 and 5 in relation to the external and internal requirements for P and K during the establishment period of the pasture species and ecotypes. With few exceptions, most of the pasture species and ecotypes required 20 kg P/ha and 20 kg K/ha.

All the pasture grasses present quite low internal phosphorus requirements in both rainy and dry seasons. On the contrary, the pasture legumes in many cases present twice the tissue P concentrations. These differential internal P requirements imply that pure stands of pasture grasses may not satisfy the animal P requirements (0.2% P). Consequently, a mineral P supplementation would be necessary since these tropical grasses even with high P fertilizer inputs did not increase their tissue P concentration beyond 0.15% P. However, grass-legume mixtures may provide enough phosphorus to fulfill the animal P requirements, and this suggests that research is needed with and without mineral P supplementation to the animal grazing grass-legume mixtures. Results indicating that mineral P supplementation could be reduced or eliminated would imply less input costs.

The differences in internal potassium requirements are less marked between legumes and grasses. In general, there are no major inter or intraspecific differences in terms of tolerance to low available soil potassium. The results presented in Tables 4 and 5 only indicate a temporary low K requirement since sooner or later an external source of K will be needed. The main reason for this is that potassium is similar to nitrogen in that potassium deficiencies increase with time due to the fast consumption by the plants and high susceptibility to leaching in most of the acid soils. All this suggests that the main avenues for increasing the efficiency of the K inputs for the establishment and maintenance of tropical pastures in highly weathered acid soils are: 1) the use of the sources of potassium with slow K release and long residual effects; cement plant kiln flue dust rich in potassium might be evaluated as an alternative for the highly soluble K sources, and 2) the recycling of potassium to the soil from the pasture litter and excreta depositions.

Table 4. External and internal critical levels of P and K of various species and ecotypes of tropical pasture legumes at the establishment period of the isohyperthermic well-drained savanna.

Species	Ecotype	External critical level*		Internal critical level*			
				Rainy season		Dry season	
		P	K	P	K	P	K
		(kg/ha^{-1})		(%)			
Category V							
Desmodium ovalifolium	350	20	20	0.10	1.03	0.08	0.43
Pueraria phaseoloides	9900	20	20	0.22	1.22	0.10	0.66
Category IV							
Stylosanthes capitata	1019	20	20	0.11	1.15	0.08	0.67
S. capitata	1315	20	20	0.18	1.18	0.08	0.60
S. capitata	1318	20	20	0.11	0.98	0.09	0.64
S. capitata	1342	20	20	0.12	1.16	0.10	0.62
S. capitata	1405	20	20	0.11	0.98	0.09	0.58
S. capitata	1441	20	20	0.12	1.18	0.09	0.61
S. capitata	1693	20	20	0.14	1.21	0.09	0.56
S. capitata	1728	20	20	0.12	1.22	0.09	0.64
Category III							
Centrosema macrocarpum	5065	11	10	0.16	1.24	0.09	0.72
C. pubescens	5053	20	20	0.18	1.50	0.09	0.76
C. pubescens	5126	20	20	0.18	1.40	0.11	0.75
Codariocalyx gyroides	3001	35	30	0.17	1.15	0.11	0.57
Other categories							
S. capitata	2013	20	20	0.13	1.28	0.10	0.68
S. capitata	1943	35	30	0.15	1.19	0.13	0.86
S. macrocephala	1582	20	20	0.10	0.93	0.08	0.50
Zornia sp.	728	11	10	0.12	1.16	0.08	0.43
Zornia sp.	9199	20	20	0.15	1.11	0.09	0.72
Zornia sp.	9286	20	20	0.18	1.28	0.09	0.60
Zornia sp.	9600	20	20	0.14	1.00	0.09	0.68
C. brasilianum	5055	20	20	0.14	0.12	0.09	0.57
Aeschynomene histrix	9690	11	10	0.19	1.25	0.07	0.47

*Critical levels associated with about 80% of maximum yields obtained at eight weeks of plant growth.

Table 5. External and internal critical levels of P and K of four tropical pasture grasses at the establishment period for the isohyperthermic well-drained savanna.

Species	Ecotype	External critical level*		Internal critical level*			
				Rainy season		Dry season	
		P	K	P	K	P	K
		(kg/ha^{-1})		(%)			
Andropogon gayanus	621	20	20	0.10	0.95	0.04	0.53
Brachiaria humidicola	679	10	10	0.08	0.74	0.05	0.39
Brachiaria decumbens	606	20	20	0.08	0.83	0.05	0.38
Brachiaria brizantha	665	20	20	0.09	0.82	0.05	0.44

*Critical levels associated with about 80% of maximum yield obtained at eight weeks of plant growth.

Effects of micronutrient applications on pasture establishment

A field experiment was set up in Carimagua to determine the external and internal micronutrient requirements for promising pasture grasses and legumes as well as to determine the residual effects of micronurient applications. Zinc, cooper, boron, manganese and molybdenum (only in legumes) were the micronutrients studied. The grasses tested were Andropogon gayanus 621, Brachiaria decumbens 606, Brachiaria humidicola 679 and, Brachiaria brizantha 665 and the legumes were Stylosanthes capitata 1019, Pueraria phaseoloides 9900, Desmodium ovalifolium 350 and Zornia latifolia 728.

The results for the establishment period are presented in Tables 6 (legumes) and 7 (grasses). After a year of establishment none of the pasture grasses or legumes showed significant responses to the micronutrient applications. Under native savanna conditions, soil analyses of the upper 20 cm provided the information that the levels of available soil zinc and cooper were higher than those considered as deficient for acid soils (0.5 ppm Zn, 0.2 ppm Cu). After a year, the availability of these two micronutrients was even higher with an increment of fertilizer levels.

In the plant tissue, marked differences in zinc concentrations among species as well as between grasses and legumes were observed. During the rainy season and without zinc applications, the pasture grasses with exception of Brachiaria humidicola 697, showed zinc tissue concentrations near or below the level required for the animal. Similar results were obtained with copper. These results indicate that although the dry matter production was not affected when zinc and copper were not applied, the concentrations of these micronutrients in the plant tissue would not fulfill the animal's requirements. Therefore, it would be important to determine whether mineral supplementation provides a more economic source of these micronutrients of whether direct application to the soil is more efficient, since both zinc and copper fertilization produce long residual effects.

Pasture legumes without zinc and copper applications to the soil all fulfilled the minimal requirements for the animal. The plant tissue concentrations showed a differential increment by species, especially Stylosanthes capitata 1019 with zinc and Pueraria phaseoloides 9900 with copper.

In the case of boron the tendency was to increase only with the first level of application (0.5 kg B/ha). In both grasses and legumes the boron concentrations in the plant tissue were higher than that considered as a deficiency level (20 ppm B for legumes and 4 ppm B for grasses). Manganese applications had no effects either on grasses or on legumes. Similar results were found with molybdenum in the case of legumes.

Table 6. Effects of micronutrient applications on the dry matter production and micronutrient contents in plant tissue[1] and soil[1] during the establishment period of four tropical pasture legumes in an Oxisol of Carimagua, Colombia.

Micronutrient		D. ovalifolium 350			P. phaseoloides 9900			S. capitata 1019			Z. latifolia		
Applied	Soil available	DM[2]	Tissue content		DM	Tissue content		DM	Tissue content		DM	Tissue content	
			Rainy	Dry		Rainy	Dry		Rainy	Dry		Rainy	Dry
kg/ha^{-1}	ppm	$ton/ha^{-1}/yr^{-1}$	---- ppm ----		$ton/ha^{-1}/yr^{-1}$	----- ppm ----		$ton/ha^{-1}/yr^{-1}$	----- ppm -----		$ton/ha^{-1}/yr^{-1}$	----- ppm ----	
Zinc													
0	1.7	6.0	20	37	4.8	71	41	4.4	82	91	3.6	70	64
2	1.5	5.1	23	30	5.0	45	35	5.6	77	66	3.0	71	81
4	2.0	6.4	22	33	5.2	60	39	4.9	102	111	2.9	73	96
8	2.2	5.2	32	38	5.0	73	45	4.4	109	72	3.2	72	83
Copper													
0	0.7	6.1	9	12	5.1	17	16	5.2	8	10	3.0	10	13
1	0.7	5.9	9	10	4.7	19	15	5.3	9	10	3.0	10	13
2	0.9	5.7	9	10	5.0	17	16	4.8	8	10	3.0	9	12
4	0.9	6.0	9	11	5.1	16	16	5.3	8	11	3.3	9	12
Boron													
0	0.3	5.4	30	22	4.9	38	27	5.1	24	23	3.5	34	31
0.5	0.4	5.7	28	22	4.9	39	34	5.4	21	23	3.5	25	29
1.0	0.4	5.9	28	25	5.4	41	39	5.3	22	21	3.2	33	32
2.0	0.5	6.1	30	26	5.0	37	36	5.7	26	23	3.3	28	28
Manganese													
0	1.9	5.6	353	184	5.0	247	168	5.4	209	160	3.1	121	173
0.25	1.9	5.8	312	206	4.9	202	218	5.1	169	209	3.6	102	165
0.50	1.7	5.2	288	220	4.9	247	338	5.6	176	288	2.7	93	209
1.00	2.0	6.2	397	187	5.2	230	184	5.1	183	142	3.0	128	193
Molybdenum			-----% N-----			-----% N-----			-----% N-----			-----% N-----	
0		6.1	1.7	1.7	5.2	2.8	2.9	5.4	2.4	2.4	3.4	2.6	2.8
0.05		5.2	1.7	1.7	5.4	2.7	3.0	5.5	2.5	2.4	2.9	2.6	2.8
0.10		6.0	1.7	1.5	5.1	2.7	2.9	5.1	2.3	2.5	3.3	2.7	2.8
0.20		6.0	1.7	1.8	5.1	2.7	3.1	5.0	2.4	2.4	3.0	2.6	3.0

[1] Deficiency level:

	Legume plant tissue	Acid soil
Zn	20 ppm (Jones and Clay, 1976)	0.5 ppm (Cox and Kamprath, 1972)
Cu	4 ppm (Andrew and Thorne, 1962)	0.2 ppm " "
B	20 ppm (Jones, 1972)	0.3 ppm " "
Mn	20 ppm (Jones, 1972)	1.0 ppm " "
Mo	- -	- - -

[2] DM = Dry matter production

Table 7. Effects of micronutrient applications on the dry matter production and micronutrient contents in plant tissue[1] and soil[1] during the establishment period of four tropical pasture grasses in an Oxisol of Carimagua, Colombia.

Micronutrient		A. gayanus 621			B. humidicola 679			B. decumbens 606			B. brizantha 679		
Applied	Soil available	DM[2]	Tissue content		DM	Tissue content		DM	Tissue content		DM	Tissue content	
			Rainy	Dry		Rainy	Dry		Rainy	Dry		Rainy	Dry
kg/ha^{-1}	ppm	ton/ ha^{-1}/yr^{-1}	ppm		ton/ ha^{-1}/yr^{-1}	ppm		ton/ ha^{-1}/yr^{-1}	ppm		ton ha^{-1}/yr^{-1}	ppm	
	Zinc												
0	0.7	8.8	14	17	6.9	19	18	7.3	13	13	6.9	15	28
2	2.7	10.1	18	17	8.2	32	27	8.9	17	25	8.7	17	26
4	2.0	8.0	28	37	6.9	24	34	7.8	20	29	7.1	18	33
8	2.2	8.1	40	52	8.1	37	47	7.8	19	35	8.6	24	44
	Copper												
0	0.4	8.6	5	9	8.2	4	6	8.4	4	5	8.1	4	6
1	0.5	8.4	5	8	7.6	4	6	6.5	4	5	7.7	5	6
2	0.9	8.9	4	8	8.3	4	6	7.7	4	6	7.0	4	6
4	1.0	9.3	5	8	6.8	4	6	7.6	4	6	7.2	4	7
	Boron												
0	0.3	8.0	7	6	7.3	4	6	7.8	5	5	8.4	6	10
0.5	0.3	7.4	10	7	7.7	6	5	8.4	7	7	8.0	7	6
1.0	0.4	8.4	8	7	7.1	5	6	8.1	6	5	8.3	6	5
2.0	0.4	8.1	8	7	7.3	6	6	8.5	7	6	7.5	7	6
	Manganese												
0	3.5	9.6	109	146	8.3	126	118	8.9	70	80	8.7	80	109
0.25	3.3	8.9	151	130	8.5	183	91	8.5	104	115	7.9	103	88
0.50	3.1	9.3	83	120	7.9	99	71	8.0	86	76	7.1	74	89
1.00	4.7	7.2	151	128	7.3	222	101	7.7	94	85	7.3	86	111

[1] Deficiency level:

	Grass plant tissue	Acid soil
Zn	20 ppm (Jones, 1972)	0.5 ppm (Cox and Kamprath, 1972)
Cu	5 ppm " "	0.2 ppm " " "
B	4 ppm " "	0.3 ppm " " "
Mn	20 ppm " "	1.0 ppm " " "

[2] DM = dry matter production

From the results obtained, the recommendation for the establishment of tropical pasture grasses and legumes in Carimagua is that there is no positive effect of micronutrient applications on the forage availability. The available amount of B and Mn under native savanna is adequate for pasture establishment. Zinc and copper applications to this soil improve the zinc and copper contents in grasses, which is important since without them the levels are below those required by the animal. Hence, maintenance fertilization with zinc and copper is important in pure stands of grasses. The presence and consumption of tropical legumes in the pasture, in addition to the quantity and quality of the protein, may supplement to a great extent the zinc and copper deficiencies in the grasses. This implies that reduction if not elimination of mineral supplementation of copper and zinc may be possible. However, this figure may change completely for tropical pastures growing in sandy soils.

Effects of sulfur fertilization on tropical pastures

Under native savanna conditions with well-drained acid soils, the available soil sulfur is often deficient, and as the soil texture becomes sandier and the organic matter decreases this deficiency is accentuated. Under Carimagua conditions the available sulfur (calcium phosphate extraction) was about 4 ppm S, a value considered as inadequate for pasture establishment.

Tables 8 and 9 show the data from a field experiment established in Carimagua to study the effect of sulfur fertilization on the response of several tropical pasture grasses and legumes. The dry matter production of both shows no significant response at any S rate. In addition, the tissue S concentrations without S application were similar to the critical concentrations determined under greenhouse conditions (Tropical Pastures Program, Annual Report, 1980). The lack of response to S fertilization by the pasture legumes and grasses was attributed to the considerable increment in availability of the native soil sulfur after conventional land preparation. This increment was about five times the initial S value found under native savanna, which was enough to support 90% of the maximum dry matter yields in both grasses and legumes. An explanation for this appears to be that the Carimagua Oxisol has a relatively high organic matter content (about 4%). With the conventional land preparation for pasture establishment, organic sulfur becomes available for the plants during the establishment period. Table 10 shows the sulfur contents and forms in the top layer of the Carimagua Oxisol under native savanna and under pasture one year after establishment. Total sulfur and mainly organic sulfur were less under the established pasture than under the native savanna. As a consequence of this, the available sulfur increased almost four times when no sulfur was applied. This has an important implication for pasture establishment on this type of soil since one can avoid S fertilization when using conventional land preparation and therefore reduce input costs.

Table 8. Effects of sulfur fertilization on the dry matter production and sulfur contents in the plant tissue and soil during the establishment period of four tropical pasture legumes in an Oxisol of Carimagua, Colombia.

S treatment		D. ovalifolium 350			P. phaseoloides 9900			S. capitata 1315			Z. latifolia 728		
Applied	Available soil sulfur	DM	S in the tissue Rainy	S in the tissue Dry	DM	S in the tissue Rainy	S in the tissue Dry	DM	S in the tissue Rainy	S in the tissue Dry	DM	S in the tissue Rainy	S in the tissue Dry
kg/ha^{-1}	ppm	$ton/ha^{-1}/yr^{-1}$	(%)		$ton/ha^{-1}/yr^{-1}$	(%)		$ton/ha^{-1}/yr^{-1}$	(%)		$ton/ha^{-1}/yr^{-1}$	(%)	
0	22*	5.3	0.12	0.14	4.7	0.17	0.19	7.8	0.12	0.15	3.2	0.17	0.17
5	24	5.9	0.13	0.12	4.9	0.18	0.17	8.4	0.13	0.13	2.9	0.18	0.17
10	24	5.6	0.13	0.14	5.0	0.20	0.17	8.6	0.13	0.16	3.2	0.20	0.15
15	29	5.3	0.13	0.13	4.6	0.20	0.19	7.3	0.14	0.16	2.7	0.22	0.16
20	27	5.5	0.14	0.15	4.7	0.19	0.22	7.1	0.16	0.18	2.8	0.21	0.17
30	27	5.7	0.15	0.15	4.7	0.20	0.19	7.8	0.16	0.18	3.1	0.20	0.18

*Before conventional land preparation: 4 ppm-available soil sulfur.

Table 9. Effects of sulfur fertilization on the dry matter production and sulfur contents in the plant tissue and soil during the establishment period of four tropical pasture grasses in an Oxisol of Carimagua, Colombia.

S treatment		A. gayanus 621			B. decumbens 606			B. humidicola 679			B. brizantha 665		
Applied	Available soil sulfur	DM	S in the tissue Rainy	S in the tissue Dry	DM	S in the tissue Rainy	S in the tissue Dry	DM	S in the tissue Rainy	S in the tissue Dry	DM	S in the tissue Rainy	S in the tissue Dry
kg/ha^{-1}	ppm	$ton/ha^{-1}/yr^{-1}$	(%)		$ton/ha^{-1}/yr^{-1}$	(%)		$ton/ha^{-1}/yr^{-1}$	(%)		$ton/ha^{-1}/yr^{-1}$	(%)	
0	25*	8.9	0.12	0.10	8.5	0.12	0.13	7.2	0.11	0.12	8.5	0.12	0.12
5	24	9.0	0.13	0.08	9.3	0.14	0.13	7.1	0.12	0.12	8.4	0.15	0.13
10	24	10.0	0.12	0.09	9.1	0.15	0.15	7.7	0.14	0.13	8.1	0.16	0.15
15	24	8.6	0.13	0.09	7.8	0.15	0.13	7.5	0.14	0.13	8.1	0.20	0.17
20	24	7.6	0.14	0.08	9.2	0.16	0.14	6.7	0.16	0.15	7.7	0.17	0.15
30	27	8.3	0.13	0.09	8.7	0.18	0.16	7.4	0.14	0.15	7.7	0.20	0.16

*Before conventional land preparation: 4 ppm available soil sulfur.

Table 10. Sulfur fractions in the Carimagua Oxisol under native savanna vegetation and under tropical pastures after one-year established with three sulfur treatments.

Sulfur fraction	Native savanna	One-year pasture established		
		0 kg S/ha	15 kg S/ha	30 kg S/ha
		ppm		
Total-S	420	280	300	295
Organic-S	231	101	113	105
Inorganic-S	189	179	187	190
Available-S*	6	23	26	27

*Calcium phosphate extraction.

However, the sulfur requirements for maintenance fertilization of pastures under grazing may be completely different. It appears that after a certain time the organic matter returns to a stable state, and there is a net sulfur immobilization. Since a pasture does not receive an annual land preparation, the available soil sulfur seems to return to the status under native savanna. This was the case of a Desmodium ovalifolium pasture established in 1978, which received in addition to a basal fertilization about 20 kg S/ha during establishment. In August 1980 it received four maintenance fertilization treatments including sulfur. The soil nutrient dynamics as a function of these four treatments is shown in Figure 2. Results regarding forage availability, protein quality, tannin content and preferential intake by the animal are presented and discussed in the Tropical Pastures Quality Section.

The available P, with exception of Treatment 4, increased five months after phosphorus was applied, which may be an effect of the end of the rainy season. A similar response was observed with the exchangeable calcium, but the increase occurred at the beginning of the rainy season and in all the treatments, except the control which did not receive any maintenance fertilizer. Treatment 4 received Mg and S in addition to P and Ca. The available P, S, and Mg but not exchangeable Ca became available in the soil as soon as the fertilizers were applied. The sulfur and magnesium levels can be acredited to the fertilizer applied, but the higher availability of P as compared with treatments 2 and 3 may be due to a better nutritional balance in the soil caused by an almost complete fertilization which might have stimulated chemical and biological activity of the soil.

The main conclusion from these results is that the only significant response of this pasture was obtained with the maintenance fertilization applied in Treatment 4. Later on this experiment was modified to test the hypothesis that sulfur is the key element in modifying the soil fertility dynamics as well as the changes in forage availability, protein quality, tannin content and intake of Desmodium ovalifolium by the animal. Preliminary evaluations are confirming the hypothesis.

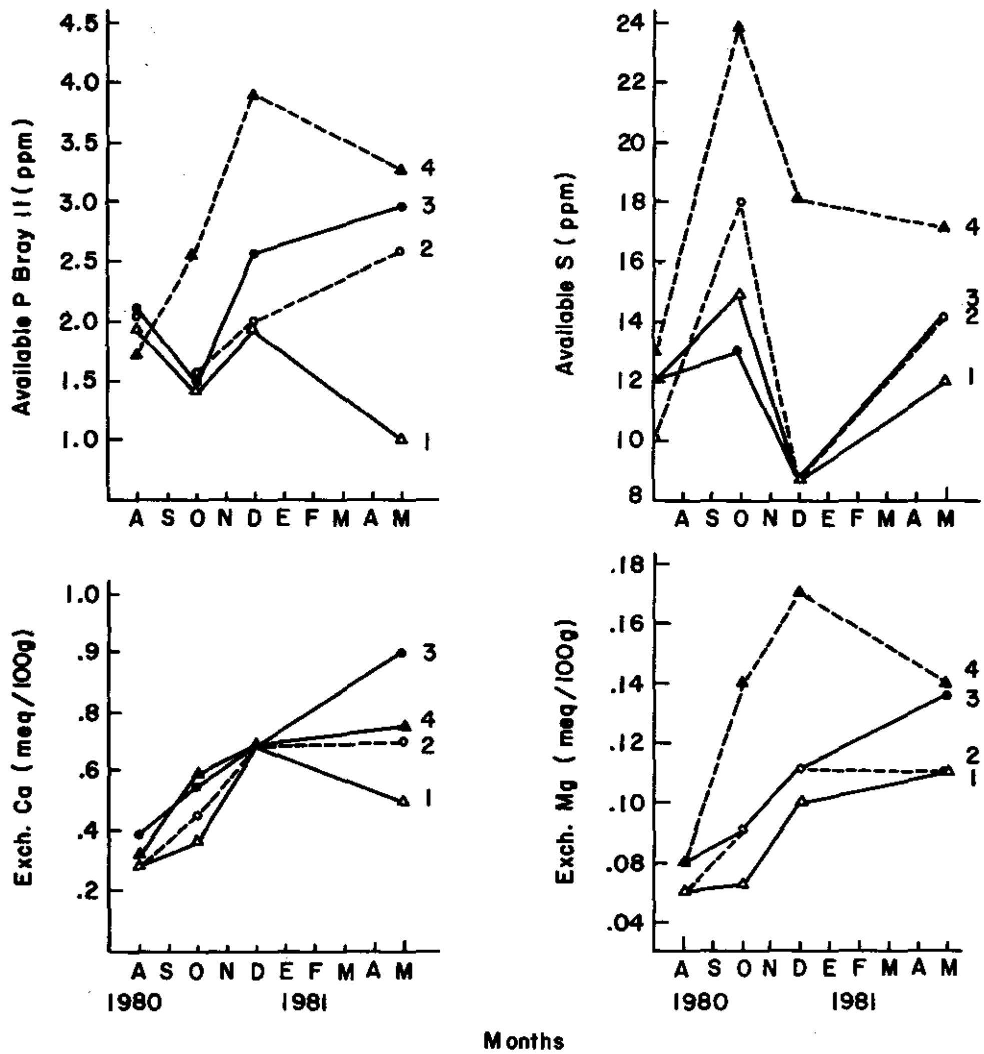

Figure 2. Soil nutrient dynamics as a function of four fertilizer treatments applied to a Desmodium ovalifolium 350 pasture under grazing at Carimagua (August 1980-May 1981). Treatments: 1 = control; 2 = P + Ca; 3 = P + Ca + K; 4 = P + Ca + K + Mg + S.

Nutrient Recycling in Pastures

In pasture production systems, there is a natural recycling mechanism in which the three main components, the soil, plant, and animal, represent the nutrient pools and determine to a great extent the pasture productivity and the yield of animal product. Thus the magnitude of nutrient recycling in pastures needs quantification in order to define maintenance fertilizer recommendations.

Legume residues as a nitrogen pool

The contribution of a legume to tropical pastures is both as high-protein feed and as plant residues which are sources of nutrients for recycling to the grass-legume components. A major pathway of nitrogen cycling is through legume leaf litter. Thus two experiments were established to evaluate the contribution of this litter to tropical pastures.

For the first experiment, legume leaf materials from two pasture legumes (Pueraria phaseoloides 9900 and Desmodium ovalifolium 350) were incubated in the presence of a growing grass (Brachiaria humidicola 679). The grass was harvested at 11, 18, and 24 weeks and N recovery was calculated. Two soils plus one lime treatment were employed: Soil from a Desmodium ovalifolium 350 pasture and the same soil plus lime (Al saturation below 40%); and a soil from an Andropogon gayanus 621 pasture. The results are shown in Figure 3. At the first harvest the N in the grass leaves apparently represented the easily mineralizable-N (soluble N). The soil from the Andropogon gayanus pasture had a lower Al saturation percentage (74% Al Sat.) than the soil from the D. ovalifolium pasture (82% Al Sat.) and this was reflected in higher net nitrogen uptake by B. humidicola. The second harvest probably represented mineralization of some of the tannin-bound protein. Apparently the soil from the A. gayanus pasture did not have a high population of the micro-organisms that could mineralize this type of protein as there was net immobilization of N, especially with the D. ovalifolium dead leaf material (moderately low in both N and tannin). Cumulative net nitrogen recovery data show that the soil from the A. gayanus pasture was able to mineralize more of the nitrogen from the dead P. phaseoloides leaf material than the other soils and this may be related to its lower Al saturation percentage. Liming the soil from the D. ovalifolium pasture apparently stimulated the microbial population responsible for mineralizing tannin-bound protein.

All the soils mineralized N in a similar way and in high quantities from the green leaf material of P. phaseoloides (high N, low tannin). However, only limed soil from the D. ovalifolium pasture was able to mineralize substantial quantities of nitrogen from the high tannin material, but for some reason this soil was much less able to mineralize the low-tannin dead P. phaseoloides leaf material than the other soils at 18 and 24 weeks, respectively.

For the second experiment, four pastures under grazing were sampled to determine the amounts and nitrogen concentrations of the litter; the soils were also sampled at different depths in order to observe the variations in nitrate and ammonia levels in the four pastures.

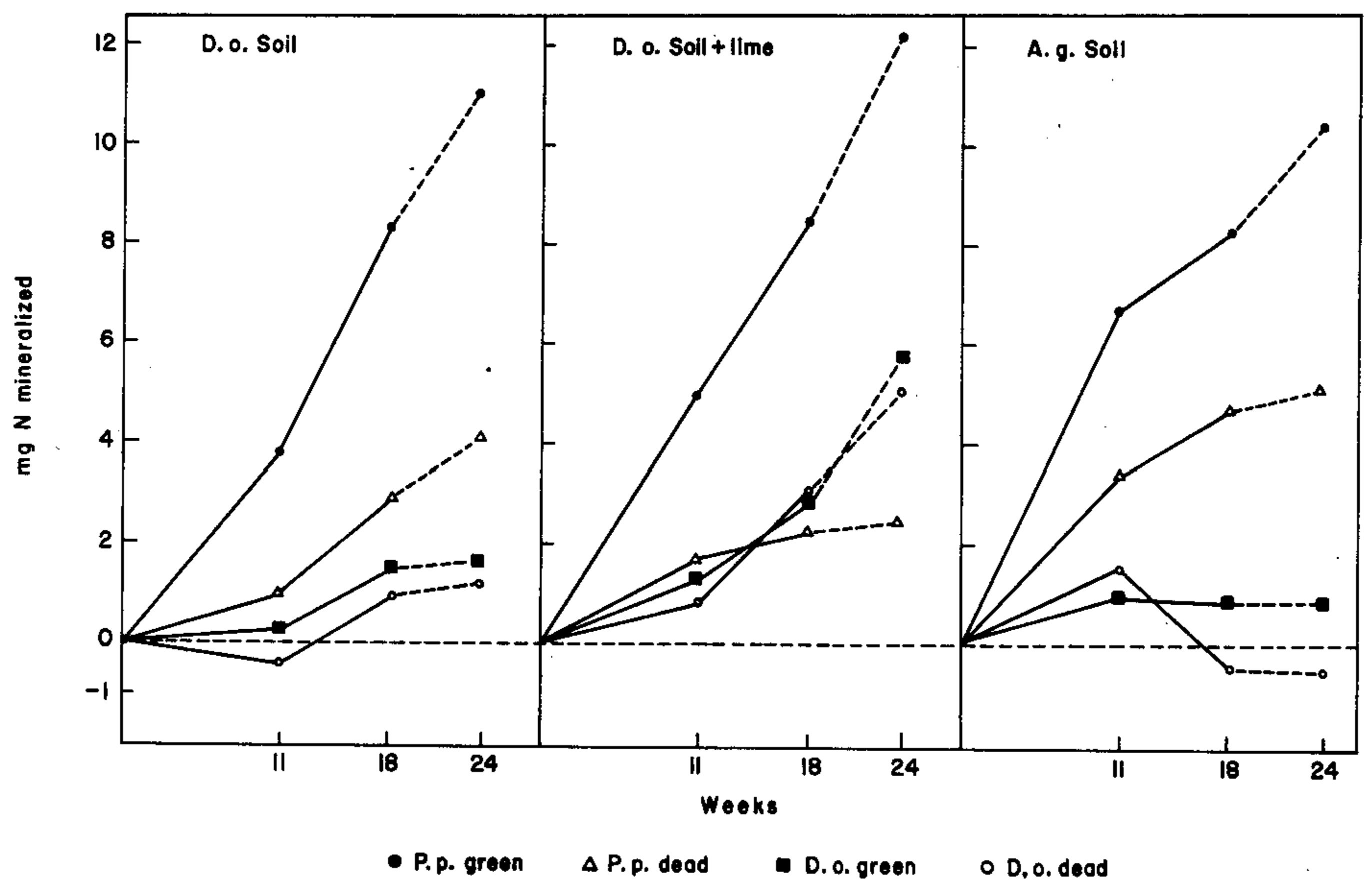

Figure 3. Nitrogen mineralized from green and dead foliar material of two forage legumes (Pp = Pueraria phaseoloides 9900, Do = Desmodium ovalifolium 350) as a function of time in the Carimagua Oxisol with three different backgrounds.

Figure 4 shows the amount of N from the litter of the four pastures as a function of time (March-August, 1981). In general, the tendency was a decrease in the amount of N as the rains increased. This reduction of N was mainly related to reduced amount of litter and not to a decrease in the N content in the litter due to the growing season in which there is a higher amount of green biomass and lesser defoliation than in the dry season. The litter present at the end of the dry season was high and correlated with the concentration of N-NO_3^- in the soil. The pasture Andropogon gayanus 621/ Pueraria phaseoloides 9900 (A.g/P.p) had high litter production (4.5 t/ha) and was the litter with the highest N content (1.8% N). The litter from the Brachiaria decumbens 606/Pueraria phaseoloides 9900 (B.d/P.p) pasture also had a relatively high N content (1.65 % N), but the amount of litter was less (2.2 t/ha). The pasture Andropogon gayanus 621/ Desmodium ovalifolium 350 (A.g/D.o) had the higher litter production (5.9 t/ha) but the N content was only 0.91%. Finally the pasture Brachiaria humidicola 679/ Desmodium ovalifolium 350 (B.h./D.o) had the least amount both of litter and N content (2.6 t/ha and 0.68% N). Continuation of the sampling for a full year will be essential to characterize the N contribution of the litter material fully.

Figures 5 and 6 show the changes in the nitrate and ammonia levels with soil depth at two sampling dates (May 5 and August 4). At the first soil sampling date the nitrate levels tended to increase with the soil depth with exception for the A.g/P.p pasture soil which had higher levels of nitrate at all depths. For the second set sampling date, nitrate levels tended to decrease and mainly for the A.g/P.p soil but only on the 20 cm topsoil. Ammonium levels decreased sharply with soil depth in the four pastures at the two sampling dates. Apparently the improved grasses are not fully exploiting the 100 cm depth. However, the improved grasses are utilizing this nitrate much more than the native savanna, where there is sometimes abundant "fossil" nitrate (up to 16 ppm NO_3^--N at 100 cm depth and up to 6.5 ppm NO_3^--N at 180-190 cm depth). This has implications for the establishment of legumes associated with improved grasses, because legumes would not be able to compete with these grasses as long as they had access to the "fossil" nitrate. Once the nitrate is depleted the legumes would be more able to compete with the grass.

Animal excreta as nutrient pools

Return of nutrients to the soil via excreta in pasture production systems is an important natural recycling mechanism but depends considerably on stocking rate, grazing management, and other factors. Preliminary data are presented in Figure 7 which shows the changes in the top 20 cm of an Ultisol from Quilichao, Colombia, caused by dung deposition in a Brachiaria decumbens pasture under rotational grazing every 15 days.

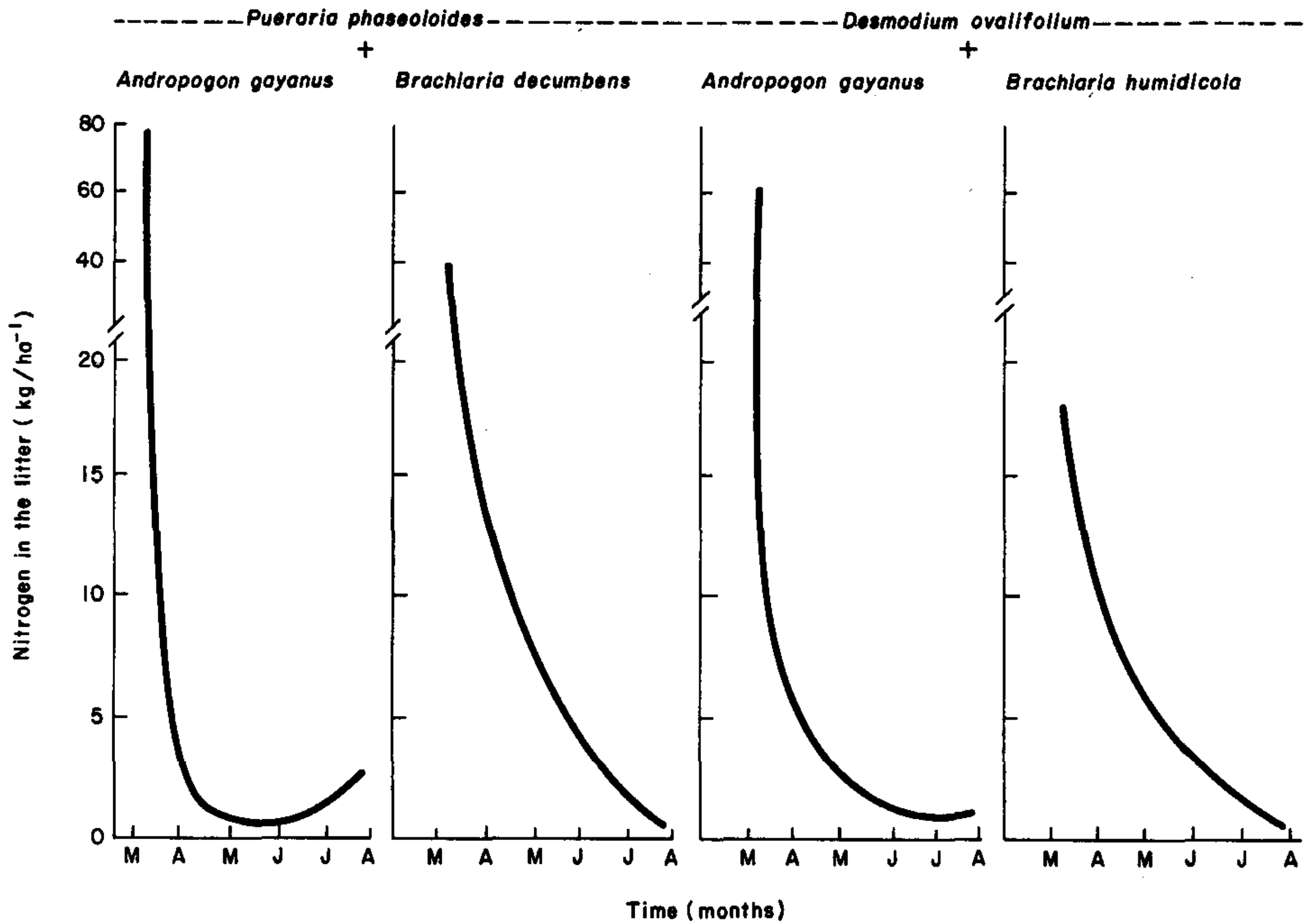

Figure 4. Total nitrogen in the litter as function of time in four pasture mixtures under grazing at Carimagua.

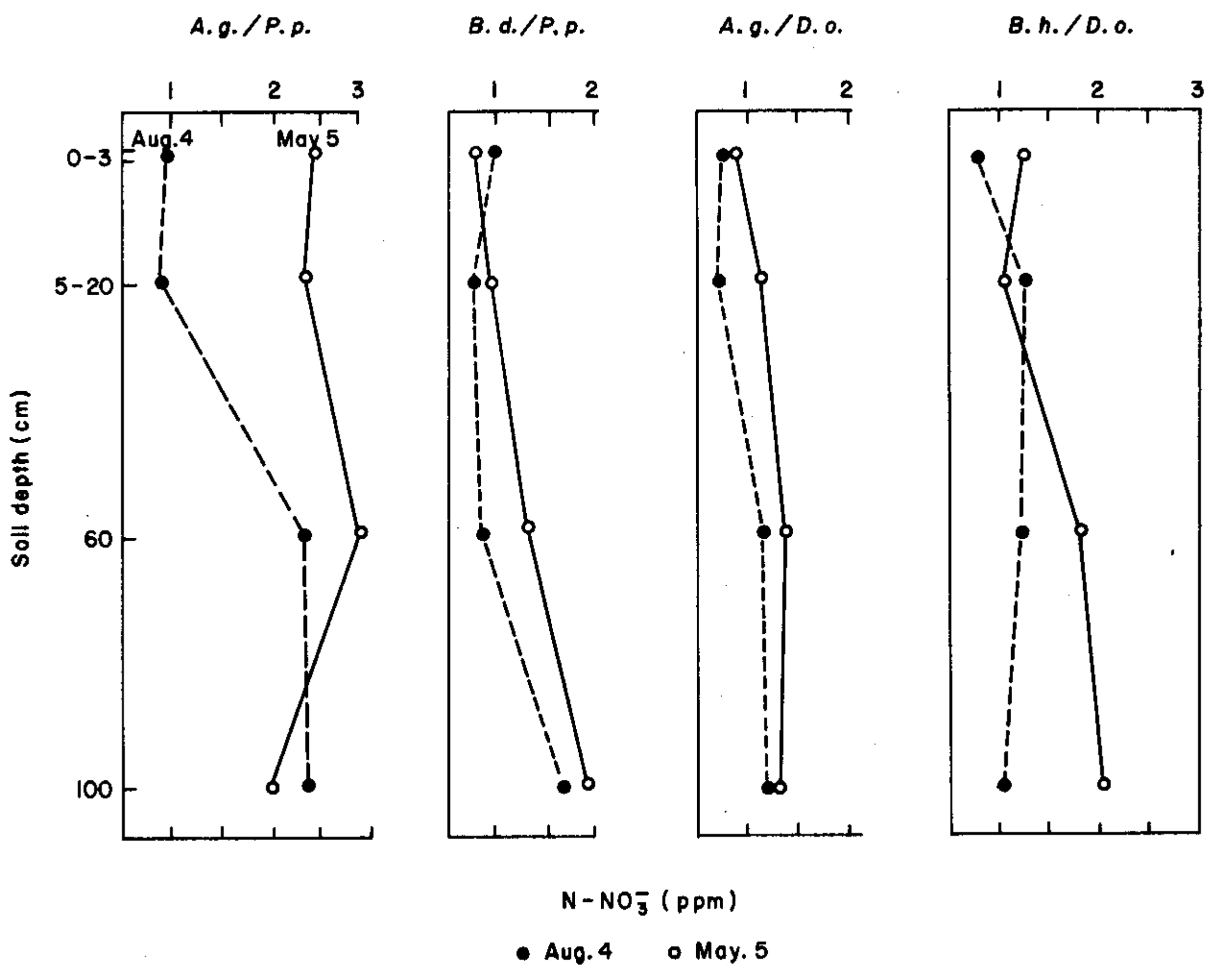

Figure 5. Nitrate distribution with the soil depth in four mixture pastures under grazing at Carimagua.

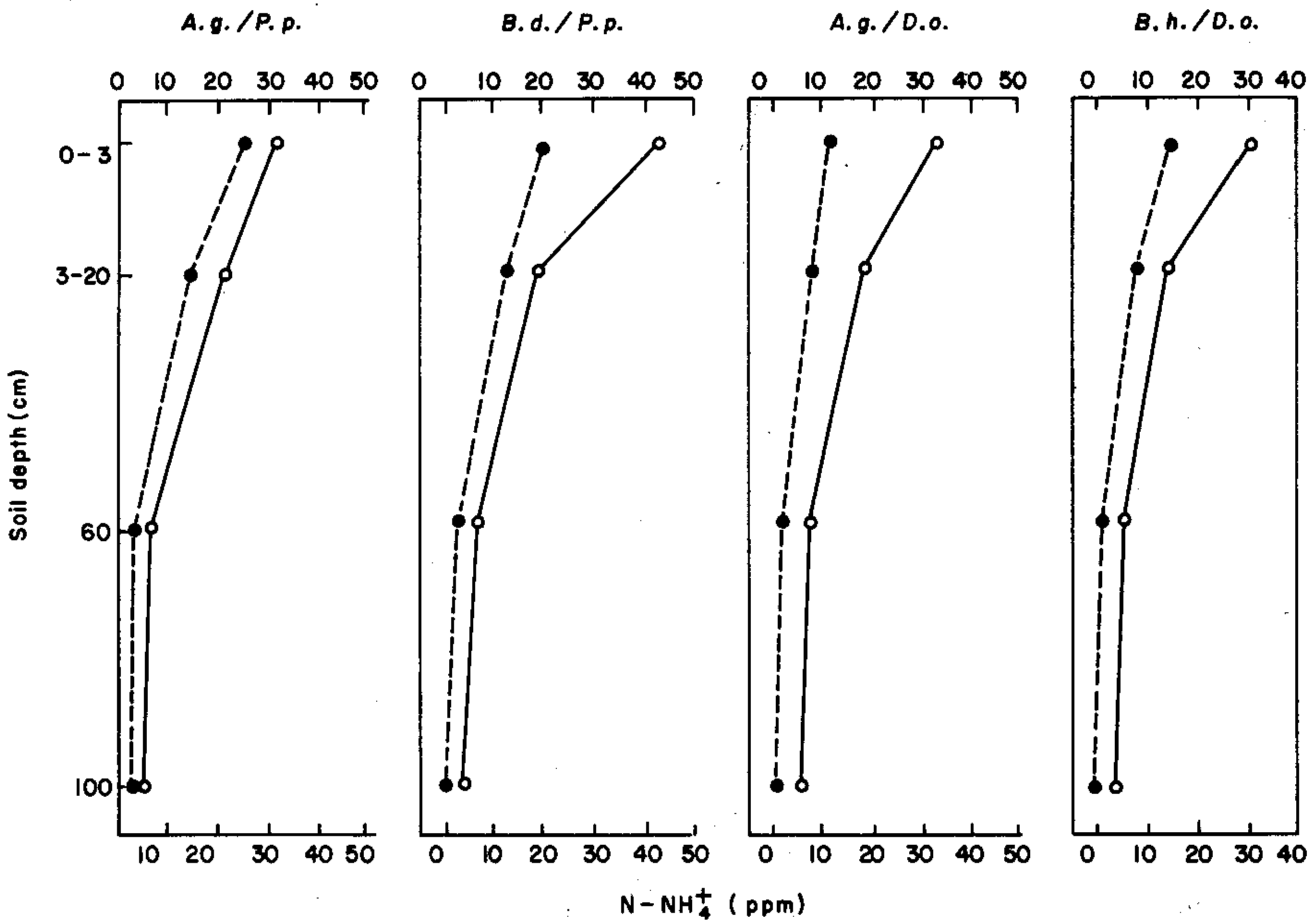

Figure 6. Ammonia distribution with the soil depth in four mixture pastures under grazing at Carimagua.

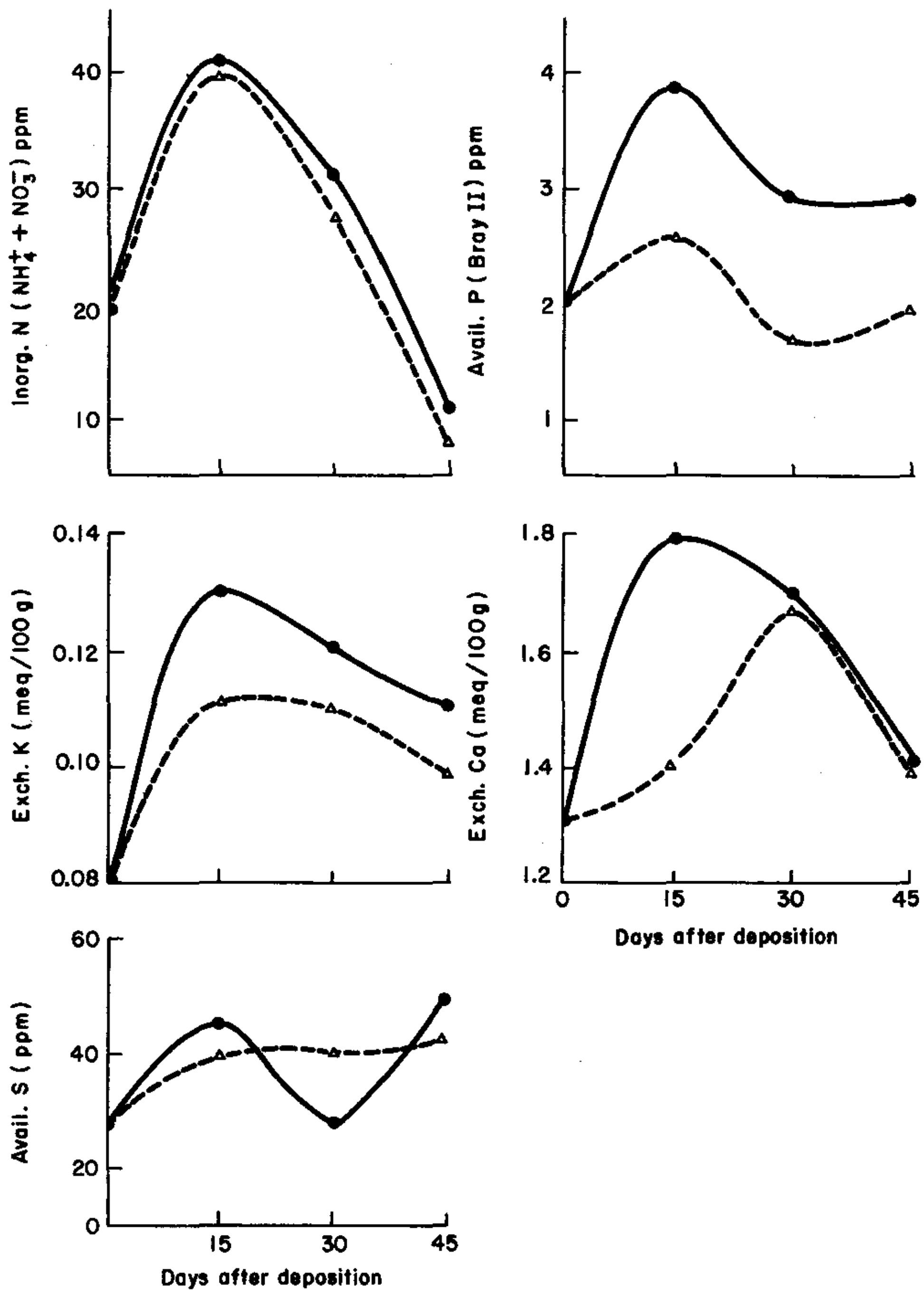

Figure 7. Nutrient recycling on the top cm of an Ultisol from Quilichao, Colombia, as a result of dung deposition by cattle grazing a *Brachiaria decumbens* pasture. Distance from dung (cm): ● 20; △ 100.

The results show that the topsoil inorganic nitrogen content doubled at the first 15 days within a 1 m radius from the excreta and declined sharply afterward. Available phosphorus, potassium, calcium and sulfur also showed a similar increase but with less effects at 1 m distance, except for sulfur, and followed by a more gradual decrease with time than nitrogen. The effects of the urine depositions (Table 11) indicate a sharper increase in potassium and sulfur than with feces, but a smaller increase in the availability of nitrogen, phosphorus and calcium. The overall effects of these additions were favorably reflected in increases of all five elements in plant tissue concentrations within the first 30 days after excreta deposition.

Table 11. Nutrient recycling on the top cm of an Ultisol from Quilichao, Colombia, as a result of urine deposition by cattle grazing a Brachiaria decumbens pasture.

Time after urine deposition (days)	Distance from urine deposition (cm)	Inorganic-N ($NH_4^+ + NO_3^-$) ppm	Available P (Bray II) ppm	Available S ppm	Exch. K meq/100g	Exch. Ca meq/100g
0	20	20	2.5	25	0.09	1.20
	100	21	3.0	26	0.10	1.24
15	20	65	2.0	36	0.19	1.39
	100	35	2.3	33	0.11	1.17
30	20	28	1.8	37	0.20	1.61
	100	27	1.8	38	0.11	1.61
45	20	13	2.1	42	0.22	1.59
	100	9	2.2	40	0.11	1.56