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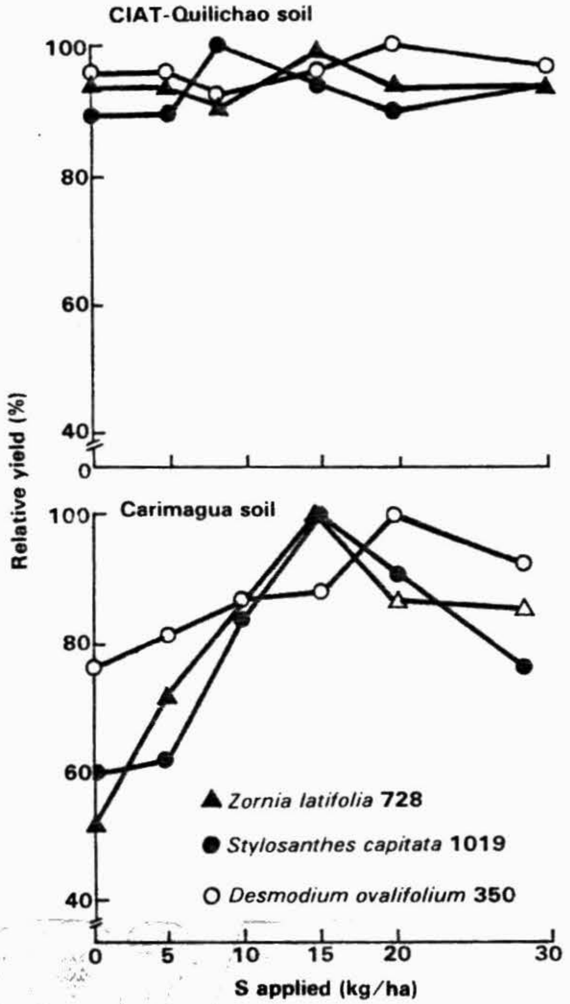

Figure 33. Relative yields of three tropical forage legumes grown under greenhouse conditions in soils from CIAT-Quilichao and Carimagua in response to fertilization with sulphur.

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

S forms	S contents (ppm) CIAT-Quilichao	S contents (ppm) 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)

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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 production plot which was plowed and disked shortly before planting to *Stylosanthes capitata* and *Zornia latifolia*. The rows that happened to fall in the wheel tracks of the tractor germinated and developed much better than the non-compacted rows. Seed bed firming appears to be especially important when the land is plowed shortly before planting, due to deep loosening and insufficient time for rains to settle the soil.

As more experience has been gained with low density planting, the importance of mother plants becomes evident, especially for planting in native savanna with only partial vegetation control. The original plants should be adequately protected from competing vegetation and insects and supplied with sufficient fertilizer so that strong plants with deep, vigorous root systems develop before being subjected to competition from other introduced or native species. Once established, well-adapted species are very persistent and some are aggressive displacers of native savanna species. The cost of fertilizer and insect control is so low, due to the reduced number of hills/ha, that optimum conditions for seedlings can be afforded to assure the development of a vigorous population.

Reducing Pasture Establishment Costs

Besides using species tolerant to acid soil conditions, pasture establishment costs can be further reduced with the low density seeding method reported in CIAT Annual Reports of 1977 and 1978. This method requires much less seed for the establishment of strong and prolific seeders such as *Andropogon gayanus* and for stoloniferous or trailing species such as *Brachiaria humidicola*, *Desmodium ovalifolium* and *Pueraria phaseoloides*. Less labor is required as fewer hills are planted and fertilized. This is especially important for vegetatively propagated species since the tasks of harvesting and transporting seeding material are greatly simplified. Little fertilizer is required initially; optimum rates for a planting density of 1000 hills/ha are 3 and 1 kg/ha of P_2O_5 and K_2O, respectively. The recommended fertilizer rate is applied only after establishment is assured. By associating legumes and grasses, fertilizer costs are further reduced since the legume/rhizobia symbiosis supplies N to the pasture.

By using well-adapted, aggressive species combined with row planting and band fertilization, weed control costs are kept to a minimum. At least one of the species in the association should be a strong competitor, capable of protecting the sward from weed invasion.

Other means of reducing establishment costs include the development of simple, mechanized planting systems. Commercial scale planting is now practiced in Carimagua with a drill-box type fertilizer-lime spreader equipped with a planting attachment. Seeding is done directly on the surface with no additional tillage required if the surface is sufficiently rough and protected from rain drop impact and erosion.

One of the major costs (after fertilizer) in pasture establishment is the tillage required for seed bed preparation. A trial was initiated last year in which four grasses and three legumes were planted in association each at 1000 hills/ha in all possible legume/grass combinations. Planting was done in 60 cm strips 3.16 m apart, prepared with the spring tines of a field cultivator to a depth of 12 cm. The native savanna in the area between strips received four control treaments: (a) burning, (b) chemical control, (c) one pass with the spring tines of the field cultivator, 30 cm apart and 12 cm deep, and (d) disking. Starter fertilizer was applied only in the hills; the intermediate areas were fertilized after stolon coverage was well advanced. There was strong species by vegetation control interaction. *Panicum maximum* was included in the trial, however, ant damage was so severe to the seedlings that no effective coverage was achieved, thus results for this species are not reported.

The two trailing legumes, *D. ovalifolium* and *P. phaseoloides*, were very effective in invading areas not colonized by grasses. Therefore, if a given treatment was not favorable to the spread of the associated grass, both legumes compensated and covered all of the area not covered by the grass. Both *D. ovalifolium* and *P. phaseoloides* covered the area completely. In the chemical control treatment, *B. humidicola* successfully colonized the entire area, thus the development of the legume was much more restricted. *B. decumbens* was less successful but its shortcomings were compensated by the legumes. *S. capitata* is quite persistent but not very aggressive and did not succeed in invading the native savanna. A summary of the observations is presented in Table 41.

This trial has demonstrated the feasibility of pasture establishment using appropriate legume/grass associations even with no tillage in the intermediate area and only low cost tine tillage in the seeded strip.

Table 41. Competitive ability of different forage species to invade and displace fertilized native savanna vegetation receiving four different treatments in Carimagua, 1979.

Treatment of native savanna	Species	Capable of: Invading	Capable of: Displacing
Burn only	*Desmodium ovalifolium*	Yes	Yes
	Pueraria phaseoloides	Yes	Yes
	Brachiaria radicans	Yes	No
Chemical control	*Desmodium ovalifolium*	Yes	Yes
	Pueraria phaseoloides	Yes	Yes
	Brachiaria humidicola	Yes	Yes
	Brachiaria radicans	Yes	No
Tine tillage to 12 cm	*Desmodium ovalifolium*	Yes	Yes
	Pueraria phaseoloides	Yes	Yes
	Brachiaria humidicola	Yes	Yes
	Brachiaria decumbens	Yes	Yes
	Andropogon gayanus	Yes	Yes
	Brachiaria radicans	Yes	No
Complete seedbed preparation	*Desmodium ovalifolium*	Yes	Yes
	Pueraria phaseoloides	Yes	Yes
	Brachiaria radicans	Yes	Yes
	Brachiaria decumbens	Yes	Yes
	Andropogon gayanus	Yes	Yes
	Brachiaria radicans	Yes	No

This reduction in tillage requirement reduces the total establishment cost. New trials established this year are exploring the possibility of even wider spacing between seeded strips since *B. humidicola* and *P. phaseoluides* were both capable of extending and invading more than the 3.16 m space between hills used in the current trial. It may be possible to gradually replace the Savanna with wide spacing (5-10 m) between rows of introduced species, while the grazing animal utilizes native savanna to complement the introduced species during the process of establishment which might take several years.

The risk of establishment is considerably reduced with low density seeding methods and also with the gradual replacement of the native savanna. The initial investment is low and the major investment in fertilizer is deferred until establishment is assured.

Additional low density trials were initiated in 1978. *A. gayanus* was planted at four densities ranging from 100 to 800 hills/ha. Table 42 shows that average plant counts obtained with complete seed bed preparation were high even at very low initial plant population. However, complete coverage was only obtained with 400 hills/ha.

Table 42. Effect of the initial plant population of *Andropogon gayanus* and three treatments to control native savanna on seedling count.

	Seedling counts (plants/m^2)		
	Control method applied		
No. hills/ha	Complete seedbed preparation	Sweeps	Chemical control
100	2.03	0.37	0.4
200	5.38	1.33	0.51
400	10.39	3.93	0.95
800	7.46	3.41	7.94

A. gayanus was planted with *D. ovalifolium, S. capitata* and *P. phaseoloides* in an experiment to study the effect of stage of savanna maturity, method of control, and P levels on establishment. The legumes were planted at 1000 hills/ha and the grass at 500 hills/ha in mature savanna and savanna recently burned, with and without stubble mulch sweep tillage to partially control the native vegetation and loosen the surface soil. The two trailing legumes *D. ovalifolium* and *P. phaseoloides* have provided essentially complete cover in all tillage and vegetation treatments at medium to high P levels. In the first year after planting, *A. gayanus* did not provide the expected stand due to late planting and limited seed production.

The low density seeding method has been used successfully for pasture establishment in wet areas along streams and lakes with species that are well adapted to inundation or saturated soil conditions. There is, however, much greater weed potential in these areas and, therefore, a higher seeding density is used (2500 hills/ha) to provide more rapid cover and minimize weed competition.

Spatial Distribution of Associated Species

The strip seeding of aggressive species like *B. decumbens* continues to show promise, both under rotational and continuous grazing. The combination *B. decumbens/P. phaseoloides* planted in alternate 2.5 m strips appears to be relatively stable after three years, but the frequent grazing favors the legume. Figure 34 shows that there was no effect of increasing the maintenance fertilizer beyond 0-15-15 kg/ha (N-P_2O_5-k_2O, respectively) on productivity and legume/grass balance under three grazing regimes. In a new trial in which the two species are planted in alternating triangles and strips as described in the CIAT 1978 Annual Report, *P. phaseoloides* has become strongly dominant under continuous grazing. This is in part due to a severe attack of spittlebug which limited *B. decumbens* production early during the rainy season. The legume has invaded over 50% of the area originally seeded to grass. The grass is not displaced and appears to be responding to improved N fertility in the area invaded by the legume. Each species initially occupied 50% of the total area.

A trial on date of seeding was established to study the effect of planting the legume prior to the grass in four different associations and three patterns of planting including broadcast, 1:1 and 2:2 grass/legume patterns in rows spaced 50 cm apart. In Figures 35 and 36, the effect of relative seeding time can be seen in three harvests. In the first harvest the effect is very large and it is surprising that it continues to be large especially in the case of *A. gayanus* and *P. maximum* even in the last harvest, a year after establishment. As shown in Figure 37, row planting was clearly superior to broadcast planting as measured by stand counts.

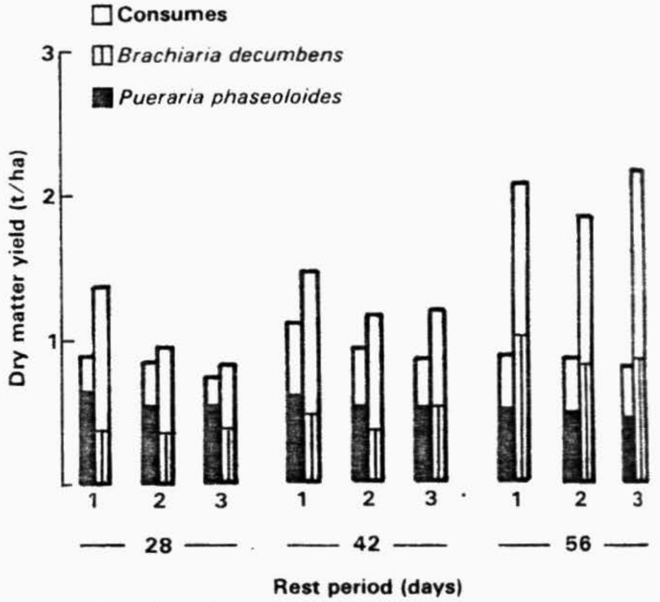

Figure 34. Effect of rest period duration and maintenance fertilizer application (1 = 0-15-15; 2 = 0-45-15; 3 = 0-45-45) on production and consumption of legume/grass associations, 1978.

In another trial on date of planting, eight species were seeded at monthly intervals through the rainy season, with two different types of seed bed preparations. Figures 38 and 39 show the effect of date of seeding and seed bed preparation on stand count after three weeks and six months. Both date of seeding and seed bed preparation appear to have large effects on some species whereas others are little affected by either. Successful seeding in Carimagua can be accomplished with most species during a long planting season in which rainfall is adequate and dependable.

Additional experience is reported on the extraction of moisture from the soil profile during the dry season. The dry season stress has naturally been viewed as moisture stress, but with the large amount of moisture

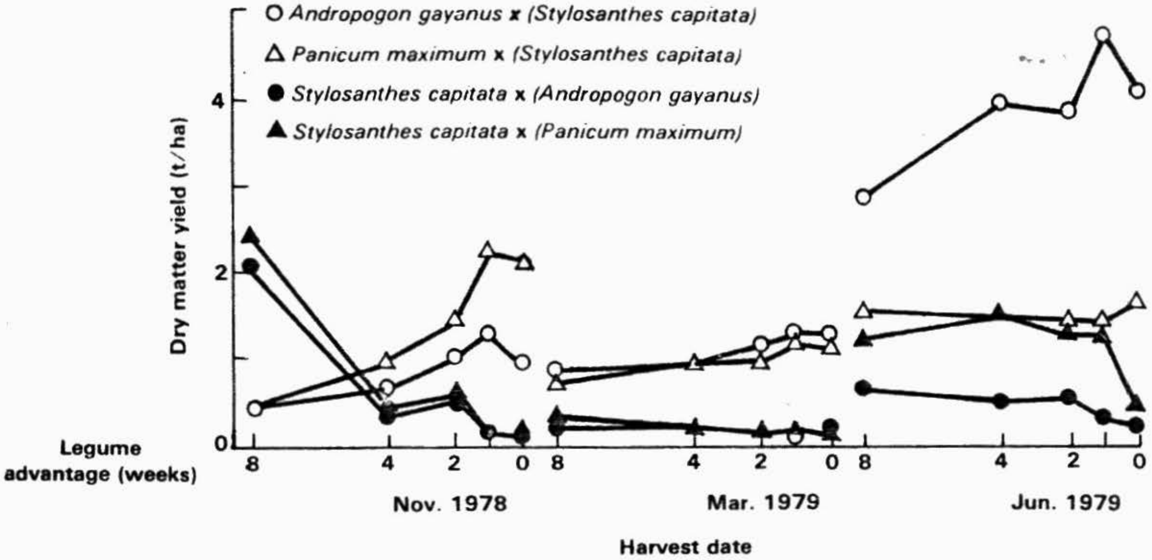

Figure 35. Effect of relative plating date of *Stylosanthes capitata* in mixture with *Andropogon gayanus* or *Panicum maximum* on forage production. Yield data are for first species listed; associated species are shown in parenthesis.

stored in the subsoil at Carimagua, it would appear that the stress is as much nutritional as it is moisture, due to the extremely low fertility of the subsoil. Most pasture species used in Carimagua are sufficiently tolerant to Al that subsoil acidity should not restrict root penetration. However, the lack of nutrients, especially Ca, may restrict penetration or at least reduce root proliferation in the subsoil, and the plant is subjected to a situation wherein there is no water where there is fertility and very little fertility where water is found. Ca would appear to be especially critical since it does not move downward to the growing root tip within the plant. Species like *S. capitata,* which appears to be exceptionally efficient in Ca uptake, may be especially capable of extracting moisture from deep friable soil profiles in Oxisols like those in Carimagua. The patterns of extraction in Figure 40 show the apparent strong effect of stage of maturity on moisture utilization by two *S. capitata* ecotypes (one early flowering and the other late flowering). By the time the

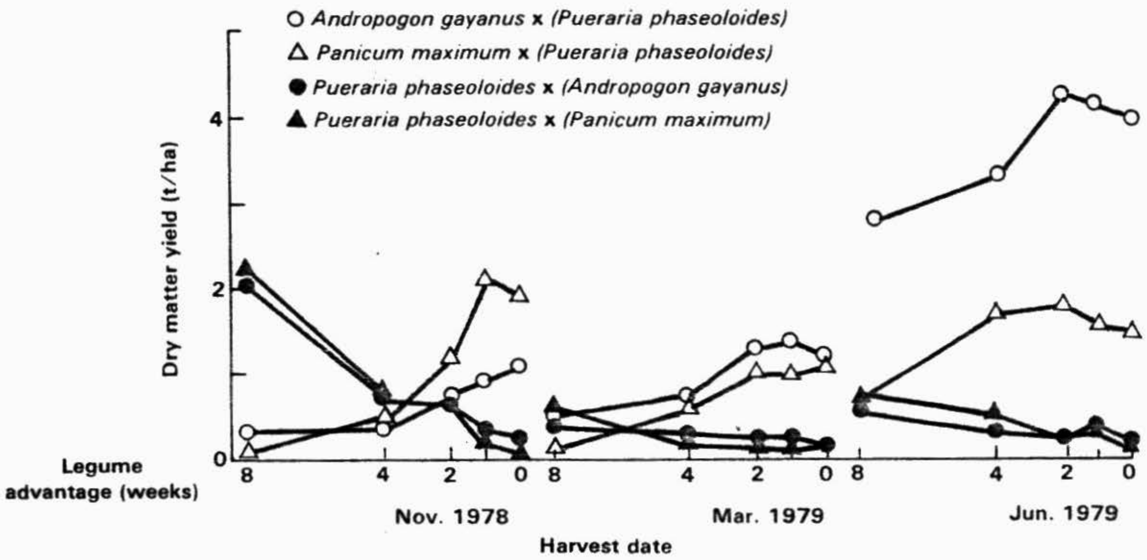

Figure 36. Effect of relative planting date of *Pueraria phaseoloides* in mixture with *Andropogon gayanus* or *Panicum maximum* on forage production. Yield data are for first species listed; associated species are shown in parenthesis.

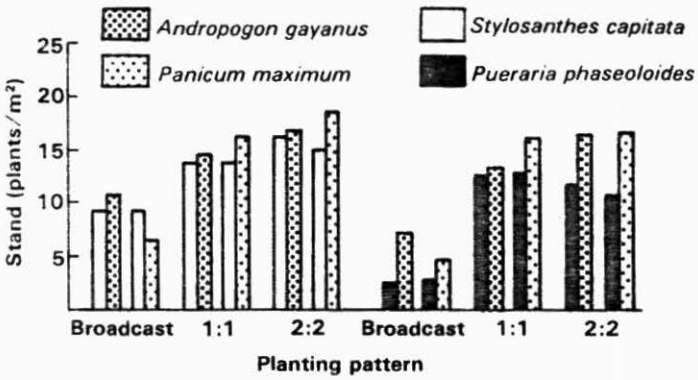

Figure 37. Effect of planting pattern (row spacing: 50 cm) on stand counts of four associations.

dry season began, *S. capitata* 1019 had flowered and was harvested; therefore, it used relatively little moisture from the profile. However, *S. capitata* 1078 flowered in early January and was harvested late in January by which time it had dried the profile to a depth of 1.50 m.

Figure 41 shows the effect of time of application of herbicide after burning the native savanna. It appears that optimum control is obtained with glyphosate and dalapon when applied 15 days after burning, and further delay considerably reduces the effectiveness of both. MSMA and DSMA were slightly more effective after 30 days delay. Figure 42 shows the effect of the application rate of the four herbicides. Little advantage was observed for increasing rates beyond the recommended levels.

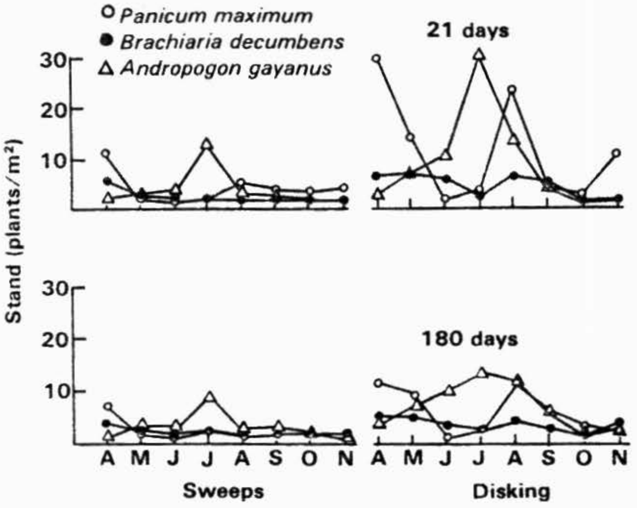

Figure 38. Effect of seed bed preparation and planting date on stand counts of three forage grasses, 21 and 180 days after seeding.

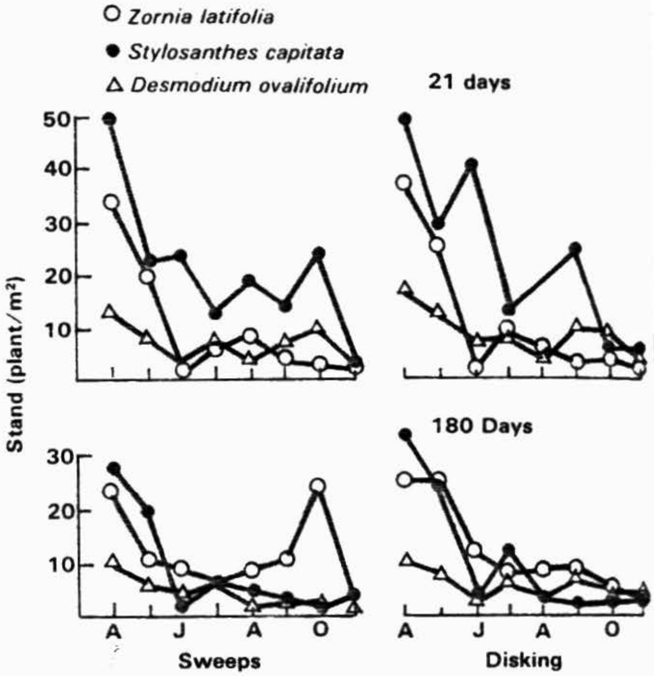

Figure 39. Effect of seed bed preparation and planting date on stand counts of three forage legumes, 21 and 180 days after seeding.

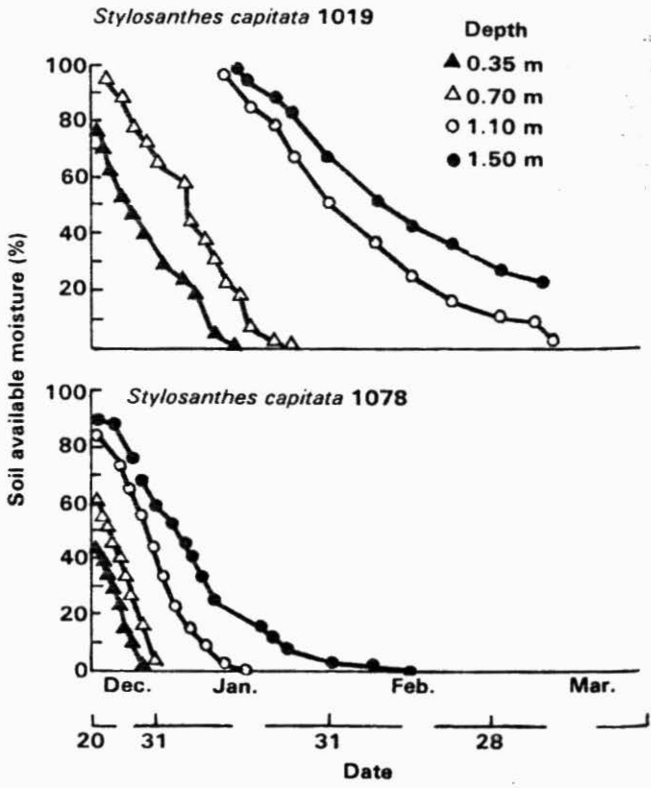

Figure 40. Soil moisture extraction patterns for *Stylosanthes capitata* 1019 (maximum flowering in early November and harvested in early December) and *S. capitata* 1078 (maximum flowering early January and harvested in late January).

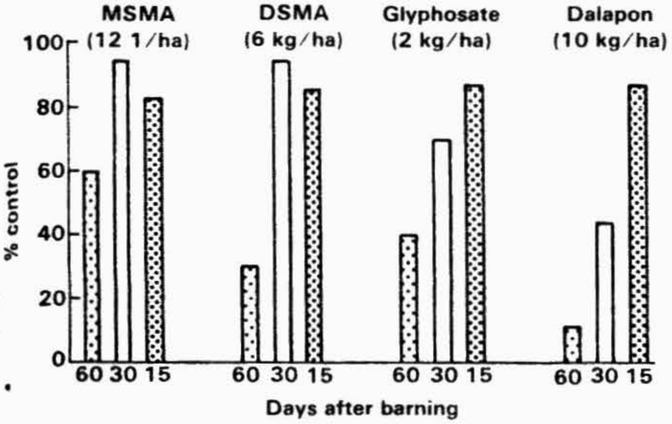

Figure 41. Effect of delaying the application of herbicides after burning on control of native savanna vegetation.

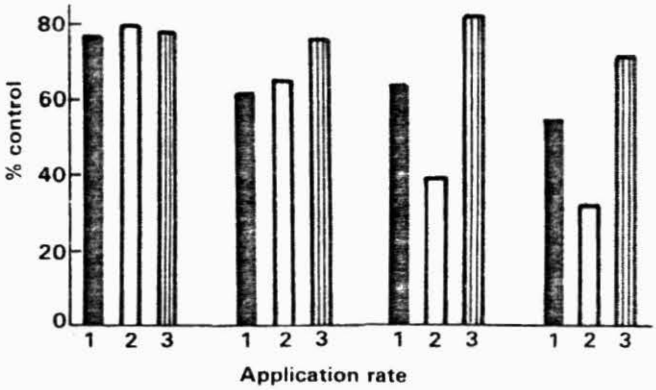

Figure 42. Effect of herbicide application rate on control of native savanna vegetation (1 = recommmended rate; 2 = twice the recommended rate; 3 = three times the recommended rate fitures in parenthesis are the recommended application rates.)

PASTURE DEVELOPMENT IN THE THERMIC SAVANNAS (CERRADO)

The objectives of the Pasture Development section of the Cerrado are: (1) to develop efficient systems of establishing forage legumes and grasses appropriate for representative ecosystems in Cerrado type savannas of South America and (2) to determine establishment and maintenance fertilizer requirements for the most promising grasses and grass/legume associations for the area.

The pasture development strategy adopted at the Cerrado center was presented in the CIAT 1977 Annual Report. The research activities designed to fill the technological gaps for implementation of this strategy include: (a) identifying the most important edaphic factors limiting pasture establishment, with emphasis on legumes; (b) determining establishment and maintenance requirements of selected grass/legume associations for Cerrado soil conditions; (c) developing efficient systems for pasture establishment with emphasis on minimum inputs; (d) developing renovation techniques for degraded pastures.

Identification of Nutrient Deficiencies

The main nutrient deficiency in the Cerrado soils is phosphorus. Other nutrients including K, Mg, Zn and Mo have been identified as limiting for some crops. Pasture species, especially the forage legumes, have specific nutrient needs to assure establishment, productivity and persistence. These requirements vary from soil to soil and among species.

Exploratory fertility experiments were initiated in 1978 on two important Cerrado soils, Yellow Red Latosol (LVA) and Dark Red Latosol (LVE), using *Centrosema pubescens* CIAT 438 and *Calopogonium mucunoides* as test forages. The experiments consisted of 2^8 factorials in a fractional replication design that included Ca, Mg, K, S, Cu, Zn, Mn, Mo and B. All pots received basal application of P equivalent to 100 kg P/ha. The effect of levels of P and $CaCO_3$ were studied in a parallel experiment.

There was a significant response to 30 kg S/ha (CIAT Annual Report, 1978) with *Centrosema* in the LVE soil. *Calopogonium,* which responded to S, also responded to 500 kg $CaCO_3$/ha. Both legumes also responded to K in both soils. Mg was not as important as S, Ca and K, but interactions of Mg with S and Mo were detected. Based on the greenhouse results, a field experiment including similar treatments was established.

A parallel experiment with levels of 50, 100, 200, and 400 kg P/ha and 0, 100, 500, and 1000 kg $CaCO_3$/ha, showed the importance of Ca as a nutrient.