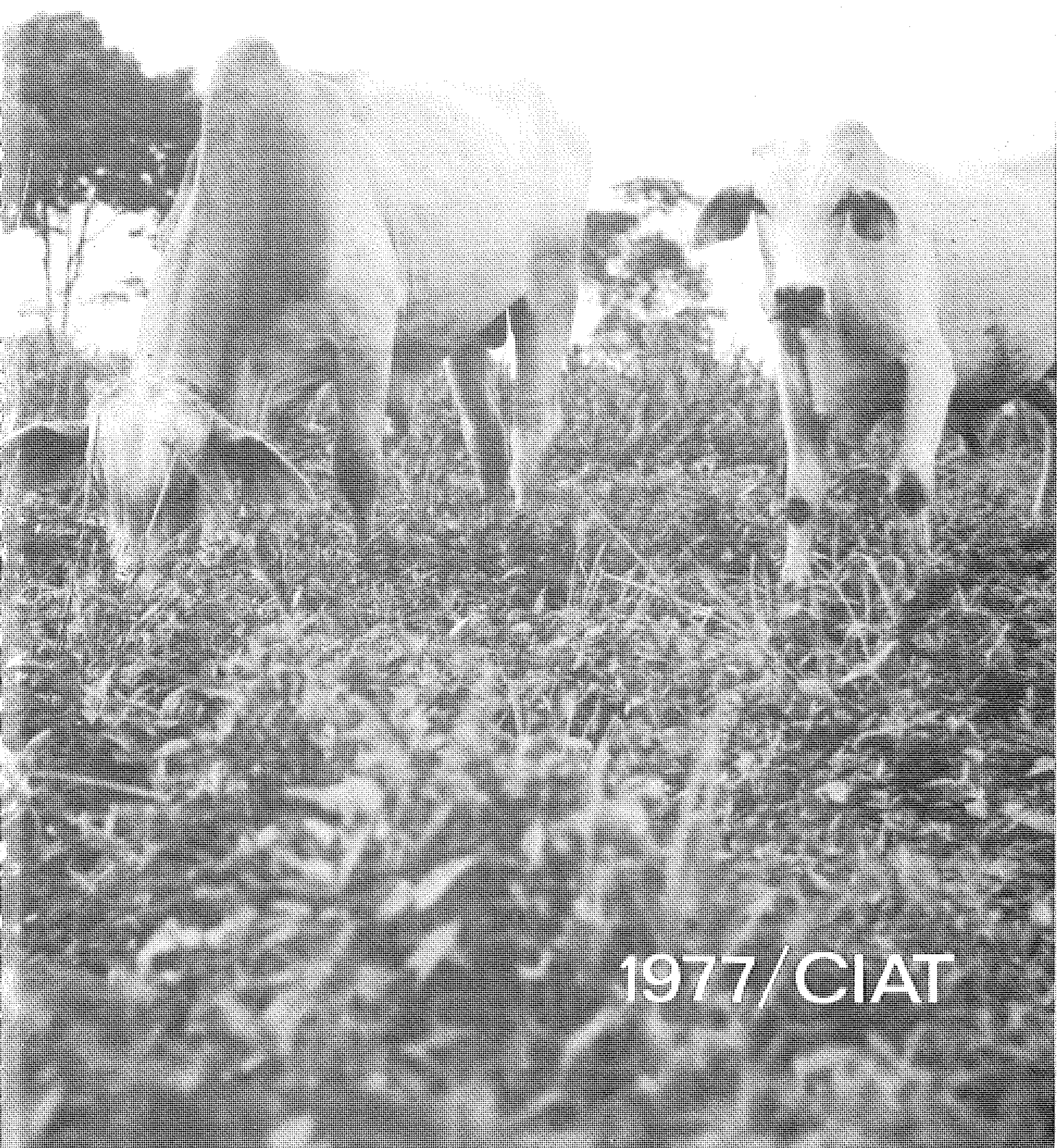
Beef program



1977/CIAT

Beef Program

The reorientation of the Beef Program was completed during the year. An interdisciplinary team was assembled for a synchronized attack at overcoming the soil-plant-animal barriers preventing increases in beef production in acid soil ecosystems. The Program impact area was defined, and a geographical study of the 850 million hectares of Oxisols and Ultisols of tropical America is in progress. A research and transfer of technology strategy was developed, and operations at three principal research stations at CIAT-Quilichao, Carimagua and Brasilia are underway. A regional testing network with locations throughout the impact area is being organized to initiate extensive testing in 1978.

The Program's objective is to develop and transfer effective low input technology for increasing beef production in acid, infertile soils of tropical America, primarily through improved, year-round pasture production, supplemented by economically-sound animal management and health practices. The following advances illustrate progress during 1977 towards attaining this objective.

The genetic base of CIAT's tropical forage germplasm collection adapted to acid soil ecosystems was doubled this year reaching a total of 3400 accessions. The number of grass and legume accessions under field evaluation in clipping or grazing trials was broadened considerably. At Carimagua, for example, the number of forage legume accessions tested under grazing, increased from six accessions of one species last year to 30 accessions of several species in 1977.

Specific selection criteria for forage legumes and grasses were established and the most promising germplasm was ranked according to its potential for cultivar release in specific ecosystems.

For the high stress savanna conditions of Carimagua, characterized by extreme acid soil infertility and devastating disease and insect attacks on legumes, several accessions of *Stylosanthes capitata, Zornia* sp. and *Desmodium ovalifolium* showed most promise among the legumes, while *Andropogon gayanus* appeared the most promising grass species. *S. guianensis* is no longer considered promising for this ecosystem because of disease or insect susceptibility and/or poor seed production potential.

For the somewhat less stressful climatic, edaphic and pest conditions at CIAT-Quilichao, *S. guianensis* 136 and 184 plus *Centrosema* hybrid 1733 appeared most promising and are at advanced stages of testing. Swards of these legumes mixed with *A. gayanus, Panicum maximum* or *Brachiaria decumbens* produced sustained liveweight gains of 561 g/steer/day at a stocking rate of 2.3 animals/ha during an unusually extended dry period which caused severe weight losses in adjacent pastures. Seed production increase of the most promising germplasm has proceeded accordingly.

CIAT's *Rhizobium* strain collection for forage legumes also doubled during 1977. Effective inoculation techniques with or without lime or rock phosphate pelleting were developed for most of the promising accessions.

Several promising legume and grass accessions were found to have extremely low requirements for phosphorus, coupled with an excellent tolerance to aluminum levels considered toxic for most cultivated plants.

Direct application of rock phosphates with low to medium reactivity typical of most Latin American deposits, performed equally as well or better than superphosphate when applied to Carimagua Oxisols growing aluminum-tolerant grass species. Considering that the cost of a kilogram of P_2O_5 as rock phosphate is one-third or one-quarter that of superphosphate, the use of these materials appears to be an important component of the emerging low-input technology.

New pasture establishment and maintenance systems featuring low-cost, space-planting techniques, and 2.5-meter wide-strip planting of grass-legume mixtures such as *Brachiaria decumbens* and *Pueraria phaseoloides* showed significant promise. Systems for conventional and nonconventional pasture establishment methods were initiated at Quilichao, Carimagua and Brasilia.

Long-term pasture utilization and herd systems studies and their economic evaluation showed that only very limited beef production levels are possible by grazing native savanna without improved, persistent pastures. Blood parameters of Zebu breeding cows grazing native savanna underscored the need for improved nutrition.

Evaluation of the Herd Systems trial, completed at Carimagua in May 1977, provided excellent information on herd performance on native savannas during four reproductive years. The most profitable improvement under such conditions was direct mineral supplementation. Salt supplementation, early weaning and the use of *Melinis minutiflora* pastures during the wet season are not profitable alternatives.

Among other improved grasses, *Hyparrhenia rufa* has failed under grazing because of its relatively high phosphorus and potassium requirements and lower tolerance to high levels of aluminum. *Brachiaria decumbens,* with modest fertilization requirements, produced annual liveweight gains of 150 to 200 kg/ha, approximately 5 to 10 times more than native savanna. Under the intense rainfall at Carimagua, these pastures are now showing severe symptoms of nitrogen deficiency, which raises questions as to how long they will remain productive.

Transfer of technology activities were integrated with research activities during the year. Training is oriented towards program objectives and operations of regional trials throughout the impact area.

Program Organization and Strategy

Beef cattle production is one of the most important agricultural enterprises in Latin America and a major source of protein for its 300 million people. The per capita beef consumption in tropical Latin America is three times higher than that of tropical Africa and about 16 times higher than Asia. At 16 kg/year, per capita consumption approaches that of Western Europe. This is probably an important reason why there is less protein malnutrition in the Latin American tropics than in tropical Africa and Asia. Studies in Cali, Colombia showed that families of all economic strata spend 10-12 percent of their total income on beef, underlying the fact that beef is a staple food in Latin America.

About two-thirds of Latin America's beef is produced in its tropical regions where 71 percent of its cattle population is found. The annual productivity per head of cattle in tropical America, however, is about one-half of the productivity in temperate South America and nearly one-fourth the productivity in the United States and Canada.

This technology gap is more acute when one considers the rapidly growing demand for low-cost beef, and the beef production potential of the vast areas of acid, infertile soils classified as Oxisols and Ultisols, presently under savanna and forest vegetation. These regions together encompass about one-half tropical America's land surface and are characterized by high annual rainfall with a dry season of varying intensity, good soil physical properties, but extremely low native soil fertility and poor infrastructure. The paramount barrier preventing beef production in these areas is inadequate year-round forage supply caused by the severe soil and water stresses.

As population pressures increase it is estimated that beef production in the fertile, high-base status soils of tropical America will be unable to compete with food crop production, while in the vast, acid infertile soil areas just the opposite occurs. In mid-1976 CIAT's Board of Trustees directed that the Program concentrate its efforts towards increasing production in these areas with primary emphasis on overcoming the nutritional gap.

A large part of 1977 was devoted to orienting the Program in this direction, developing a clear objective, a research strategy, recruiting new staff, obtaining appropriate research facilities to do the work, and formulating means for technology transfer to the national institutions.

OBJECTIVES

The **objective** of the Beef Program is to develop and transfer effective technology for increasing beef production in acid, infertiles soils of tropical America, primarily through improved year-round forage production.

The **expected result** of the Program's activities is the development of improved pasture production systems both in terms of quantity and quality, complemented by economically viable animal management and health practices. The national research and extension institutions are the **clients**, the beef producers the **users** and the **consumers** the beneficiaries. Hence the final objective is to benefit consumers through increasing production leading to lower prices of beef in tropical America, and other regions of the world with similar conditions.

The Program's orientation toward acid soil ecosystems also represents a significant effort towards the development of the 300 million hectares of infertile, acid soil savannas of Latin America, and the increasing proportion of the 550 million hectares of similar soils presently under forest vegetation which are being cleared for agricultural production. These vast areas are recognized as one of the most important underutilized land resources of the world with great potential for increasing food production at a global scale. The comparative advantage of beef cattle can serve as a major tool bringing these areas into efficient and ecologically-sound agricultural production and therefore an important factor in the overall economic development of these countries.

STRATEGY

The research and outreach strategy is illustrated in Figure 1. Through worldwide plant exploration efforts plus the new plant breeding section, a wide variety of forage grass and legume accessions is assembled, multiplied in the greenhouse or field nurseries, screened for tolerance to the main disease and insect pests as well as for aluminum toxicity and low phosphorus availability typical of the Oxisols and Ultisols of the impact area. The surviving accessions are observed in space-planted field plots for growth, vigor and other agronomic traits at the Quilichao substation. Seed of the promising ones is increased for further testing, including the inoculation needs for effective nitrogen fixation of the legumes and laboratory estimates of intake and digestibility. Clipping trials then follow, testing compatibility of grass-legume mixtures, cutting frequency, height, fertilization requirements and drought tolerance.

The most promising material is then tested in small regional screening trials conducted by collaborating national institutions throughout the impact area to provide an early estimate of adaptation to different environments. The necessary seed production technology is then developed and a second seed increase effort takes place in order to permit plantings of 5 to 10 hectares of the promising accessions. These promising lines are subjected to grazing pressure trials involving several variables such as stocking rates, grazing intervals and fertility levels, primarily to test for persistence under grazing, without making animal measurements as such. A second level of regional trials follows, testing agronomic variables and persistence under grazing throughout the impact area. All germplasm rejected through this process is given to CIAT's Genetic Resources Unit for their maintenance and possible future use.

The survey of the impact area will characterize the variability of the 850 million hectares of interest in terms of climate, soils, topography, existing pasture and beef production systems, animal health problems and the economics of the beef industry. This knowledge will increase the Program's ability to focus its technology to the most crucial aspects. Among them are the different pasture establishment and maintenance methods including oversowing native savannas, planting grass-legume mixtures either directly or preceded by annual crops, and intensively managed pastures in small irrigated areas or in the pockets of fertile soils found in some ranches. The results of these efforts and the regional trials permit the final evaluation of the potential cultivars through animal performance, measuring liveweight gains and other parameters. Foundation seed is then increased and new cultivars are then recommended for release.

Animal management trials are conducted with the promising pasture systems in order to synchronize the improved nutritional levels with the needs of different types of animals in the herd, through seasonal mating, early weaning and other herd management practices. The diseases of Zebu cattle which are likely to disappear with improved nutrition are identified as well as those diseases that are likely to increase as a consequence of higher animal density because of improved

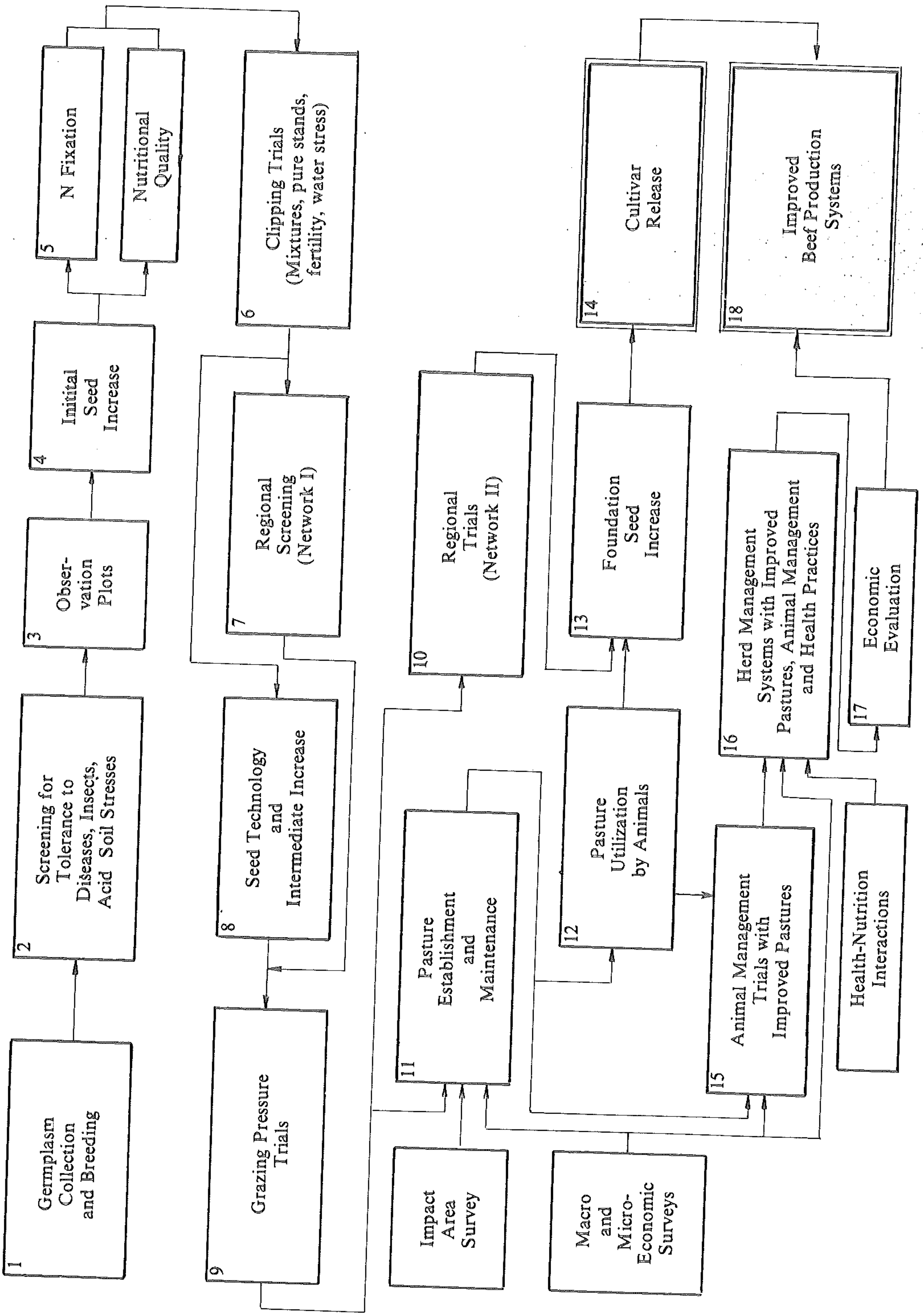


Figure 1. Flow chart of activities and strategies in the CIAT Beef Program.

nutrition. The control of these diseases is then attacked. A package of the new technology consisting of improved pastures, animal management and health practices is then put together to quanitify it at the herd level. After economic evaluation, improved beef production systems will be released.

The complexity of the program and the nature of the impact area dictate that research and international cooperation be totally integrated. Training of national institution personnel is linked with their role as actual or potential collaborators in regional trials and other means of technology transfer.

RESEARCH LOCATIONS

Because of the fertile, high base status soils at Palmira, most field research has to be conducted elsewhere, with the CIAT facilities serving as headquarters and for greenhouse, laboratory and library work. During 1977, arrangements were made to operate in three important field research locations suitable to the Program's objectives and providing a wide range of climatic and soil conditions.

The three locations are CIAT-Quilichao, 40 kilometers south of Cali, the Centro Nacional de Investigaciones Agropecuarias of the Instituto Colombiano Agropecuario (ICA) at Carimagua, in the Colombian Llanos and the Centro de Pesquisa Agropecuaria dos Cerrados (CPAC) of Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), 35 kilometers northeast of Brasilia, Brazil. Long-term climatic data are shown in Figure 2. The most important difference between these locations is the dry season length. At Quilichao there are two short but intense dry seasons a year, each of about two to three months duration. Carimagua has a strong four-month dry season and Brasilia, a strong six-month dry season.

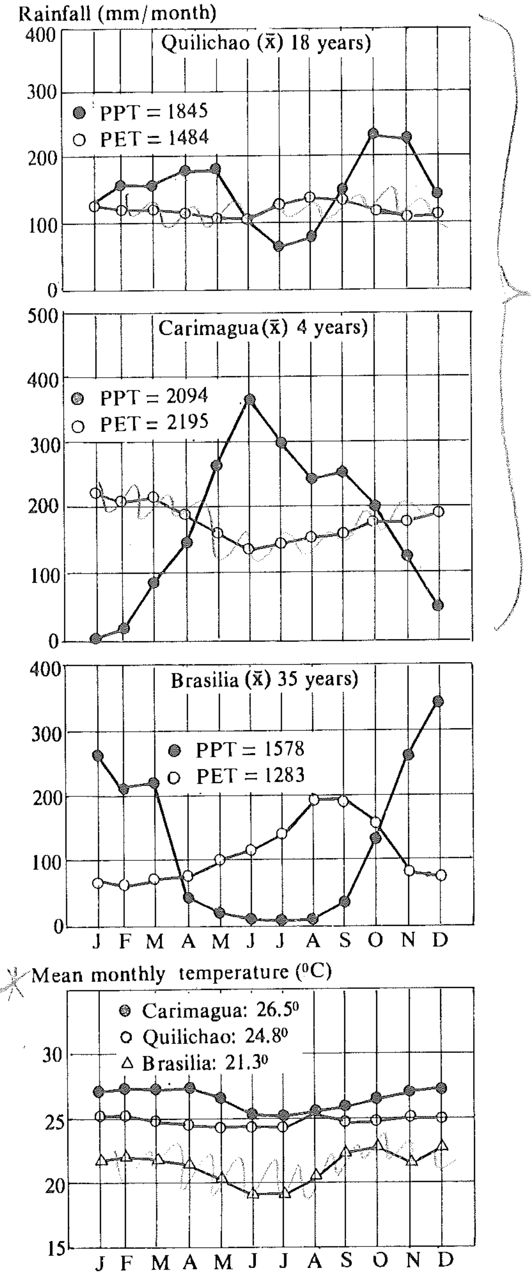


Figure 2. Mean rainfall (PPT), potential evapotranspiration (PET) and temperature regimes at the three main stations of Beef Program research. Quilichao, Cauca, Col: Lat. 3°06'N, Long. 76°31'W; elev. 990m. Carimagua, Meta, Col.: Lat. 4°02'N, Long. 71°10'W., elev. 200 m. Brasilia, Dist. Fed., Brazil: Lat. 15°36'S., 47°42'W., elev. 1010 m.).

The soil at Quilichao is classified as an Ultisol, while those of Carimagua and Brasilia are Oxisols. They are all acid (pH 4.1 to 4.9), high in aluminum saturation (64 to 82%), very low in available phosphorus and deficient in many of the other nutrients. Their well-granulated structure, however, provides excellent physical properties. Details on soil properties are presented in the Soil Fertility section.

In addition to climatic and edaphic properties, the three sites offer significant contrasts of pests and disease attacks on forage legumes. The incidence of anthracnose and stemborer at Carimagua is high, at Quilichao moderate to slight, while these pests are not yet important at Brasilia.

Although beef production is the principal activity in all three locations and the productivity of native pastures is low, the degree of infrastructure development also provides a range of economic possibilities. The closeness of Quilichao to the Cali metropolitan area contrasts with the fairly developed but more difficult conditions in the Cerrado near Brasilia. Both in turn are totally different from the relatively isolated Carimagua station, representative of an area with poor roads and communications infrastructure.

Many of the Program's sections have been in operation for several years and have accumulated a significant amount of data. Other sections were established this year, and are at the early stages of development.

Impact Area Survey

The Beef Program's impact area consists of 850 million hectares of acid, infertile soils of tropical America classified as Oxisols and Ultisols. A detailed breakdown of these soils in tropical America is shown in Table 1, ranking the countries in terms of the extent and importance of these soils.

Most of these areas are sparsely populated and devoted to extensive beef cattle production. In order to obtain detailed information a survey was initiated in mid-1977 to classify the land resources and provide a geographically-oriented economic synthesis to serve as the basis of the Program's transfer of technology strategy. The survey and analysis of the impact area is to be completed in two years.

The "Land Systems" approach developed by Christian and Stewart in northern Australia was the methodology adopted. For our purposes, a Land System has been defined as "an area or group of areas throughout which there is a recurring pattern of climate, landscape and soil". The environmental parameters affecting land utilization are classified in the following categorial order:

1. Climate
   a. Radiant energy received
   b. Temperature
   c. Potential evapotranspiration
   d. Water balance
   e. Other climatic factors
2. Landscape
   f. Land-form
   g. Hydrology
3. Soil
   h. Soil physical characteristics
   i. Soil fertility characteristics

Professor George Hargreaves with his associate Mr. Karl Hancock of the Utah State University (USA) are carrying out the climatic work using data from over

Table 1. **Distribution of Oxisols and Ultisols in Latin American countries, calculated from the FAO World Soil Maps at the scale of 1:5 million.**

Country	Million hectares	Percentage of country	Importance[1]
Brazil	572.71	68	***
Colombia	67.45	57	*
Peru	56.01	44	**
Venezuela	51.64	58	***
Bolivia	39.54	57	**
Guyana	12.25	62	***
Surinam	11.43	62	***
Paraguay	9.55	24	*
Ecuador	8.61	23	*
Fr. Guayana	8.61	94	***
Mexico	4.42	2	
Panama	3.59	63	***
Honduras	3.13	29	**
Nicaragua	2.92	30	**
Cuba	2.42	21	*
Chile	1.37	2	
Argentina	1.28	0.4	
Guatemala	0.96	9	
Costa Rica	0.70	14	*
Haití	0.52	19	*
Jamaica	0.45	41	**
Trinidad	0.42	84	***
Dominican Republic	0.42	9	
Belize	0.40	18	*
Puerto Rico	0.16	18	*
Guadalupe	0.09	47	**
Martinique	0.05	43	**
Totals:			
Latin America[2]	851.10	42	**
Tropical America	848.45	51	***
Tropical South America	828.21	59	***
Central America and Caribbean	15.80	23	*

[1] *** More than 50% of the country
** More than 25% of the country
* More than 10% of the country

[2] Includes the following countries where Oxisols and Ultisols are not present: Uruguay, El Salvador, Antigua, Bahamas, Barbados, Curacao ad other lesser Antilles.

1000 metereological stations in the impact area. Satellite imagery with supporting aerial and land reconnaissance is being used to define landscape patterns. A complete collection of LANDSAT imagery for the impact area was assembled. Soil fertility characteristics are being described according to the Soil Fertility Capability Classification System developed by Dr. Stanley Buol and co-workers in North Carolina.

The study will be complemented by a preliminary definition of the conditions of growth of the major grasses and legumes throughout the area, to help forage introduction. Further, an attempt will be made to locate the geographical boundaries of major cattle disease problems in cooperation with the animal health specialist.

Following the geographical delineation of Land Systems, geographical priority areas for the introduction of improved beef cattle production technology will be made according to economic considerations. This work, to be carried out by the economist, will be complemented by field studies of management practices of specific areas to help identify production systems. This latter work will come under the direction of the animal management specialist.

The survey, as it crosses national boundaries, involves the cooperation of various national agencies. In Brazil where work has started, the project is a joint venture with the Cerrado Center of EMBRAPA, with Dr. Luiz Guimaraes de Azevedo as coordinator.

At this time, the climatic studies by Dr. Hargreaves' group are proceeding normally and the organization of the literature review and cartographic aspects are under way.

In-situ checking of the preliminary interpretation of the satellite imagery of approximately 200 million hectares of land has been carried out over the major savanna regions of tropical South America, including the central-west of Brazil and a part of eastern Bolivia between latitudes 10°S and 20°S. This represents about 23 percent of the project area as a whole and about 60 percent of the savanna regions to be studied. Presently the preliminary satellite image interpretation is being revised according to field checks, and data compilation is under way for eventual classification and storage in a data-bank, prior to report compilation.

Some provisional findings can be highlighted:

(1) Throughout the area studied to date, approximately 40 percent of the lands classify as well-drained savannas, principally Oxisols, 25 percent as poorly drained savannas, mainly Ultisols, and the remainder as other ecological forms. Cattle production on the well-drained savannas is generally limited by a lack of dry season fodder, whereas on the poorly-drained savannas there is often a problem of wet season feeding due to flooding and a shortage of accessible non-flooded higher lands with adequate fodder.

(2) Over 85 percent of the well-drained savannas have a relatively continuous tree-shrub cover, commonly referred to as "Cerrado" in Brazil, and only a relatively small fraction would classify as open savannas. As the density of tree-shrub vegetation has a positive correlation with soil fertility, this would indicate that whilst these savannas undoubtedly classify with the low fertility soil circumstance, this circumstance is by no means as extreme as is found in the northern eastern plains area of Colombia. Further, it is common to find significant intrusions of more fertile soils, especially along the drainage patterns, in these lands.

(3) It is clear that there are vast areas in

western Brazil which might be used for more intensive cattle production, with the application of innovative, low-cost technology.

Plant Introduction

The objective of this section is to augment and broaden the genetic diversity of tropical forage germplasm with potential for the Beef Program's impact area. Activities started at the end of 1976, and during 1977 were focused on: (1) assembling of germplasm through direct collection and exchange with other institutions; (2) initial increase and maintenance of germplasm; (3) preliminary evaluation of germplasm; and (4) identification and classification of germplasm through a reference herbarium.

COLLECTION AND INTRODUCTION OF FORAGE GERMPLASM

Since the creation of the Plant Introduction Section in 1977, CIAT's tropical forage germplasm has increased significantly (Fig. 3). This increase is the result of systematic collection trips through Oxisol and Ultisol regions of the Llanos of Colombia—mainly in the departments of Meta and Vichada, the Llanos of Venezuela—in the states of Bolivar, Anzoátegui and Monagas; and in the Cerrado regions of the state of Mato Grosso in Brazil. The latter expedition was with the participation of scientists from CIAT, EMBRAPA and CSIRO (Australia).

These systematic expeditions and several occasional collection trips within Colombia contributed considerably to CIAT's forage germplasm collection, which is specialized in materials originating from regions with very acid, infertile savanna and jungle soils. Besides direct collection, germplasm was introduced through exchanges with other institutions. The major contribution was obtained from the International Development Research Centre (IDRC, Canada) University of West Indies Forage Legume Project in Belize and Antigua. Direct collections and introduction through exchange of germplasm during 1977 more than doubled CIAT's forage germplasm collection to 3400 accessions. Table 2 shows the germplasm acquisitions during 1977 for major genera and groups in the forage germplasm bank.

INITITAL GERMPLASM INCREASE AND MAINTENANCE

In most cases the amount of seed or vegetative material introduced per accession is not sufficient for any evaluation work nor for maintenance of germplasm. For this reason, much of the section's work during 1977 consisted of maintaining and increasing germplasm. In addition to 493

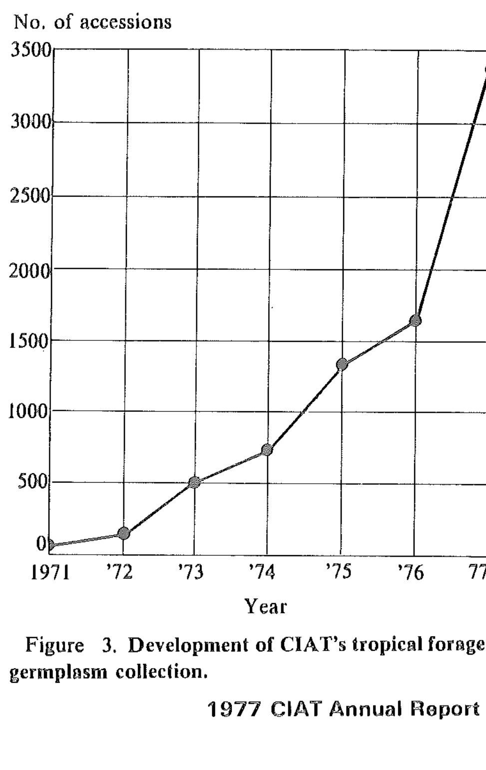


Figure 3. Development of CIAT's tropical forage germplasm collection.

Table 2. **Introductions of forage germplasm by direct collection and exchanges with other institutions during 1977.**

Genera	No. of accesions acquired by collections in:				No. of accessions acquired by exchange from: IDRC/Univ. of W. Indies Forage Legume Project					Total accessions in CIAT Forage Germplasm Bank
	Colombia	Venezuela	Brazil	Total	Belize	Antigua	USDA	Others	Total	
Stylosanthes	62	67	148	277	48	24	-	10	82	1021
Desmodium	125	5	114	244	61	7	-	6	74	525
Zornia	42	-	74	116	1	-	-	-	1	145
Aeschynomene	40	2	32	74	2	-	-	-	2	92
Macroptilium group[1]	60	1	32	93	32	12	-	7	51	278
Centrosema	25	5	13	43	35	4	-	3	42	232
Galactia	30	-	16	46	-	4	-	-	4	70
Arachis	-	-	6	6	-	-	42	-	42	77
Miscellaneous legumes[2]	171	4	158	333	146	13	-	12	171	806
Grasses	3	-	1	4	-	-	13	20	33	154
Total	558	84	594[3]	1236	325	64	55	58	502	3400

[1] *Macroptilium, Phaseolus* and *Vigna.*

[2] *Calopogonium, Pueraria, Teramnus, Glycine, Cassia, Rhynchosia, Crotalaria, Tephrosia, Eriosema, Clitoria, Indigofera: Leucaena* and others.

[3] Plus 41 accessions of which only vegetative material was collected and which are presently under seed increase in EMBRAPA's Centro Nacional de Pesquisa de Gado de Corte, Campo Grande, N.T.

Table 3. **Forage plant germplasm acquired in 1977 that is under initial seed increase for maintenance and working collection.**

Genera	No. of accessions
Stylosanthes	342
Desmodium	121
Zornia	71
Aeschynomene	50
Macroptilium group[1]	99
Centrosema	47
Galactia	31
Arachis	47
Miscellaneous legumes	170
Grasses[2]	48
Total	1026

[1] *Macroptilium*, *Phaseolus* and *Vigna*.

[2] Also for preliminary evaluation, including earlier introductions.

accessions from earlier introductions (1971-1976 germplasm), initial seed increase of 60 percent of the 1977 materials was initiated under screenhouse conditions at CIAT-Palmira and in the field at CIAT-Quilichao (Table 3).

Furthermore, maintenance of non-seed-producing grasses was initiated by establishing a living collection of 28 accessions in CIAT-Quilichao.

PRELIMINARY EVALUATION OF GERMPLASM

Preliminary evaluation of some of the potentially most promising 1977 legume germplasm was initiated in CIAT-Quilichao. New accessions of the *Macroptilium* group, *Zornia* spp., *Aeschynomene* spp., *Centrosema* spp. and *Stylosanthes capitata,* all of which originate from acid soil savanna regions, and of which sufficient seed was available, were established in introduction plots with 24 spaced plants

Table 4. **Forage legume germplasm acquired in 1977 that is under preliminary field evaluation in CIAT-Quilichao.**

Species	No. of accessions
Zornia spp.	55
Macroptilium group	31
Aeschynomene spp.	26
Centrosema spp.	14
Stylosanthes capitata	10
Total	136

each. They are being tested against the most outstanding accessions of previous collections (Table 4).

Figure 4. **Sample of forage germplasm (*Stylosanthes capitata*), with brief description and collection data, in CIAT's reference herbarium.**

DEVELOPMENT OF A REFERENCE HERBARIUM

In cooperation with CIAT's Genetic Resources Unit, development of a reference herbarium was initiated. Herbarium specimens (Fig. 4) of a wide range of genera, species and ecotypes will document the broad variation of tropical forage plants and enable identification and classification of new germplasm as well as of native savanna vegetation. During 1977, 208 specimens were assembled (Table 5).

Table 5. **Specimens of tropical forage plants and savanna vegetation in CIAT's reference herbarium, as of November 1, 1977.**

	No. of specimens
CIAT forage germplasm	
Gramineae	20
Leguminosae	39
Savanna vegetation	
Graminae and *Cyperaceae*	34
Leguminosae	55
Other families	60
Total	208

Forage Breeding

In the past, the Beef Program has relied entirely on the evaluation of native forage legume ecotypes obtained from CIAT-sponsored collecting expeditions or from germplasm collections available at other institutions in the attempt to identify suitable ecotypes for commercial planting in the impact area. This rationale has been sound because of the many promising, native tropical forage legume genera, species within genera and ecotypes within species that have not been adequately evaluated to assess both their direct utility in commercial production and their feasibility for consideration within a plant breeding framework. Priority emphasis is and will continue to be given to evaluating new accessions.

Therefore, the forage breeding section as presently conceived has two major funtions. First, breeders will participate in evaluating existing germplasm in close coordination with other Beef Program scientists to identify ecotypes suitable either for direct, commercial utilization or as parental types for use in crosses. Second, the section will initiate breeding investigations involving those forage legume species which have demonstrated the most general promise within the impact area as indicated by previous and continuing experiences of the Beef Program.

Inititally, the legume breeding section is placing first priority with the complex of *Stylosanthes* species, primarily *S. capitata*. Secondary priority will be given to other promising genera — *Centrosema, Desmodium, Macroptilium, Leucaena* and *Zornia*. Until recently introduced ecotypes of species of these genera have been more fully field-evaluated and/or a wider genetic base has been collected, primary emphasis will remain with *Stylosanthes*.

Specific breeding investigations have been initiated with *Stylosanthes* species, particularly with *S. capitata*. The chromosome number of this species is unknown. Initial chromosome counts made with *S. capitata*, using root-tips squashes, have been inconsistent. Some ecotypes appear to have $2n = 20$ chromosomes, the same as *S. guianensis*, while others apparently are tetraploids with $2n = 40$. The morphology of the chromosomes of these two species, in addition, appears to be markedly different (see Fig. 5) which could indicate dif-

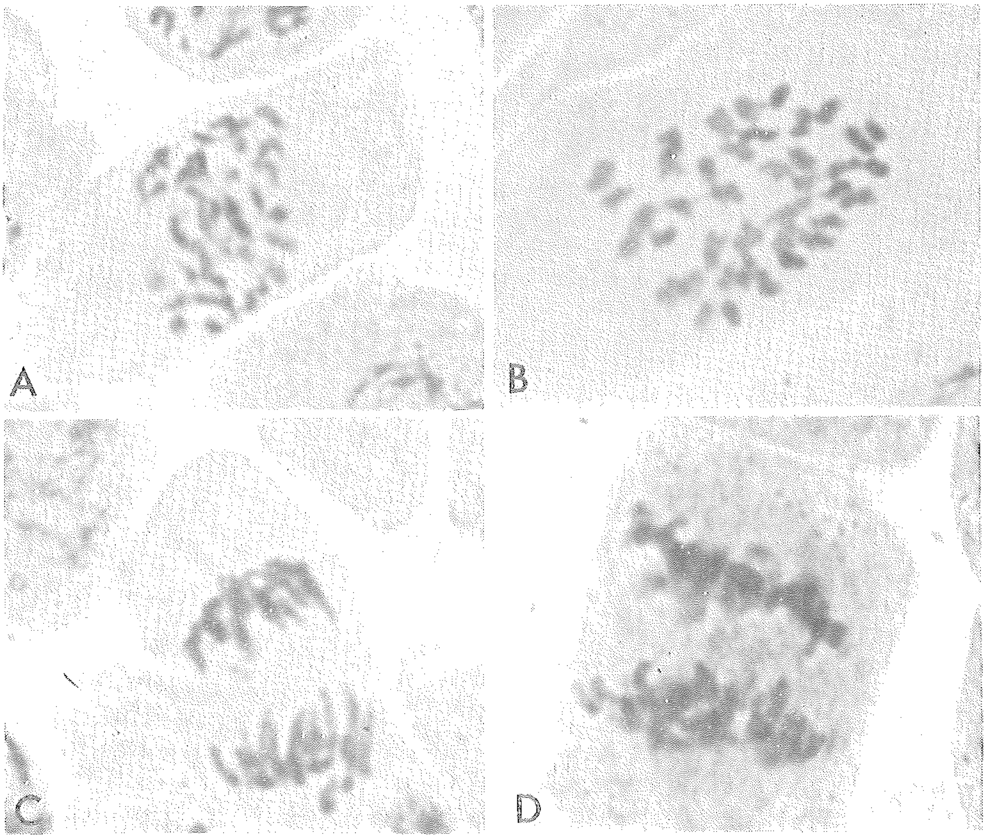


Figure 5. Somatic chromosomes of two *Stylosanthes* species. (A) *S. guianensis*, metaphase (2n = 20); (B) *S. capitata*, metaphase (2n = 40); (C) *S. guianensis*, anaphase; (D) *S. capitata*, anaphase.

ficulties in making inter-specific hybridizations between these two species.

Pure line selections are being made within ecotypes of various *Stylosanthes* species to determine both intra-ecotype as well as inter-ecotype variability for certain traits. Laboratory-greenhouse screening methods to identify resistance to *Colletotrichum gloeosporiodes* (anthracnose) are being modified to eventually handle segregating populations coming from crosses. Experiments in Carimagua, in cooperation with the entomologist, were initiated to characterize and separate the effect of anthracnose and stem borer in order to develop reliable field screening methods for identifying resistance to both problems.

Plants of ecotypes of the several *Stylosanthes* species with known valuable characteristics have been established in the greenhouse and will be used for preliminary crosses both within and between species. These plants will serve to develop the most appropriate controlled pollinization methods and the resulting hybrids will provide a small, but representative sample of segregating populations to use as a prototype for developing efficient screening procedures.

Legume Agronomy

The Program's legume agronomists are responsible for evaluating germplasm believed to be adapted to acid soil conditions through a series of steps ranging from observation plots to clipping and grazing trials. During 1977, 226 accessions of 34 species were evaluated at six locations, including the base sites at Quilichao and Carimagua. The number of accessions under grazing in Carimagua increased from 6 in 1976 to 30 in 1977.

ESTABLISHMENT OF SELECTION CRITERIA

A program Germplasm Committee was formed in mid-1977 with three functions: (1) to establish selection objectives for grasses and legumes; (2) to establish promising categories and project seed increase priorities; and (3) to classify the promising accessions according to selection criteria into promising categories.

The legume selection objectives are shown in Table 6. The criteria will be reviewed and quantified further as new information on tolerances to the various stresses become available. The criteria for general adaptation to specific ecological conditions are based on growth and vigor observations. Although adaptation to moderate and high soil fertility conditions is not part of the Program's mandate, promising accessions from the working collection are identified for possible use outside of the impact area as well as in the pockets of high fertility soils found within the impact area. The promising categories developed are shown in Table 7.

CLASSIFICATION OF LEGUME GERMPLASM

Tables 8 and 9 group 21 promising accessions into the two most advanced categories, describing their known reaction to the selection objectives. Twelve accessions of five species are listed in the most promising Category 4 and are now in grazing pressure testing at either Quilichao or Carimagua, or in both locations. This table shows that accessions of *Stylosanthes capitata*, *Zornia* sp. and *Desmodium ovalifolium* are promising under the environmental stresses at Carimagua, where tolerance to anthracnose and stem borer is of paramount importance for *Stylosanthes*. The *Centrosema* hybrids and the two *Stylosanthes guianensis* accessions are more promising for the somewhat lower stress ecosystem found at Quilichao, particularly in terms of disease and insect attacks. The many blank spaces in this table underline the need for further evaluation, particularly persistence under grazing and throughout the impact area via regional trials, before any cultivar can be recommended for release.

Table 6. Preliminary selection criteria for CIAT forage legumes.

Criteria	Symbol
Adaptation to Carimagua conditions[1]	YC
Adaptation to Quilichao conditions[1]	YQ
Adaptation to medium fertility soils	YM
Adaptation to high fertility soils	YH
Disease tolerance	D
Insect tolerance	I
Nitrogen fixation potential	N
Seed production potential	Sp
Water stress tolerance	W
Aluminum and low phosphorus tolerance	S
Nutritional quality	Q
Persistence under grazing	P
Ease of management	M
Animal productivity	A

[1] Described in Figure 2 and Table 26.

Table 7. **Promising categories for CIAT forage legume accessions and implications for evaluation and seed increase.**

Promising category	Level of evaluation	Stages[1]	Seed production planning[2]
1	Initial tolerance and/or small scale agronomic trials	1-4	Initial: (Up to 0.2 ha)
2	Complete agronomic trials	1-7	Primary: (Up to 5.0 ha)
3	Complete agronomic and grazing pressure trials	1-11	Secondary: (Up to 10 ha)
4	Complete agronomic and animal trials	1-17	Tertiary: (More than 10 ha)
5	Pre-cultivar release	1-14	Foundation: (More than 10 ha)

1 Refers to numbered activities in the Beef Program Flow Chart (Fig. 1)

2 Seed production sufficient to plant the indicated area.

Table 8. **CIAT forage legume accessions classified as promising Category 4 as of November 1977.**

Species	CIAT No.	Selection criteria[1] (blanks represent unknown)											
		YC	YQ	YM	YH	D	I	N	Sp	W	S	Q	P
Centrosema sp.	1733	-	+	+		+	+	+	+			-	
" "	1787	-	+	+		+	+		+				
" "	845	-	+	+		+	+		+				
Desmodium ovalifolium	350	+	+			+	+	+					
Stylosanthes capitata	1019	+	-	-	-	+	+	+	+				
"	1078	+	-	-	-	+	+	+	+				
"	1097	+	-	-	-	+	+	+	+				
"	1315	+	-	-	-	+	+		+				
"	1405	+	-	-	-	+	+		+				
Stylosanthes guianensis	136	-	+	-	-	-	-	+	+				
"	184	-	+	-	-	-	-	+	+		+		
Zornia sp.	728	+	-	-	-	+	+		+				

1 Codes are described in Table 6.

Table 9. CIAT forage legume accessions classified as promising Category 3 as of November 1977.

Species	CIAT No.	Selection criteria[1] (blanks represent unknown)											
		YC	YQ	YM	YH	D	I	N	Sp	W	S	Q	p
Desmodium distortum	335	-	-	+				+	+			+	-
Desmodium heterophyllum	349	-	+	+				+	+				
Desmodium sp.	336	-	-	+			+						
Glycine wightii	201	-	-	-	+				+		-		
" "	204	-	-	-	+				+		-		
Macroptilium sp.	535		+			+	+	+	+				
Pueraria phaseoloides	9900	+	-	+		+	+	+	+		+		
Stylosantes hamata	118	-	-	-	+				+				
"	147	+							+				

[1] Codes are described in Table 6.

Being a first attempt at a systematic classification of tropical legume germplasm these lists should be considered tentative and subject to change as not all the projected evaluations have been completed.

STYLOSANTHES

Anthracnose, caused by *Colletotrichum gloeosporiodes* Penz, is a highly destructive disease of *Stylosanthes* spp. The disease is endemic in South and Central America, and plant resistance is the only practical means of control. The widespread occurrence of stylo anthracnose in tropical and subtropical America and recent reports of its presence in Australia, Africa and Florida emphasize the need for disease-resistant genotypes.

Systematic screening of 850 accessions of *Stylosanthes* spp. for anthracnose resistance was initiated some three years ago. Simultaneously, the genetic diversity of the germplasm in CIAT's forage legume collection has been increased by exploring and collecting new accessions from the savanna regions of tropical America. Information and results from these investigations may be summarized as follows.

The seed-borne nature of anthracnose was explored in one accession of *S. scabra* as the subject of a special project. *C. gloeosporioides* was isolated from surface sterilized pods and seeds of *S. scabra* grown in field plots at Palmira. This isolate produced anthracnose symptoms and killed seedlings of *S. guianensis* CIAT 1198 and also affected several other species and ecotypes of *Stylosanthes*.

A high degree of resistance was found by screening a large number of *Stylosanthes* accessions. *S. capitata* Vog. displayed the best tolerance to anthracnose in glasshouse and laboratory pathogenicity tests. Results of a series of experiments are summarized in Figure 6a-f. Several accessions of *S. capitata* maintained strong resistance to anthracnose under actual field conditions at Carimagua over the past two years. Ecotypes of *S. capitata* were tolerant to a wider spectrum of physiological races of the pathogen than other species of the genus, although variation between ecotypes was indicated in this character (Table 10).

Effective nodulation after inoculation was observed on *S. capitata* in all plantings at Carimagua.

S. capitata is one of the most promising legumes for the environmental conditions of the Llanos of Colombia. Tolerance to anthracnose and stemborer attack coupled with good adaptation to low base status soils which are also high in aluminum are important agronomic characteristics of the species. Indeed, this species is rather intolerant of soils with high pH or high calcium status. When grown on a Carimagua Oxisol limed to pH 6.1 in the greenhouse, *S. capitata* showed distorted growth and symptoms of nutrient disturbances which have not been identified.

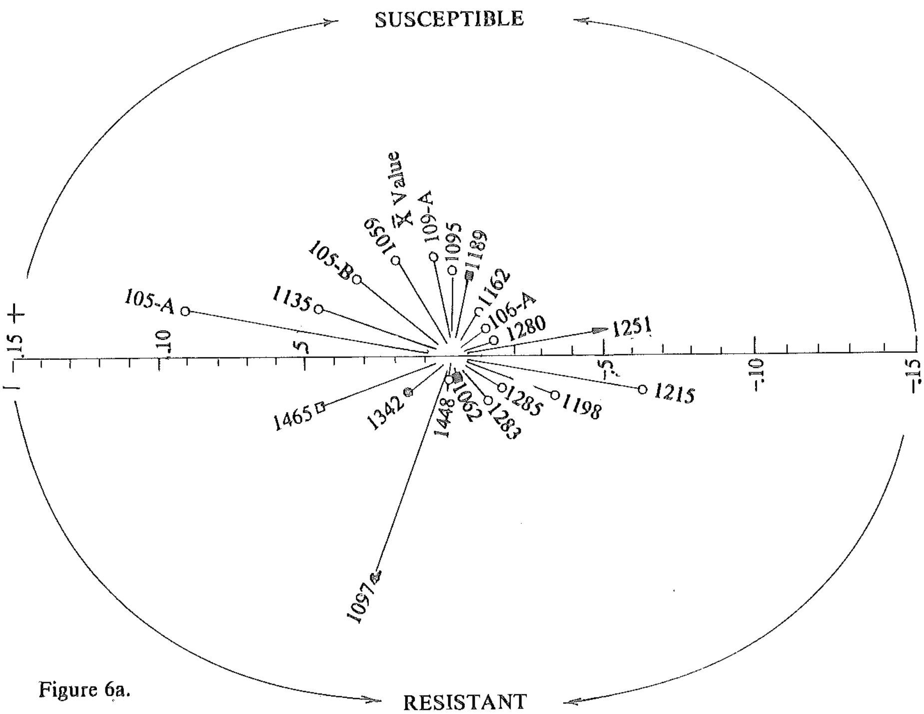


Figure 6a.

Figure 6. a-f. Disease severity indices (DSI) for *Stylosanthes* spp. and deviation (±) from mean values. Positive values represent susceptible lines of *Stylosanthes* and negative values indicate various degrees of resistance. DSI was calculated from the formula:

$$\text{DSI} = \frac{\text{Mean Disease Score of Accession - Mean Disease Score of Experiment}}{\text{Standard Deviation of Mean Score of Experiment}}$$

Disease Score = weighted means of five score classes: 1 = no infection; 2 = spots $<$ 1 mm; 3 = 25% of leaf area infected; 4 = 50% of leaf area infected; 5 = dead plant.

○ *S. guianensis*
□ *S. guianensis* (fine-stemmed)
• *S. capitata*
△ *S. bracteata*
▲ *S. humilis*
△ *S. viscosa*
⊙ *S. scabra*
□ *S. hamata*
◉ *S. montevidensis*
– *Stylosanthes* sp.

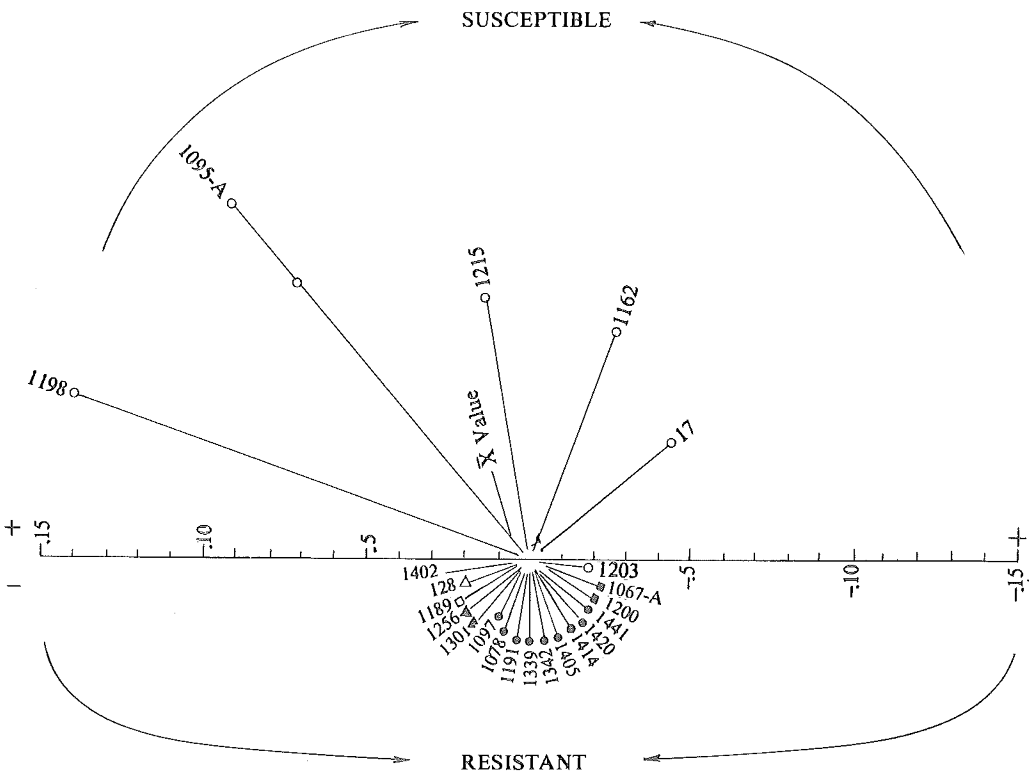


Figure 6b.

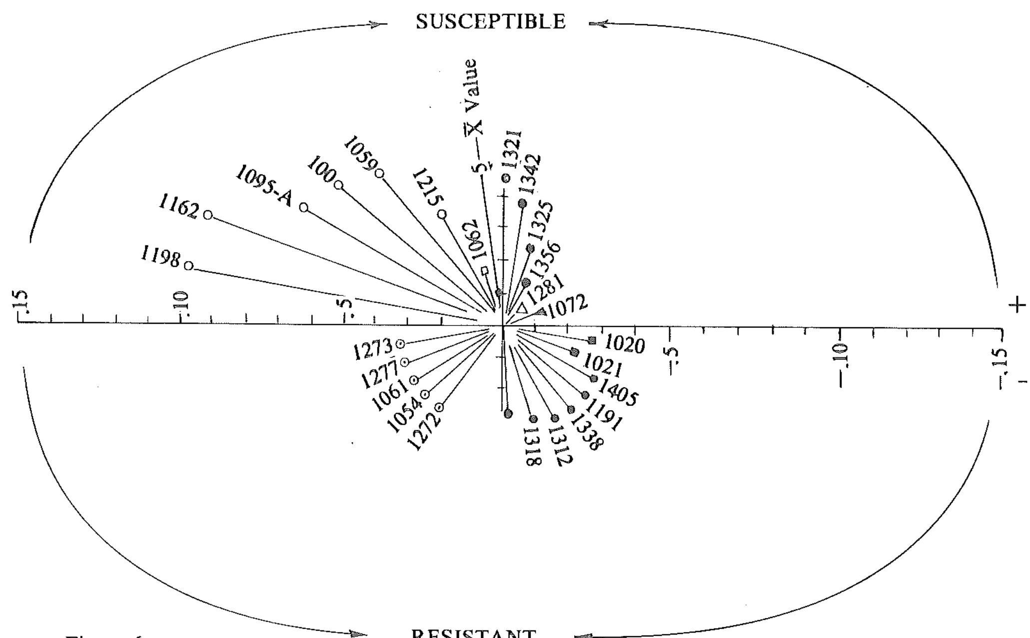


Figure 6c.

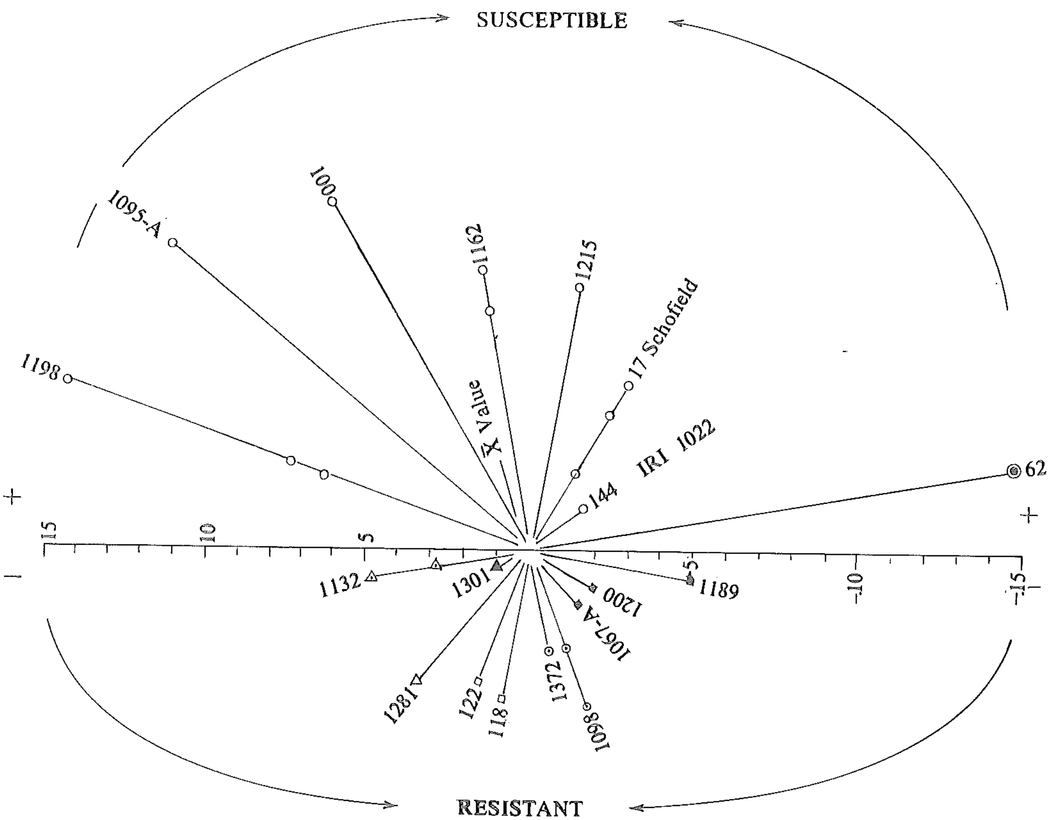


Figure 6d.

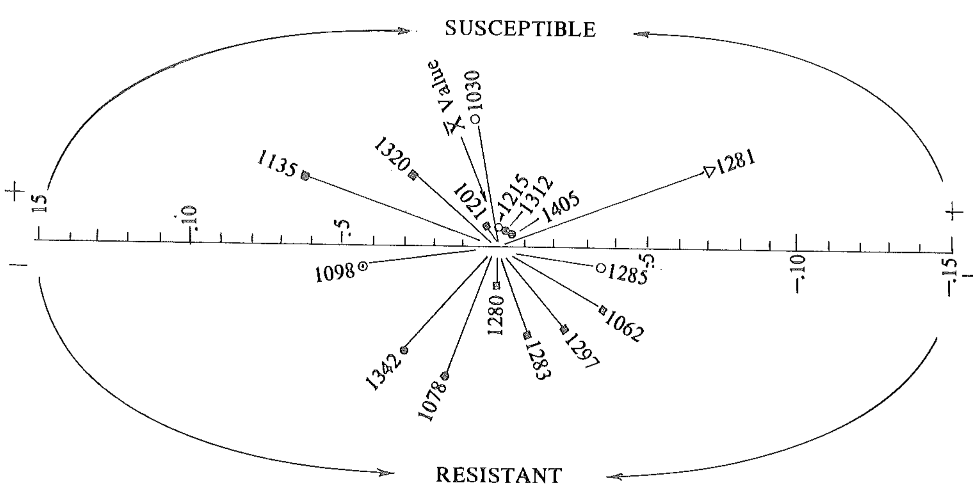


Figure 6e.

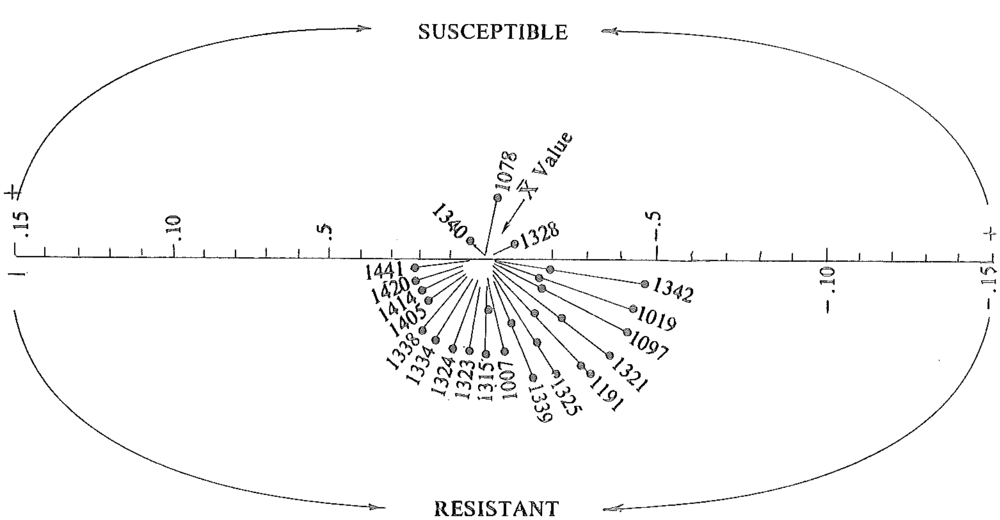


Figure 6f.

Table 10. **Reaction of *Stylosanthes* spp. to two isolates of anthracnose.**

CIAT accession No.	Species	Disease score[1]	
		Isolate I	Isolate II
1054	*Stylosanthes* sp.	2.33	5.00
1061	*S. scabra*	1.00	1.00
1062	*S. guianensis*	1.50	1.00
1078	*S. capitata*	1.00	1.33
1097	*S. capitata*	1.33	1.00
1098	*S. scabra*	1.00	1.67
1068A	*S. guianensis*	2.17	1.00
1087A	*Stylosanthes* sp.	1.00	2.83
1191A	*S. capitata*	2.00	1.33
1129	*S. guianensis*	5.00	1.00
1162	*S. guianensis*	3.00	1.00
1297	*S. guianensis*	1.50	1.33
1298	*S. capitata*	1.67	1.00
1312	*S. capitata*	1.00	1.00
1338	*S. capitata*	1.00	1.00
1379	*S. hamata*	1.00	1.67
1405	*S. capitata*	1.00	1.00
1497	*S. capitata*	1.67	2.17
1526	*Stylosanthes* sp.	1.33	1.17
1527	*S. scabra*	1.00	1.83
1538	*Stylosanthes* sp.	1.00	1.00

1 Weighted means of five score classes: 1 = no infection; 5 = dead plant. Isolate I from *S. capitata* 1097, Isolate II from *S. guianensis* 64 A.

The species is known only from Brazil and Venezuela, however, it is rather wide-ranging in the savannas of Brazil (Fig. 7). The first accession of *S. capitata* was introduced from Brazil in mid-1974. Presently, some 57 ecotypes of this species are held in CIAT's forage germplasm bank.

Ecotypes differ morphologically and considerable variation was observed in flowering date. At Quilichao, accessions from the southern limit of distribution of the species (latitude 16° - 21°S) commenced flowering in August, at least one month ahead of the accessions from the northeastern states of Brazil at latitudes 3° - 5°S (Table 11).

During late 1977 about three hectares of *S. capitata* grass mixtures have been seeded at Carimagua. Twelve accessions of stylo are included. The two companion grasses of contrasting growth habit are *Brachiaria decumbens* and *Andropogon gayanus*. Anthracnose-tolerant accessions selected from the collection will have to be exposed to a wide spectrum of strains of the fungus in several ecological regions where the disease is present to ascertain the existence of stable, horizontal resistance.

For the Quilichao site varieties of the common plant type of *S. guianensis* appear to be very well adapted. Observations and yield data over two years indicate that the fine-stemmed varieties also showed good field resistance to anthracnose and stem-borer at Quilichao. Unfortunately, most of the fine-stemmed stylo accessions are poor seed producers. Selection pressure should be directed toward the fine-stemmed

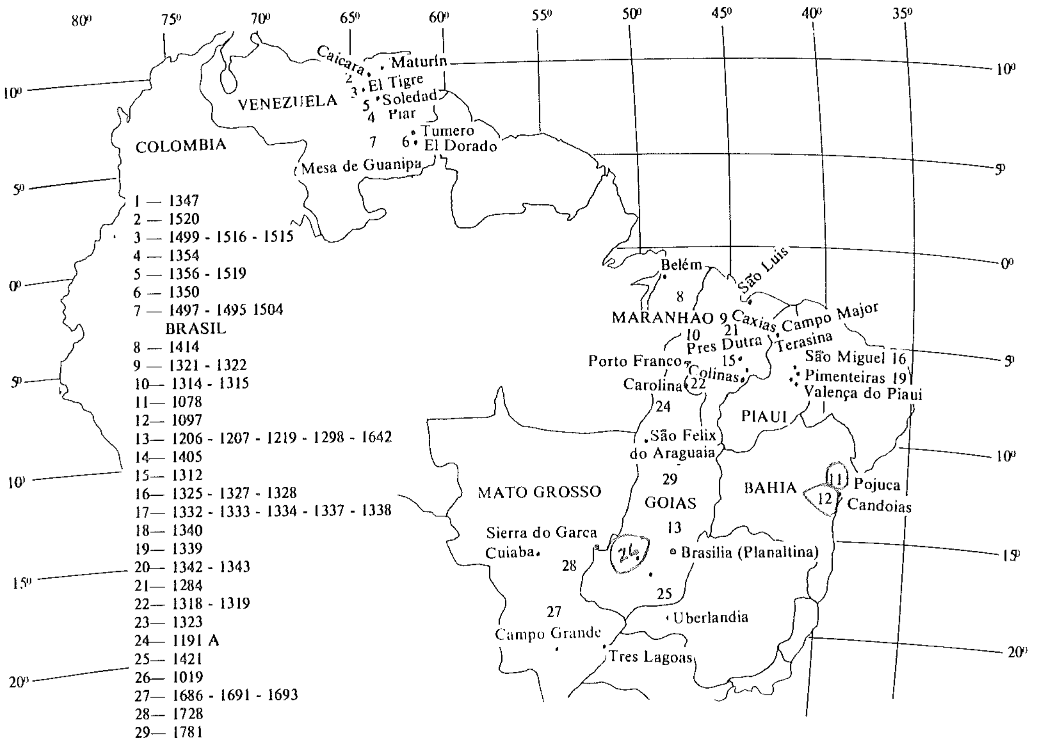


Figure 7. Collection sites of *Stylosanthes capitata* Vog. in Brazil and Venezuela.

Table 11. **Yield attributes of 15 *Stylosanthes capitata* and two *S. bracteata* accessions grown as spaced plants at Quilichao.**

CIAT accession No. and species		Mean of four yield cuts (g/plant)	Flowering response[1]
1078	*S. capitata*	187.17 a[2]	L
1323	"	150.83 ab	MS
1342	"	146.75 ab	MS
1318	"	142.08 ab	MS
1339	"	141.42 ab	MS
1315	"	123.92 abc	MS
1324	"	121.92 abc	MS
1382	*S. bracteata*	121.24 abc	MS
1340	*S. capitata*	115.42 bc	MS
1328	"	113.17bc	MS
1325	"	106.25.bc	MS
1334	"	102.92 bc	MS
1281	*S. bracteata*	97.58 bc	MS
1333	*S. capitata*	92.50 bc	MS
1338	"	89.83 bc	MS
1375	"	80.95 bc	MS
1298	"	61.58 c	E

1 L = late flowering (November); MS = mid-season flowering (October); E = early flowering (mid-August).

2 Means followed by a different letter are significantly different at P= 0.05 by Duncan's Multiple Range Test.

ecotypes with better seed producing capacity.

At Quilichao, 10 accessions of *S. guianensis* were established during the current season to compare fine-stemmed varieties with the two high-yielding typical forms of *S. guianensis* e.g., 184 and 1175.

Two accessions of *S. guianensis,* 184 and 136, have been included in cutting and grazing experiments. The former is a local variety, native to the Quilichao region; the latter is an accession from the Llanos. Data obtained so far indicate that 184 is the higher yielding of the two accessions, in both cutting (Table 12) and grazing trials.

Since October 1975, a total of 158 *Stylosanthes* accessions have been established at El Limonar (near Quilichao) for initial observation. Some high-yielding ecotypes were identified among the accessions of the typical robust growth form of stylo. The incidence of anthracnose in the Quilichao area has been rather low during the last two exceptionally dry years and some of the promising material selected on the basis of yield data must be checked for anthracnose tolerance over one or more seasons.

CENTROSEMA

Preliminary testing of new accessions of *Centrosema* originating from Oxisol savanna regions has been done in the greenhouse. Dry matter yields of 12 accessions of *Centrosema* grown in pots containing eight kilograms of soil are presented in Table 13.

At Quilichao *Centrosema* was regularly

Table 12. **Dry matter yields,plant nitrogen and phosphorus contents of two advanced accessions of *Stylosanthes guianensis* cut at five- and nine-week intervals at Quilichao, July 1976 to July 1977.**

	CIAT 184			CIAT 136		
Cutting frequency (weeks)	Dry Matter (t/ha/year)	Protein (%)	P (%)	Dry Matter (t/ha/year)	Protein (%)	P (%)
5	15.9	16.0	0.17	13.6	17.6	0.18
9	10.9	15.0	0.17	9.7	17.8	0.17

Table 13. **Yields attributes of 12 accessions of *Centrosema* spp. grown on Llanos soil.**

CIAT accession No.	Origin	Dry Matter yield, mean of three harvests (g/plot)
495	Venezuela	4.54 a[1]
5039	Brazil	4.50 a
411	Colombia	4.27 ab
420	Venezuela	4.04 ab
400	Venezuela	4.01 ab
497	Colombia	3.97 ab
491	Brazil	3.84 abc
5008	Colombia	3.48 bcd
458	Colombia	3.29 bcd
492	Brazil	2.99 cd
Commercial	Australian	2.87 cd
5040	Colombia	2.76 d

Means followed by a different letter are significantly different (P= 0.05) by Duncan's Multiple Range test.

higher in plant nitrogen and phosphorus content than *Stylosanthes*. This observation was recorded in various grass/legume combinations under cutting and grazing (Fig. 8).

Desmodium

Desmodium ovalifolium has shown promise at both testing sites, and it was selected for further evaluation. It is being compared with *Centrosema* and *Galactia* under six- and eight-week cutting regimes at Quilichao. Establishment and early growth of this *Desmodium* is rather slow but once established it produces yields comparable to the other legume species (Table 14).

Its stoloniferous habit and apparent compatibility with *Brachiaria decumbens* make *D. ovalifolium* a fairly attractive

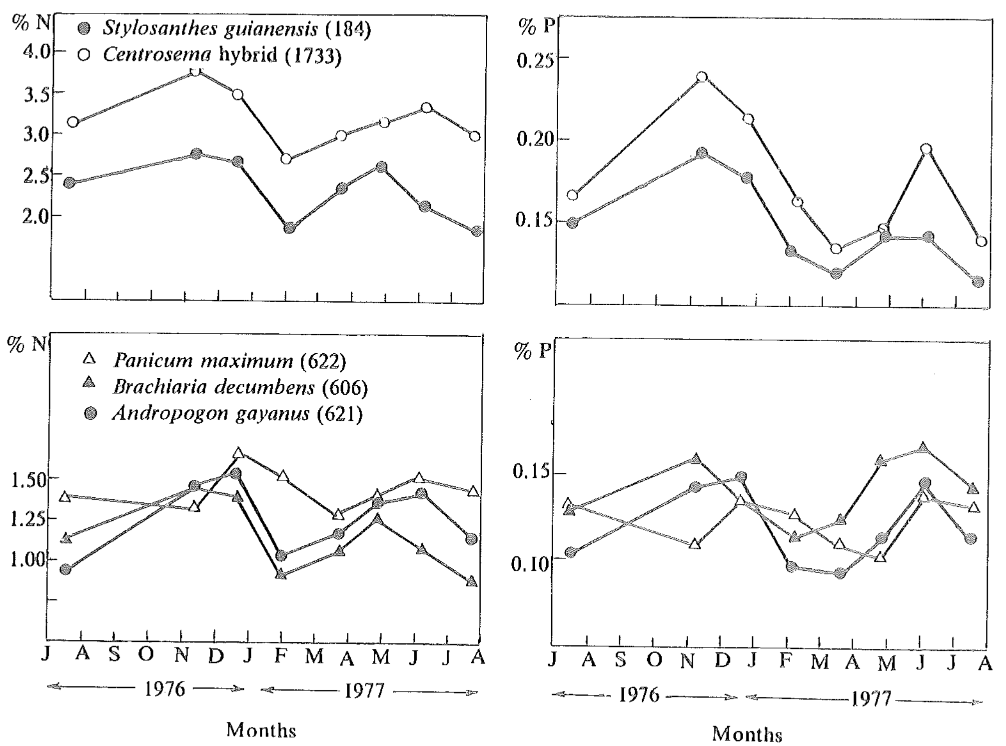


Figure 8. **Plant nitrogen and phosphorus contents of *Stylosanthes guianensis* CIAT 184, *Centrosema* CIAT 1733, *Panicum maximum* cv. Makueni, *Brachiaria decumbens* cv. Basilisk and *Andropogon gayanus* CIAT 621 all under grazing at El Limonar, (near Quilichao).**

Table 14. **Dry matter yields of *Centrosema* hybrid, *Galactia striata* and *Desmodium ovalifolium* at El Limonar (near Quilichao), from March 1977 to October 1977.**

Species and CIAT accession No.	Harvest I	II	III	IV	Total
	(kg/ha)				
Centrosema sp. (1733)	4831 a[1]	938 cde	1692 c	1080 c	8543 a
Galactia striata (964)	3655 b	857 e	1707 c	1389 cde	7608 a
Desmodium ovalifolium (350)	3255 b	905 e	1657 cd	1166 cde	6984 a

1 Means followed by a different letter are significantly different at P = 0.05 by Duncan's Multiple Range Test

prospect for the better Oxisols. It has been established with *Andropogon gayanus, B. decumbens* and *B. humidicola* for further evaluation under cutting and/or grazing. Following preliminary studies, promising accessions of *D. scorpiurus, D. barbatum, D. heterocarpon* and *D. canum* have been established in sward plots at Quilichao.

ZORNIA

Several introductions of this little-known forage legume show promise under Llanos conditions and at Quilichao. Four accessions have been included in yield trials seeded with *Andropogon* or *Brachiaria*. Of them only CIAT 728 appears to be perennial and the others are free-seeding annuals. The annuals regenerate well from self-sown seed early in the wet season, but provide little or no feed for the dry season. Preliminary data (Table 15) indicate that the perennial form, CIAT 728, is more productive and better adapted to the longer growing season of the Llanos as well as the Quilichao site. To date, no serious insect or disease problems have been identified in *Zornia*.

Table 15. **Wet and dry season yields (two harvests) of five accessions of *Zornia* spp. at Quilichao.**

CIAT accession No.	Dry Matter yield March to October, 1977 (kg/ha)
728	8168
814	4067
883	2072
802	2048
897	1496

EVALUATION IN MIXED STANDS UNDER GRAZING

The African gamba grass *(Andropogon gayanus)* continued to show good potential at Quilichao as well as at Carimagua. This introduction is being observed in the third year and it was included in cutting experiments and grazing tests, in mixtures with several legume species e.g.: *S. guianensis, Centrosema* hybrid, *Galactia striata,* and *S. capitata.*

It is well-adapted to acid soils, tolerant to drought and fire, has a rather moderate requirement for phosphorus, and is also tolerant to high aluminum levels. *Andropogon* out-yielded *Hyparrhenia rufa* under a five weekly cutting regime. It was compatible with stylo and centro under both cutting and grazing (Table 16).

Three hectares of *A. gayanus* were established at El Limonar in May, 1976, to test the reaction of various pasture species and grass/legume mixtures to grazing. In one experiment *S. guianensis* 184 and 136 were established with *B. decumbens* and *A. gayanus*. *Brachiaria* was the more productive of the two grass species. *Brachiaria* in association with stylo varieties produced 111-114 kg/ha/day of dry matter, while

Table 16. **Dry matter yields of *Andropogon gayanus* and *Hyparrhenia rufa* each with *Centrosema* or *Stylosanthes* under a five weekly cutting regime at El Limonar (near Quilichao) 1976-77.**

Mixture	Dry Matter yield (kg/ha/year)	Protein (%)	P (%)
Andropogon gayanus +	18,710	8.8	0.14
Centrosema hybrid 1733	4,005	19.8	0.19
Total	22,715		
Andropogon gayanus +	15,295	8.9	0.13
Stylosanthes guianensis 136	6,158	14.7	0.16
Total	21,453		
Hyparrhenia rufa +	13,665	7.5	0.11
Centrosema hybrid 1733	4,039	20.9	0.19
Total	17,704		
Hyparrhenia rufa +	13,710	7.7	0.11
Stylosanthes guianensis 136	9,563	16.1	0.18
Total	23,273		

Andropogon ranged from 46 - 71 kg/ha/-day. Maximum dry matter production of stylo was only 29 kg/ha/day. This yield was obtained in the *Andropogon*/stylo mixture (Fig. 9). The result of the slower growth rate of *Andropogon* was a higher legume content in the mixtures containing this grass species (Figure 10).

In another mixture containing the same two grass species with a mixture of legumes i.e. stylo + centro + *Galactia*, a better grass/legume balance was maintained during the first seven-month grazing period (Fig. 11).

In the third grazing test, five varieties of *Centrosema* were established with *A. gayanus* as the common companion grass. The four centros, including three hybrid varieties, outyelded (P = 0.05) the local ecotype of *C. pubescens* (Fig. 12)

The area has been under grazing since February, 1977. A rotational grazing system was adopted and the plots were

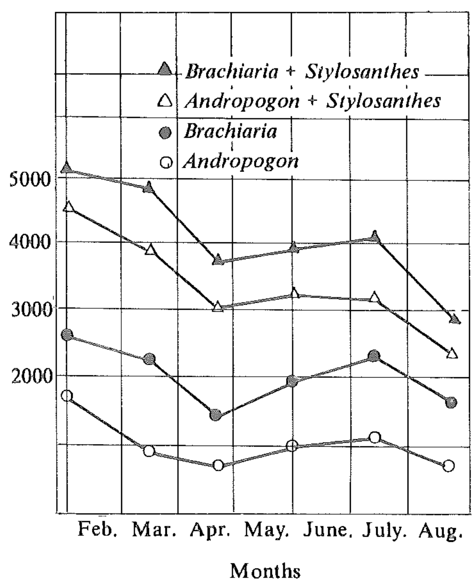


Figure 9. **Grass and legume presentation yields of *Brachiaria* and *Andropogon* alone and mixed with *Stylosanthes guianensis* (CIAT 184 & 136) at El Limonar (near Quilichao).**

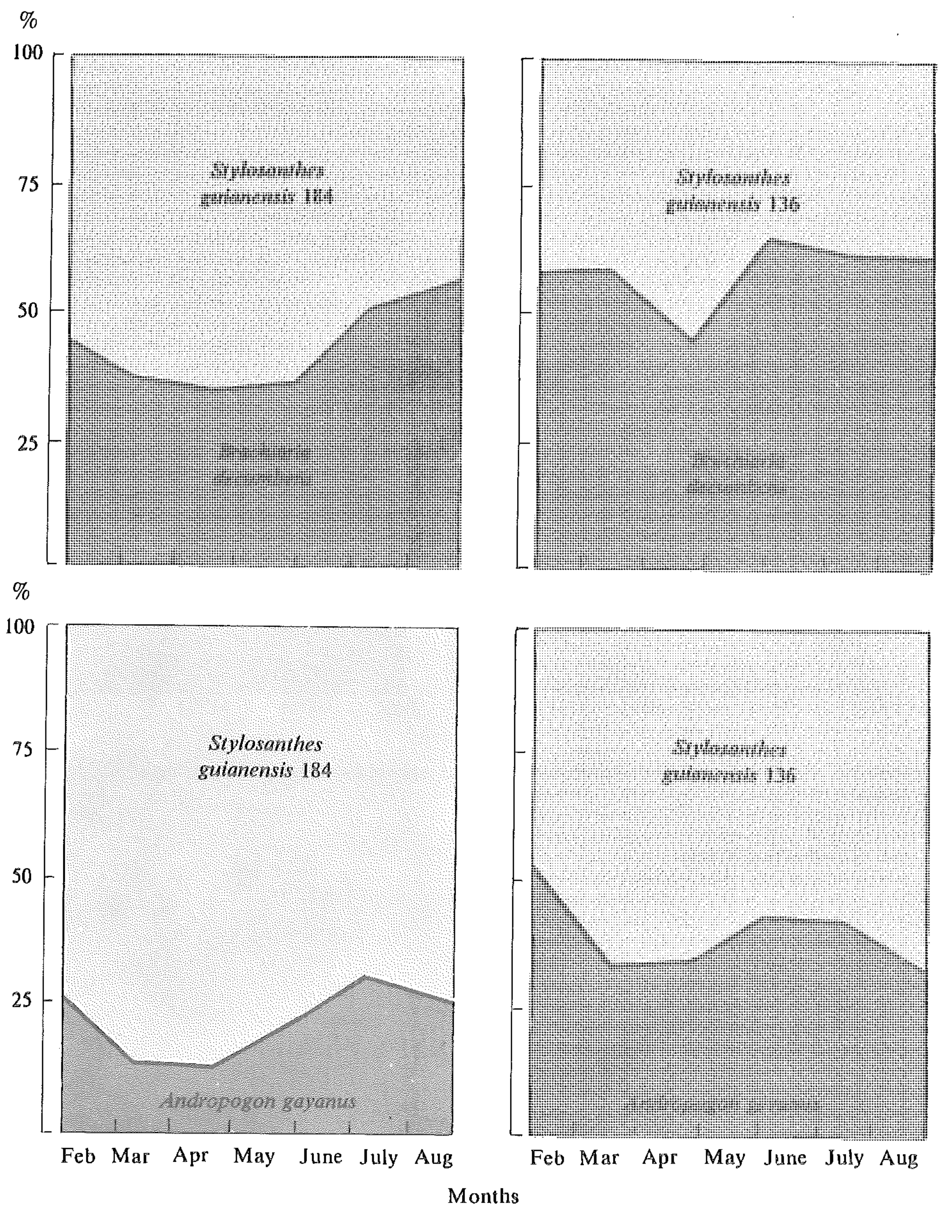


Figure 10. **Grass/legume composition of four pasture mixtures under grazing at Quilichao.**

grazed at the uniform rate of 2.3 animals/ha. The first 214-day period has been completed and in spite of the long dry season an average liveweight gain of 561 g/animal/day was obtained from Zebu steers introduced from the Colombian Llanos. These animals reached the slaughtering weight of 450 kilograms at the age of 2.5 years; in sharp contrast, animals grazing on the native *Paspalum notatum* savanna suffered severe weight losses.

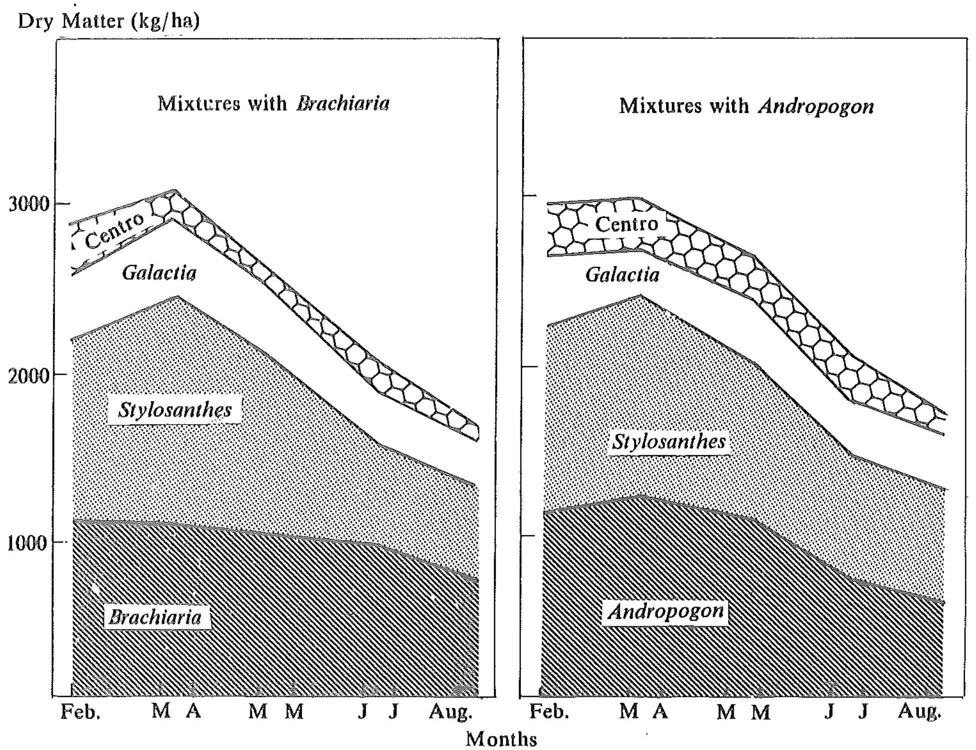


Figure 11. Dry matter yields available in two grass/legume pastures under grazing at El Limonar (near Quilichao).

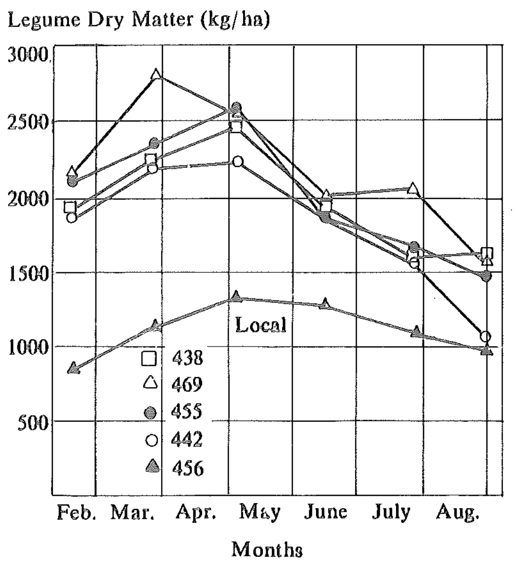


Figure 12. Dry matter available in grazed plots of five *Centrosema* varieties at El Limonar (near Quilichao).

Grass Agronomy

The newly-formed Grass Agronomy section has begun work in four areas. First, initial evaluation and characterization of accessions is being conducted at Quilichao and will be extended by regional testing to other parts of the impact area. Second, promising and well-known varieties are being studied at Quilichao and Carimagua to determine their response to drought stress, nitrogen and phosphorus requirements, tolerance to burning, and response to clipping. Third, the relative importance of competition for light and nutrients is being studied at Quilichao. Finally, mass selection for productivity, quality, and date of flowering is being conducted in *A. gayanus* (CIAT 621).

The Program's Germplasm Committee has identified the selection criteria and has determined the outstanding characteristics and research priorities for each of the most promising grass accessions (Tables 17 and 18). This list will be periodically revised to reflect changing knowledge and priorities.

Table 17. **Preliminary selection criteria for CIAT forage grasses.**

Criteria	Symbol
Adaptation to Carimagua	YC
Adaptation to Quilichao	YQ
Adaptation to medium fertility soils	YM
Disease tolerance	D
Insect tolerance	I
Water stress (drought) tolerance	W
Acid soil stress tolerance	S
Vegetative vigor	V
Flood tolerance	F
Burning tolerance	B
Seed production	Sp
Persistence under grazing	P
Nutritional quality	Q
Ease of management	M
Animal productivity	A
Compatibility with legume	C

Table 18. **CIAT forage grass accessions classified according to selection criteria, as of November 1977.**

Species	CIAT No.	Selection criteria[1] (blanks represent unknowns)											Category
		YC	YQ	YM	C	D	I	W	S	Sp	B	Q	
Andropogon gayanus	621	+	+		+	+	+	+	+		+		4
Andropogon gayanus	635								+				1
Brachiaria decumbens	6012	+	+		-	+	+	+	+	+			3
Brachiaria sp.	664								+				2
Brachiaria humidicola	6013	+	+		-				+				2
Brachiaria humidicola	679		+		-				+				2
Brachiaria ruziziensis	6019			+									1
Hemarthria altissima	603			+								+	1
Panicum maximum	622		+	+									3
Paspalum plicatulum	600								+				1

Seed Production

The objectives of the seed production section are: (1) the production of seed for the experimental needs of the Beef Program, and (2) the identification and study of the restrictions to commercial seed production within the impact area of this program. The Program's Germplasm Committee defines which genetic materials are required for experimental purposes and the seed section responds with a field production program. The strategies applied are first to identify suitable geographic regions for forage seed production and then to develop efficient production systems for particular species.

SEED INCREASE

Establishment of lots for grass seed production was continued at both Quilichao and Palmira while legumes were concentrated in the Quilichao region. Sixty-five legume accessions were increased under non-irrigated conditions at El Limonar (near Quilichao). Because of the large number of lines and small plot sizes, almost all harvesting was done manually. Most were harvested twice during the year, with the main harvest period between March-April and lighter crops in August.

The total amounts of seed produced and average annual yields are presented in Table 19. This seed provided the basis for extensive new forage evaluation studies initiated by other team members at both Carimagua and Quilichao and will provide material for regional trials. The high yield levels for the majority of legume accessions combined with low weed infestation, confirmed the utility of the Quilichao region for basic seed increase of a wide array of germplasm.

The current promising accession lists (Tables 8, 9, and 18) show the revised orientation of seed increase for the coming year. Included are 37 accessions of 23 legume species and 10 accessions of 8 grass species. Some 8.5 hectares of new lots were established at the Quilichao site during September and October and will be managed with supplemental irrigation and mechanical harvesting.

LEGUME SEED PRODUCTION TECHNOLOGY

The two most advanced *Stylosanthes guianensis* accessions (CIAT 136 and 184) showed highly contrasting phenology and yield patterns at Quilichao. CIAT 136 was harvested once, in January, and yielded 95 kg/ha of pure seed. CIAT 184, however, flowered throughout the year and was harvested in January, May and August, yielding 41, 102 and 117 kg/ha respectively, for a total yield of 260 kg/ha/year. Neither accession responded to phosphorus above 45 kg P_2O_5/ha. Defoliation prior to the January harvest, while not affecting yield of CIAT 184, did increase yield of CIAT 136 at the 135 kg/ha level of P_2O_5.

Stylosanthes capitata proved to be a good seed producer as low density, hand-harvested stands produced yields averaging 266 kg/ha during the establishment year.

Seed yield of *Centrosema* sp. (CIAT 1733) was studied on a trellis support system at Quilichao, with row spacings of one, two and three meters. Yield declined with increasing spacing from 877 to 515 to 466 kg/ha, respectively. At Palmira by comparison, a two-meter trellis system yielded 90 kg/ha. In another hand-harvested varietal comparison at Quilichao, but without a support system, CIAT 1733 and common centro produced equal seed yields. The high hand-harvested seed yields of *Centrosema* spp. at Quilichao, averaging 750 kg/ha, indicate a

Table 19. **Summary of forage seed produced at CIAT from October 1976 to October 1977.**

Species	Number of accessions	Total seed produced (kg)	Average seed yield (kg/ha/year)	Type of seed
Sylosanthes				
capitata	5	41.0	266	in pod
guianensis	11	43.0	64	"
hamata	2	51.0	283	"
scabra	8	5.9	254	"
sympodialis	2	4.5	163	"
viscosa	2	0.5	45	"
Desmodium				
heterophyllum	1	15.1	302	pure
canum	4	1.2	162	"
spp.	24	5.6		"
Centrosema				
pubescens	1	17.4	650	pure
spp.	3	162.3	750	"
Macroptilium spp.	2	8.7	192	pure
Andropogon gayanus	2	350.0	120	graded
Panicum maximum	2	20.0	48	graded
Brachiaria decumbens	2	31.0	57	graded

high potential for successful mechanical harvesting in this region (Fig. 13).

Desmodium heterophyllum produced abundant seed at Quilichao during 1977. The below average rainfall (about 450 millimeters) during the second 1976 rainy season may have provided ideal conditions for successive flushes of flowering, seed maturity and accumulation of shed seed on the ground. Seed was harvested by clipping to remove all above-ground growth (which contained no seed) followed by several passes with a small suction harvester (Fig. 14). The average pure seed yield per crop was 265 kg/ha, but the average annual yield was 302 kg/ha. This is the first instance where economic seed production appears possible for this valuable species.

GRASS SEED PRODUCTION TECHNOLOGY

Andropogon gayanus CIAT 621 initiates flowering throughout the year at Palmira and Quilichao. Flowering is variable between plants and very prolonged within plants. Mature spikelets are shed progressively. As a result, optimum harvest maturity is difficult to determine and harvest efficiency is low. To date all lots have been hand-harvested with flowering stems left in the field for 3-6 days before hand threshing and natural shade drying.

Figure 13. High seed yields were obtained with *Centrosema* hybrid on trellises at Quilichao.

Figure 14. Suction harvesting of *Desmodium heterophyllum* at Quilichao.

Spikelets have been machine-threshed or hand-rubbed over wire screens then passed over a gravity table. Graded seed lots contained as much as 45 percent cariopses. Yields last year were extremely variable, ranging from 30-300 kg/ha of graded seed and reflecting the below-average rainfall. Germination of untreated pure seed has been as high as 65 percent at nine months from harvest.

Seed yield of *Brachiaria decumbens* was recorded in various crops in the Cauca Valley where the species flowers from early June until October. The earliest crop matured in late June and the majority from mid- to late July. Hand-harvested crops yielded from 15-50 kg/ha pure seed. With irrigation and nitrogen fertilizer a second crop was harvested in early September. The highest yield recorded from one such area was 68 kg/ha/yr. These modest yields reflect a low proportion of flowering tillers, poor synchronization of flowering, and inadequate nitrogen nutrition.

Plant Protection

The Plant Protection section of the Beef Program was established in July 1977, with the arrival of an entomologist. It has three objectives: (a) to conduct basic studies (taxonomy, biology, ecology, population dynamics of the main insect pests); (b) to determine economic thresholds to define priorities; and, (c) to develop an integrated control program of the pests on promising pasture legumes. The plant pathology dimension is expected to start in 1978.

STEM BORER

A survey of stem borer damage caused possibly by *Zaratha* spp. on stylo accessions together with biological and preliminary evaluation of plant resistance have been initiated, to establish the status and importance of the pest. The initial evaluation was carried out on available material at Quilichao and Carimagua. At both locations random samples of all available accessions were evaluated for stem borer damage (Tables 20 and 21). At Quilichao, all 19 accessions evaluated showed damage, but CIAT 1019, 1152, 1102, 184, 1009, 1057 and 1094 showed the lowest levels of infestation.

An average of 88 percent of infestation was recorded at Carimagua, and 84 percent at Quilichao. However, a high percentage of accessions growing at Quilichao, showed low infestation. At Carimagua, *S. guianensis* CIAT 1385 which was not planted at Quilichao, did not show any stem borer damage. This may indicate that this material could have better levels of resistance or tolerance to this insect, or that the environment and/or other factors may favor higher insect populations at Carimagua. These possibilities will be further evaluated.

To determine which part of the plant is the most attacked by the borer, evaluations were made on upper, middle and lower thirds (Table 22). Observations indicated that stem borer attacks begin at the basal part of the plant in which the females

Table 20. **Preliminary evaluation of *Stylosanthes* spp. to stem borer (possibly *Zaratha* sp.) at Quilichao.**

Accessions	No. of random samples	Stem borer damage
Stylosanthes guianensis		
136	3	+[1]
184	3	+
191A	3	+
1094	3	+
1098	3	+
1071	3	+
1067A	3	+
Stylosanthes capitata		
1019	3	+
1078	3	+
Stylosanthes scabra		
1064	3	+
1009	3	+
Stylosanthes viscosa		
1057	3	+
1096	3	+
Stylosanthes angustifolia		
1102	3	+
Stylosanthes sp.		
1043	3	+
1051A	3	+
1051B	3	+
1122	3	+
1152	3	+

1 + Indicates stem borer damage.

Table 21. **Preliminary evaluation of *Stylosanthes* spp. to stem borer (possibly *Zaratha* sp.) at Carimagua.**

Accessions	No. of random samples	Stem borer damage
Stylosanthes guianensis		
1182	3	+[1]
1203	3	+
1285	3	+
Stylosanthes capitata		
1298	3	+
1315	3	+
1342	3	+
1191A	3	+
Stylosanthes viscosa		
1273	3	+
1059	3	+
1062	3	+
Stylosanthes sp.		
1152	3	—
1281	3	+
1051B	3	+
1385	3	—
1448	3	+
1215	3	+
1277	3	+

1 + Indicates stem borer damage; — indicates no damage.

presumably oviposit. The larvae then penetrate the stem and commence to build tunnels. Plants attacked by stem borer

Table 22. **Stem borer distribution, within *Stylosanthes* plants, at Quilichao.**

Distribution	No. of plants examined	No. of lesions	Infestation (%)
Upper third	57	8	5
Middle third	57	64	38
Lower third	57	94	57

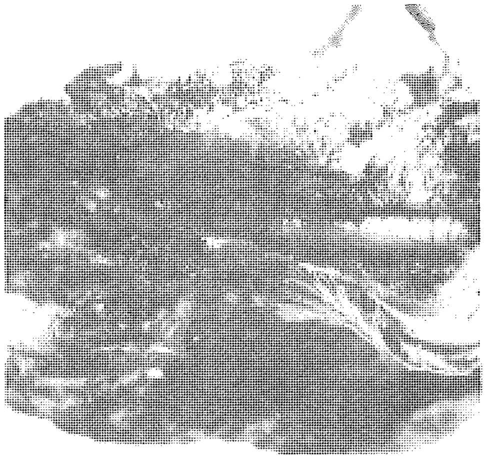


Figure 15. *Stylosanthes scabra* **affected by the stem borer (possibly *Zaratha* sp.), showing pupation site.**

develop gall-like malformations. In these structures, which become soft and decomposed, several larvae and pupae can be found.

Last instar larvae are approximately 8.5 millimeters long and white in color. The adult is a microlepidoptera and is brown-grey in color with very long filiform antennae. (Figs. 15, 16, 17).

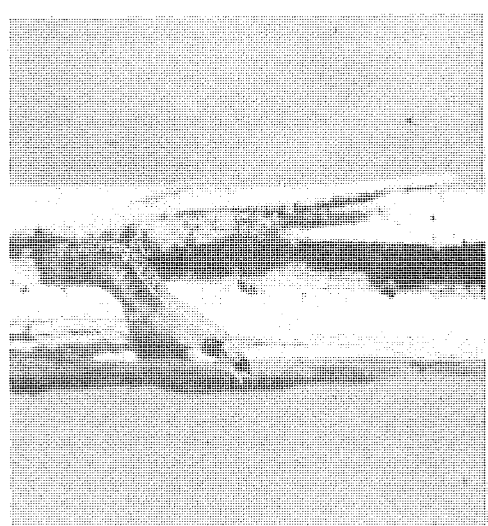


Figure 16. *Stylosanthes capitata* **showing damage caused by the stem borer larva (possibly *Zaratha* sp.).**

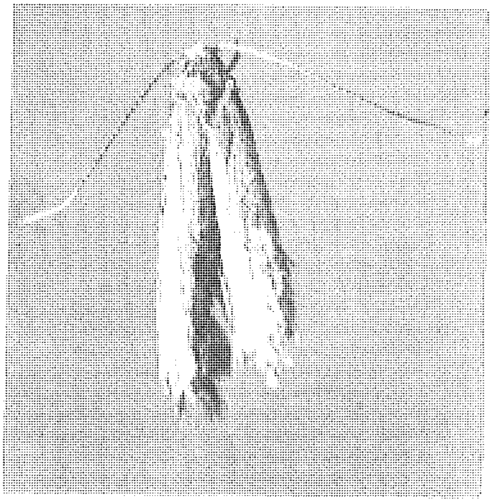


Figure 17. Stem borer adult (possibly *Zaratha* sp.).

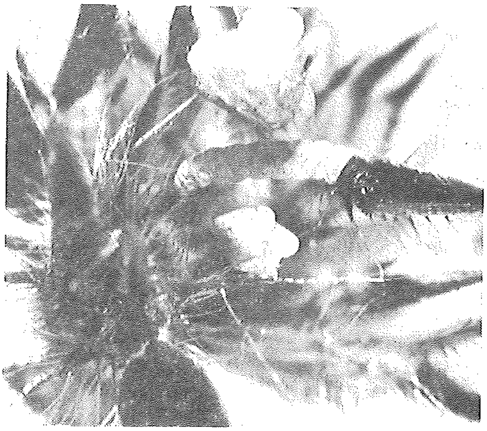


Figure 18. *Stylosanthes guianensis* attacked by the budworm, *Stegasta bosqueella* (Chambers) Lepidoptera, Gelechiidae.

Stem Borer Parasite

Adult parasites of the order Hymenoptera were found in laboratory examinations of material collected from Quilichao. Studies of these parasites will continue.

Alternate Hosts

In Carimagua, the weed called "Escoba" (*Sida* sp.) has been observed infested with stem borers. This weed is also host to another borer, a beetle probably belonging to the family Curculionidae, which occasionally attacks stylo plants.

BUDWORM

The budworm, identified as *Stegasta bosqueella* (Chambers) Lepidoptera, Gelechiidae, is another pest of *Stylosanthes*. The eggs of *Stegasta* are white and elongated, about 0.2 millimeters long, and have a corrugated surface. The females lay their eggs on the trichomes of the external bracts of the inflorescence. One larva is usually found per bud. First instar larvae are approximately 1 millimeter long, and milky-white in color with a dark-reddish cervical plate. Last instar larvae become pinkish in color and are approximately 6 millimeters long. The adult is a microlepidoptera, 5 millimeters long, black in color with a yellow spot on the dorso and two small lateral spots on the wings (Fig. 18 and 19). Two different parasites of the budworm belonging to the order Hymenoptera have been obtained at Quilichao.

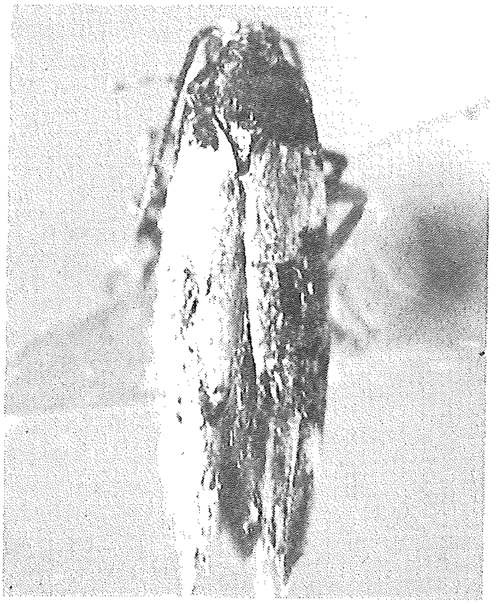


Figure 19. Adult of the budworm, *Stegasta bosqueella* (Chambers) Lepidoptera, Gelechiidae.

Soil Microbiology

The objective of the Soil Microbiology section is to maximize the benefits of biological nitrogen fixation to adapted forages in the acid, infertile soils of tropical Latin America. Although "forages" implies both grasses and legumes, priority has been given to the legume/*Rhizobium* symbiosis. The research strategy is: (1) to maintain and augment the CIAT *Rhizobium* germplasm resource; (2) to evaluate the symbiotic nitrogen fixation potential of *Rhizobium* strains with adapted legumes; and, (3) to test expression of symbiotic potential of selected strains in field situations, initially at Quilichao, Carimagua and Brasilia, and then in regional trials throughout the Beef Program's target area.

RHIZOBIUM COLLECTION

There were 1051 strains for forage legumes in the CIAT *Rhizobium* Collection as of October 31, 1977; of these, 644 were added during 1977. These have been isolated from 111 species in 50 genera. For each strain the following information is recorded and stored in an information retrieval system.

Relating to origin:

- **Genus*** from which strain was isolated.
- **Species*** from which strain was isolated.
- **Accession number*** of plant of origin (seed of the plant of origin may be conserved in the CIAT Forage Germplasm Bank).
- **Source***. If isolated and supplied by another laboratory this is acknowledged by inclusion of the original strain number. If isolated at CIAT the collector is acknowledged.
- **Country** where collected.
- **State** where collected.
- **Rainfall** (mm/year) at collection site.
- **Temperature*** (mean daily temperature (°C) during growing season).
- **Land use** at collection site.
- **pH*** of soil at collection site.

Relating to growth in pure culture:

- **Days*** to reach 2 mm colony diameter on YMA (28°C).
- **Acid*** or **alkali*** producer on YMA with bromthymol blue.
- **Comments** on colony appearance.

Relating to strain efficiency:

- **Effectiveness*** with individual plant species (and accessions).
- **Acetylene reduction** (per plant and per unit weight of nodules).

A catalogue which includes those parameters of wide interest (marked with an asterisk above) was published and is available from the Beef Program on request. A compact, sturdy kit which facilitates surface sterilization of legume root nodules and the transfer of nodule bacteria onto culture plates has been developed for use by plant explorers during prolonged collecting expeditions in remote regions. The main advantages offered over conventional collection methods based on retrieval of dessicated nodules are that the success rate with isolations from small nodules (especially from *Stylosanthes* spp.) is increased from 12 to 85 percent and that quarantine regulations prohibiting the importation of plant material and/or soil are not applicable to this system.

STRAIN SELECTION

The fives stages of strain selection are described in Table 23. The following is a summary of the trials conducted during

Table 23. **Procedure for *Rhizobium* strain selection.**

Stage	To assess	Method
I	Genetic compatibility	Inoculation of plants cultured aseptically in agar deeps of Hensen's medium in 150 x 25 mm tubes. Five replicates. Data: + or -nodulation
II	Nitrogen fixation potential	Inoculation of plants cultured in Leonard jar assemblies using washed river sand as rooting medium and Norris and Date's nutrient solution. Five replicates. Data: dry matter and N content.
III	Physical and chemical stress	Inoculation of plants cultured in pots of sterilized (methyl bromide) site soils. Five replicates. Data: dry matter and N content.
IV	Biological and climatological stress	Field trial of three best strains from III inoculated by three techniques (simple inoculation, lime pelleting and rock phosphate pelleting). Randomized complete block design (3 replicates) using 4 x 2 m plots with 1 m drainage canals around each. Data: dry matter and N content; % nodulation due to inoculant strain.
V	Range of applicability of recommendation	Regional trial of inoculation recommendation (strain and technology) compared with uninoculated and nitrogen fertilized plots. Three replicates. Data: dry matter and N content; % nodulation due to inoculant strain.

1977 (no trials were done in Stages III and V).

Stage I

Desmodium heterophyllum (CIAT 349) was nodulated by 10, and *Desmodium ovalifolium* (CIAT 350), by 35 of a total of 39 *Rhizobium* strains originally isolated from *Desmodium* species (Table 24).

Stage II

In an evaluation of 48 strains (all *Centrosema* isolates) with the *Centrosema* hybrid CIAT 1733 (*C. brasilianum* x *C. virginianum*) the commercial strain for *C. pubescens* was only partially effective, whereas several local isolates (CIAT 193, 221, 224, 227, 590, and 602) were outstanding, giving higher dry matter yields than those plants that were grown with combined nitrogen (Fig. 20). The best two strains (CIAT 583 and CIAT 584) were isolated at CIAT from dessicated nodules collected in Mexico from *C. brasilianum*, one of the parents in the cross. The black nodule strain C 101a (CIAT 49) was among the most efficient strains. Crude protein content (Kjeldahl Nx6.25) of shoots of plants with efficient symbioses averaged 20.7 percent, compared to 6 percent in non-nodulated plants, 11.3 percent in plants with nitrogen available in the media, and 12 percent in inefficient symbioses.

In a trial of 35 strains with *Desmodium distortum* (CIAT 335), the current Australian recommendation for *D. intor-*

Table 24. **Contrasting compatibility ranges of *Desmodium heterophyllum* (CIAT 349) and *Desmodium ovalifolium* (CIAT 350) with 39 *Rhizobium* strains.**

CIAT[1] Strain No.	*Desmodium heterophyllum*	*Desmodium ovalifolium*	CIAT[1] Strain No.	*Desmodium heterophyllum*	*Desmodium ovalifolium*
13	-[2]	+	296	-	+
31	+	-	297	+	+
46	-	+	298	-	+
59	-	+	299	-	+
80	+	+	304	-	+
109	+	+	310	-	-
164	-	+	329	+	+
187	-	+	353	-	+
259	-	-	359	-	+
272	-	-	388	+	+
282	-	+	507	+	+
283	-	+	512	-	+
284	-	+	529	+	+
288	+	+	533	-	+
289	-	+	571	-	+
290	-	+	572	+	+
291	-	+	573	-	+
293	-	+	592	-	+
294	-	-	595	-	+
295	-	+			

All strains isolates from nodules of *Desmodium* species. [2] +: Nodulated (two or more of the five replicates nodulated); –: Non-nodulated.

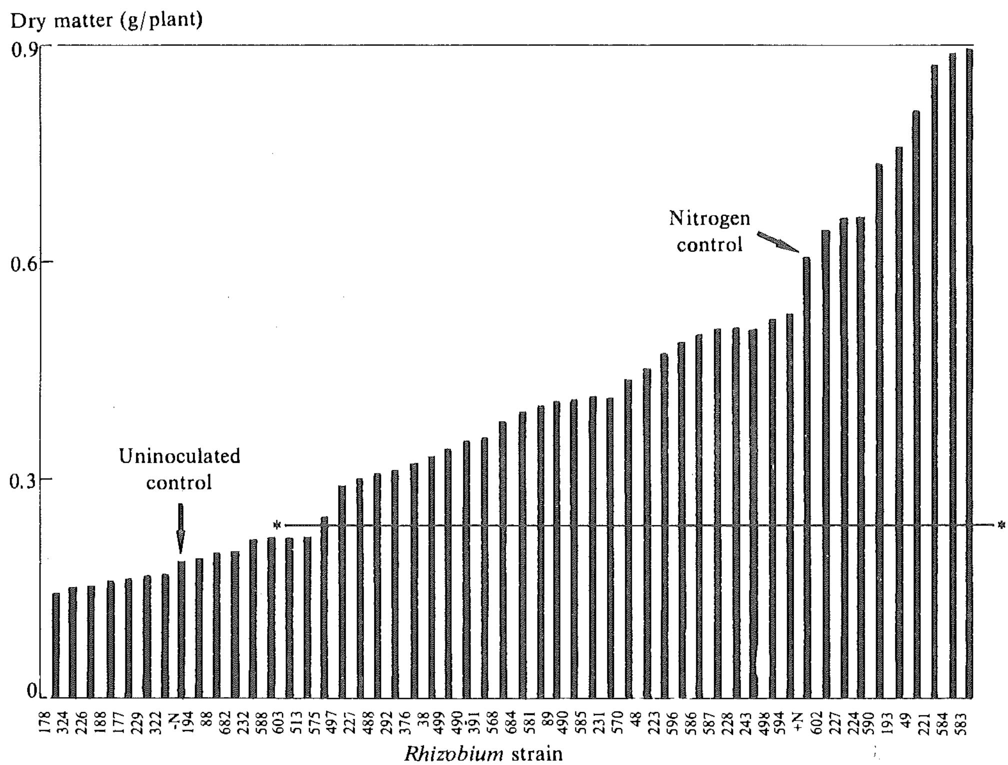


Figure 20. *Rhizobium* **strain selection for** *Centrosema* **hybrid (Stage II). (* Upper confidence limit (95%) to mean of uninoculated control.)**

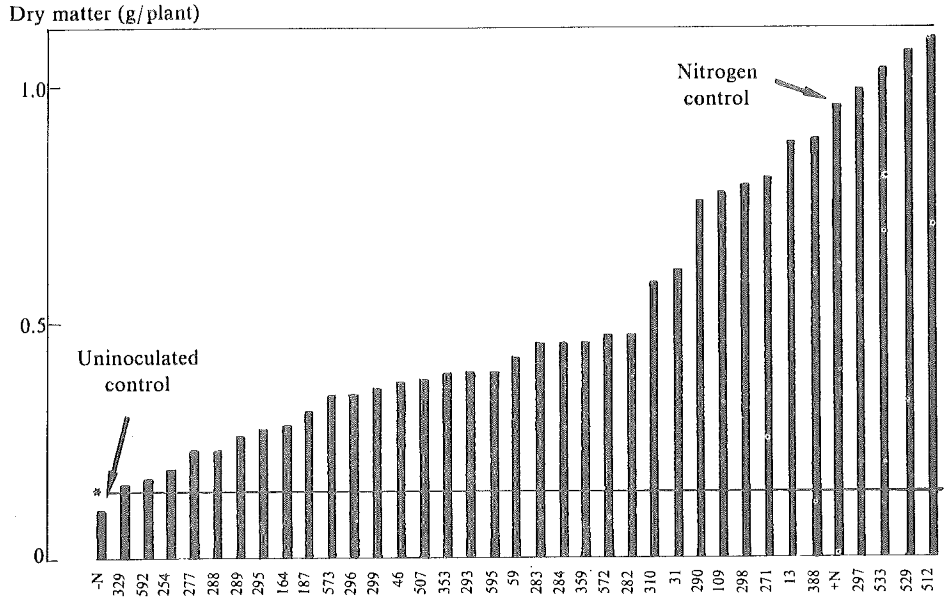


Figura 21. *Rhizobium* **strain selection for** *Desmodium distortum* **(Stage II). (* Upper confidence limit (95%) to mean of uninoculated control.)**

tum (CB 627) was ninth in efficiency order (Fig. 21). CIAT 512 and 533 gave 33 percent more dry matter than CB 627. The best strain in the test (CIAT 512) was the

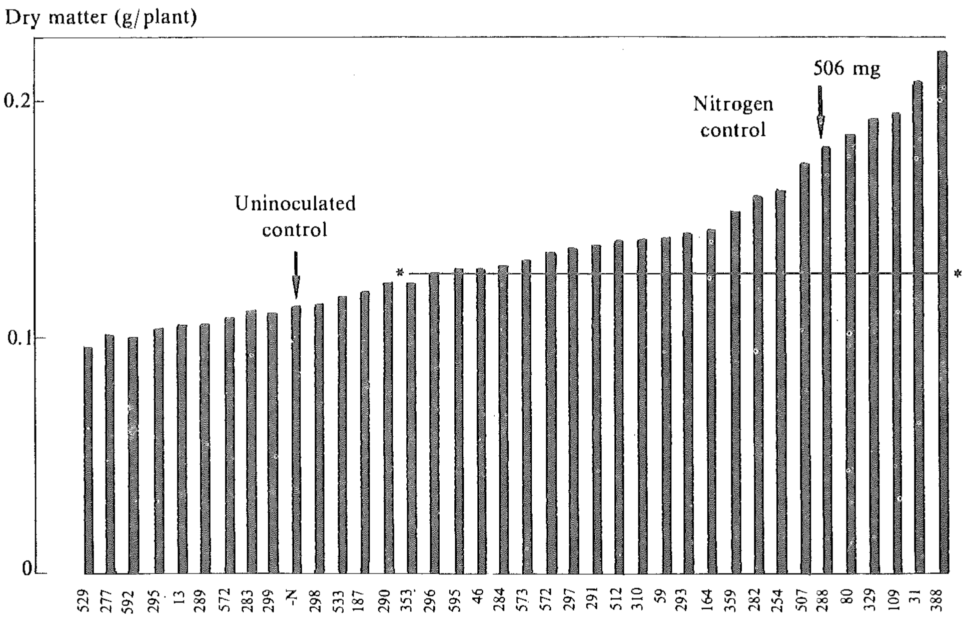


Figure 22. *Rhizobium* **strain selection for** *Desmodium heterophyllum* **(Stage II). (* Upper confidence limit (95%) to mean of uninoculated control.)**

only one originally isolated from nodules of *D. distortum*.

D. heterophyllum is known to be specific in its *Rhizobium* strain requirement. Only seven of 37 *Desmodium* isolates formed effective associations (Fig. 22). The Australian recommendation (CB 2085) for *D. heterophyllum* was efficient in this test.

Stage IV

Ten field experiments of the standardized design outlined in Table 23 were sown, six at Quilichao and four at Carimagua.

Quilichao. Inoculation of *Galactia striata* (CIAT 969) with *Rhizobium* strain CIAT 378 increased the dry matter yield 20 percent and the percentage protein of cut forage by 18 percent during establishment (Fig. 23); at the second cut, however, dry matter yield of inoculated plots was not significantly different from the uninoculated control. The *Centrosema* hybrid (CIAT 1733) responded slightly to inoculation with CIAT 590 and CIAT 594, with no consistent effect due to the inoculation method (Fig. 23). *Stylosanthes guianensis* (CIAT 136) responded to inoculation with all three strains, and rock phosphate-pelleting was consistently superior to lime-pelleting (Fig. 23). Simple inoculation, i.e. wetting seeds with an aqueous suspension of inoculant, was adequate for the strains CIAT 71 and CIAT 702 (isolates from acid soils) but not for CIAT 79 (CB 756) a wide-spectrum cowpea strain. Plots inoculated with CIAT 71 were markedly superior to all others at weekly visual assessments during the first two months of establishment but less so during the third month. By the time of the first cut (14 weeks after sowing) plots inoculated with CIAT 71 did not differ significantly from those inoculated with CIAT 79. CIAT 71 had proven much more efficient than CIAT 79 in Stage II and Stage III (CIAT Annual Report, 1976). This early advantage from inoculation with *Rhizobium* suggests its exploitation as a strategy to impart early vigor to legumes which are notoriously slow to establish in mixed pastures.

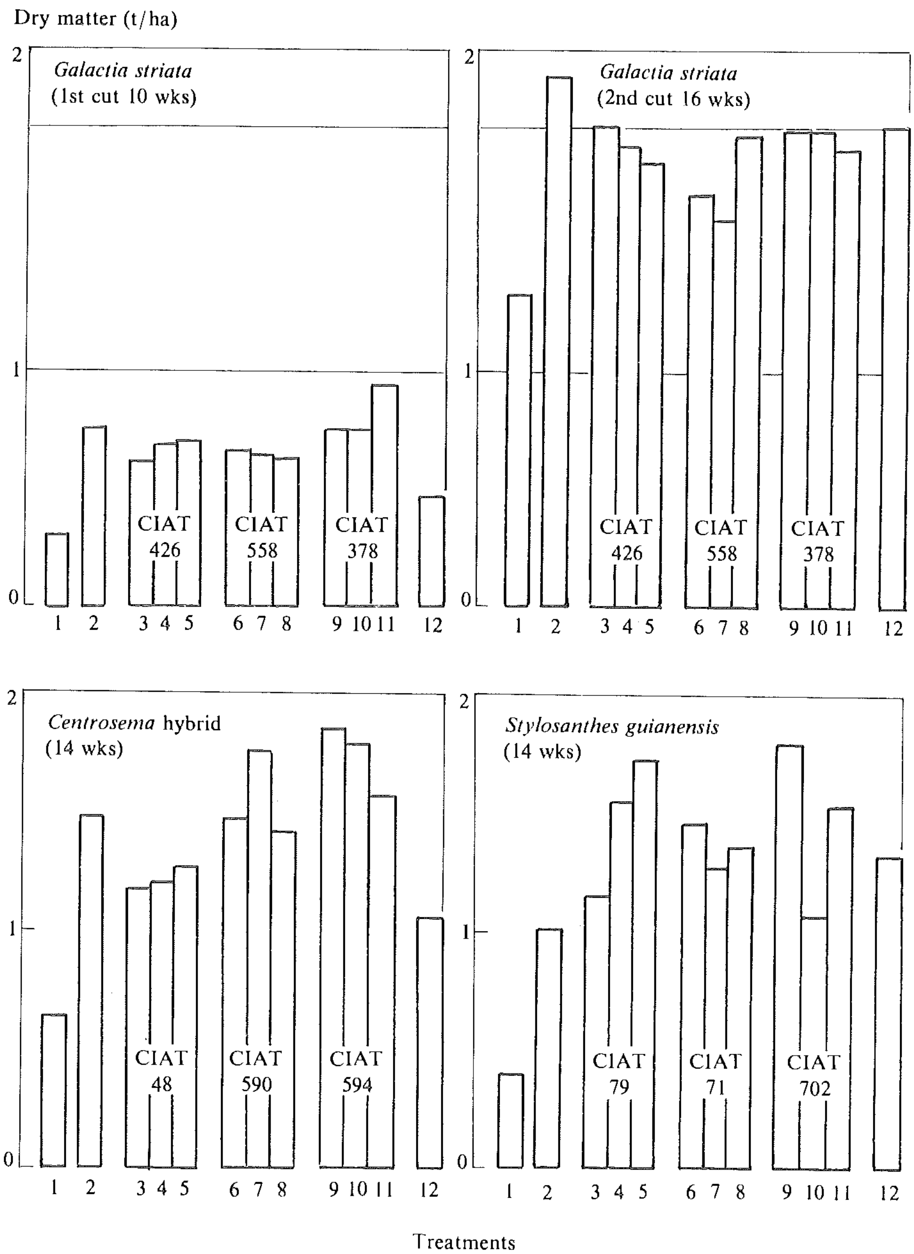
Carimagua. *Macroptilium* sp. (CIAT 535) responded to inoculation with all three *Rhizobium* strains (Fig. 24). CIAT 318 was the most effective strain and lime-pelleting was the best inoculation technology. These results contradict traditional concepts that *Macroptilium* is unresponsive to *Rhizobium* inoculation and that slow growing (tropical) rhizobia should not be lime-pelleted. Trials with *D. ovalifolium, S. capitata* (CIAT 1019) and *S. capitata* (CIAT 1078) are in progress.

INOCULATION RECOMMENDATIONS

An inoculation recommendation has been made for each promising legume accession under evaluation (Table 25). Although preferable that each recommendation is based on field evaluations (Stage V) it has been necesary to make tentative recommendations based on early screening stages or, in the case of accessions still pending investigation, Australian recommendations. In a few cases, tentative recommendations were made on the basis that the strain was isolated from the same species.

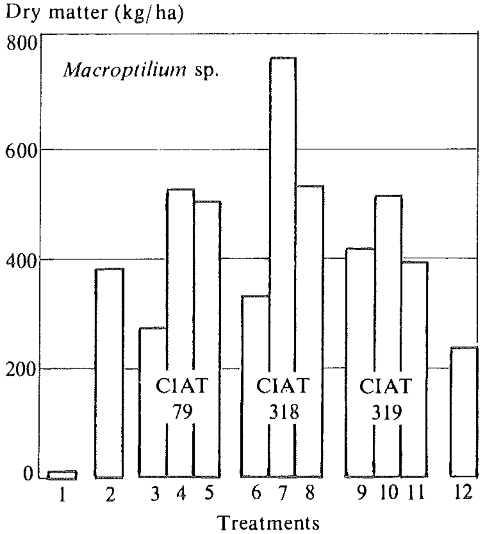
INOCULANT CARRIERS

Peat-based legume inoculant is available for all accessions for which inoculation is recommended (and also for all agriculturally important forage legumes). Finely-milled peat is widely accepted as the most satisfactory carrier for rhizobia but is not available in many countries, or is of variable and unpredictable quality. In Colombia peat from only one of nine deposits tested for use as an inoculant base exhibited satisfactory survival of rhizobia. The inconvenient location of this peat source and suspicions about quality variability within the deposit was the motive for comparative evaluation of peat with coals from three local mines.



Treatments: (1) Not fertilized, not inoculated; (2) Fertilized (no N), not inoculated; (3), (6), (9) Inoculated with aqueous suspension of *Rhizobium;* (4), (7), (10) Inoculated with *Rhizobium,* lime-pelleted; (5), (8), (11) Inoculated with *Rhizobium,* rock phosphate-pelleted; (12) Fertilized (100 kg N/ha), not inoculated.

Figure 23. *Rhizobium* **strain selection Stage IV (field trial, Quilichao).**



Treatments: See Figure 23.

Figure 24. *Rhizobium* **strain selection Stage IV (field trial, Carimagua).**

The survival of rhizobia in coal- and peat-based inoculants was determined by the plant dilution method. Peat afforded best survival, having 1.2 x 10^9 rhizobia/gram of inoculant after six months of storage. One of the three coals tested supported acceptable survival of rhizobia (Fig. 25) but could not be recommended as an inoculant base due to its tendency to aggregate into hard lumps during storage and to resist wetting at the time of seed inoculation.

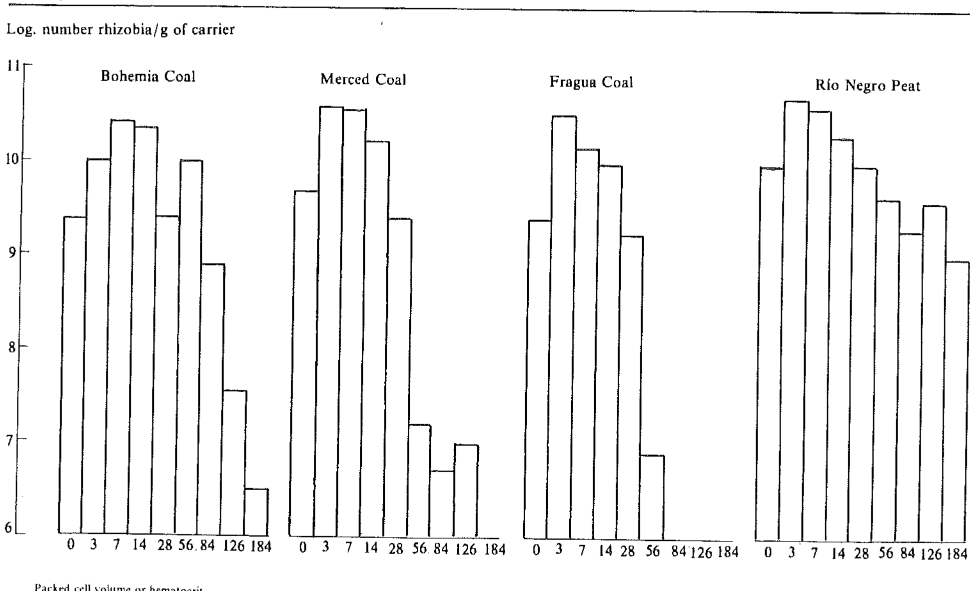
Table 25. **Current inoculation recommendations for promising forage legumes (31 October, 1977).**

Species	CIAT No.	Strain	Technology	Basis[1]
Alysicarpus sp.	706	CIAT 503	Rock Phosphate Pellet	SS
Centrosema sp.	1733	CIAT 594	Rock Phosphate Pellet	I, II, IV
"	1787	CIAT 594	Rock Phosphate Pellet	I; II; IV
"	845	CIAT 594	Rock Phosphate Pellet	I; II; IV
Desmodium barbatum	3063	CIAT 359	Rock Phosphate Pellet	SS
" *canum*	3005	—	-	
" *distortum*	335	CIAT 512	Rock Phosphate Pellet	SS; II
" *heterocarpon*	365	—	—	
" *heterophyllum*	349	CIAT 80	Rock Phosphate Pellet	AUS; II; FB
" *leonii*	3001	—	—	
" *ovalifolium*	350	CIAT 46	Rock Phosphate Pellet	II; IV; FB
" *scorpiurus*	3022	—	—	
" sp.	336	—	—	
" sp.	3019	—	—	
Glycine wightii	201	CIAT 79	Rock Phosphate Pellet	AUS
" "	204	CIAT 79	Rock Phosphate Pellet	AUS
Macroptilium sp.	535	CIAT 318	Lime Pellet	IV
Pueraria phaseoloides	(common)	CIAT 79	Rock Phosphate Pellet	AUS
Stylosanthes capitata	1019	CIAT 71	Rock Phosphate Pellet	III; FB
" "	1078	CIAT 71	Rock Phosphate Pellet	III; FB
" "	1097	CIAT 71	Rock Phosphate Pellet	III
" "	1405	CIAT 71	Rock Phosphate Pellet	III

Basis: AUS = Australian recommendation; SS = Isolate from same species; FB = Feed Back Program use. Strain Selection Stages: I = Tube culture; II = Leonard jar; III = Pot trial; IV = Field trial; V = Regional trial.

Table 25. (continued)

Species	CIAT No.	Strain	Technology	Basis[1]
S. guianensis	64A	CIAT 71	Rock Phosphate Pellet	I; II
" "	136	CIAT 71	Rock Phosphate Pellet	I; II; III; IV; FB
" "	184	CIAT 71	Rock Phosphate Pellet	I; III
" "	1135	CIAT 111	Rock Phosphate Pellet	AUS
" "	1200	CIAT 111	Rock Phosphate Pellet	AUS
" "	1062	CIAT 111	Rock Phosphate Pellet	AUS
S. hamata	118	CIAT 71	Rock Phosphate Pellet	III
" "	147	CIAT 71	Rock Phosphate Pellet	III
S. humilis	1304	CIAT 71	Rock Phosphate Pellet	III
S. scabra	1047	CIAT 71	Rock Phosphate Pellet	III
S. sympodialis	1044	CIAT 71	Rock Phosphate Pellet	III
S. viscosa	1074-A	CIAT 71	Rock Phosphate Pellet	III
Teramnus uncinatus	508	CIAT 452	Rock Phosphate Pellet	SS
Zornia sp.	728	CIAT 103	Rock Phosphate Pellet	SS



Packed cell volume or hematocrit.

Figure 25. Survival of rhizobia in four prospective carriers.

Soil Fertility

Soil fertility research is conducted by program soil scientists with the purpose of: (1) identifying soil limitations where field research is undertaken; and, (2) to develop more efficient methods of fertilizer management. Emphasis during 1977 was on characterizing the soil properties at the new CIAT-Quilichao station, determining

Table 26. **Characteristics of the main soils at Quilichao, Carimagua and Cerrado Center Stations.**

Horizon (cm)	Clay (%)	Sand (%)	pH (H_2O)	Org. C (%)	Exchangeable cations (meq/100 g)					Al satn (%)	Avail. P[1] (ppm)	Avail. H_2O (%, vol)
					Al	Ca	Mg	K	ECEC			
CIAT-Quilichao: Ultisol (Orthoxic Palehumult, clayey, kaolinitic, isohyperthermic).												
0-20	71	4	4.1	4.1	2.7	.65	.49	.36	4.2	64	1.8	16
20-35	77	5	4.0	2.3	2.7	.31	.04	.13	3.2	83	1.1	13
35-62	64	2	4.3	1.1	3.2	.24	.02	.09	3.6	88	0.9	16
62-91	88	1	4.4	0.4	1.1	.15	.02	.06	1.4	77	0.9	9
91-150	90	1	4.4	0.3	2.0	.22	.01	.04	2.3	85	1.2	14
Carimagua: Oxisol (Typic Haplustox, clayey, kaolinitic, isohyperthermic).												
0-12	38	12	4.5	2.2	3.8	0.2	0.2	0.4	4.7	81	0.9	9
12-32	41	11	4.6	1.2	2.8	0.1	0.1	0.1	3.1	89	0.9	7
32-58	43	11	4.8	0.9	2.1	0.1	0.1	0.1	2.3	91	0.4	5
58-88	45	12	5.2	0.4	0.7	0.1	0.1	0.1	0.9	78	0.4	6
88-148	45	12	5.1	0.3	0.6	0.1	0.1	0.1	0.8	75	0.4	7
Cerrado Center: Oxisol (Typic Haplustox, fine, kaolinitic, isohyperthemic - LVE).												
0-10	45	36	4.9	1.8	1.9		0.4	.10	2.4	79	tr.	11
10-35	48	33	4.8	1.2	2.0		0.2	.05	2.2	89	tr.	11
35-70	47	35	4.9	0.9	1.6		0.2	.03	1.8	88	tr.	9
70-150	47	35	5.0	0.7	1.5		0.2	.01	1.7	88	tr.	9
150-260	42	39	4.6	0.3	0.7		0.2	.02	0.9	76	tr.	9

[1] Bray II extraction method.

the limiting soil factors at that location, and evaluating sources and methods of phosphorus application in Oxisols and Ultisols.

SOIL PROPERTIES AT THE PRINCIPAL RESEARCH SITES

Representative profiles of well-drained positions at Quilichao, Carimagua and Brasilia are shown in Table 26. All sites are very acid, with surface pH values ranging from 4.1 to 4.9, with toxic levels of aluminum saturation. They are very low in available phosphorus, exchangeable calcium, magnesium, potassium and several micronutrients. The basic cation contents of Quilichao however, are considerably higher than at Carimagua and Brasilia, but still very much within the realm of acid, infertile soils.

Because of their high clay contents and the presence of iron and aluminum oxides, the three locations have a high capacity to fix fertilizer phosphorus. The phosphorus fixation curves in Figure 26 indicate an extremely high fixation capacity —on the order of 620 to 750 ppm phosphorus for Quilichao and Brasilia, and about one-half that amount (350 ppm) for Carimagua. For comparison, the phosphorus fixation level of the Mollisol from CIAT's headquarters at Palmira is about 50 ppm of phosphorus.

A detailed soil survey of CIAT-Quilichao was contracted with the Corporación Autónoma Regional del Valle del Cauca (CVC) at the scale of 1:20,000. The soil map indicates little variability from the profile shown in Table 26 on plateau and slope positions, all of which are classified as Orthoxic Palehumults. The poorly-drained soils in lower topographic positions are also extremely acid and low in exchangeable bases, indicating that the entire landscape is base-depleted, similar to conditions at Carimagua and Brasilia. The poorly-drained soils are also Ultisols but are classified as Umbric Paleaquults.

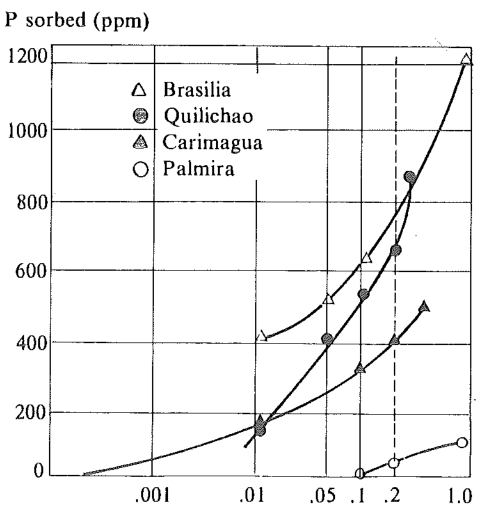


Figure 26. **Phosphorus fixation isotherms of research sites at Brasilia, CIAT-Quilichao, Carimagua and CIAT-Palmira.**

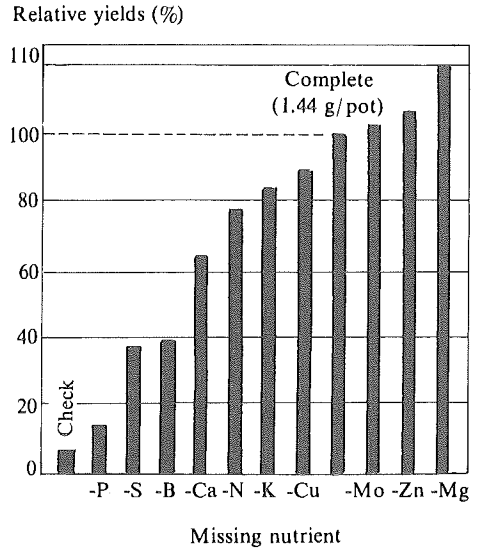


Figure 27. **Response of *Centrosema plumieri* to missing nutrient elements in the Quilichao Ultisol. (Dry matter production, at first cutting, mean of four replications.)**

Detailed mineralogical analyses conducted at North Carolina State University (USA) show that kaolinite and halloysite are the dominant layer silicate minerals. The well-drained soils average 15 percent free Fe_2O_3 and 11 percent free Al_2O_3 contents, which account for their high phosphorus fixation capacity.

FERTILITY LIMITATIONS AT CIAT-QUILICHAO

A series of greenhouse experiments were conducted with the topsoil samples of the Quilichao Ultisol described in Table 26 in order to describe its fertility status. A missing element trial showed this soil to be extremely deficient in phosphorus, sulfur and boron and, to a lesser extent, calcium (Fig. 27). The extremely low yield of the check plot created the suspicion of aluminum and manganese toxicity.

The magnitude of phosphorus response was then tested with *Panicum maximum* and a *Centrosema* hybrid (CIAT 1733). Both species responded sharply to

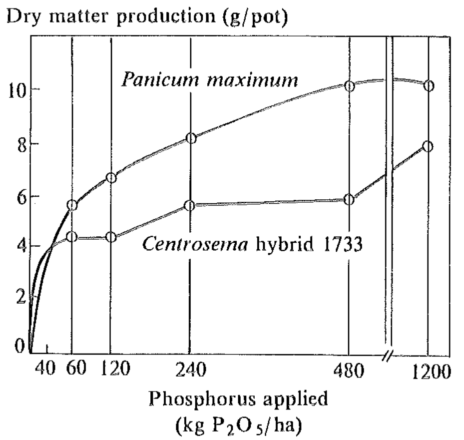


Figure 28. **Phosphorus response by a grass and a legume species in the Quilichao Ultisol. (Sum of two cuts and mean of four replications.)**

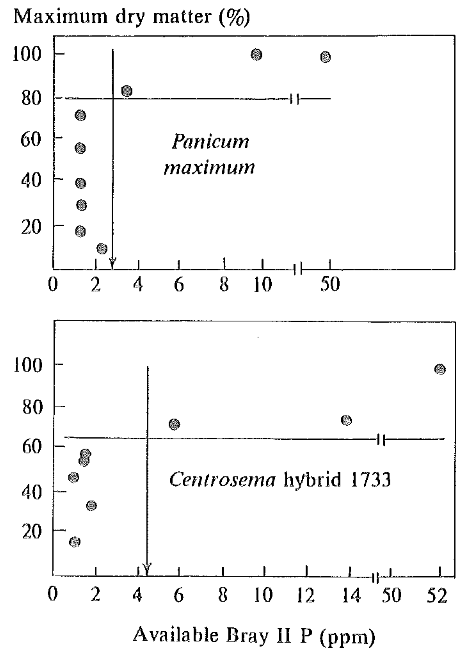


Figure 29. **Estimation of the critical phosphorus levels in the Quilichao Ultisol in the greenhouse. (Sum of two cuts and mean of four replications.)**

superphosphate applications but the amounts required to approach maximum yields were higher in the grass than in the legume. The response curves show the first inflection point at 40 kg P_2O_5/ha for *Centrosema* and 60 kg P_2O_5/ha for *P. maximum*, but each species yielded only 56 percent of its maximum at those levels (Fig. 28). The subsequent gradual increase may be related to the ameliorating properties of superphosphate although soil chemical analysis did not show marked differences.

An estimation of critical soil test phosphorus levels in the unlimed Ultisol is shown in Figure 29. In both cases, the Bray II critical level is about 3 ppm phosphorus. In order to obtain about 80 percent of the maximum yield, these two figures suggest a broadcast rate of about 240 kg P_2O_5/ha for either species.

The relationship between pH, percentage aluminum saturation and exchangeable manganese as a fuction of liming are shown in Figure 30. The buffering capacity of this soil is extremely high, probably because of its high organic matter content. In order to raise the soil pH to 5.5 approximately 16 tons/ha of $CaCO_3$ are needed. The contrasting lime response of three forage legumes is shown in Figure 31. *Stylosanthes guianensis* 136 yielded best without lime applications, confirming its tolerance to the relatively high aluminum saturation and exchangeable manganese levels. The decrease at high lime rates is due to a calcium:magnesium inbalance. The *Centrosema* hybrid (CIAT 1733) showed a marked response to the 1 t/ha lime rate and decreased afterwards. The reasons for this response are unknown. *Centrosema plumieri*, a species adapted to high pH soils, required 8 t/ha of lime to approach maximum yields. This figure underscores the importance of selecting for aluminum tolerance as part of CIAT's low input strategy.

In summary, the Quilichao Ultisol is extremely deficient in phosphorus, sulfur and boron, moderately deficient in calcium, potassium and nitrogen and aluminum toxic for certain species.

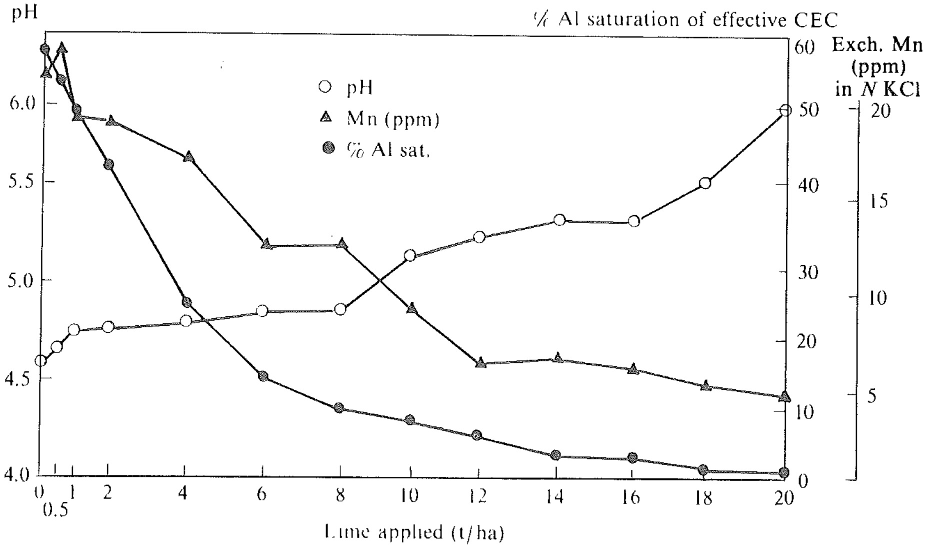


Figure 30. Soil pH, exchangeable manganese and percentage aluminum saturation of effective CEC as affected by increasing lime rate of application on an Ultisol from CIAT-Quilichao. (Incubation time 60 days.)

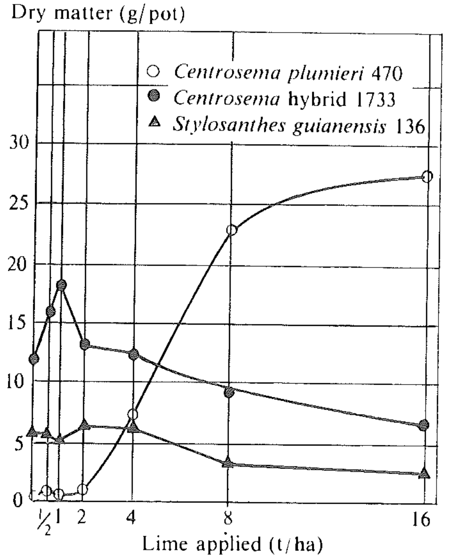


Figure 31. Lime response of three forage legumes in the Quilichao Ultisol under greenhouse conditions.

ROCK PHOSPHATE EVALUATION

Direct application of rock phosphate to acid soils offers a promising low-cost alternative for supplying this element in Oxisols and Ultisols that are both extremely deficient in phosphorus and fix large quantities of phosphorus fertilizers. Since late 1975 CIAT has been evaluating the various rock phosphate deposits found in Latin America. In July 1977 a special project on phosphorus was established, with International Development Research Centre (IDRC) financial support as a collaborative project between the International Fertilizer Development Center (IFDC) and CIAT. IFDC has stationed two of its senior scientists at CIAT to conduct this work. The project is an integral part of the Beef Program although work with other crops is also done, and is described elsewhere in this annual report.

Initial greenhouse experiment. Figure 32 shows the results of initial evaluation in the greenhouse with *Panicum maximum* growing on an unlimed Oxisol from Carimagua. High reactivity rocks from Sechura (Peru) and North Carolina (USA) were superior to triple superphosphate applications and similar to basic slag. The two Colombian rock phosphates, Huila and Pesca, considered of medium and low reactivity, respectively, were less efficient than superphosphate. Figure 32 also

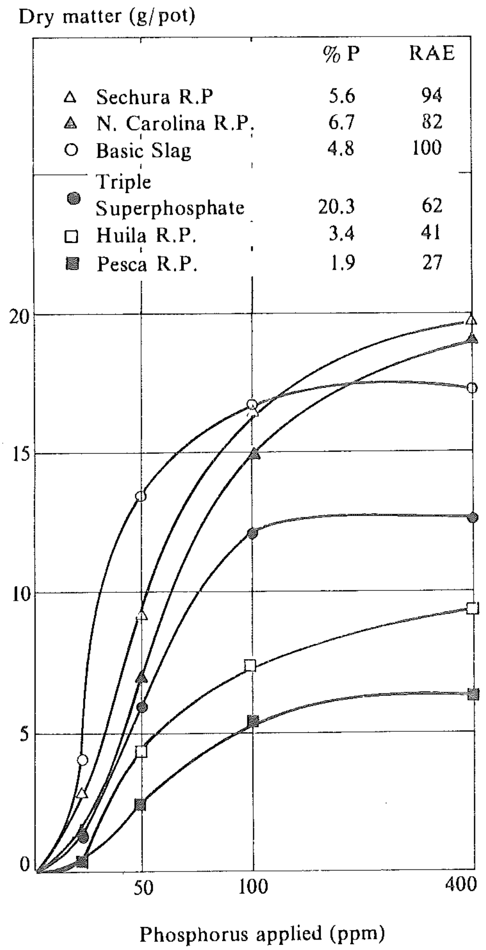


Figure 32. **Effect of sources of phosphorus on *Panicum maximum* dry matter production (sum of three cuts) grown in the Carimagua Oxisol without liming in the greenhouse. (% P = citrate-soluble P of entire material; RAE = relative agronomic effectiveness.)**

illustrates the Relative Agronomic Effectiveness (RAE) of each rock relative to basic slag. The poor response to superphosphate is probably related to inhibited growth by the low calcium and high aluminum saturation level of the soil. The Sechura and North Carolina rocks and basic slag ameliorated the soil because of their calcium release properties.

The relative availability of phosphorus from phosphate rock sources has been shown to be well-related to the citrate-soluble phosphorus content of the material. The correlation between citrate-soluble phosphorus in the phosphate rock and yield or phosphorus uptake was highly significant and improved as the rate of application increased. The citrate-soluble P_2O_5 of the phosphate rock was better correlated with yields when expressed as "percent of the rock" rather than "percent of total P_2O_5 in the rock" (Fig. 33).

Differences in reactivity of phosphate rocks were also reflected in the soil test parameters. The citrate-soluble P_2O_5 content of the phosphate rocks was well-correlated with Bray I extraction. Higher crop response was observed with the phosphate rocks than with triple superphosphate at a given level of Bray I extractable phosphorus (Fig. 34). This suggests that *P. maximum* was responding to the calcium supplied by the phosphate rock in addition to the phosphorus. Citrate-soluble phosphorus in the rock was significantly correlated with the concentration of water-soluble phosphorus in the soil at the 200 and 400 ppm phosphorus rates. At the 50 and 100 ppm phosphorus rates, however, there was not a significant correlation.

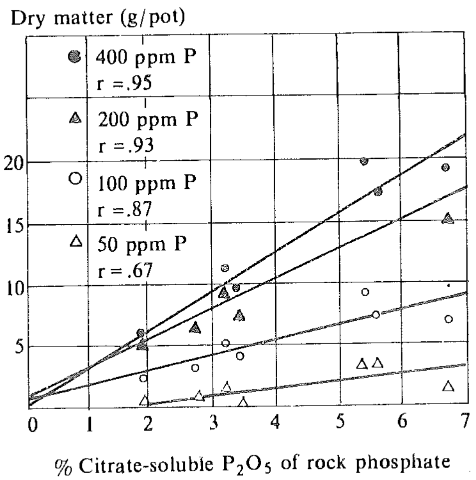


Figure 33. **Relationship between yield of three cuttings of *Panicum maximum* and citrate soluble phosphorus in rock phosphate (Sig. 0.01 level).**

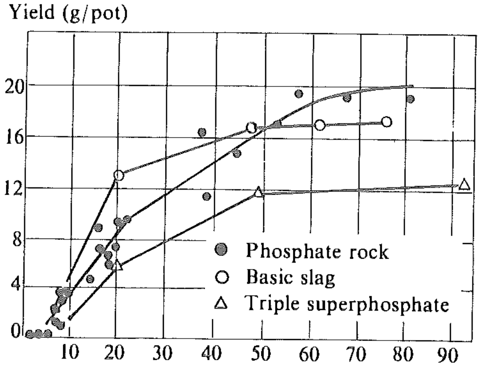


Figure 34. **Relationship between yield of three cuttings of *Panicum maximum* and Bray P-1 extractable phosphorus measured 90 days after application to a Carimagua Oxisol in the greenhouse.**

Phosphorus uptake by *P. maximum* was linearly correlated with water soluble phosphorus ($r = 0.918^{**}$). Dry matter yield was related to water soluble phosphorus by one curvilinear relationship for the phosphate rocks and basic slag, and another curvilinear relationship for triple superphosphate (Fig. 35).

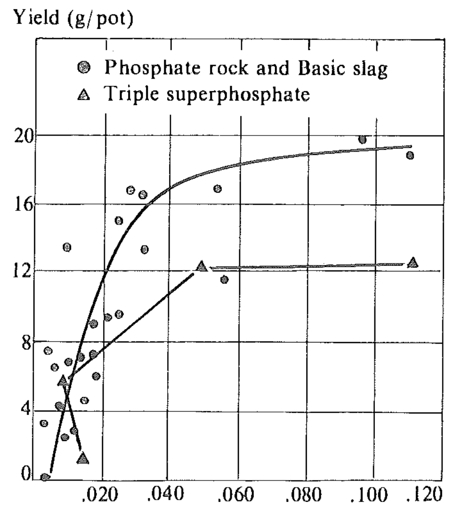


Figure 35. **Relationship between yield of three cuttings of *Panicum maximum* and water soluble phosphorus in a Carimagua Oxisol, in the greenhouse.**

Field Experiment. A long-term field experiment with *Brachiaria decumbens* was established in May 1976 at Carimagua to compare effects of six rock phosphates with triple superphosphate. Application rates range from 0 to 400 kg P_2O_5/ha, all broadcast and incorporated into the topsoil. The first four cuts of this experiment were harvested at 3, 6, 13, and 16 months after phosphorus applications. The lag between the second and third harvest includes the dry season.

The absolute and relative yield responses are shown in Figures 36 and 37, respectively. Triple superhosphate was only superior to rock phosphates during the first cut; afterwards all rock phosphate sources increased their effectiveness with time, approaching or surpassing the yields from superphosphate during the third and fourth cuts. The overall results during the first 16 months show that the high reactivity rocks Gafsa and Sechura were 105 and 99 percent as effective as superphosphate; the medium reactivity Huila rock was 91 percent as effective, and the low reactivity rocks, Tennessee and Pesca, were 87 and 88 percent as effective as triple superphosphate.

Figure 37 shows excellent performance of low and medium reactivity rocks not previously reported elsewhere. Normally, phosphorus from these rocks is very unavailable during the first year. By keeping the pH low (4.6 to 4.8), the soils became, in effect, an efficient superphosphate factory. By using a species tolerant to the high levels of aluminum saturation encountered (72 to 85 percent), the low pH did not affect growth. Total dry matter produced was 13.1 t/ha in 16 months, without irrigation and a basal fertilization of only 50 kg N, 100 kg K_2O and 20 kg S/ha. This indicates a very exciting potential for the medium and low reactivity rocks, so common in Latin America, as an important component of the Program's low input strategy.

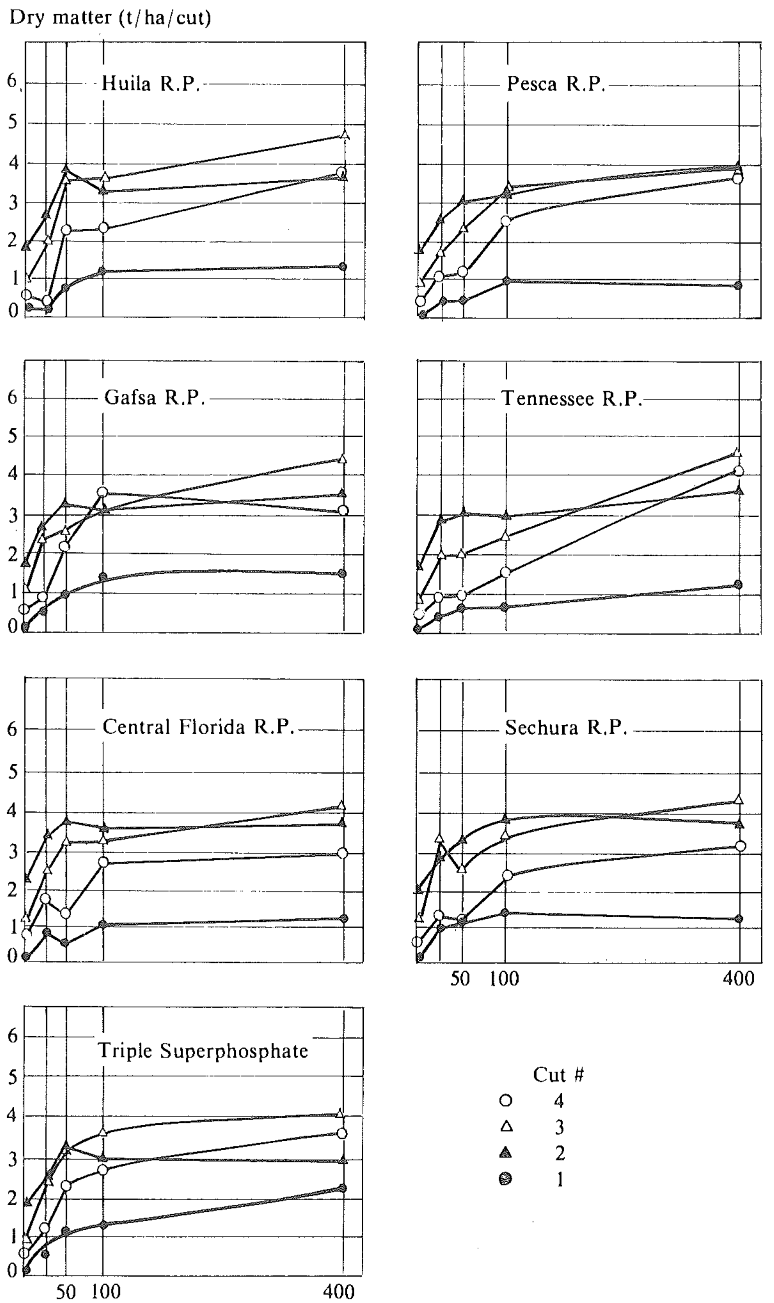


Figure 36. **Dry matter yield of four cuttings of *Brachiaria decumbens* as affected by rate and source of phosphorus in a Carimagua Oxisol.**

An evaluation of the residual effect must continue for several years, in order to fully appraise the value of such applications. An extra set of treatments of annual

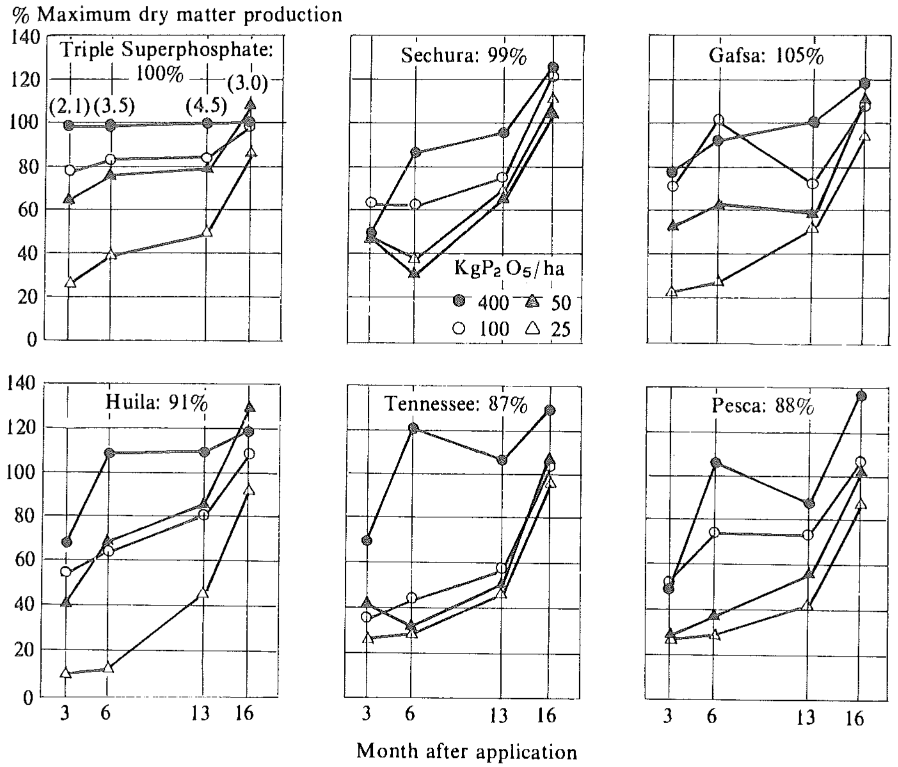


Figure 37. **Initital and residual effects of five phosphate rocks relative to superphosphate applications on** ***Brachiaria decumbens*** **yields in an Oxisol from Carimagua. (Percent figures indicate Relative Agronomic Effectiveness; maximum yields for each cut shown in parenthesis as t D.M./ha.)**

applications of triple superphosphate is being included for comparison.

Figure 38 shows that the application of the different phosphate rocks and soluble phosphorus fertilizers modified some chemical properties of the soil measured 12 months after application. This modification is more pronounced when phosphorus is applied at 400 kg P_2O_5/ha. Available phosphorus, measured as Bray I, increased substantially in the soil after application of triple superphosphate and high to medium reactivity rocks like Gafsa, Sechura and Central Florida. Changes in pH were not significant, but increases in exchangeable calcium were remarkable in the high reactivity rocks. Applications of 400 kg P_2O_5/ha of Huila tripled the exchangeable calcium in the soil, while the same amount of Sechura rock doubled it. These changes produced a decrease in aluminum saturation from 85 to 72 and 78 percent, respectively.

The greenhouse and field results show that direct applications of low (Pesca), medium (Huila) and high (Sechura) reactivity Latin America rocks to aluminum-tolerant grasses such as *Brachiaria* and *P. maximum* are superior to triple superphosphate in Oxisols of the Llanos of Colombia. A rate of 100 kg P_2O_5/ha appears optimum. Considering the low relative cost of a kilogram of P_2O_5 as rock phosphate compared with superphosphate, rock phosphates can significantly lower pasture establishment costs in the impact area.

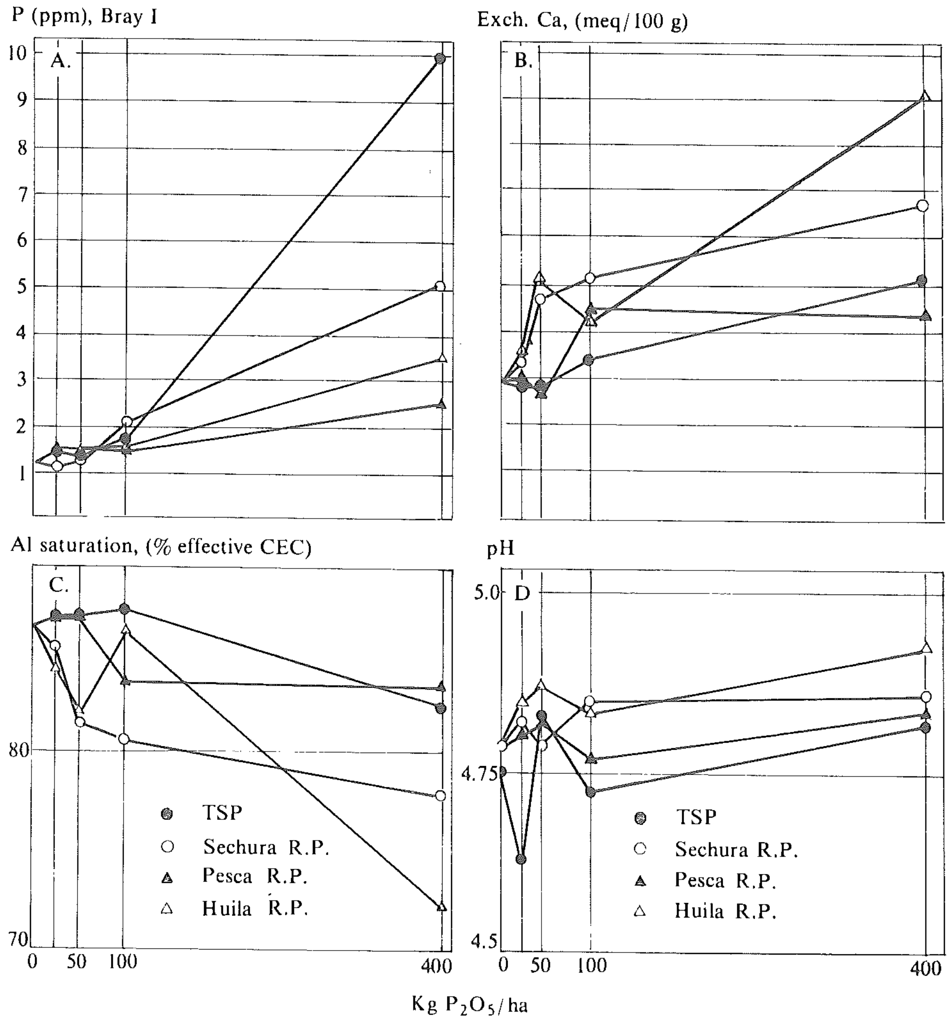


Figure 38. **Chemical properties of a Carimagua Oxisol supporting *Brachiaria decumbens* as affected by rate and source of phosphorus, measured 12 months after application.**

THERMOPHOSPHATE EVALUATION

Fused magnesium phosphate (FMP) is a phosphorus source produced by fusing rock phosphate with magnesium and silicate, usually supplied in the form of serpentine or a related material. The product is a glass whose chemical characteristics are very similar to basic slag. The latter has been shown to be more effective than triple superphosphate in Colombian Oxisols, but unfortunately, the supply is very limited.

This experiment was designed to compare the FMP produced in Japan with two other thermophosphates produced with native Colombian phosphate rocks and with other phosphorus sources in use. Materials were evaluated in the greenhouse with *Stylosanthes guianensis* (CIAT 136) on Carimagua Oxisol. Treatments with magnesium (as MgO) and silicate (as calcium silicate slag from TVA) equivalent to the amounts contained in FMP were included to separate the possible contributing factors, Lime was also included to separate the effect of the liming capacity of the calcium silicate from the possible beneficial effects of silicate anion.

Dry matter yields of the average of two cuttings are in Figure 39. In general, *S. guianensis* responded up to the highest rate of phosphorus applied. Only when the phosphorus source was TSP was the increase in yield between the two highest rates not significant. On the other hand, when TSP was mixed with MgO and calcium silicate or lime the response was almost linear.

When FMP was added to the soil yields were comparable to those produced by fertilization with basic slag supplemented with MgO and much higher than those of the TSP treatments.

Yields were not very different due to the use of coarse or fine FMP, but coarse Rhenania phosphate presented the lowest yields in this experiment. The Huila (Huila phosphate rock fused with serpentine) and Pesca thermophosphates (Pesca phosphate fused with dolomite) give better yields than TSP and coarse Rhenania phosphate, but were very similar to those produced using Huila phosphate rock mixed with MgO and calcium silicate. The results in Figure 39 also show that both magnesium and silicon are probably limiting the phosphorus response of *S. guianensis* in this soil.

Soil analyses did not show important variations in the chemical properties of the soil, except for available phosphorus measured as Bray I-P. There was little or no influence in the exchangeable magnesium of the soil. On the other hand, the thermophosphates and the Huila phosphate rock with MgO and calcium silicate increased appreciably the percentage of phosphorus and magnesium in the tissue of *Stylosanthes*. The use of TSP or Rhenania phosphate decreased the magnesium content of the tissue. Calcium content was also increased by the application of these thermophosphates to the soil.

SILICATES AND MAGNESIUM APPLICATIONS

In order to study the effect of silicates and MgO on the response of *S. guianensis* (CIAT 136) to phosphorus, a greenhouse experiment was established using an Oxisol from Carimagua. Triple superphosphate and Huila phosphate rock were the phosphorus sources. Magnesium oxide and calcium silicate were mixed and applied with the phosphorus sources at three different rates but always keeping the same ratio MgO: SiO_2 of 0.75:1.00.

Dry matter yields of the first cut are shown in Figure 40. When no phosphorus was added to the soil, stylo responded slightly to the first increment of MgO and SiO_2 but no response was detected afterwards. With added phosphorus, the response to MgO and calcium silicate was appreciable for the lowest level of these two compounds when TSP or Huila phosphate rock were used. Magnesium oxide and calcium silicate produced strong yield responses at high rates of TSP. Stylo yields are not markedly influenced by applications of MgO and calcium silicates when high levels of phosphorus are applied as Huila phosphate rock. It is possible that high rates of phosphate rock are adding enough calcium, magnesium and silicate to the soil to supply the plant requirements.

MIXING PHOSPHATE ROCKS WITH TRIPLE SUPERPHOSPHATE

One possibility for improving phosphorus availability in phosphate rocks is by mixing them with acid-forming substances like sulfur or triple superphosphate. Two greenhouse experiments were conducted using mixtures at different ratios of Huila phosphate rock and labeled triple superphosphate in a

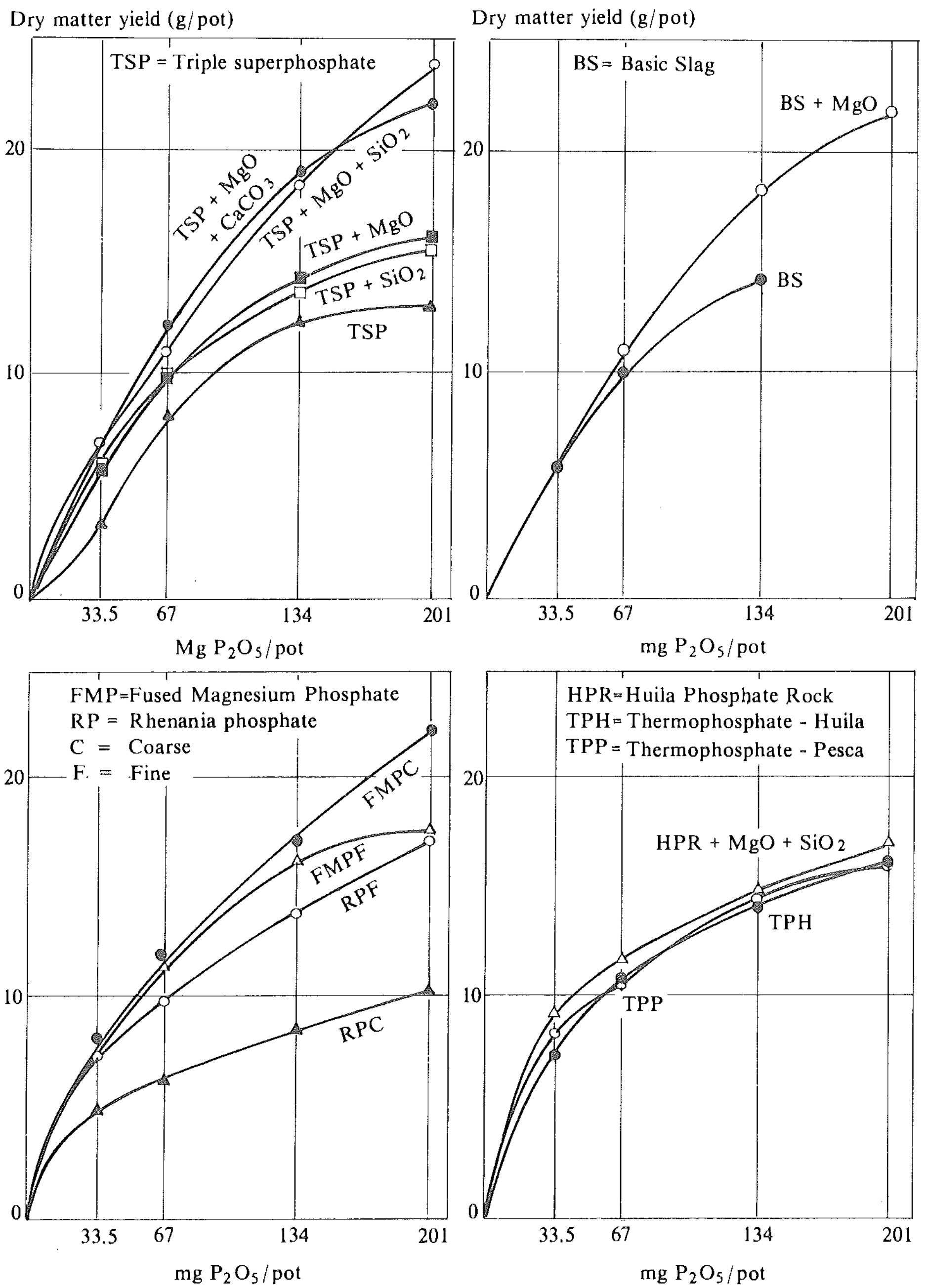


Figure 39. **Dry matter yield of two cuttings of *Stylosanthes guianensis* 136 as affected by rate of phosphorus with MgO, $CaCO_3$ and SiO_2 and by different thermophosphate, on a Carimagua soil in the greenhouse.**

Carimagua Oxisol and Quilichao Ultisol. *Desmodium distortum* (CIAT 335) and *P. maximum* were used as indicator plants, respectively. Figure 41 shows that yields

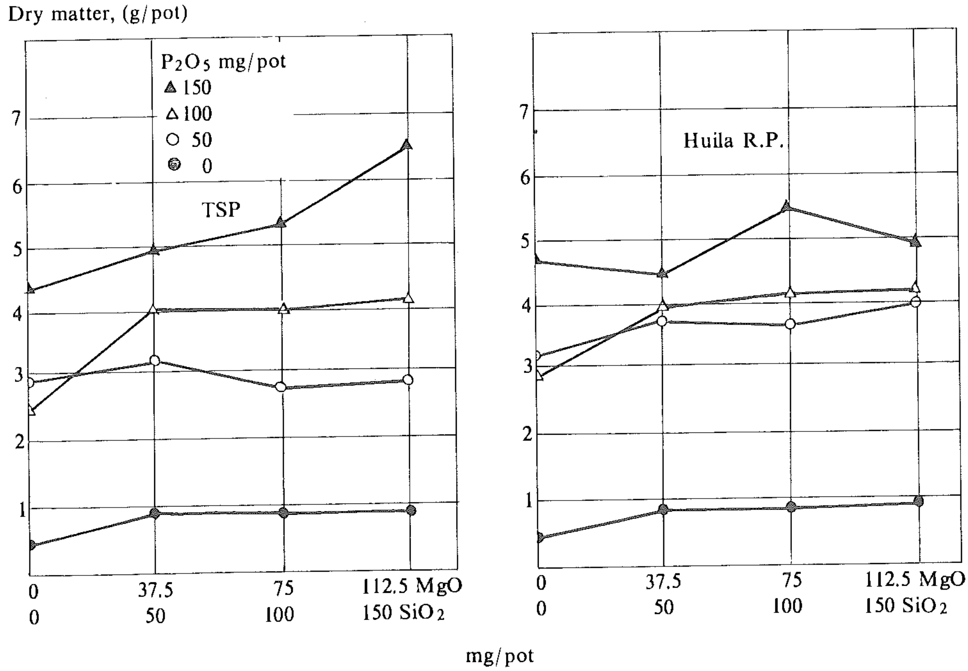


Figure 40. **Dry matter yield of one cut of *Stylosanthes guyanensis* 136 as affected by rates of MgO and SiO_2 and by rate and source of phosphorus on a Carimagua soil in the greenhouse.**

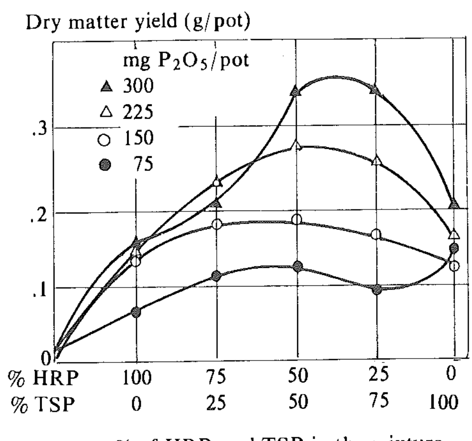


Figure 41. **Dry matter yield of *Desmodium distortum* CIAT 335 as affected by rate of P and mixtures of Huila rock phosphate (HRP) and triple superphosphate (TSP) on a Carimagua soil in the greenhouse.**

increased with the addition of triple superphosphate to the rock.

In the Ultisol from CIAT-Quilichao *P. maximum* responded almost linearly to phosphorus fertilization and there was no appreciable difference in yield by the use of 100 percent Huila phosphate rock or triple superphosphate and the mixture of the two products (Fig. 42). Only at high rates of phosphorus did the grass respond markedly to the increase in soluble phosphorus in the fertilizer. It seems that *P. maximum* can use phosphorus from insoluble forms. The mixtures of soluble and insoluble phosphorus sources, therefore, are of limited value in such circumstances.

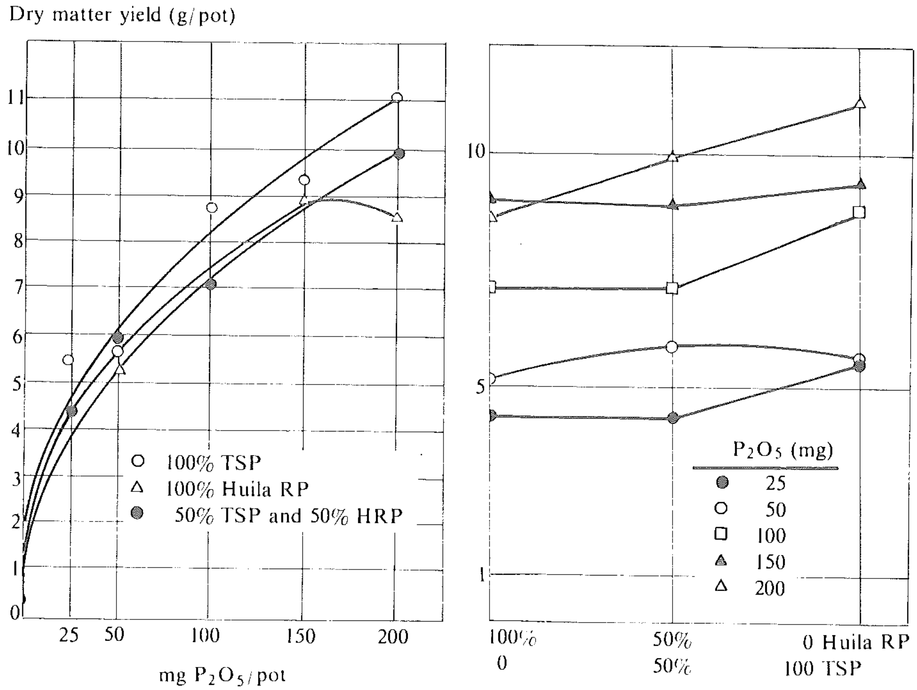


Figure 42. Dry matter yield of *Panicum maximum* as affected by rate and mixture of phosphorus sources on an Ultisol from CIAT-Quilichao. (Sum of averages of two cuttings.)

Plant Nutrition

The nutritional requirements of many grass and legume species of interest to the Beef Program are not well understood. During 1977 studies conducted by agronomists and soil scientists provided new information on: (1) tolerance to soil acidity (aluminum toxicity) and response to liming, and (2) tolerance to low available phosphorus. A Plant Nutrition section will be established with the arrival of a full time senior scientist in 1978.

ALUMINUM TOLERANCE

Fourteen grass and 24 legume species have been planted on existing lime blocks at Carimagua to study their tolerance to aluminum. Lime levels are 0, 0.5, 2 and 6 t/ha of calcium carbonate equivalent as described in previous annual reports, which provided topsoil aluminum saturation values of approximately 90, 85, 50, and 10 percent respectively. Dry matter yields were recorded in a series of harvests and the average yields for all cuts to date as affected by lime levels are shown for 11 grasses in Figure 43. Excellent aluminum tolerance was observed for a number of the most important grass species including *Brachiaria decumbens*, *Andropogon gayanus*, *Panicum maximum*, and other species of *Brachiaria*, all of which approached maximum yields at the 0 or 0.5 t/ha lime levels. In the case of *A. gayanus*, *B. humidicola* and *B. radicans*, maximum yields were attained without lime applications. In contrast, *Hyparrhenia rufa*, a very common grass throughout the

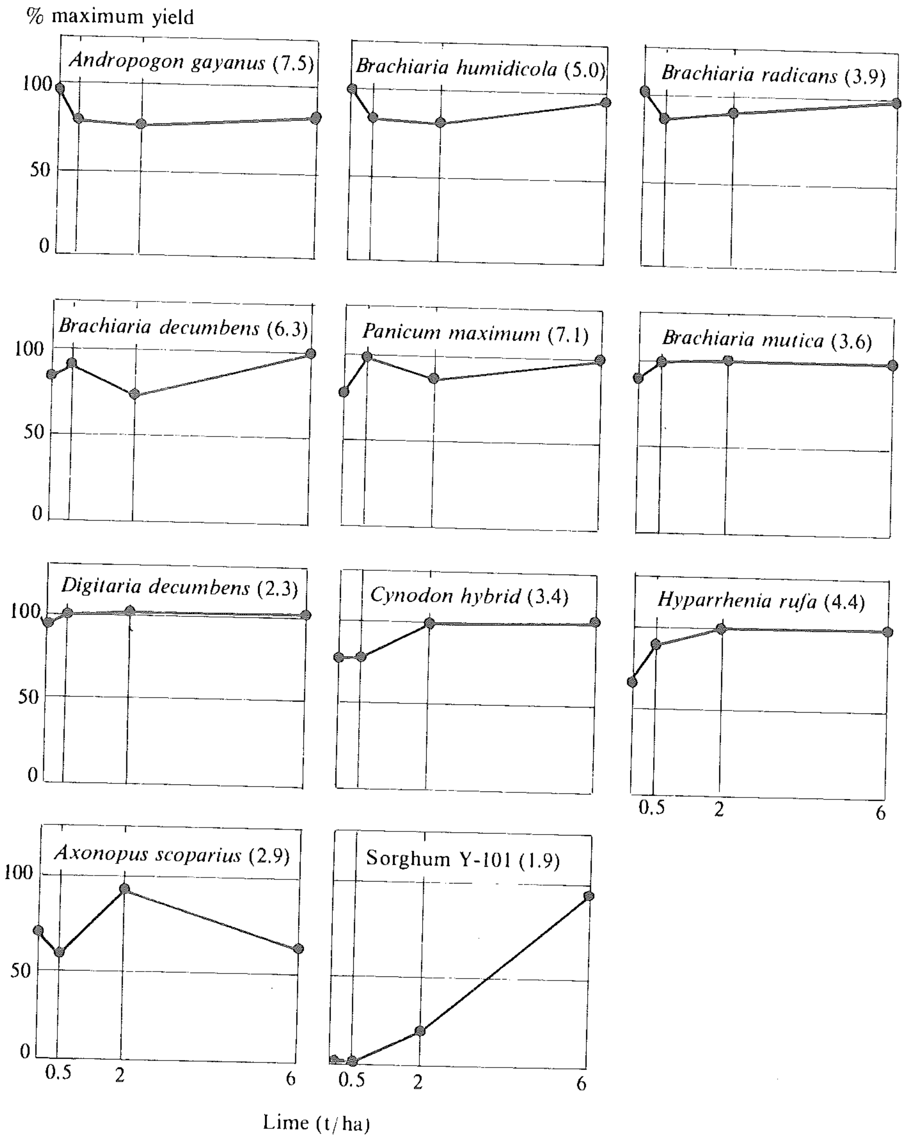


Figure 43. **Differential response of 11 grass spzcies to liming in an Oxisol from Carimagua. (Maximum yields in t/ha/cutting of dry matter are in parentheses and are averages of four and five cuttings in one season.)**

tropics, responded strongly to the relatively high level of 2 t/ha. This observation confirms greenhouse experiments conducted in 1976 in which six tropical grasses were grown in solution cultures ranging in aluminum concentration from 0 to 4 ppm. The effect of aluminum on four species can be seen in Figure 44. *Cenchrus ciliaris* was the most severely affected of all the grasses, followed by *H. rufa*. *P. maxiumum* reponded positively to the first increment of aluminum and was adversely affected only at the highest level of aluminum. *B. decumbens* was unaffected over the range of concentrations studied. *H. rufa* is clearly much more susceptible to aluminum

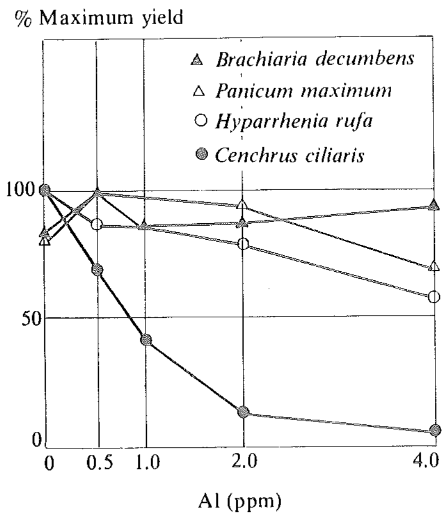


Figure 44. **The effect of aluminum concentration on dry matter yields of four tropical grasses grown in solution culture.**

toxicity than *B. decumbens* in both greenhouse and field trials. Yields of *P. maximum* were reduced at the zero-lime level (highest aluminum level) in the field as they were in solution culture.

Digitaria decumbens appears to be tolerant to aluminum, although the absolute yield levels were rather low. A *Cynodon* hybrid (African Star Grass) and Imperial grass *(Axonopus scoparius)* responded strongly to lime. The grain sorghum hybrid Taylor Evans Y-101 was included because of reported aluminum tolerance in the Cerrado of Brazil. The strong response observed indicates that it is more susceptible to aluminum toxicity than any of the forage grass species used.

Dry matter yields of eight legumes are shown in Table 27. These data are from the first harvest only. Magnesium was subsequently added to the zero lime treatment which had not previously received that nutrient. All other lime treatments had received magnesium to maintain a constant calcium: magnesium ratio of 10:1 in lime added. Some of the responses to 0.5 t/ha lime may well be to magnesium, especially in the case of *Desmodium ovalifolium* and *Pueraria phaseoloides* and possibly in the case of *Centrosema pubescens* and the hybrid *Centrosema sp.* 1733. *Stylosanthes capitata* and *Zornia sp.* 728 are notable for their vigor and lack of response to lime, whereas *C. plumierii* is obviously the most sensitive species to soil acidity in this group of legumes.

TOLERANCE TO LOW AVAILABLE PHOSPHORUS

Twenty *Stylosanthes* species and ecotypes were screened for their phosphorus requirements in a pot trial with the Carimagua Oxisol using the following levels of applied phosphorus: 0, 5, 10, 20, 30, 60, 120 and 240 kg P/ha. The critical level of phosphorus according to the Bray II soil test was chosen as an

Table 27. **Effect of lime on dry matter yields (kg/ha) of tropical legumes, first cutting, 1977.**

Species	Lime (t/ha)			
	0	0.5	2	6
Centrosema plumieri 470	0	0	582	1698
Centrosema sp. 1787	445	912	2014	2769
Centrosema sp. 1733	356	1330	1568	1317
Centrosema pubescens	680	1729	1996	2035
Desmodium ovalifolium	1118	2302	2018	2480
Pueraria phaseoloides	1286	1688	1422	1434
Zornia sp. 728	3000	3108	2686	2628
Stylosanthes capitata 1019	2365	2361	3011	2458

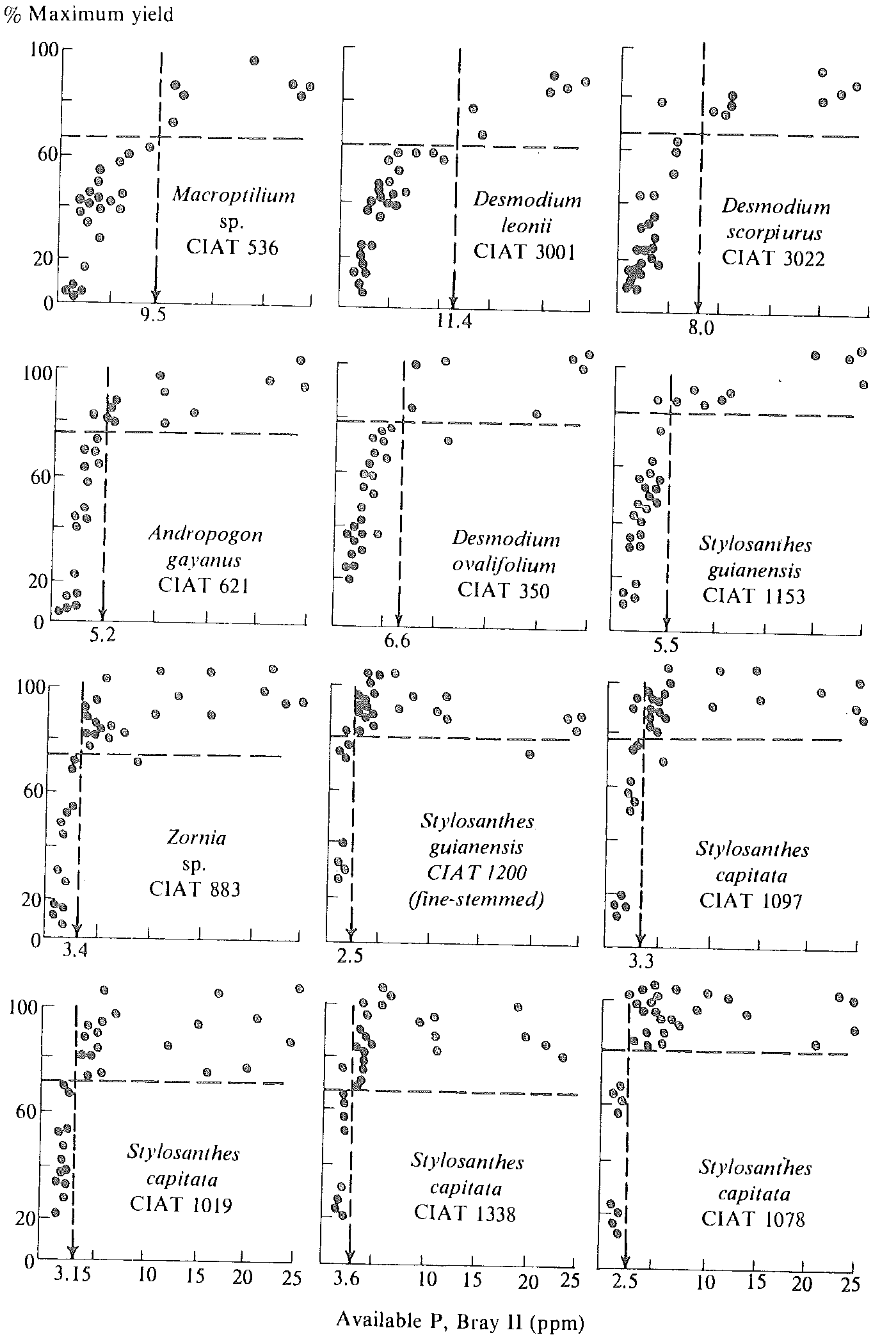


Figure 45. **External phosphorus requirements of 12 CIAT forage accessions on Carimagua Oxisol.**

indication of the external phosphorus requirement of the species. Attempts to estimate the internal phosphorus requirements were not successful, because of the small changes in percentage phosphorus in plant tissue at the crucial

Table 28. Relationship between phosphorus applied in the field and in the greenhouse to phosphorus content (% P in dry matter) of plants of *Andropogon gayanus*

	Rate applied (kg P_2O_5/ha)								
Test	0	10	20	40	60	80	120	160	240
Greenhouse	0.10	0.09	0.10	-	0.10	-	0.12	-	0.15
Field	0.09	0.08	0.09	0.09	-	0.12	-	0.16	-

low phosphorus rates. This is shown in Table 28.

The external phosphorus requirements are given in Figure 45 using the Cate-Nelson method to determine the critical soil test level. Large differences among forage species and ecotypes can be observed from this figure. The two lower rows include accessions with critical levels of 4 ppm or less available phosphorus. There are four accessions of *S. capitata*, a fine-stemmed *S. guianensis* and one *Zornia*. These accessions utilized limited amounts of phosphorus more efficiently than others. They are among the most promising entries for Carimagua conditions, except for *S. guianensis* 1200 which does not produce seed.

Three other accessions have a critical level between 5 and 6 ppm phosphorus, thus showing considerable adaptation to phosphorus stress. Two of them: *A. gayanus* and *D. ovalifolium*, are in the most promising list for Carimagua conditions.

Finally, three species have critical levels higher than 8 ppm: *Macroptilium* 536, *D. leonii* 3001 and *D. scorpiurus* 3022. They are not well-adapted to Carimagua conditions. The generally accepted critical level of Bray II phosphorus for crops in Colombia is on the order of 15 ppm. All forage species tested have lower phosphorus requirements than most arable crops, confirming the comparative advantage of tropical pastures adapted to low input management in Oxisol savannas.

Pasture Establishment and Maintenance

Two new Pasture Development units were established this year at Carimagua and Brasilia with the overall objective of developing systems for pasture establishment and maintenance at different levels of investment in tropical savannas. The different systems are illustrated in Figure 46. Studies will include: (1) low cost methods of establishing improved pastures on native savanna; (2) establishment of grass-legume mixtures after plowing native savanna; (3) using crops as precursors to pasture establishment at a somewhat higher level of investment; and, (4) establishment of intensively managed grass, legume or mixed pastures for small irrigated areas or pockets of fertile soils to provide cut forage for strategic supplementation. The maintenance requirements of all these systems will also be studied, The main variables involve land preparation, planting methods and fertilization rates for establishment and maintenance under different grazing intensity. Work reported this year concentrates on a new low-cost pasture establishment system, and fertilization requirements of the principal grasses both at Carimagua.

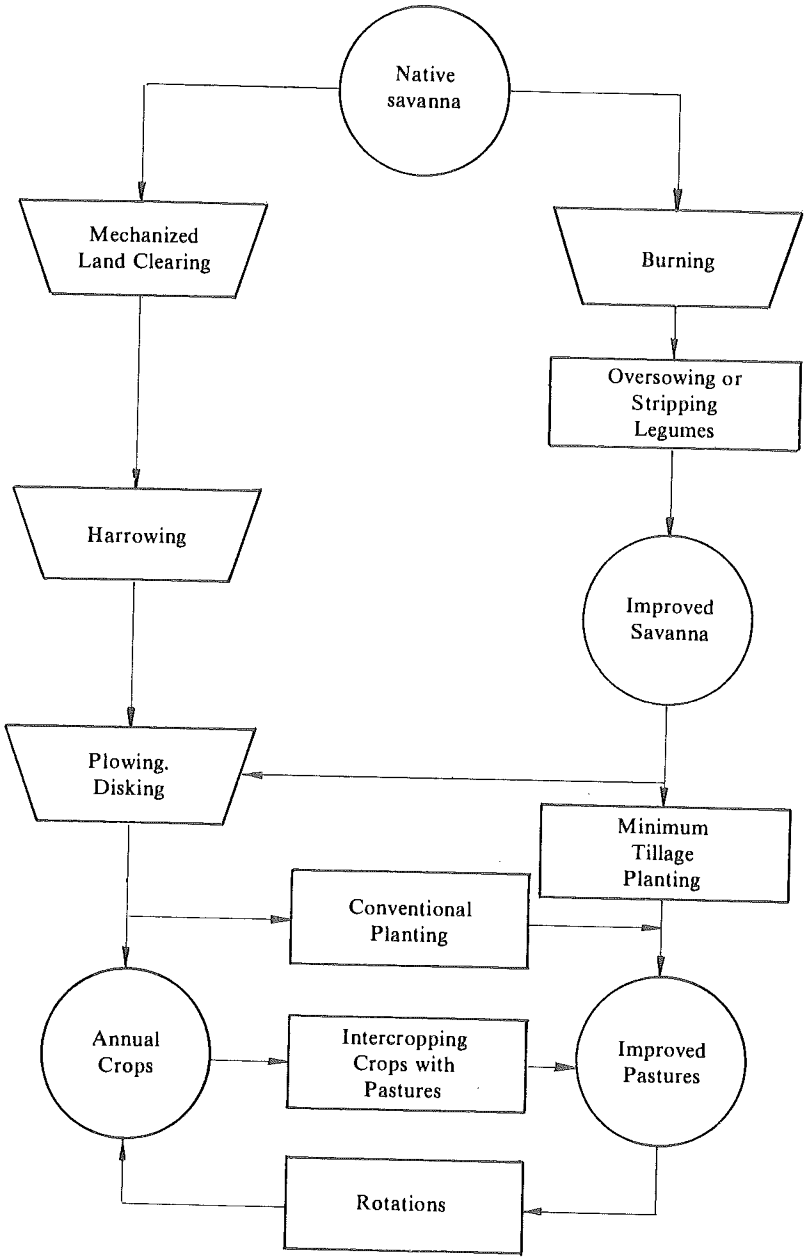


Figure 46. **Outline of pasture establishment and maintenance systems for Oxisol-Ultisol savannas.**

LOW DENSITY ESTABLISHMENT SYSTEM AT CARIMAGUA

Resources such as capital, labor and fertilizer are almost always limiting in savanna areas. In the particular case of improved pastures, seed or vegetative planting material is rarely available in sufficient quantity and is often very expensive in the early stages of livestock development programs. An experiment was initiated in 1977 to study the feasibility of low density plantings of ten species expected to self-seed or spread via stolons and provide an acceptable stand in one year or less, taking advantage of the lack of weed competition for several months after land preparation and before fertilizer application in Oxisols of the Colombian Llanos.

A three-hectare field was prepared with an offset disc to control native vegetation. Fertilizer was initially applied only in the planting hill in a manner to affect approximately 0.1 m^2. With a population of 1000 plants/ha, the initial rate of phosphorus application ranged from 0.5 to 9 kg P_2O_5/ha. Within the 0.1 m^2 treated area, phosphorus application rates ranged from 50 to 900 kg P_2O_5/ha. Potassium applications ranged from 0 to 1.5 g K_2O/hill, equivalent to 0 to 1.5 kg K_2O/ha initial application and from 0 to 150 kg K_2O/ha for the area treated.

The second stage of fertilizer application in the area between hills will be completed after initial stolon development (or seed production from non-stoloniferous species) to avoid weed competition until stands are assured. *Brachiaria decumbens, B. humidicola, B. radicans* and a *Cynodon* hybrid were expected to spread primarily via stolons although *B. decumbens* is already setting seed. *Andropogon gayanus, Panicum maximum, Zornia* sp., *Pueraria phaseoloides, Desmodium ovalifolium* and *Stylosanthes capitata* depend primarily on seed production for self-propagation, but some also spread by trailing stems. Five different fertilizer treatments will be applied in the area between hills in order to cover the range of probable response of the 10 species which vary in fertilizer requirements. All are assumed to be reasonably well-adapted to the acid soil environment.

Figure 47 includes results for four stoloniferous grasses showing the response to phosphorus and potassium in terms of percentage maximum length of the four longest stolons per plant and number of solons per plant longer than one meter, and in the case of *B. radicans,* stolons longer than two meters. Stolon length was only slightly affected by phosphorus, primarily in the range of 0.5-1.0 g/hill for *B. decumbens, B. humidicola* and *B. radicans.* The *Cynodon* hybrid responded up to 3 g/hill. However, the effect of phosphorus on number of stolons longer

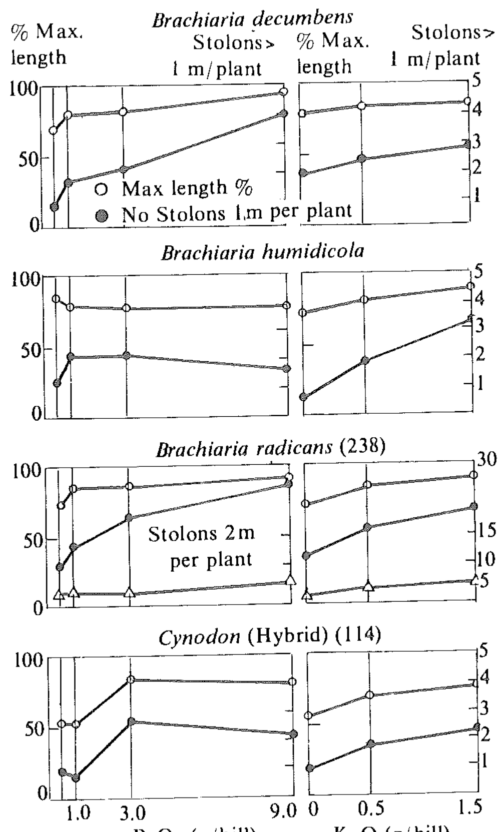


Figure 47. Effects of phosphorus and potassium on stolon number and percentage maximum length of the four longest stolons for four grasses, 12 weeks after planting vegetative material in hills 3.16 meters center to center (1000 hills/ha) on an Oxisol in Carimagua. The average length (cm) of the four longest stolons per hill in the best treatment is shown in parenthesis.

than one meter was very striking for both *B. decumbens* and *B. radicans* over the entire range of phosphorus application (0.5 - 9 g/hill). Response to potassium was especially marked in terms of number of stolons longer than one or two meters.

In less than three months, *B. radicans* has covered almost the entire area between hills, spaced at 3.16 meters, center to center. *B. humidicola* is also providing rapid cover but was slower in establishing and initiating vigorous stolon growth. *B. decumbens* has developed rapidly but initial development is largely vertical before appreciable stolon development occurs. Leaf cutter ants caused damage during the establishment phase, especially on *D. ovalifolium.*

This system may result in important advantages in pasture establishment in savanna areas characterized by infertile, acid soils where labor, capital, seeding material and fertilizer are scarce and where the farmer is willing to trade time for initial capital investment.

FERTILITY REQUIREMENTS FOR CONVENTIONAL ESTABLISHMENT AT CARIMAGUA

The major limiting fertility factors for pasture establishment and maintenance in the Oxisols of Carimagua appear to be nitrogen, phosphorus, potassium, magnesium and sulfur. Response profiles of four grasses to phosphorus, potassium, magnesium and sulfur are shown in Figure 48. All four species responded strongly to applied phosphorus; *P. maximum* and *H. rufa* were the most responsive and *A. gayanus* the least responsive. *H. rufa* was by far the most responsive to potassium. In the absence of applied potassium, the population of *H. rufa* deteriorated very rapidly; yields of treatments without potassium averaged over all levels of phosphorus were only 15 percent of maximum. Nitrogen has become a severely limiting factor during 1977 and uniform applications are now being made to all treatments. Sulfur and magnesium have also become limiting for some species; uniform applications of both nutrients were made to all treatments except controls.

Four legumes were seeded in 1976 but establishment was unsuccessful and the experiment was reseeded in June, 1977 with *P. phaseoloides* (kudzu), *D. ovalifolium, Zornia* sp. (CIAT 728) and *Centrosema pubescens.* Early stands were excellent for all four species but *C. pubescens* later failed. Only one harvest was made in 1977, the results of which are shown in Figure 49.

Zornia sp. is the least demanding of the three species that survived. *D. ovalifolium* is intermediate in response to phosphorus and potassium. *P. phaseoloides* development was limited so severely by magnesium deficiency that data on the response to phosphorus and potassium are not included. *D. ovalifolium* is also extremely responsive to magnesium as shown in Table 29. *Zornia* was least affected by addition of magnesium; *D. ovalifolium* yields doubled and *P. phaseoloides* yields tripled after adding magnesium. Uniform applications of magnesium and sulfur have now been made to all plots except controls.

STRIP PLANTING OF LEGUME-GRASS MIXTURES

Pueraria phaseoloides (tropical kudzu) is being grazed in association with *B. decumbens, M. minutiflora* and *H. rufa* in a trial established in 1976. The legume was seeded in 2.5-meter strips alternated with 2.5-meter strips of the associated grass. The trial includes three rest periods of 28, 42 and 56 days and three maintenance fertilizer rates and is managed with mob grazing. The strip system and grazing management has resulted in good legume-grass balance between kudzu and *B. decumbens* and legume dominance over both *H. rufa* and *M. minutiflora* during the

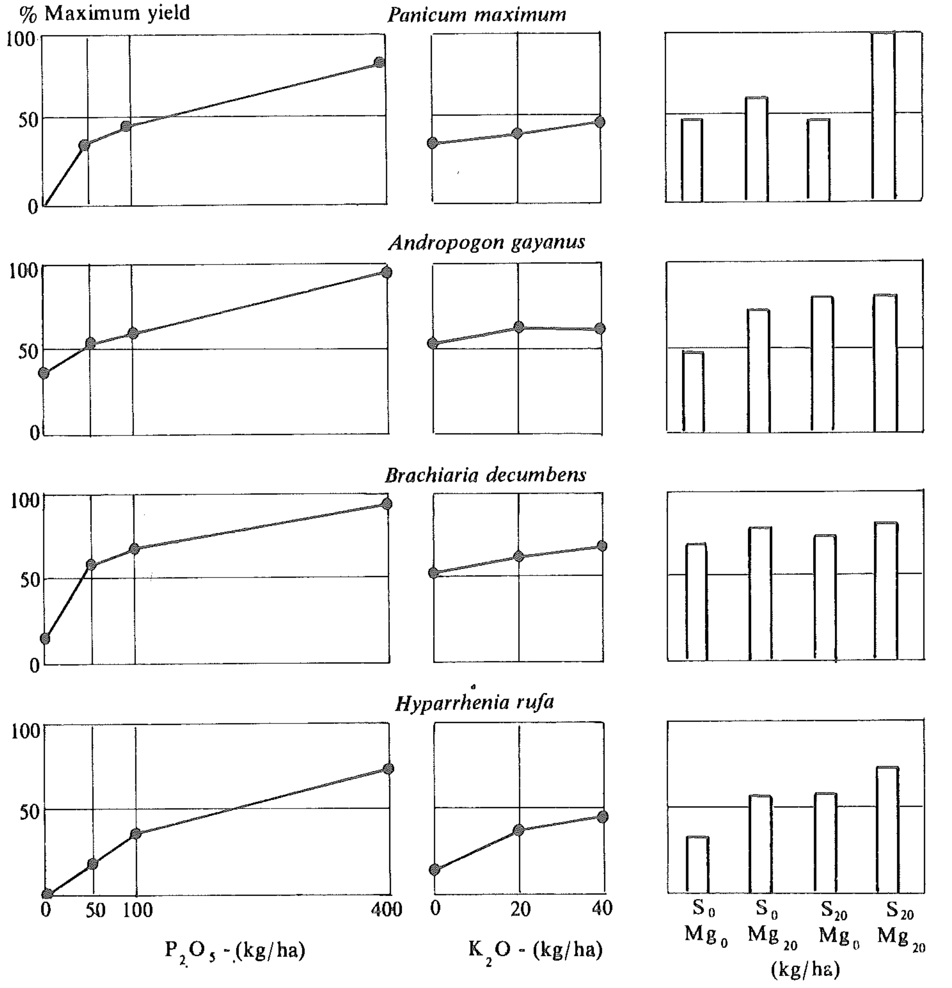


Figure 48. **Response of four grasses to phosphorus, potassium, magnesium and sulfur in an Oxisol at Carimagua. Dry matter yields are averages of three and four harvests during the first year after establishment.**

first season of grazing. *B. decumbens* is producing three or more times the volume of forage produced by the other two grasses and is invading the companion legume strips while the kudzu is also invading the *B. decumbens* strips. It appears that the two species may remain compatible for a reasonable period of time using this planting system.

PASTURE MAINTENANCE FERTILIZATION REQUIREMENTS

Small enclosures within grazing paddocks have been used for the past year to study the response of previously grazed grass pastures to phosphorus, potassium, magnesium and sulfur. Nitrogen was applied in 1977 on a split-plot basis. Yield responses have been erratic, with no consistent response to the fertility variables.

During the 1976-77 dry season, stands of *H. rufa* in three grazing paddocks were almost entirely lost but variability within the plot area was too great to permit positive identification of causal factors. In

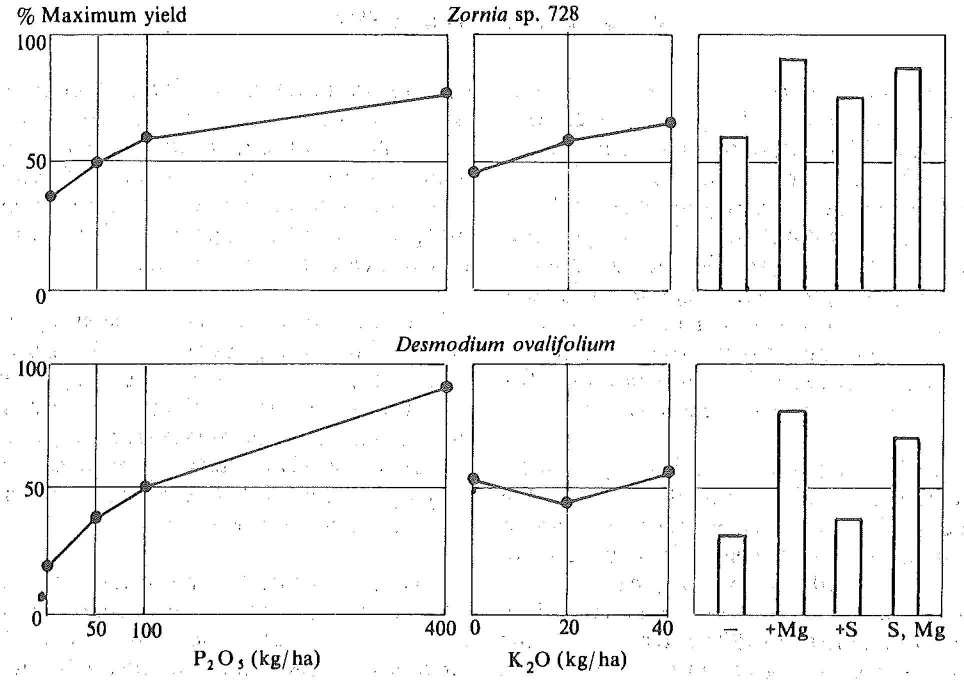


Figure 49. **The effect of phosphorus, potassium, magnesium and sulfur on dry matter yield (kg/ha) of two tropical legumes; first cutting, 1977. Rates of magnesium and sulfur were 20 kg/ha.**

other trials reported in the Plant Nutrition section, *H. rufa* was shown to be extremely susceptible to both phosphorus and potassium deficiency and only moderately tolerant to acid soil conditions. These stresses, exaggerated by drought, were probably the principal causes of failure.

Work is continuing with stubble mulch sweeps as a low cost alternative for control of the native savanna and seed bed preparation with minimum erosion hazard. Satisfactory control of vegetation requires several days without rain after cultivation, thus limiting the use of sweeps to very early in or late in the rainy season (December-November or March-April).

Table 29. The effect of magnesium on dry matter yields (kg/ha) of three forage species, at first harvest, 1977.

Species	(kg Mg/ha) 0	20
Zornia sp. 728	2436	3151
Desmodium ovalifolium	675	1552
Pueraria phaseoloides	229	739

ANNUAL CROPS AS PRECURSORS OF PASTURES

In many savanna regions crops such as upland rice, corn, and peanuts are sown following land clearing, and after their harvest the land is planted to pastures. Two field trials were established at Quilichao and Carimagua to study the possible use of several crops as pasture precursors, in which forage legumes and grasses are interplanted at different stages of crop growth and at different fertility levels. The results will be available in the next Annual Report.

Pasture Utilization

Activities of the Pasture Utilization Section of the Beef Program were discontinued at CIAT-Palmira. Towards the end of 1977 a series of experiments were established in the newly acquired substation of CIAT-Quilichao. The acquisition of this substation provides the opportunity to study the grazing management of grass-legume mixtures—particularly of new CIAT germplasm—as they relate to managing potentially useful mixtures for Ultisol areas of low climatic stress.

At Carimagua, two grazing experiments were terminated in December 1977, at the end of the rainy season. One experiment was designed to measure the beef production potential of the tropical savanna under two systems of management of fire. This trial started in 1971 and after six years had given valuable information. The second experiment terminated, studied, in its first part, the effect of phosphorus and potassium fertilization at the time of establishment on the beef production of *Melinis minutiflora* and, in its second phase, measured the effect of three grazing managements. The first part started in 1971 and the second, in 1973.

CIAT-QUILICHAO

Two types of research activities are being conducted at this station. The first will measure the nutritive value of new, promising accessions of legumes and grasses, particularly those about which little information is available. Nutritive value measurements include *in vivo* digestibility and intake studies with the plant material offered unchopped and fresh to crated wethers. In instances when nitrogen utilization appears of interest, nitrogen balance is measured.

The other projects involve the study of the grazing management of CIAT selections which are in advanced stages of selection (Category 4). Each is studied in mixtures with several grasses and subjected to various levels of fertilizer application, varying rest periods between grazing and at least two grazing pressures.

Two such projects were established in 1977, one with the *Centrosema* hybrid (CIAT 1733) and the other with *S. guianensis* (CIAT 136). Grazing will begin approximately in February 1978.

CARIMAGUA

The grazing year between November 1976 and November 1977 was a hard one in Carimagua. The dry season, which normally ends in late March or early April, extended until May. In most instances this meant that rainy season stocking rates could not be adjusted until May and, in a few instances, until June 1977. Also, weight losses were unusually high in all of the pasture treatments involved. This was the first year in which weight losses of any magnitude were registered in *B. decumbens* pastures.

Table 30. **Body weight changes (kg/animal) of steers grazing an Oxisol savanna in Carimagua (November 1976 - November 1977).**

	Burning the total area			Sequential burning		
Stocking rate (steers/ha)	Dry season	Rainy season	Year	Dry season	Rainy season	Year
0.20	-7	83	75	-20	110	90
0.35	-43	98	55	-44	104	60
0.50	-50	72	22	-52	78	26

Table 30 presents the weight changes of steers on the native savanna. Losses were registered in all treatments and amounted to as much as 50 kilograms per animal in the higher stocking rates. Weight gains in the following rainy season were high, compensating strongly for the poor performance of the dry season. Gains registered in this period ranged from 365 g/day/animal in the highest stocking rate to as high as 558 g in the lowest stocking rates. On a yearly basis, gains were similar to preceding years, averaging 16 kg/ha/yr. This underscores the low beef production levels of native savanna per unit area.

Also because of the severity of the dry season, supplementation with urea + molasses (80 g/animal/day + 400 g/animal/day) to animals grazing *M. minutiflora* had a greater effect this year than previously. It was calculated that 0.28 kilogram of urea and 1.40 kilograms of molasses were required to produce one kilogram of additional weight gain in the pastures grazed at 0.44 animals/ha while 0.71 kilogram of urea and 3.50 kilograms molasses were required in pastures stocked at 0.44 animals during the dry season and at 0.88 animals in the rainy season. The difference is only due to the lower rate of gain during the rainy season between the two groups, as can be seen in Figure 50. At the prevailing prices of the area, the supplement costs equal 46 and 116 percent of the cost of one kilogram of liveweight at the lower and higher stocking rates, respectively.

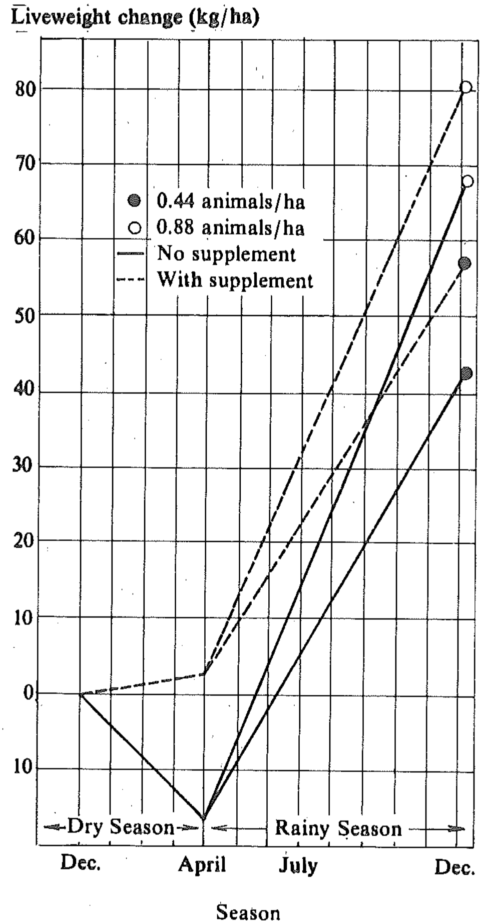


Figure 50. Four-year average per hectare weight change of steers grazing *Melinis minutiflora* in Carimagua. (Supplemented animals received 80 g/day of urea + 400 g/day of cane molasses during the dry period.)

Supplementation of animals grazing the native savanna, with urea + cassava meal, was studied again during the 1977 dry season. One comparison included a 3 x 3 incomplete factorial of 0-40-80 grams of urea and 0-200-400 grams of cassava meal/animal/day, fed mixed with a salt + dicalcium phosphate mineral mixture. Table 31 presents the average weight changes. There was a response during the dry period to urea + cassava meal, but no effect to urea alone. Actually, after a few weeks of supplementation it was realized that the steers did not totally consume their diet of urea + cassava meal without the addition of a small quantity of molasses; 50 grams of cassava were replaced by 50 grams of molasses, by weight, starting in February 1977. Consumption of urea when not fed with cassava meal was not 40 grams as designed, but averaged 23 g/animal/day. Consumption of urea in the 40-gram urea + cassava treatments averaged 36 g/animal/day and 52 grams in the 80

Table 31. **Weight changes (kg/animal) of steers grazing an Oxisol savanna in Carimagua with various levels of urea + cassava meal supplementation.**

Level of cassava meal (g° animal/ day)	Level of urea (g/animal/day)								
	0			40			80		
	Dry season	Rainy season	Year	Dry season	Rainy season	Year	Dry season	Rainy season	Year
0	-7	65	58	-6	55	49		-	
200	1	48	49	10	54	64	13	37	50
400		-		20	34	54	14	44	58

grams urea + cassava groups. These averages include the period prior to and during the time when molasses was added.

Because of the very strong compensatory gain during the rainy season, there were no differences in the yearly weight gain. The large compensation can be observed in Figure 51. The slope of the line indicates the proportion by which the weight gain of the rainy season is influenced by the weight change of the dry season.

Figure 52 presents a similar relationship for the burning management trial. In both cases compensatory gain was 74-78 percent.

The second comparison of this trial was a 2 x 3 factorial in which the interaction of mineral supplementation at different times of the year and nitrogen supplementation during the dry season was studied. Minerals offered were salt + dicalcium phosphate (50% + 50%) *ad libitum* and

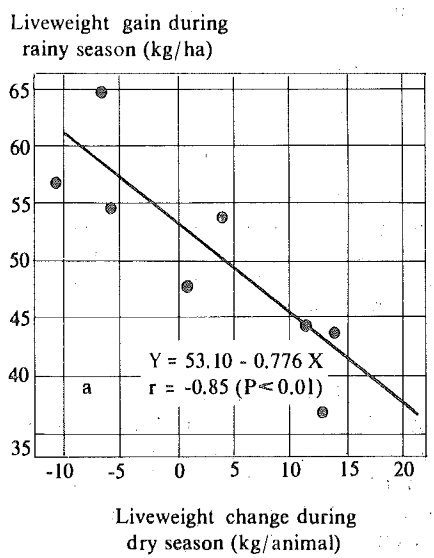


Figure 51. **Relationship between weight change during the dry period and gain during the rainy period in supplemented steers grazing the Carimagua savanna. Point a, not included in the regression, corresponds to a group of totally unsupplemented animals.**

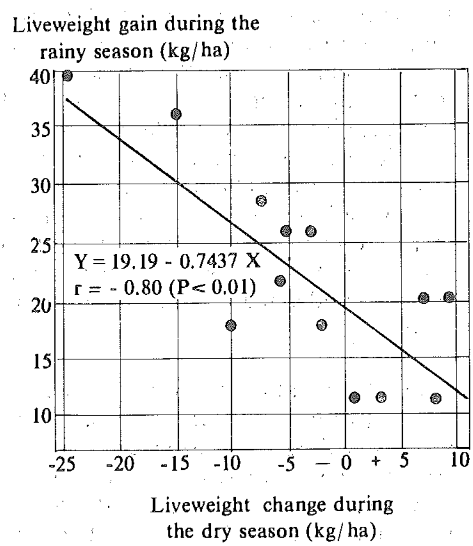


Figure 52. **Relationship between body weight change during the dry period and gain during the rainy period in a burning management trial in the tropical savanna of Carimagua. Individual values represent average of one stocking rate group in one year and cover a period of four years.**

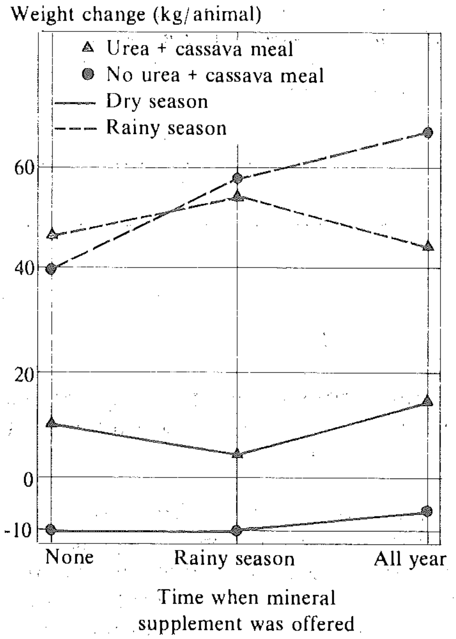


Figure 53. **Relationship between mineral supplementation and urea + cassava meal supplementation during the dry period, to steers grazing the tropical savanna at Carimagua.**

the nitrogen supplement was 80 grams of urea + 400 grams of cassava meal/animal/-day. Also in this trial, 50 grams of cassava were replaced by 50 grams of molasses. Consumption of urea averaged 69 g/animal/day in those treatments receiving the nitrogen supplement. Figure 53. represents the weight changes during both seasons. The results suggest a response to nitrogen supplementation during the dry period, independent of the supplementation of minerals and a linear response to mineral supplementation during the rainy season. This part of the trial will be repeated in 1977-78 with twice the animals to help understand the large between-animal variation found.

The results of the third year of grazing of *B. decumbens* at fixed stocking rates during the year are presented in Table 32. Weight losses for the dry season were large and increased with increasing stocking rates. Annual production was, however, very similar to the previous year. Average annual per hectare production over all stocking rates was 110 kilograms in 1975-76 and 105 kilograms in 1976-77.

A second experiment with *B. decumbens* explores the possibility of increasing per hectare production using high stocking rates during the rainy season and a low stocking rate during the dry season. Table 33 presents the results of the second year of grazing of this pasture. At the higher stocking rates, rainy season weight gains decreased markedly, but per hectare gains reached as much as 200 kilograms per year.

A third pasture of *B. decumbens* was incorporated this year to explore the effect of varying the stocking rate during the dry season and maintaining a medium stocking during the rainy season. Table 34 indicates gains of around 200 kg/ha/year. The paddocks appear to be depleting, par-

Table 32. Liveweight changes of steers on *Brachiaria decumbens* pastures in Carimagua in the third year of grazing.

Stocking rate (steers/ha/year)	Liveweight changes					
	kg/animal			kg/ha		
	Dry season	Rainy season	Year	Dry season	Rainy season	Year
0.9	- 6	124	118	- 5	111	106
1.3	-21	118	97	-27	153	126
1.7	-19	105	86	-32	179	147

Table 33. **Liveweight changes of steers on *Brachiaria decumbens* pastures in Carimagua in the second year of grazing with low stocking in the dry season and variable stocking in the rainy season.**

Stocking rate (steers/ha)		Liveweight change				
		kg/animal		kg/ha		
Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Year
0.7	1.63	-11	81	- 8	132	124
0.7	2.34	-16	77	-12	180	168
0.7	3.06	16	63	12	193	205

ticularly at the higher stocking rate and their future is uncertain.

Three small areas of these pastures were fenced and nitrogen fertilization experiments were initiated in July 1977. The response to nitrogen, in the three pastures of different ages, was very evident, suggesting that this may be one of the limiting factors involved. The quantification of this observation must wait until the 1978 Annual Report.

Twenty-five hectares of land were planted, by cuttings, with *A. gayanus,* to measure the beef production potential of this species in the tropical savanna. Grazing will start during the rainy season of 1978.

Table 34. **Liveweight changes of steers on *Brachiaria decumbens* pastures in Carimagua in the first year of grazing with a variable stocking in the dry season and medium stocking in the rainy season.**

Stocking rate (steers/ha)		Liveweight change				
		kg/animal		kg/ha		
Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Year
0.72	2.18	3	87	2	190	188
1.03	2.08	9	114	9	236	227
1.36	2.04	-8	112	-11	227	216

Animal Management

The objective of the Animal Management section is to develop economically-sound production systems in the impact area, through herd management research emphasizing the utilization of natural and improved pastures. Main activities during the year were: (1) analysis of the results of the Carimagua Herd Systems experiment, which terminated in May 1977; (2) description and evaluation of the prevailing beef production systems of the impact area in order to obtain a range of their technology and productivity, with emphasis on herd productivity and particularly, reproductive performance; (3) research on the effect of single herd management components and their interaction with improved pasture availability; and, (4) management of the Program's test herd to provide animals for research and training functions.

HERD SYSTEMS

The extensive cow-calf operation is the predominant beef production system in the Llanos of Colombia. Under these environmental conditions, herd productivity generally is low. In 1972, ICA and CIAT started a cooperative research project at Carimagua, to study the effects of several management techniques on reproductive and growth performance of breeding herds on a life-cycle basis. The experiment included the following variables: mineral supplementation, utilization of savanna and molasses grass *(Melinis minutiflora)* pastures, urea and molasses supplementation, and early weaning.

Data on animal performance were recorded over four reproductive years and the experiment was concluded in May 1977. Size and structure of the data set are summarized in Table 35. The Harvey method was applied in analyzing main effects. Therefore, not the given absolute values, but the **differences** between values are relevant, in quantifying treatment effects. The following parameters are used in reporting this experiment:

μ = overall mean values

$\bar{c}$ = least squares corrected means

n = number of observations

Mineral Supplementation

The effect of mineral supplementation can be analyzed by comparing Herds 2 to 5, all on native savanna. The treatment included *ad libitum* supplementation of salt (Herds 2 and 3), and a mixture of minerals (Herds 4 and 5), with 47 percent salt, 47 percent dicalcium phosphate and 6 percent of a minor elements premixture. The minerals mixture contained 7- 7.5 percent phosphorus.

Overall average intake was: salt 33.5 g/A.U./day (12.2 kg/A.U./year) and of minerals 59.5 g/A.U./day (21.7 kg/A.U./year). Therefore, 4.0-4.5 grams of phosphorus were consumed, or approximately 50 percent of the daily requirements. There was no seasonal effect on mineral consumption.

The minerals intake of animals grazing molasses grass *(M. minutiflora)* year-round (Herds 8 and 9) was 70 percent higher (71.2 grams) than that of animals grazing native savanna. This may indicate that periodic burning of the savanna could contribute to satisfying mineral requirements, through the mineral content of the ash.

Mineral supplementation resulted in higher body weights of dams at different reproductive stages, as shown in Table 36. Minerals are particularly effective on lactating cows, thus favoring reconception. This becomes evident when fertility parameters are analyzed (Table 37). Conception rates were increased through mineral supplementation and a sharp decrease in abortions was observed. As a result, a 29 percent increase in calving rate was obtained when breeding stock was supplemented with minerals when grazing on native savanna

Mineral supplementation also reduced pre-weaning mortality of calves. While mortality in Herds 2 and 3 was 19.2 percent, in Herds 4 and 5 it was 10.5 percent. Likewise, mineral supplementation positively affected calf growth, as shown in Table 38. All differences in body weight were significant, and, of all the systematic effects, mineral supplementation was the most important source of variance, across all ages. According to the results in Table 38, mineral supplementation has maximum effect on calf weight at 6 and 9 months. This may indicate higher

Table 35. **Structure of data in analysis of Carimagua Herd Systems Project.**

	Treatments				Performance (4-year total)					
Herd	Pasture	Minerals	Urea/Molasses dry season	Cows[1] n	Cows[2] n	Parturitions n	Early weaning n	Abortions n	Mortality pre-weaning n
1	native	salt	no	36	26	46	-	32	13
2	native	salt	yes	35	33	68	16	13	17
3	native	salt	no	36	30	65	14	12	13
4	native	minerals	yes	35	32	88	18	1	11
5	native	minerals	no	34	33	93	17	1	8
6	mol.+nat.	minerals	no	36	35	95	17	4	8
7	mol.+nat.	minerals	yes	35	35	94	17	0	8
8	molasses	minerals	no	36	29	86	17	1	8
9	molasses	minerals	yes	37	32	90	15	4	11
Total				320	285	725	131	68	97

Initial herd at end of experiment
At end of experiment.

Table 36. **Effect of mineral supplementation on body weight (kg) of dams,[1] grazing on savanna.**

Reproductive Status	μ		Salt only		With minerals	
	n	$\bar{c}$	n	$\bar{c}$	n	$\bar{c}$
At mating	131	304	67	292	64	316
Prior to calving	308	352	130	335	178	369
After calving	307	307	131	285	176	327
At weaning	194	289	72	272	122	305

[1] Nearest body weight to indicated status.

milk production of dams and/or a higher roughage intake of calves older than 3 months.

In summary, it can be concluded that supplementation of breeding herds with minerals substantially increased overall productivity through:

(1) a 29 percent increase in calving rate, mainly due to a reduction in abortions;

(2) a 26 percent increase in weaning weight of calves, and 17 percent increase at 18 months of age; and

(3) a 45 percent reduction in pre-weaning calf mortality.

The results suggest that in the Llanos of Colombia, mineral deficiency and particularly phosphorus, may be considered the primary limiting factor for cattle reproduction and growth. This conclusion agrees with Faber's study of the heifers' performance at Carimagua (see publications list).

Early Weaning

In 1973-74, five cows from Herds 2 to 9 were selected for early weaning at 86 days. All other cows had their calves weaned normally at nine months. During the first 30 days after early weaning, the calves received 750 g/day of concentrate and cut Imperial grass *(Axonopus scoparius)*. Afterwards, calves grazed on planted pastures *(Hyparrhenia rufa, M. minutiflora* and *Stylosanthes guianensis,* when available) and were supplemented with 500 g/day of concentrate. At six months the calves were placed on savanna, without concentrate supplementation.

As reported for previous years, the 1976-77 early weaned cows had higher calving rates compared to the others (Table 39), indicating that under the conditions of this experiment, early weaning can increase calving rate by 18-21 percent.

Analyzing the calving interval, only the cows which calved in the first year were

Table 37. **Effect of mineral supplementation on fertility rates of dams, grazing on savanna.**

Reproductive parameters	μ		Salt only		With minerals	
	n	$\bar{c}$	n	$\bar{c}$	n	$\bar{c}$
Conceptions[1]	140	73.2	71	69.5	69	76.8
Abortions[1]	140	4.9	71	9.3	69	0.4
Calving	140	67.9	71	59.4	69	76.4

[1] Assumed, through palpation.

Table 38. **Effect of mineral supplementation on calf growth (body weights, kg) on savanna (Herds 2-5).**

Age of calves (months)	µ		Salt only		With minerals		Relative to Salt=100
	n	c̄	n	c̄	n	c̄	
3	228	72.2	87	66.5	141	77.9	117
6	213	104.0	80	92.4	133	115.7	125
9	191	131.8	72	116.7	119	146.9	126
12	169	134.3	59	122.1	110	146.5	120
15	156	138.3	61	125.7	95	151.0	120
18	138	162.1	51	149.6	87	174.6	117

considered. Results (Table 40) indicated that regardless of other treatments, early-weaned cows had a calving interval of 15 months, while normally weaned cows varied between 18 and 20 months. With this technique, a cow would produce one more calf during her lifetime.

However, in these tropical savanna regions, early weaning seriously affects calf growth, as shown in Figure 54. Between 6 and 9 months, early weaned calves showed a severe growth check, which was still not compensated by 18 months. This applied especially to cows born during the late rainy season (September to December) and weaned during the dry season (January to April). This is illustrated in Figure 55, which shows least square constant estimates of the interaction season x type of weaning for calf weight at 9 and 18 months.

Early weaning of calves has serious limitations in the Colombian Llanos, with regard to animal management and, especially, calf feeding. Due to low soil fertility and rainfall distribution, there is presently no technology available to produce on-farm at low input levels: (1) the components for an adequate concentrate; (2) year-round high yielding cut forage species; and (3) pasture species with adequate feed value. This emphasizes the need to develop a forage base for the region which would assure satisfactory calf growth after weaning.

Pasture Treatments

The type of pastures used in Herd Systems generally had little effect on animal performance. Pastures were: savanna throughout the year; molasses grass

Table 39. **Effect of age at weaning on percentage calving rate.**

Weaning treatment	1976-77 Herds 2-5[1] c̄	1976-77 Herds 4-9[2] c̄	Average 1975-77 Herds 2-5[1] c̄	Average 1975-77 Herds 4-9[2] c̄
Early (86 days)	80.0	66.7	76.7	78.9
Normal (270 days)	62.7	59.8	63.1	66.6

1 Herds on savanna with mineral treatments.
2 Herds with pasture treatments, all with minerals.

Table 40. **Effect of early weaning on calving interval (days).**

Weaning treatment	Herds 2-5[1]		Herds 4-9[2]	
	n	$\bar{c}$	n	$\bar{c}$
Normal (270 days)	39	595a[3]	103	541a
Early (86 days)	19	450b	30	450b
μ	58	523	133	496

[1] Herds with mineral treatment
[2] Herds all supplemented with minerals
[3] Values in columns with different letters are significantly different ($P < .05$).

throughout the year; and molasses grass during the rainy season and savanna during dry season.

Cows grazing native savanna were heavier after parturition and at weaning than those grazing molasses grass. Cows on molasses grass plus savanna had intermediate body weights. Consequently, cows grazing savanna were slightly more fertile than cows on molasses grass.

Pasture treatments had no effect on calf growth performance. Nevertheless, due to the different stocking rates, 3.3 times more calves (kilogram basis) have been weaned per hectare of molasses grass, and 2.5 times more on molasses plus savanna, than on savanna all year-round (Table 41).

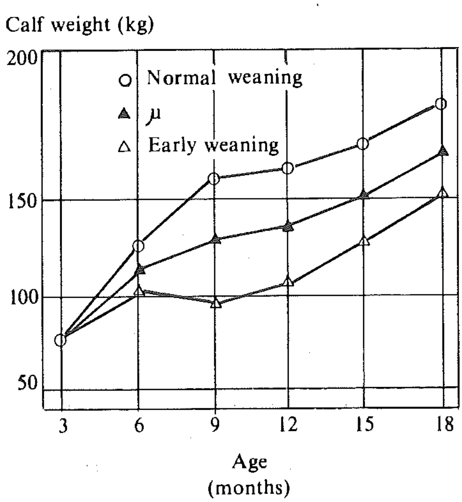


Figure 54. **Effect of weaning age on calf growth in Herds 4-9 (corrected LSQ means).**

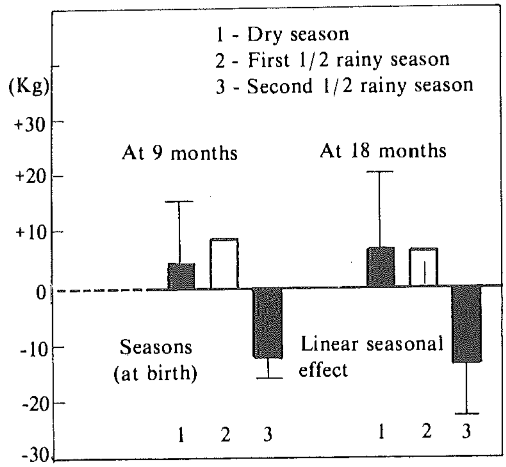


Figure 55. **Season-weaning age interaction effects on weight of early weaned calves (86 days old).**

Urea and Molasses Supplementation

Cows from Herds 2, 4, 7 and 9 were supplemented daily, during the dry season, with a mixture of 500 grams molasses, 80 grams urea and 4 grams sulfur per animal. The supplementation period averaged 90 days. No effect of supplementation on reproductive parameters was detected. Supplemented cows were slightly heavier than non-supplemented ones on the average. Although calves from supplemented cows were eight kilograms heavier at 6 months and seven kilograms heavier at 9 months of age, this difference did not persist after weaning.

It is not clear if the quantity of supplementation was sufficient, particularly for an adequate period of time, to compensate the effect of the dry season. On the other hand, even if substantial animal response could be obtained, the economy of urea-molasses supplementation is

Table 41. **Calf production in relation to pasture treatments and stocking rate.**

Pasture treatments	Weaned calves n	Weaning weight (kg) $\bar{c}$	Stocking rate ha/A.U.[1]	Calf production (kg/ha/year)	Relative production
Savanna	162	130	3.5	16.0	100
Molasses grass	157	126	1.7	52.6	329
Molasses + savanna[2]	173	132	2.3	39.7	248

[1] Weighed means

[2] Molasses nine months, savanna three months.

questionable, since the ingredients of the mixture must be imported to the region at a high transport cost.

Seasonal Effects

To identify techniques to increase productivity within an ecosystem, it is necessary to have quantitative information on the influence of natural environment on animal performance. The most important environmental factor is the seasonality of feed availability, determined in the tropics mainly by rainfall regime.

The seasonal effects on relative calving distribution are illustrated in Figure 56. Independent of the treatments, the most common season for conception is between April and July, i.e., at the beginning of the rainy season, since 46 percent of all cows calve between January and April.

An analogous seasonal effect on calf

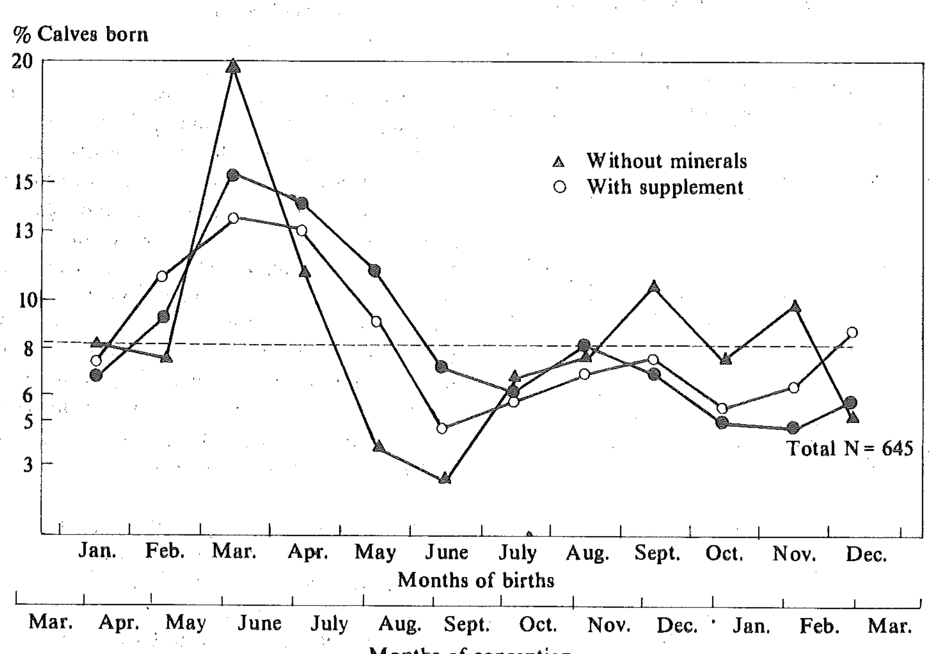


Figure 56. **Seasonal effects on relative calving distribution**

Table 42. **Influence of season at birth on calf weight (kg) (Herds 4-9).**

Age of calves	Season born: Dry January n	April $\bar{c}$	First half rainy May n	August $\bar{c}$	Second half rainy September n	December $\bar{c}$
3 months	213	79a[1]	143	79ab	91	75b
9 months	188	145a	129	129b	66	114c
18 months	142	195a	89	179b	57	152c

[1] Values followed by different letters are significantly different (P<.05).

growth can be observed. The results are summarized in Table 42.

Although calves born during the dry season showed the strongest growth depression after weaning, which coincides with the end of the rainy season, at 18 months they weighed 43 kilograms more than calves born during the second half of the rainy season. A similar seasonal effect on body weight of dams was found.

Considering the significant influence of season on animal performance, the importance of adapting the critical periods of the production cycle (conception, calving, lactation) to the most favorable season of the year becomes evident.

Calf Mortality

High calf mortality is one of the reasons for low extraction rates of herds in the region. The overall mean for all treatments of calf mortality before weaning was 13.4 percent. The analysis of relative distribution of mortality according to age showed that 9 percent of all calves born died within the first 30 days (Table 43). Mortality between 9 and 18 months of age was 2.5 percent.

Through improved management and closer supervision of calves in special paddocks calf mortality rate could be considerably reduced, especially during the first stage of life.

EVALUATION OF BEEF PRODUCTION SYSTEMS IN SAVANNA REGIONS OF LATIN AMERICA

This project is a cooperative effort of the Animal Management and Economics sections, in collaboration with the Institute of Animal Production, the Technical University of Berlin. The main objective of the study is the identification of management technology which assures an economic increase in reproductive efficiency, under actual beef production conditions. At the same time, the feasibility of transferring modern technology is also being studied.

The management aspects of the project are: (a) a situational analysis of reproductive performance of breeding herds in relation to different technology levels

Table 43. **Relative distribution of calf mortality until weaning.**

Life Period	% of dead calves
Perinatal	35
Between 2 and 30 days	37
Between 31 and 270 days	28

existing on commercial beef cattle ranches; (b) quantification of the effects of management techniques, combined into systems, which increase herd productivity; and, (c) specification of demand for new technology and possibilities of adoption.

This study constitutes a part of the Impact Area Survey. Data will be collected on selected farms at different locations, in the following countries: (1) Colombia: Eastern Plains; (2) Brazil: Cerrado; (3) Venezuela: Orinoco Plains; and (4) Peru: Jungle Region.

Outside of Colombia, the project will be in collaboration with national research institutions. In Brazil and Venezuela, activities will begin in December 1977 or early 1978, as soon as the German collaborators are integrated into the team.

In Colombia, the project started in August 1977. Twenty farms, characterized in Table 44 were selected and in October 1977, the CIAT team began collecting data. Locations of the farms are shown in Figure 57.

The following characteristics are evaluated for each farm.

(1) Farm characteristics: location, area, soil properties, physical inputs, production system.

Table 44. **Characterization of selected farms in Colombian Llanos portion of beef cattle technology project.**

Farm No.	Intensity level[1]	Type of operation[2]	Area		Animals	
			Total (ha)	Planted pastures (ha)	Cows	Total
1	III	Cr-L	900	150	200	500
2	III	Cr-L	2000	140	150	400
3	IV	L	800	400	-	400
4	II	Cr-L	3200	-	250	750
5	IV	Cr-L	1200	10	66	230
6	IV	Cr-L-C	3500	250	400	900
7	IV	Cr-L-C	5200	900	180	1000
8	IV	Cr-L	600	60	60	120
9	I	Cr-L	1100	-	50	96
10	IV	L-C	2800	1500	-	500
11	IV	Cr-L-C	5000	30	450	1100
12	III	Cr-L-C	3000	120	210	600
13	I	Cr-L	1500	-	150	300
14	I	Cr-L	3000	30	200	500
15	III	Cr-L	4300	-	500	1000
16	I	Cr-L	4000	-	200	400
17	II	Cr-L	6000	130	200	400
18	III	Cr-L-C	5000	80	200	600
19	I	Cr-L	4500	-	150	400
20	III	Cr-L	2500	250	200	500

[1] Intensity levels: I — Savanna pasture only, few minerals, without weaning, without herd subdivision; II – Savanna pasture only, minerals, with weaning, with herd subdivision; III — Improved pastures, few minerals, without weaning, without herd subdivision; IV — Improved pastures, minerals, with weaning, with herd subdivision.

[2] Operation: CR = Cow-Calf; C = Fattening; L = Raising.

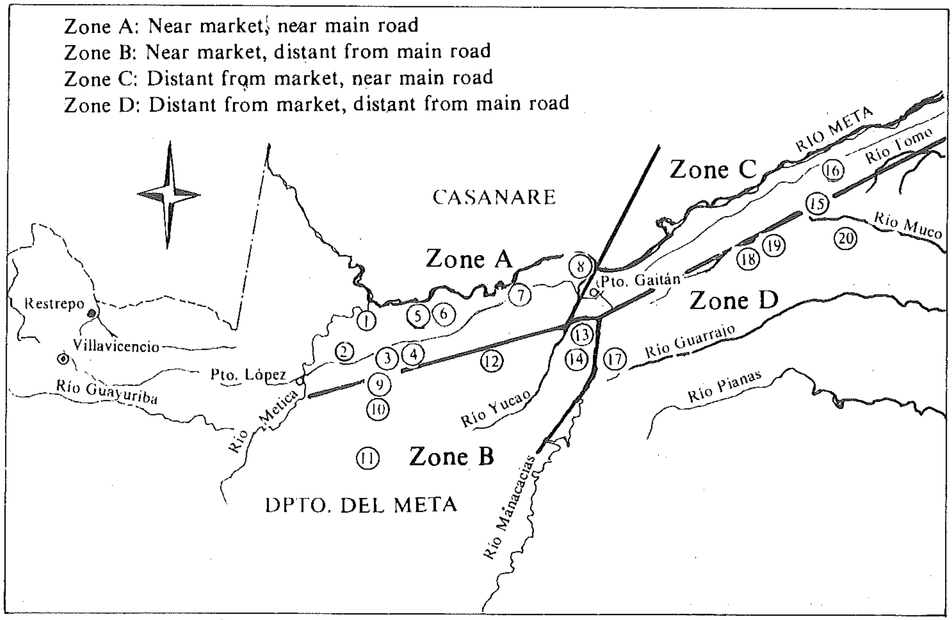


Figure 57. **Location of the 20 farms selected for characterizing beef production systems in the Colombian Llanos.**

(2) Feed resources: savanna, planted pastures, other feed resources.

(3) Utilization of feed resources: stocking rates, pasture management.

(4) Animal production: reproductive performance, mortality, type of animal product, animal output.

(5) Production techniques: with regard to feeding, herd management, animal health.

BREEDING HERDS MANAGEMENT SYSTEMS

In August 1977, an experiment on managing breeding herds was initiated at Carimagua. After a preliminary period, the experimental phase will start in May 1978. The data collection period will include three reproductive cycles.

The main objective is to study reproductive performance of breeding herds related to: (1) strategic use of planted pastures (5 percent of total available area), for the critical periods of the year (dry season) or critical growth stages (parturition, lactation, reconception and weaning); (2) adaptation of the critical periods (of higher demand) to periods of better forage availability, by restricted mating seasons; and (3) duration of lactation.

To study these components of herd management systems, six herds were established with the treatments described in Table 45.

For Herds 2,4 and 6, 120 hectares of *B. decumbens* and 30 hectares of *S. guianensis* were planted. The mating periods have been established according to the findings from the Herd System experiment, in relation to seasonal effects on animal performance. All herds will be supplemented *ad libitum* with minerals, and undergo preventive health measures.

Table 45. **Treatments in breeding herds management system experiment, Carimagua.**

Herds	No. of cows	Treatments between herds[1] Pastures	Mating period Type	Months	Duration (days)
1	50	Savanna	Continuous	Jan-Dec.	365
2	50	Savanna+*Brachiaria*+Legumes			
3	50	Savanna	1 Period	June-Sept.	120
4	50	Savanna+*Brachiaria*+Legumes			
5	50	Savanna	2 Periods	May-July	150
6	50	Savanna+*Brachiaria*+Legumes		Dec.-Jan.	

[1] Also, within herds, 50 percent of calves weaned at 6 months, 50 percent weaned at 9 months.

TEST HERD

At Carimagua Pasture Utilization, Animal Management and Animal Health sections are carrying out or have planned large experiments with cattle. In practice, it is difficult to purchase sufficient numbers of cattle having uniform ages, weights and health status and with good background information on pre-experimental treatments. At Carimagua, with its 22,000 hectares of savanna, it is feasible to produce the stock required for experiments.

After new working agreements were developed this year, the land, part of the infrastructure and cattle stock became available to set up a cattle pool with the following objectives:

(1) To provide adequate animals for experimental purposes.

(2) To collect detailed information on herd performance under reasonable, commercial-like management.

(3) To verify management techniques which have been experimentally tested or observed to work in the environment, under practical conditions and with large herds.

On a total area of about 4,600 hectares, there are 16 fenced savanna fields, from 150-750 hectares in size, and four paddocks, totaling 100 hectares of *B. decumbens*. Overall carrying capacity of savanna pasture is estimated to be 6-7 ha/A.U. Further area for expansion is available.

Cattle stock in the Test Herd as of 30 September 1977 was as listed below:

Breeding cows	195
Unweaned calves (0-9 months)	89
Replacement heifers for mating	149
Heifers (9 months - 3 years)[1]	306
Steers (9 months - 3 years)[1]	265
Bulls	35
Total	1039

[1] Includes animals that were later culled.

By late 1978 it is hoped to have 300 breeding cows, to produce 160-180 steers and heifers per year.

Table 46. **Breeding stock in the Carimagua Test Herd.**

Category	No.	Lactating cows	Pregnant cows	Abortions
Cows	197	108	69	14
Mated heifers[1]	51	9	40	-

[1] These heifers have been made available for an experiment.

Two small herds—of 20 Zebu and 65 San Martinero cows, with their respective calves and bulls — are managed within the cattle pool, to maintain a pure breeding stock of these two breeds.

Comparing the availabie fenced land and the existing stock, it is evident that grazing areas are partially overstocked, the main reason for low animal performance in the past.

Table 47. **Animals culled from Carimagua Test Herd.**

Category	No.	Reason
Cows	34	No calf over 2 years
Heifers	17	Genital infantilism
Heifers	4	Underdeveloped
Steers	187	Unsuitable for experiments
Cows	28	Unsuitable, crosses with European breeds
Bulls	24	Age, fertility
Bulls	14	San Martinero breed
Total	308	

The first activity (June 1977) was to initiate selection or screening, based on existing records and individual checks, with the results shown in Table 46. Approximate calving rate for 1977 will be 63 percent, compared to 36.4 percent in 1975 and 42 percent in 1976.

Based on this thorough check of all animal categories, the animals were culled in June, and in November, all herds were checked again for records information and further culling. (Table 47). It was decided to replace all San Martinero bulls by Zebu, bulls to obtain a more uniform calf crop. Twelve young Zebu bulls were purchased.

Numbers of cattle furnished for experiments are listed below.

Category	No.	Section
Mated heifers	51	Herd Management
Steers	77	Pasture Utilization
Steers	15	Legume Agronomy
Heifers for mating	149	Animal Health
Total	292	

Animal Health

Activities in animal health are centered on problem analysis and problem solving investigations. The section is responsible for establishing and maintaining preventive medicine schemes in animals under experimentation and herds that provide experimental cattle. Monitoring of health in both groups of cattle is a complementary activity.

Investigations continue in areas associated and complementary to the main thrust of the program, the increase in feed supply. Four main areas have been identified. (1) Diseases associated with or augmented by nutritional deficits (leptospirosis and others). (2) Diseases expected to increase as animal density increases because of improved feed supply. They include gastro-intestinal parasitism, infectious bovine viral rhinotracheitis and viral respiratory infections. (3) Epidemiological surveillance of cattle at the Carimagua station, preventive medicine and control. (4) A disease inventory of the impact area as part of the overall survey. (5) Disease-nutrition interaction studies through blood parameter analysis in the Herd Systems trial.

LEPTOSPIROSIS

Infectivity under High Nutritional Stress

Observations continued on natural infection occurring in a herd of 100 breeding cows and seven bulls grazing in 400 hectares of native savanna and receiving salt and bonemeal supplementation. The farm is located 65 kilometers from Puerto Lopez in the Meta region.

The basic objective of this study is to obtain a thorough understanding of the pathogenesis, epidemiology, diagnosis and effect on productivity of *Leptospira hardjo* while at the same time, studying a control procedure.

The herd is examined every 10 weeks. Blood samples are examined for clinico-pathological measurements and serum examined for leptospiral antibodies, which are used to monitor evolution of infection. Urine samples are obtained from animals with increasing antibody titers and cultured for isolation of Leptospiras to identify shedders and chronic infections.

Animals in the herd have been assigned to three groups. One group of 35 cows received two doses of Streptomycin by intramuscular injection 16 weeks apart at the end of the rainy season October-December 1976. The second group of 35 cows received one dose of Streptomycin (intramuscularly) at the end of the dry season (April 1977). A third group of 30 cows remains untreated as the control. The three groups graze the same pasture.

Infection has appeared to diminish overall in the herd as a consequence of the treatment (Fig. 58).

It could be argued that infection in the herd is slowly decreasing by itself. However, some decrease in the number of infected animals in the untreated group could be expected since all cows are in the same pasture, and a decrease in shedders in one group reduces the chances of re-infection in other groups. Also, infected titers are kept apparently by constant re-infection.

Animals with high serum titers —1:400 or more— have also decreased as a whole in the herd (Fig. 58), as have average titers, which decreased from 447 to 300. At this rate it would seem possible to eliminate the infection from the herd by further treatments.

Some cows with active infection seem to have abortion problems; however, of 35 abortions occurring from July 1976 through September 1977, 14 were in cows with no detectable infection (Table 48).

Twenty-five abortions occurred in late pregnancy, a characteristic of Leptospira infection. Some of these fetal deaths reported as abortions might actually have been perinatal mortality (calves dying in the first 24 hours of life) which is sometimes undetected in the field. This is especially interesting in view of the findings from experimental reproduction of the disease reported below. Abortion data should be carefully interpreted since most cows have not had a chance to have at least two pregnancies. The Leptospira strain isolated from this herd, and reported last year, was confirmed at the Pan-American

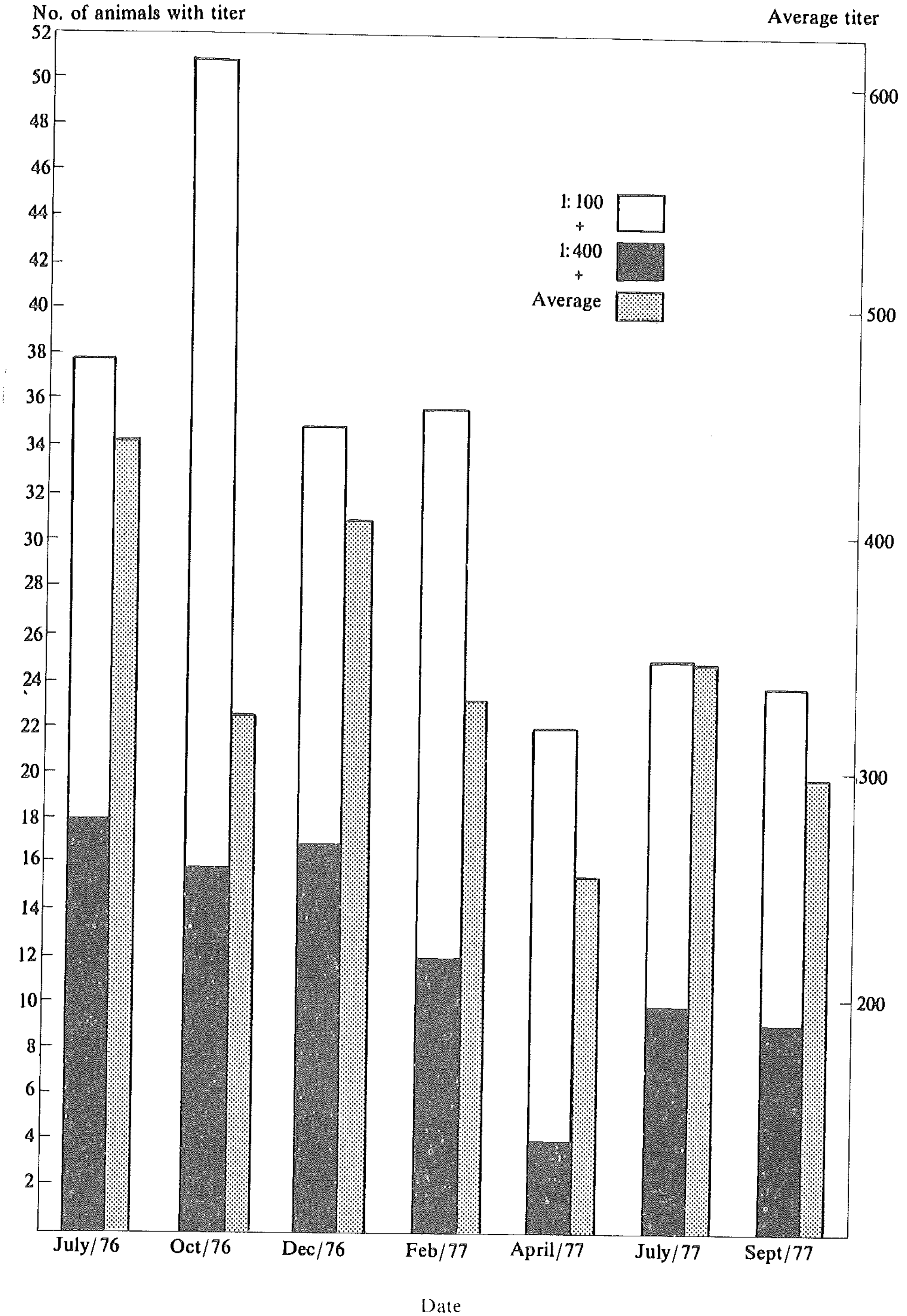


Figure 58. Cows from the Colombian Llanos trial herd with antibody titers over 1:100 and 1:400 compared with average titers at ten-week intervals.

Table 48. **Abortions in Colombian Llanos trial herd, comparing Leptospira infection in the cow and stage of pregnancy, July 1976 thru September 1977.[1]**

Detectable infection	Pregnancy		Totals
	Late	Early	
With antibodies	16	5	21
Without antibodies	9	5	14
Totals	25	10	35

All abortions detected by palpation.

Zoonosis Center, Buenos Aires, to be *L. hardjo*. This strain is being used to experimentally reproduce the disease. Urine cultures from infected animals have produced three more isolations tentatively identified as *L. hardjo*.

Culturing could be a very useful tool for diagnosing the disease and detecting shedders. However, chronically infected animals with high titers did not give rise to cultures. All three isolations came from cows with low serum antibody levels.

Infectivity in Well-nourished Cows under Artificial Inoculation

The *L. hardjo* isolated from naturally occurring infections was inoculated into 10 pregnant cows to study its capacity to produce infection and alterations in well-fed animals. Cows are receiving sugar cane, cottonseed meal and minerals. Six cows have ended their pregnancies. Cow No. 4 gave birth, almost at full term, to a very weak calf that died after 36 hours, with damages in the liver and kidneys. This cow had a retained placenta and developed a severe metritis. She was treated locally to control secondary infections but died 30 days after parturition with evidence of Leptospira infection in the kidneys and secondary bacterial infections in other organs. Three cows gave birth to weak

Table 49. **Alterations observed in pregnant cows inoculated with *Leptospira hardjo* and neonatal changes, at 110 days after challenge.**

Cow No.	Age pregnancy at inoculation (months)	Average cow antibodies[1]	Retained placenta and Metritis	Calf condition	Calf antibodies
1	5.0	80	+	O.K.	-
2	6.5	110	—	O.K.	-
3	7.0	235	—	Weak	1600
4[2]	6.5	35	+	Weak-died	No serum available
5	5.0	185	—	Weak	400
6	5.0	105	+	Weak	400
7	4.0	145	(Still pregnant)		
8	4.0	255	(Still pregnant)		
9	3.5	605	(Still pregnant)		
10	3.5	255	(Still pregnant)		
11	Non-inoculated	Control	—	Normal	–
12	Non-inoculated	Control	—	Normal	—

[1] 110 days after inoculation.
[2] Cow died 120 days after inoculation and 30 days after parturition.

calves that were infected, as evidenced by high serum antibody levels (Table 49). Calves were sacrificed 24 hours after birth.

All cows developed antibody levels immediately after challenge; antibodies peaked at 14 days (Fig. 59). Infection levels decreased and reached their lowest level after 75 days, after which a second rise occurred, reaching a smaller peak at 102 days. Apparently, after the initial infection recedes, re-infection occurs in some animals that are exposed to shedders, since cows are all in the same pasture. Animals that remain infected tend to increase their antibody levels even further and could remain chronically affected.

There are obvious differences in individual animals (Fig. 60). Cow No. 4 developed a low level of infection, and antibody defenses did not last over 52 days. This might be one of the reasons this animal died later from a complicated infection in which the primary cause was leptospirosis. It might also explain the *in utero* infection of the calf and its death some hours after birth. Cow No. 5 developed high antibody levels from 14 to 32 days after challenge and dropped to low levels up to 109 days. The calf from this cow developed a reasonably high infection level corresponding to the dam's level. Cow No. 3 had a very clear re-infection after initial infection and decreased antibody levels from 39 to 75 days. This high infection seems to be reflected in her calf's reaction, which has been the greatest in the group.

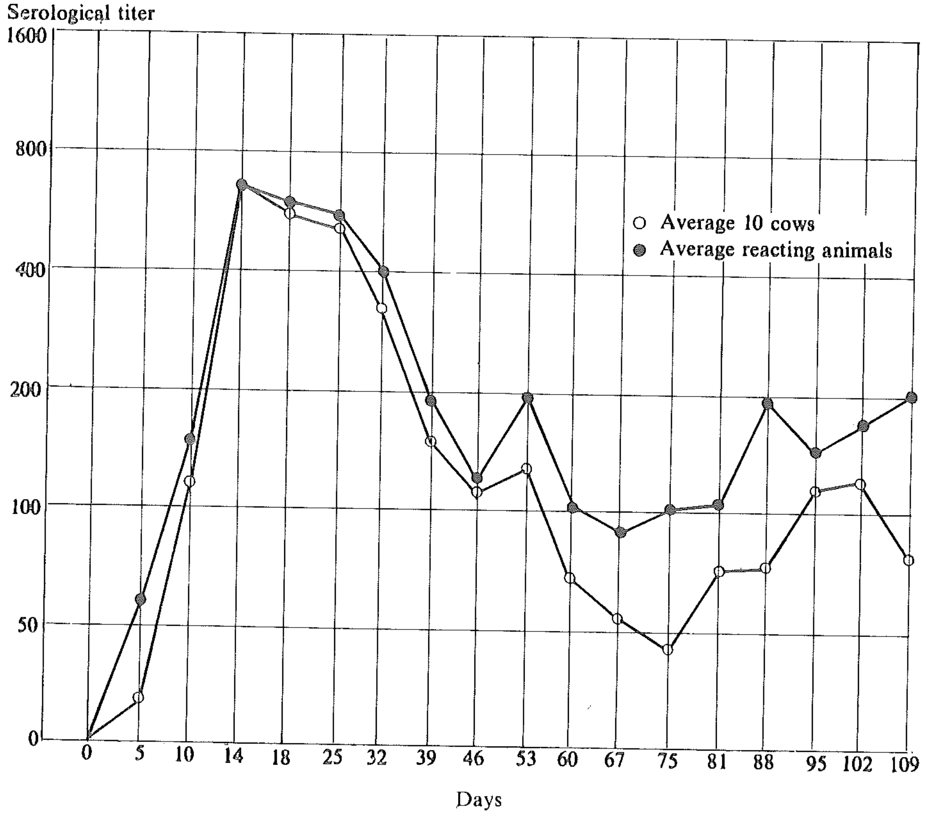


Figure 59. **Infection measured by antibody response in ten pregnant cows inoculated with** *Leptospira hardjo*.

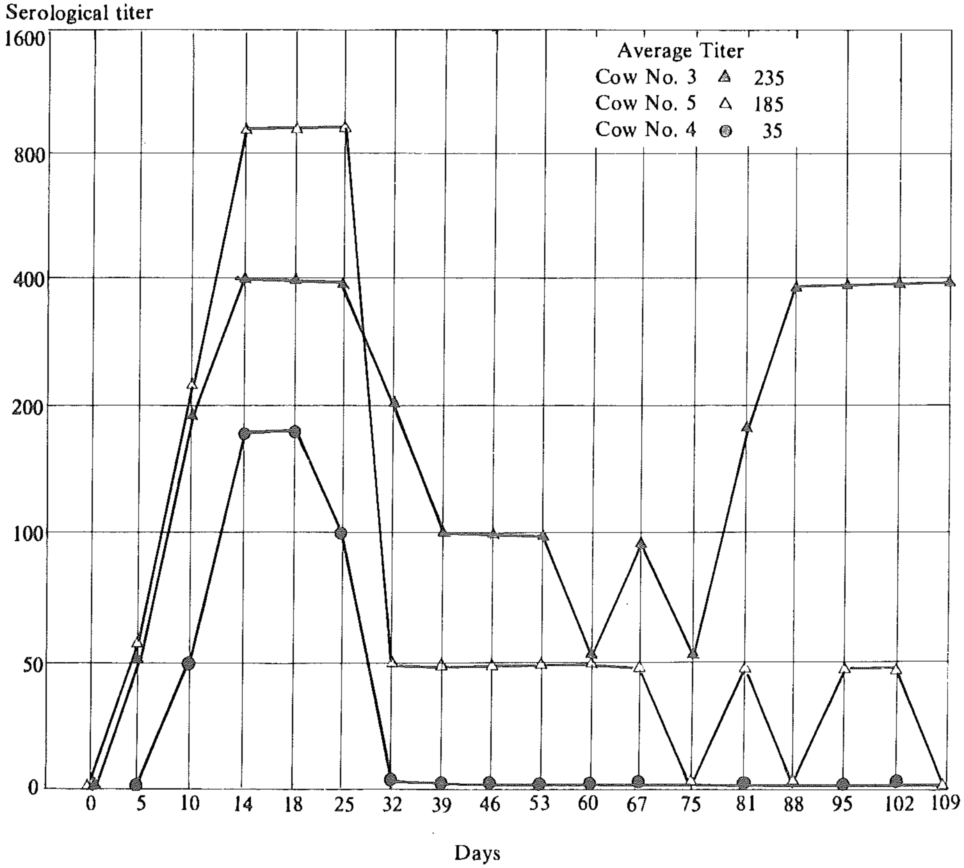


Figure 60. **Infection detected by antibody response in three pregnant cows inoculated with** *Leptospira hardjo.*

Isolation of Leptospira from urine samples has closely followed the antibody levels in the blood serum. Leptospira were isolated from most cows up to 75 days post-inoculation and are beginning to appear in animals that are getting re-infected. Shedding of Leptospiras in the urine began five days after inoculation. It has been possible to detect shedders by direct examination of the urine under dark ground illumination. When bacteria are observed with this procedure, it has also been possible to isolate them in artificial media and, very frequently, by hamster inoculation. Even though the trial is continuing (four more cows have to calve), it appears that the *L. hardjo* isolated from field cases in the Llanos of Colombia has considerable ability as a pathogen. The kidney and the liver lesions with generalized icterus seen in a calf, have not been described in the literature for this Leptospira. There is some tendency to produce weakened calves that might not survive under field conditions. This could explain some calf losses in cows at full term that are reported in the field as abortions, since very few cows are seen during parturition. Some abortions apparently related to Leptospira infections have not been explained by the artificial infection and some unknown triggering mechanism may exist.

From the natural and artificial infection results it can be hypothesized that cows in late gestation (over 6 months) will lose their calves to perinatal death, if exposed to *L. hardjo* infection and not having antibodies. It is not known if treatment or vaccination could prevent this. Also the influence of nutritional deficiencies on the development of the infections is still unclear. On the other hand, with natural infections, cows with chronic infection and elevated antibody levels tend to lose condition.

Response to Vaccination In Heifers before First Pregnancy

Strategic use of a vaccine might give sufficient protection to a heifer in overcoming a Leptospiral infection. A commercial vaccine (not available locally) containing *L. hardjo, L. pomona* and *L. gryppotyphosa* was obtained. One-hundred and fifty heifers to be kept for breeding in the herds of the experimental cattle pool were vaccinated with this product. Fifty of these heifers are kept in a separate group and closely observed for development of protective serum antibody levels. Vaccine will be applied every six months and blood serum samples collected at 30 days, and every two months thereafter. Antibody development is compared against a similar group of non-vaccinated heifers. Both groups are exposed to low-level field challenge.

EPIDEMIOLOGICAL STATUS OF THE CARIMAGUA HERD

Epidemiological surveillance of cattle in Carimagua is done by a pathologist, who will be joined by an ICA senior parasitologist and a research assistant at the end of the year. The most common clinical conditions encountered have been: bone fractures, retained placenta, polyarthritis, metritis and wasting disease. Ectoparasites (ticks and *Dermatobia hominis)* and internal parasites are commonly in an equilibrium state with the host and become problems if not strategically treated. A search is underway for an inventory of diseases in the area of influence of this experimental station.

Polyarthritis is a bacterial infection of various joints. Bacteria probably enter the system through a non-treated navel infection. The condition is gaining importance in Carimagua due to the extensive areas where calving takes place. Because many calves are not seen in the first 48 hours, infection can easily occur. A limited trial will be set up to prepare an immunizing product that, given to the cow, would help the calf withstand infection.

Routine vaccination schemes for brucellosis, aftosa, black-leg and hemorrhagic septicemia are being used and adapted to management conditions.

Internal nematodes interfere with normal growth and performance of beef cattle. Parasite control, however, should be used strategically to insure economic use of resources. Seasonal changes in parasite content of calves in the Carimagua area will be determined with a *bio-climatogram* where the level of parasitism is compared against climatological data such as temperature, rainfall, and potential evapotranspiration. For the analysis, fifty calves born during the rainy season were selected and 50 more will be selected from animals born during the dry period. A comparison will be established between level of parasitism and nutritional status measured by weight and some blood parameters.

IMPACT AREA SURVEY

A disease inventory of the Beef Program's impact area is being constructed. The basis for analysis of the information will be gathered by the impact area survey project of the Program.

Local teams of scientists will collect

information and, when possible, samples for laboratory analysis. Professionals from national institions are also being contacted to obtain descriptions as complete as possible. While initial information is not necessarily quantitative, it is hoped to obtain rather precise information for calf mortality causes, reproductive diseases and internal parasitism.

Work began in Brazil through EMBRAPA and in collaboration with their staff at the Cerrado, Center, Brasilia and the Centro Nacional de Pesquisa de Gado de Corte in Mato Grosso. Data collection also started in Paraguay with the collaboration of the Diagnostic Center of the Ministry of Agriculture. Blood serum samples for examination of reproductive problems from the three places will be analyzed in CIAT laboratories. Other examinations will be performed locally.

DISEASE-NUTRITION INTERACTIONS

In large parts of the tropics the main animal health problems are associated with killing diseases such as the tsetse-transmitted trypanosomiasis, rinderpest, theileriasis and contagious bovine pleuropneumonia. In Latin American countries, however, synergism between malnutrition and disease probably is the main factor influencing livestock productivity.

Epidemiologic studies, clinical investigations and laboratory experiments have clearly shown that malnutrition and infectious diseases are mutually aggravating and together, they can produce more serious consequences for the animal than would be expected from the sum of independent effects. In veterinary medicine, the close association of nutrition and husbandry to production disease is marked in tropical countries where grazing and crops are dependent upon a seasonal rainfall.

A one-year experiment was conducted on the nine herds of Zebu breeding cows of the Carimagua Herd Systems trial. The objective was to evaluate the usefulness of blood parameters in identifying abnormal situations arising in beef animals subjected to severe climatic stress, different management practices and production inputs.

Most blood parameters studied indicated the effect of season, mineral supplementation, urea-molasses-sulfur supplementation, type of weaning, reproductive condition and pasture type.

Blood parameters influenced by season in herds receiving salt and/or mineral supplementation (Group I) were packed cell volume (PCV), serum glucose, urea, inorganic phosphate, calcium, magnesium, sodium, potassium, total protein, globulin, hemoglobin, weight and weight gain ($P<0.01$); albumin was the least variable parameter ($P<0.05$) Most variable, as influenced by mineral supplementation, were serum urea, inorganic phosphate, total protein and weight ($P<0.01$); serum magnesium and globulin were the least variable ($P<0.05$). For urea-molasses-sulfur supplementation, the most variable parameters were PCV, serum urea, calcium, sodium, inorganic phosphate, hemoglobin and weight ($P<0.01$); albumin was the least variable ($P<0.05$). For weaning type, serum albumin and weight gain were most variable ($P<0.01$); globulin was the least variable ($P<0.05$). For reproductive condition, most variable were PCV, serum inorganic phosphate, albumin, hemoglobin, weight and weight gain ($P<0.01$); glucose was the least variable ($P<0.05$) (Table 50).

Blood parameters influenced by season in Group II (Herds 4, 5, 6, 7, 8, 9) are shown in Table 51. They were: PCV, serum glucose, urea, inorganic phosphate, calcium, magnesium, sodium, potassium, total protein, albumin, globulin, hemoglobin, weight and weight gain ($P<0.01$). Most variable, as influenced by pasture treatments were serum glucose, urea, inorganic phosphate, calcium,

Table 50. Effect of seasonal periods, pasture type, urea-molasses-sulphur supplementation weaning type and reproductive conditions on blood parameters, weight and weight gains of beef cattle in Group II (herds 4, 5, 6, 7, 8, 9). June 1976 to May 1977.

Treatment	Herd	Year	Season	No. of cows	PCV[1] (%)	Glucose (mg/100 ml)	Urea (mg/100 ml)	P (mg/100 ml)	Ca (mg/100 ml)	Mg (mg/100 ml)	Na (meq/100)	K (meq/100	Total Protein (g/100/ml)	Albumin (g/100 ml)	Globulin (g/100 ml)	Hemoglobin (g/100 ml)	Weight (kg)	Weight gains (kg)
					Blood Parameters													
Control	1	1976	1	52	40.29	71.96	29.35	3.09	10.70	2.37	138.60	5.68	8.22	2.56	5.66	14.38	317.87	-0.75
	1	1976	2	50	41.54	65.60	21.17	6.64	10.68	2.98	178.28	7.18	7.84	2.49	5.34	13.94	319.02	3.58
	1	1977	3	49	39.08	82.30	29.16	5.85	9.12	2.70	144.23	4.16	7.84	2.58	5.29	13.14	282.76	-28.96
	1	1977	4	24	41.77	77.60	36.56	5.07	13.11	2.69	151.11	3.85	8.15	2.61	5.50	13.72	306.79	43.08
Season																		
Early rainy season	4,5,6,7,8,9	1976	1	385	37.84	67.18	23.74	5.16	10.17	2.17	145.26	5.79	7.84	2.57	5.26	13.90	328.54	11.58
Late rainy season	4,5,6,7,8,9	1976	2	390	41.45	79.12	17.27	6.36	9.71	2.32	146.39	5.68	7.85	2.46	5.40	13.93	340.06	7.11
Dry season	4,5,6,7,8,9	1977	3	385	39.35	74.77	23.18	6.19	8.97	2.32	144.04	4.52	7.33	2.51	4.82	13.29	309.29	-25.45
Early rainy season	4,5,6,7,8,9	1977	4	190	39.53	83.49	28.47	5.15	10.11	2.24	132.02	3.71	7.95	2.64	5.31	13.26	327.03	33.86
Pasture[2]																		
Native grass	4,5	1976-77	1-4	450	39.66	74.84	26.67	5.39	10.11	2.57	148.11	5.09	7.97	2.63	5.34	13.69	339.98	3.53
Native grass + molasses grass	6,7	1976-77	1-4	481	40.11	79.27	21.33	5.67	9.36	2.16	138.36	5.19	7.68	2.54	5.15	13.77	332.34	2.73
Molasses grass	8,9	1976-77	1-4	419	38.79	70.55	18.97	6.38	9.61	2.06	144.01	5.01	7.47	2.41	5.05	13.46	304.24	2.32
Supplement (Dry season)[3]																		
None	5,6,8	1976-77	1-4	664	39.32	73.66	21.88	5.85	9.64	2.28	140.58	5.13	7.69	2.52	5.17	13.60	318.96	1.20
Urea + molasses	4,7,9	1976-77	1-4	686	39.78	76.47	22.85	5.75	9.73	2.26	146.05	5.07	7.74	2.54	5.19	13.69	333.14	4.48
Weaning																		
Normal	4,5,6,7,8,9	1976-77	1-4	1141	39.39	75.44	22.67	5.78	9.70	2.27	143.41	5.12	7.70	2.54	5.16	13.59	321.50	3.25
Early	4,5,6,7,8,9	1976-77	1-4	209	40.44	73.19	20.78	5.92	9.62	2.24	143.15	5.00	7.80	2.49	5.32	13.96	351.65	0.78
Reproductive state control herd																		
Lactating - pregnant	1	1976-77	1-4															
Dry pregnant	1	1976-77	1-4	76	41.98	73.31	26.88	5.57	10.75	2.76	150.61	5.29	8.06	2.61	5.43	14.37	324.76	5.39
Lactating - open	1	1976-77	1-4	36	36.89	72.10	29.44	4.40	10.45	2.61	154.50	5.29	7.60	2.38	5.28	12.72	277.11	-11.78
Dry - open	1	1976-77	1-4	63	40.58	75.39	28.39	5.07	10.46	2.63	155.91	5.67	8.14	2.59	5.55	13.78	302.22	-3.67
Reproductive state experimental herd																		
Lactating - pregnant	4,5,6,7,8,9	1976-77	1-4	65	38.45	76.52	23.74	5.33	10.06	2.37	143.70	5.22	7.91	2.63	5.27	13.36	316.71	6.69
Dry - pregnant	4,5,6,7,8,9	1976-77	1-4	590	41.50	73.49	21.54	6.10	9.71	2.33	143.00	5.04	7.81	2.59	5.23	14.23	352.44	18.00
Lactating - open	4,5,6,7,8,9	1976-77	1-4	549	37.60	76.04	23.76	5.42	9.60	2.22	142.49	5.08	7.60	2.45	5.14	13.01	301.72	-16.47
Dry - open	4,5,6,7,8,9	1976-77	1-4	146	39.52	77.33	19.97	6.24	9.71	2.16	147.98	5.35	7.66	2.54	5.13	13.82	316.14	12.72

[1] Packed cell volume or hematocrit.

[2] L.S.D. between mean values at .01 and .05 levels.

[3] From January to April, 1977.

Table 51. Effect of seasonal periods, mineral supplement, urea-molasses-sulfur supplementation, weaning type and reproductive conditions on blood parameters, weight and weight gains of beef cattle in Group I (herds 2, 3, 4, 5). June 1976 to May 1977.

Treatment	Herd	Year	Season	No. of cows	PCV[1] (%)	Glucose (mg/100 ml)	Urea (mg/100 ml)	P (mg/100 ml)	Ca (mg/100 ml)	Mg (mg/100 ml)	Na (meq/liter)	K (meq/liter)	Total Protein (g/100 ml)	Albumin (g/100 ml)	Globulin (g/100 ml)	Hemoglobin (g/100 ml)	Weight (kg)	Weight gains (kg)
					Blood Parameters													
Control	1	1976	1	52	40.29	71.96	29.35	3.09	10.70	2.37	138.60	5.68	8.22	2.56	5.66	14.38	317.87	-0.75
	1	1976	2	50	41.54	65.60	21.17	6.64	10.68	2.98	178.28	7.18	7.84	2.49	5.34	13.94	319.02	3.58
	1	1977	3	49	39.08	82.30	29.16	5.85	9.12	2.70	144.23	4.16	7.84	2.58	5.29	13.14	282.76	28.96
	1	1977	4	24	41.17	77.60	36.56	5.07	13.11	2.69	151.11	3.85	8.15	2.61	5.50	13.72	306.79	43.08
Season																		
Early rainy season	2,3,4,5	1976	1	254	37.63	77.70	28.88	3.78	10.33	2.24	144.36	5.92	7.90	2.63	5.27	14.42	326.67	7.08
Late rainy season	2,3,4,5	1976	2	253	41.76	76.03	29.04	5.90	9.58	2.58	153.67	5.81	8.21	2.57	5.63	13.99	343.57	13.33
Dry season	2,3,4,5	1977	3	247	39.89	71.22	26.66	5.51	9.37	2.67	147.28	4.36	7.41	2.62	4.78	.3.44	313.77	-25.90
Early rainy season	2,3,4,5	1977	4	123	40.39	84.23	36.08	4.32	11.85	2.57	153.28	3.67	8.05	2.68	5.38	13.55	328.73	29.07
Minerals																		
Salt	2,3	1976-77	1-4	427	40.05	77.86	32.09	4.50	10.00	2.43	150.23	5.17	7.77	2.61	5.16	14.12	315.78	1.78
Salt + minerals	4,5	1976-77	1-4	450	39.66	74.84	26.67	5.39	10.11	2.57	148.11	5.09	7.97	2.63	5.34	13.69	339.98	3.53
Supplement (Dry season)[2]																		
None	3,5	1976-77	1-4	432	39.28	75.85	27.64	5.22	9.92	2.50	146.11	5.18	7.87	2.61	5.25	13.68	320.04	1.36
Urea + molasses	2,4	1976-77	1-4	445	40.40	76.75	30.93	4.70	10.19	2.51	152.08	5.08	7.87	2.62	5.25	14.11	336.13	3.96
Weaning																		
Normal	2,3,4,5	1976-77	1-4	739	39.60	76.79	29.76	4.96	10.07	2.50	149.07	5.14	7.86	2.63	5.22	13.84	327.16	2.82
Early	2,3,4,5	1976-77	1-4	138	41.17	73.74	26.87	4.97	9.99	2.52	149.48	5.06	7.95	2.56	5.39	14.21	333.80	1.91
Reproductive stage control herd																		
Lactacting - pregnant	1	1976-77	1-4															
Dry-pregnant	1	1976-77	1-4	76	41.98	73.31	26.88	5.57	10.75	2.76	150.61	5.29	8.06	2.61	5.43	14.37	324.76	5.39
Lactating - open	1	1976-77	1-4	36	36.89	72.10	29.44	4.40	10.45	2.61	154.50	5.29	7.60	2.38	5.28	12.72	277.11	-11.78
Dry - open	1	1976-77	1-4	63	40.58	75.39	28.39	5.07	10.46	2.63	155.91	5.67	8.14	2.59	5.55	13.78	302.22	-3.67
Reproductive state experimental herd																		
Lactating - pregnant	2,3,4,5	1976-77	1-4	36	37.75	77.02	31.68	4.54	10.54	2.61	147.18	5.08	8.08	2.75	5.35	13.11	317.78	9.44
Dry - pregnant	2,3,4,5	1976-77	1-4	415	41.74	74.00	27.94	5.40	10.05	2.51	149.07	5.14	7.96	2.66	5.29	14.50	349.85	14.29
Lactating - open	2,3,4,5	1976-77	1-4	305	37.15	75.99	30.85	4.45	10.04	2.54	149.83	5.14	7.80	2.56	5.24	12.96	304.08	-15.52
Dry - open	2,3,4,5	1976-77	1-4	121	40.81	84.82	29.41	4.84	9.97	2.36	148.20	5.09	7.70	2.60	5.10	14.46	317.87	6.69

[1] Packed cell volume or hematocrit.

[2] From January to April, 1977.

magnesium, sodium, total protein, albumin, globulin and weight ($P<0.01$); potassium was the least variable ($P<0.05$). For urea-molasses-sulfur supplementation, most variable were serum sodium and weight ($P<0.01$); glucose and albumin were the least variable ($P<0.05$). For weaning type, most variable were serum albumin, globulin, weight and weight gain ($P<0.01$); total protein was the least variable ($P<0.05$). For reproductive condition, most variable were PCV, serum inorganic phosphate, potassium, total protein, albumin, hemoglobin, weight and weight gain ($P<0.01$); glucose and sodium were the least variable ($P<0.05$).

The largest correlation coefficients in decreasing order of all possible pairs of blood and production parameters (Table 52), were found between total protein and globulin (0.91), PCV and hemoglobin (0.80), weight and hemoglobin (0.44), potassium and sodium (0.44), weight and PCV (0.41), magnesium and calcium (0.38), PCV and total protein (0.33), weight gain and weight (0.32), total protein and albumin (0.31), PCV and globulin (0.30), weight and total protein (0.28), hemoglobin and total protein (0.28).

Three of 12 blood parameters studied namely, serum total protein, PCV and hemoglobin, were influenced by weight. Concentrations of all three increased with weight ($P<0.01$) (Fig. 61).

Seasonal variations of blood parameters and weight in relation to reproductive condition (Herds 1 to 9), showed that the highest serum mean value concentrations for inorganic phosphate, total protein, PCV, hemoglobin and weight across seasons 1 to 4 corresponded to the dry-pregnant condition (Figs. 62, 63, 64). The condition lactating-pregnant had the highest serum mean value concentrations for albumin, urea, calcium and magnesium. The condition dry-open had the highest mean value concentrations for globulin, sodium, potassium and glucose.

The lowest serum mean value concentrations for total protein, PCV, hemoglobin, albumin, sodium, calcium, magnesium and weight corresponded to the lactating-open condition. The lowest serum mean value concentrations for glucose, potassium and urea, corresponded to the dry-pregnant condition. The condition lactating-pregnant had the lowest mean value concentrations for inorganic phosphate and globulin.

Seasonal variations of blood parameters and weight in relation to type of weaning (Herds 1 to 9) showed that the highest serum mean value concentrations for PCV, total protein, globulin, hemoglobin and weight corresponded to early weaning cows during the late rainy season of 1976 (Table 53). The highest mean values for serum urea, calcium and albumin corresponded to normal weaning cows during the early rainy season of 1977. The highest mean values for serum sodium and potassium corresponded to normal weaning cows during the late rainy season of 1976. The highest mean values for serum magnesium corresponded to normal weaning cows during the dry season of 1977. The highest mean values for serum inorganic phosphate and glucose corresponded to early weaning cows during the dry and early rainy seasons of 1977, respectively.

The lowest serum mean values for calcium, total protein, globulin, hemoglobin and weight corresponded to normal weaning cows during the dry season of 1977. The lowest mean values for serum inorganic phosphate and PCV corresponded to normal weaning cows during the early rainy season of 1976. The lowest mean values for serum glucose and magnesium, urea and albumin, sodium and potassium corresponded to early rainy season and late rainy season of 1976 and early rainy season of 1977, respectively.

Herd 1 (negative control) was not included in the general statistical analyses. However, the highest mean values for PCV

Table 52. Pearson correlation coefficient for all possible pairs of blood and production parameters.[1]

	Glucose	Urea	Albumin	Globulin	Total protein	Hemoglobin	PCV	P	Ca	Mg	Na	K	Weight	Weight gain
Glucose	1.00													
Urea	0.00	1.00												
Albumin	0.02	0.19	1.00											
Globulin	0.05	-0.03	-0.07	1.00										
Total protein	0.06	0.04	0.31	0.91	1.00									
Hemoglobin	0.02	-0.06	0.19	0.22	0.28	1.00								
PCV	0.09	-0.19	0.12	0.30	0.33	0.80	1.00							
P	-0.04	-0.23	-0.08	-0.08	-0.10	-0.07	0.05	1.00						
Ca	0.05	0.07	0.11	0.17	0.20	0.14	0.12	-0.14	1.00					
Mg	-0.05	0.08	-0.16	0.04	0.10	0.02	0.14	0.05	0.38	1.00				
Na	-0.02	0.12	0.02	-0.01	0.00	-0.03	-0.05	0.07	0.12	0.15	1.00			
K	-0.17	-0.05	-0.03	0.09	0.07	0.15	-0.02	-0.01	0.00	-0.05	0.44	1.00		
Weight	-0.13	-0.03	0.21	0.22	0.28	0.44	0.41	0.02	0.06	0.10	0.01	0.13	1.00	
Weight gain	0.03	0.14	0.24	0.08	0.17	0.16	0.06	0.00	0.18	-0.04	0.02	0.12	0.32	1.00

1 Correlations > 0.26 have been found significant ($P \leq 0.01$) due to the high variability observed in experimental parameter values.

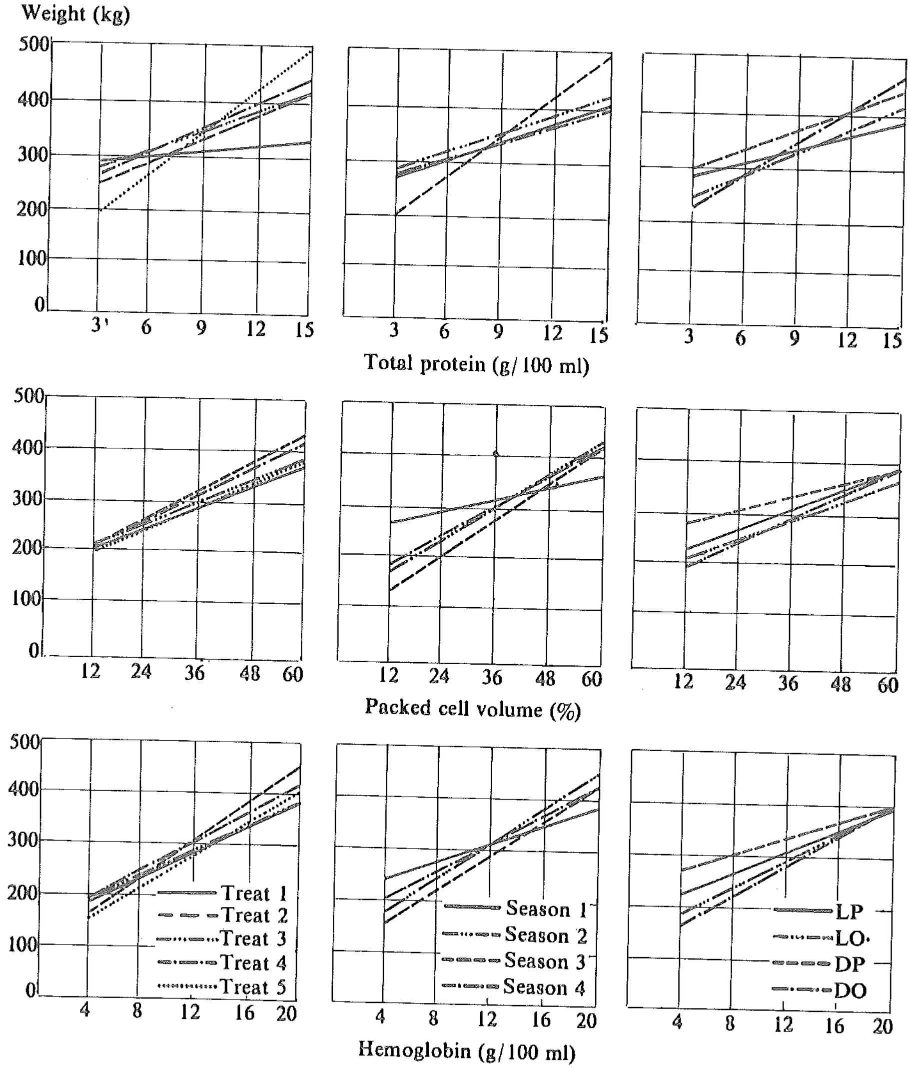


Figure 61. **Concentrations of total protein, packed cell volume (PCV), and hemoglobin, adjusted to treatment groups, seasonal periods and reproductive conditions, for 282 beef cows (Herds 1 to 9), plotted against their weights.**

serum inorganic phosphate, magnesium, sodium, potassium and weight corresponded to the late rainy season of 1976. The highest mean values for serum urea, calcium, albumin and weight gain corresponded to the early rainy season of 1977. Highest mean values for total protein, globulin and hemoglobin corresponded to the early rainy season of 1976. Serum glucose highest mean values corresponded to the dry season of 1977.

Lowest mean values for PCV, serum calcium, globulin, hemoglobin, weight and weight gain corresponded to the dry season of 1977. Lowest mean values for glucose, urea, total protein and albumin corresponded to the late rainy season of 1976.

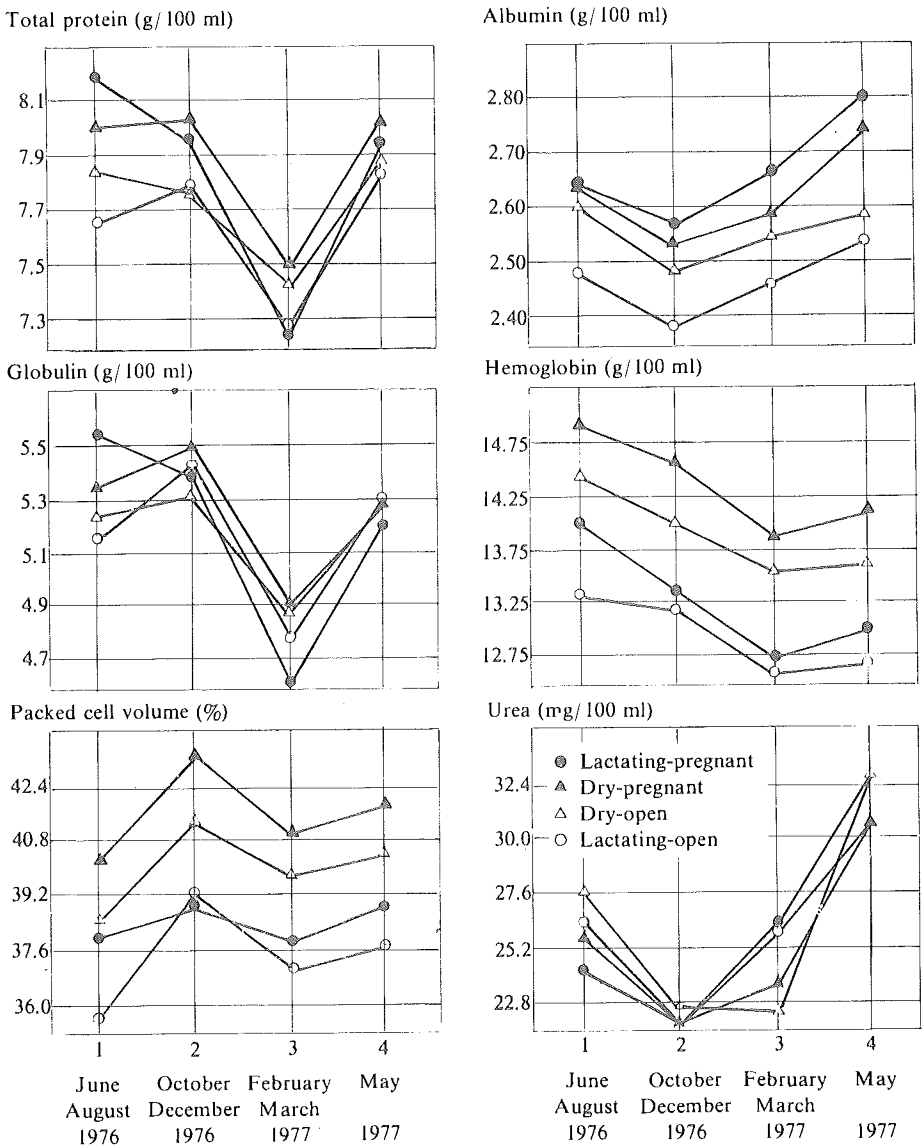


Figure 62. Seasonal variations of serum total protein, albumin, globulin, hemoglobin, packed cell volume (PCV) and urea for 282 beef cows in relation to reproductive condition (Herds 1 to 9).

Lowest inorganic phosphate serum mean values, magnesium and sodium, corresponded to the early rainy season of 1976. Serum potassium had its lowest value in the early rainy season of 1976.

The condition lactating-pregnant did not occur across the experiment. Highest mean values for PCV, inorganic phosphate, calcium, magnesium, albumin, hemoglobin, weight and weight gain corresponded to the dry-pregnant condition. Highest serum mean values for glucose, sodium, potassium, total protein

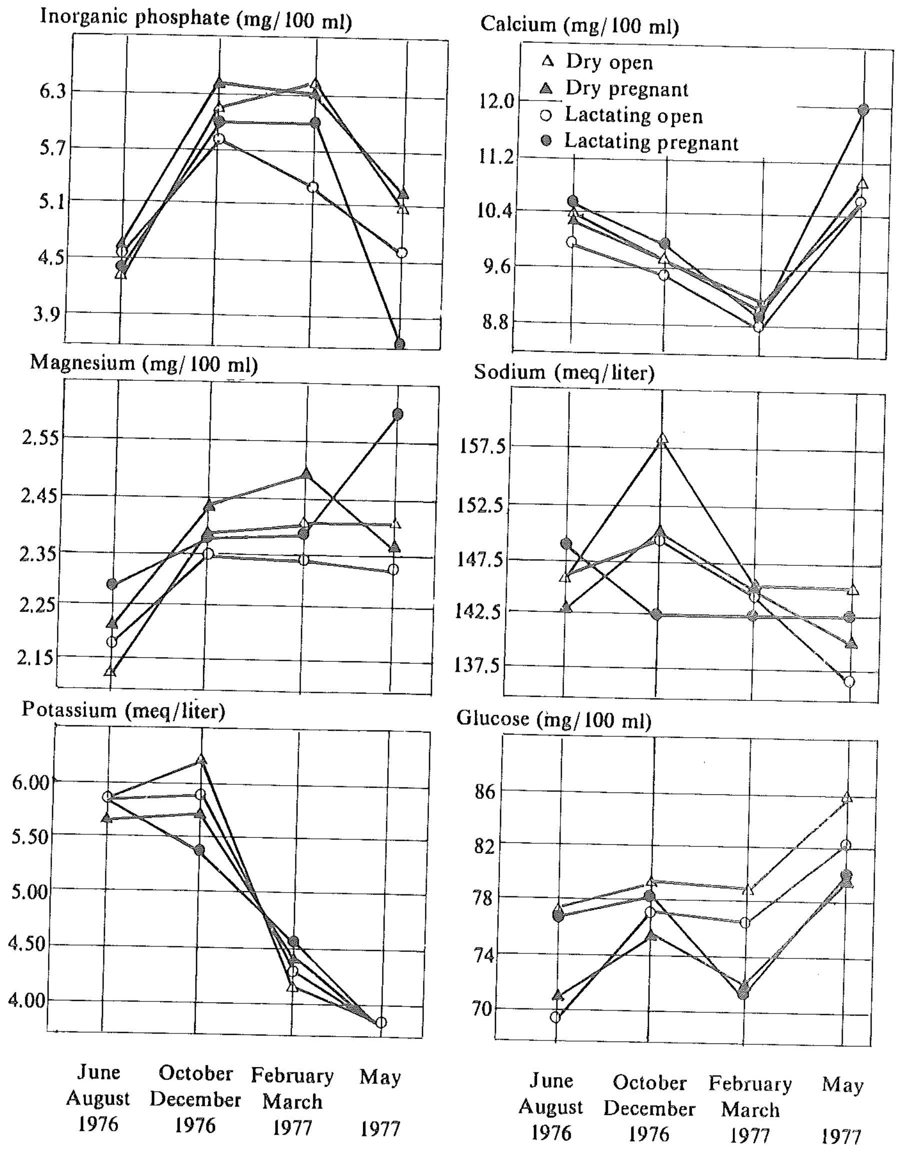


Figure 63. Seasonal variations of serum inorganic phosphate calcium, magnesium, sodium, potassium and glucose for 282 beef cows in relation to reproductive condition (Herds 1 to 9).

and globulin corresponded to the condition dry-open. Highest mean values for serum urea corresponded to lactating-open.

Lowest mean values for PCV, glucose, inorganic phosphate, calcium, magnesium, potassium, total protein, albumin, globulin, hemoglobin, weight and weight gain corresponded to the lactating-open condition. Lowest mean values for urea and sodium corresponded to the condition dry-pregnant.

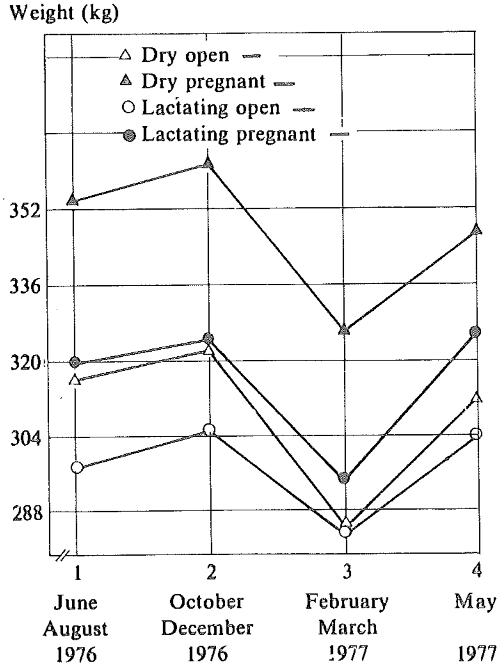


Figure 64. Seasonal variations of weight of 282 beef cows in relation to reproductive condition (Herds 1 to 9).

The soil chemical data (Table 54) showed a low pH indicating the acid nature of the soil, with a medium organic matter content. Exchangeable minerals (calcium, magnesium, potassium and sodium) were low, as well as the available phosphorus content. The aluminum saturation percentage was high, and is a common feature of Llanos soils in general.

The pasture chemical data (Table 55) showed that the phosphorus and calcium content of molasses grass was higher than that of native grass across seasons. The magnesium content was similar in both types of pastures. The nitrogen content of native grass was lowest in the late rainy season of 1976 and early dry season of 1977. The same seasons showed the highest nitrogen values for molasses grass.

Native grass had highest nitrogen values in the late dry and early rainy seasonal periods of 1977; these also showed the lowest values of the same element for molasses grass.

The interpretation of these preliminary results should be done cautiously, since many more estimates are needed. However, it has been established that blood parameters of Zebu breeding cows grazing in acid soils were influenced in decreasing order of importance by season, pasture type, reproductive condition, mineral supplementation, urea-molasses-Sulfur supplementation and weaning type. Clear seasonal patterns were evident for all twelve blood parameters studied, including the production parameters weight and weight gain. Highest mean values corresponded to wet seasons, and lowest to the dry season.

The direct relation of pasture phosphorus to phosphorus content of blood was evident. Animals on molasses grass had the highest blood concentrations, followed by those grazing native + molasses grass and native grass alone. This may partly explain the greater number of bone fractures that occurred in animals grazing native grass alone (Herds 1 to 4) from 1974 to 1977. It also suggests the advantange of establishing an improved grass efficient in phosphorus absorption in acid soils.

Low phosphorus content in these tropical soils and native grasses also leads to "pica" or depraved appetite, which predisposes animals to botulism, a toxic condition that undoubtedly killed several animals this year near the Carimagua Station.

Burning of native grass augmented the phosphorus content, as was observed by Lebdosoekojo in 1976. However, chemical analyses showed that molasses grass always had higher phosphorus content across seasons.

Other important parameters like serum

Table 53. **Seasonal variations of blood parameters and weight in relation to type of weaning (herds 1 to 9). June 1976 to May 1977.**

Type of weaning	Season[a]	Year	No. of cows	Blood Parameters: PCV[1]	Glucose (mg/100 ml)	Urea (mg/100 ml)	P (mg/100 ml)	Ca (mg/100 ml)	Mg (mg/100 ml)	Na (meq/liter)	K (meq/liter)	Total protein (g/100 ml)	Albumin (g/100 ml)	Globulin (g/100 ml)	Hemoglobin (g/100 ml)	Weight (kg)
Normal	Early rainy season	1976	592	38.10	71.87	26.69	4.48	10.29	2.19	144.70	5.86	7.85	2.59	5.26	14.20	322.17
Normal	Late rainy season	1976	593	41.40	77.29	21.73	6.19	9.75	2.41	151.34	5.91	7.88	2.49	5.39	13.91	333.80
Normal	Dry season	1977	583	39.15	75.26	24.69	5.95	9.05	2.43	144.63	4.39	7.38	2.55	4.83	13.21	300.97
Normal	Early rainy season	1977	287	39.67	81.63	31.17	4.83	10.80	2.37	139.14	3.79	7.92	2.65	5.27	13.31	320.62
Early	Early rainy season	1976	99	38.49	70.40	23.25	4.59	10.21	2.14	142.63	5.61	7.89	2.52	5.37	14.23	341.89
Early	Late rainy season	1976	100	42.68	77.03	20.62	6.12	9.47	2.32	150.34	5.79	8.13	2.46	5.69	14.32	352.20
Early	Dry season	1977	98	41.20	71.08	22.09	6.28	9.15	2.42	145.98	4.32	7.39	2.48	4.91	13.95	325.60
Early	Early rainy season	1977	50	40.33	84.69	30.19	4.95	10.25	2.28	138.69	3.69	8.01	2.60	5.41	13.51	334.83

Table 54. **Mean chemical data for soils of pastures for experimental Herds 1-9, June 1976 to May 1977.**

					Exchangeable							Available:			
Herd	Type of pasture	pH	Organic matter (%)	P Bray II (ppm)	Al (meq/ 100 g)	Ca (meq/ 100 g)	Mg (meq/ 100 g)	K (meq 100 g)	Na (meq/ 100 g)	CEC (meq/ 100 g)	% Al sat.	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)
1	Native	4.9	3.6	1.7	2.3	0.10	0.07	0.06	0.09	9.1	88	0.58	1.9	0.75	34
2	Native	4.8	4.2	2.7	2.3	0.09	0.07	0.06	0.06	9.1	89	0.69	1.8	0.38	45
3	Native	4.6	4.4	1.8	2.8	0.14	0.10	0.07	0.06	9.4	88	0.61	5.4	0.55	59
4	Native	4.7	4.1	0.9	3.2	0.18	0.12	0.09	0.06	11.0	88	0.67	6.8	0.56	45
5	Native	4.8	4.2	1.9	2.7	0.10	0.08	0.07	0.06	9.2	90	0.63	3.7	0.46	45
6	Native	4.7	4.1	1.5	3.2	0.17	0.09	0.09	0.06	11.2	89	0.54	4.6	0.54	42
7	Native	4.8	3.8	0.9	3.1	0.16	0.12	0.10	0.07	10.7	87	0.53	4.1	0.55	44
6	Molasses	4.7	4.2	1.8	3.1	0.44	0.17	0.14	0.07	11.8	79	0.61	5.7	0.62	37
7	Molasses	4.9	3.1	1.3	2.2	0.28	0.10	0.08	0.05	7.8	81	0.55	4.2	0.50	49
8	Molasses	4.8	3.8	2.0	2.9	0.51	0.16	0.11	0.05	11.0	78	0.68	7.0	0.64	65
9	Molasses	4.9	3.4	1.4	2.4	0.36	0.13	0.11	0.04	8.8	79	0.54	4.5	0.54	61

Table 55. **Seasonal variations of nitrogen, phosphorus, calcium and magnesium in native and molasses grasses.**[1]

Pasture	Sampling period	Year	Month	No. of observ.	N (%)	P (%)	Ca (%)	Mg (%)
Native savanna	Late rainy season	1976	December	5	0.53	0.04	0.14	0.12
	Early dry season	1977	February	7	0.40	0.02	0.12	0.10
	Late dry season	1977	March	7	0.60	0.04	0.10	0.09
	Early rainy season	1977	May	7	0.82	0.06	0.13	0.10
Molasses grass	Late rainy season	1976	December	4	0.58	0.08	0.15	0.12
	Early dry season	1977	February	4	0.50	0.05	0.13	0.10
	Late dry season	1977	March	2	0.48	0.05	0.14	0.09
	Early rainy season	1977	May	4	0.74	0.07	0.16	0.10

[1] Values for all nutrients expressed on a dry matter basis.

calcium, magnesium, sodium, urea, total protein, albumin, globulin, hemoglobin, PCV and weight were consistently higher in animals grazing native grass during the dry season, than in those grazing native + molasses and molasses grass alone during the dry season. This possibly reflects improved management practices upon animals and native savannas in this critical season, as well as the low drought resistance of molasses grass.

The condition known as "secadera" occurred more often in cows of the lactating-open condition, grazing molasses grass in the dry season (CIAT Annual Report, 1976). Animals in this condition had consistently lower mean value concentrations of total protein, albumin, globulin, PCV, hemoglobin, urea, glucose, magnesium, potassium and weight than animals in the same reproductive condition grazing other pastures. These findings support the hypothesis that the stress of lactation without adequate nutrition plays the most important role in the ocurrence of this syndrome, together with secondary infectious and parasitic diseases.

The condition Hydrallantois ("vaca inflada") was only seen in Herds 1 to 3 grazing native grass without mineral supplementation. Serum inorganic phosphate and potassium mean value concentrations for the nine cases observed were low. Other blood parameters studied were within normal limits.

Table 56. **Values of blood parameters, weight and weight gains of 282 Zebu breeding cows sampled every two months on seven occasions. June 1976 to May 1977.**

	Mean	Range
PCV (%)	39.0	23.0 - 55.0
Glucose (mg/100 ml)	102.0	13.9 - 190.0
Urea (mg/100 ml)	32.2	0.2 - 64.2
Inorganic phosphate (mg/100 ml)	9.6	0.9 - 18.3
Ca (mg/100 ml)	10.5	3.8 - 17.2
Mg (mg/100 ml)	2.9	1.1 - 4.7
Na (meq/liter)	141.4	50.1 - 232.6
K (meq/liter)	8.8	2.1 - 15.4
Total protein (g/100 ml)	7.3	4.0 - 10.5
Albumin (g/100 ml)	2.6	1.5 - 3.7
Globulin (g/100 ml)	4.7	1.4 - 7.9
Hemoglobin (g/100 ml)	14.0	8.4 - 19.5
Weight (kg)	361.0	180.0 - 542.0
Weight gain (kg)	- 13.5	-141.0 - 114.0

Mean values of blood parameters, weight and weight gains for 282 Zebu breeding cows in the Llanos were established (Table 55). Although the Herd Systems Experiment was location specific, these parameters could serve as a base for future work to be undertaken.

Economics

The Economics section is responsible for both micro-economic analyses of the experimental results and macro analyses of the beef industry in tropical America. Results presented this year concentrate on: (1) simulation of alternative beef production systems in the Colombian Llanos, and, (2) the economics of foot and mouth disease control.

ALTERNATIVE BEEF PRODUCTION SYSTEMS IN THE LLANOS

Cow-Calf Operations

Using preliminary results obtained in the Herd Systems experiment, farm level adoption of alternative cow- calf production systems was evaluated through simulation using the computerized, activity-budgeting model (HATSIM) developed at CIAT. The experimental treatments considered as alternative systems were:

Systems 1 and 2: Traditional systems with all animals grazing native savanna and *ad libitum* salt supplementation with an average intake of 12 kg/year/A.U. of salt (as in Herds 2 and 3 of the experiment described in Table 35).

Systems 3 and 4: Same as above but *ad libitum* supplementation with a full mineral mixture with an average intake of 16 kg/year/A.U. (as in Herds 4 and 5).

Systems 5 and 6: Same as above but weaning all calves at 86 days of age. During one month, early weaned calves are fed 0.75 kg/day of a caloric-proteic supplement (20% protein) and *ad libitum* fresh chopped *Axonopus scoparius* (Imperial grass). During another two months they are fed 0.5 kg/day of the same supplement, grazing in rotation *Paspalum plicatulum* (pasto negro) and a mixture of *Melinis minutiflora* (molasses grass) and *Hyparrhenia rufa*. After six months of age, calves graze native savanna and receive only mineral supplementation. Given the location and conditions of the pastures used in the early weaning treatments of the experiment, and in order to extrapolate treatment results to farm level, it was assumed that such pastures need to be irrigated during the dry season. Hence, the cost of small-scale irrigation equipment and associated operating and labor costs are charged to this treatment.

Systems 7 and 8: Cows, bulls and unweaned calves grazing *M. minutiflora* during the rainy season and native savanna during the dry season; all animals are supplemented *ad libitum* with a mineral mixture with average intake of 22 kg/year/A.U. (as in Herds 6 and 7).

Systems 9 and 10: Same as above but weaning at 86 days, with the same early weaning treatment as Systems 5 and 6.

System 11: Same as System 7, but grazing *Brachiaria decumbens* during the rainy season with a stocking rate of 1.7 A.U./ha., and savanna during the dry season. Reproductive as well as productive performance is assumed to be the same as in System 7.

Odd-numbered systems represent experimental results (four-year averages) directly extrapolated to farm level, with the exception of Systems 1 and 11. In System 1, calf-mortality was assumed to be 15 percent rather than the experimental result of 26 percent, since this value appears to overestimate actual farm losses. In fact, even a 15 percent calf mortality implies a decreasing herd over time. In even-numbered systems, calving rates and calf mortality are hypothetical values considered valid for the farm level, based on survey experience in the Colombian Llanos and preliminary estimates of the experimental variance obtained for the corresponding treatment in the Herd Systems experiment.

The main biological parameters used to simulate herd development in each system are shown in Table 57. Based on these parameters, the same initial herd was developed over a 25-year period and the net income flow was used to calculate the internal rate of return of each system using the discounted-cash-flow method. All prices corresponded to average farm prices of 1976, which were assumed constant over time and expressed in real terms. Since prices of inputs as well as output (cattle) vary according to distance to market, the economic evaluation was carried out for two areas: (A) from Puerto Lopez to Puerto Gaitan, and (B) from Puerto Gaitan to Carimagua. Prices of both inputs and cattle were corrected for transportation costs.

Table 57. **Parameters used in herd development of alternative production systems.**[1]

	Treatments			Parameters					
					Mortality rate (%)		Heifer mating rate (%)[3]		
System	Pasture	Minerals	Weaning	Calving rate (%)	Calves[2]	Adults	1-2 years	2-3 years	3-4 years
1	native	salt	normal	46	15	5	0	60	100
2	native	salt	normal	50	8	5	0	60	100
3	native	full mixture	normal	65	12	5	0	90	100
4	native	full mixture	normal	61	8	5	0	90	100
5	native	full mixture	early	87	13	4	0	80	100
6	native	full mixture	early	77	8	4	0	80	100
7	molasses+native	full mixture	normal	64	10	5	10	90	100
8	molasses+native	full mixture	normal	60	7	5	10	90	100
9	molasses+native	full mixture	early	85	8	4	0	90	100
10	molasses+native	full mixture	early	77	7	4	0	90	100
11	*Brachiaria decumbens* + native	full mixture	normal	64	10	5	10	90	100

1 Other parameters such as: proportion of bulls to cows (1:20), culling rates of cows (15%) and bulls (20%) and proportion of males: females at birth (50:50) are assumed equal for all systems.
2 Up to one year of age.
3 Weight ≥ 270 kgs.

Table 58 summarizes the performance of all systems for commercial ranches of 2500-3000 hectares. Results are described below, using the return on capital as a criterior.

Minerals. Systems 3 and 4, grazing native savanna with mineral supplementation, are the most profitable of the alternatives considered. They are followed by Systems 5 and 6 (which include early weaning), and by System 2 (native system supplementing only with salt). One of the reasons why *ad libitum* mineral supplementation is not a widespread practice in the Colombian Llanos may be the reduced net income occurring during the first few years after implementation until the additional calf crop obtained is sold.

Early weaning. This practice is not profitable at present cost and under current management (Systems 3 and 4 versus 5 and 6). It becomes an economic alternative, compared to normal weaning, only in intensive pasture systems for breeding cows (Systems 7 and 8 versus 9 and 10), by increasing breeding performance, and thus reducing pasture invest-

Table 58. **Simulation performance of alternative production systems in the Colombian Llanos.**

System	Area of improved pasture (ha)		Breeding herd size (cows)		Initial investment[1] ($ US'000)		Annual net income[1] ($ US'000)		Rate of return (%)	
	initial	total	initial	final	pasture	total[2]	year 4	year 13	region A	region B
1	-	-	190	127	-	90	6.4	5.2	5.5	3.6
2	-	-	190	182	-	90	7.5	7.3	8.1	6.3
3	-	-	190	230	-	91	6.3	10.7	10.0	9.0
4	-	-	190	230	-	91	5.9	10.2	9.8	8.9
5	12	12	190	190	4	97	5.0	10.8	9.1	7.5
6	12	12	190	190	4	97	5.6	7.6	8.4	7.4
7	450	650	190	325	56 (81)[3]	147 (172)[3]	6.7	9.6	5.0	3.7
8	450	650	190	325	56 (81)	147 (172)	6.7	9.0	4.6	3.3
9	450	516	190	250	61 (67)	154 (160)	4.2	18.2	6.3	4.8
10	450	516	190	250	61 (67)	154 (160)	4.7	16.0	5.2	4.6
11	100	190	190	325	13 (24)	103 (114)	6.7	9.6	8.5	n.a

1 Values corresponding to region A.
2 Includes value of cattle and improvements, excludes value of land.
3 Figures in parenthesis are investment values including the total area of improved pastures.

ment per unit of output (sales of steers). In addition to management problems, early weaning implies a substantial reduction in net income during the first few years after implementation.

The relatively poor performance of early weaned calves, (especially those weaned during the dry season), the high cost of caloric-proteic supplement and labor, and the establishment and maintenance costs of improved pasture contribute to this result, overshadowing the economic benefits from a larger calf crop. Nevertheless, if seasonal mating can improve calf performance and, at the same time, reduce calf feeding costs by reducing the need to maintain good quality pasture during the dry season, it might become an economic alternative for the Colombian Llanos, particularly in the case of widespread adoption of improved pastures for breeding herds.

Pastures. Systems based on grazing molasses grass during the wet season (7 and 8) were found to be only half as profitable as systems based on native savanna (3 and 4), both using mineral supplementation. Total investment nearly doubled in the former systems because of the low stocking rate of this pasture (0.5 A.U./ha). With a higher stocking rate (1.7 A.U./ha) as in System 11 (a simulated case with *B. decumbens,* assuming the same reproductive and productive performance as for molasses grass), the return on capital increases markedly.

Pasture persistence and establishment failures. Table 59 illustrates the effect of pasture duration on the returns to capital. In systems using a limited area of improved pasture for early weaning (such as System 5), low persistence has a negligible effect. However, when the area planted is sizeable, returns on capital are quite sensitive to pasture duration (Systems 7 and 9).

Table 59. **Percentage rates of return of Systems 5, 7 and 9; sensitivity analysis with respect to pasture persistence.**

	Pasture persistence (years)			
System	24	12	9	6
5	9.1	9.0	8.9	8.8
7	5.0	2.8	1.3	
9	6.3	4.2	2.7	0.9

Negative value.

Table 60 shows the result of a sensitivity analysis on pasture persistence and establishment losses. Two cases are considered: System 7 and 7', the latter assuming a 50 percent reduction in establishment costs of this particular pasture (molasses grass). It may be observed that reducing establishment costs without affecting carrying capacity not only increases returns to investment but also implies that these returns are less sensitive to establishment failures and to persistence risk. This is one of the reasons why a minimum input philosophy, and practices such as minimum tillage represent promising alternatives when the improved pasture is grazed by the entire breeding herd. They may not be as relevant when dealing with small areas for strategic use only.

Financing. In Colombia, as in some other countries of Latin America, the nominal interest rate on loans is smaller than the inflation rate. This implies financing under subsidized conditions. Table 61 is included to illustrate the effect of this type of incentive on the return to the cattleman's own capital. The following are assumed: an annual expected inflation rate of 30 percent and an 18 percent nominal interest rate and four years of grace on a 12-year loan. These conditions are found in the Colombian Llanos, although they may not prevail over the long-run. As the proportion of initial investment financed under these conditions increases, so does the profitability of all systems. But, even

Table 60. **Percentage rates of return of System 7: sensitivity analysis with respect to pasture persistence and establishment failure.**

Pasture establishment failures[1] (% of area)	Pasture persistence (years): 24		12		9	
	7[2]	7'[2]	7	7'	7	7'
0	5.0	7.1	2.8	5.9	1.3	5.0
20	4.4	6.7	2.4	5.5	0.9	4.6
40	4.0	6.3	2.0	5.2	0.6	4.3
60	3.5	6.0	1.7	4.9	0.3	4.0
80	3.2	5.7	1.3	4.6	0.0	3.8

[1] First year failures in pasture establishment.
[2] 7: Actual cost; 7': Assuming 50 percent reduction in establishment costs.

under 60 percent financing, System 7 (including molasses grass) is not as profitable as Systems 2 and 3 (native pasture plus salt and minerals, respectively) with zero financing. However, such is not the case with System 11 based on *B. decumbens*. Beyond 30-40 percent financing under such subsidized conditions, it becomes more profitable than Systems 2 and 3. This may explain why many producers in the Llanos are adopting this particular grass species.

Land values. When analyzing the profitability of alternative production systems which are relatively equal in intensity of land use, the value of land is not included in the amount of initial investment. The relevant question is: Which of the production systems is more profitable, given that the producer has already invested in land?

However, when comparing the returns on capital of a given technology in two

Table 61. **Percentage rates of return on producer's own capital from alternative systems receiving credit under subsidized conditions.[1]**

System	Percent financing of initial investment: 0	20	40	60	80
2	8.1	(n.a.)	(n.a.)	(n.a.)	(n.a.)
3	10.0	10.8	(12.8)	(15.1	(18.8)
7	5.0	5.6	6.3	7.2	(8.8)
7'[2]	7.1	7.9	8.9	10.2	(12.0)
11	8.5	9.6	11.0	13.1	(16.8)

[1] Figures in parenthesis are improbable cases included only for illustration.
[2] 7': Assuming 50 percent reduction in establishment costs.

ecologically homogeneous regions facing different input-output prices (because of distance to markets) the value of land has to be incorporated in the analysis to explain profitability differences between the regions. If the same technology is adopted in both areas, land prices are expected to compensate for the difference in profitability due to different input-output prices. The regions further from the market, and hence with the least favorable prices, will have a lower return on capital when the value of land is not included in the amount of initial investment. This explains the difference in returns between Region A and Region B, as shown in Table 58. Comparing normal weaning systems (3 and 7) against early weaning systems (5 and 9) it may be observed that the regional differences in return are larger in the case of systems incorporating early weaning. This indicates the obvious—technology using more inputs has a lower probability of adoption in regions further away from the market than in regions closer to the market. In order to obtain widespread adoption, not only it is preferable that the given technology minimize input use in terms of value, but also in terms of volume.

Table 62 illustrates the effect of a land-saving technology on the total return to producer's own capital (including land value). It was assumed that the real price of land increased at an annual rate of 2 percent. The area below the line represents situations in which System 11 (*B. decumbens* plus minerals) is preferable to System 3 (native pasture plus minerals) using total returns on capital as the criterion. This partly explains why land saving technology (pastures with high carrying capacity), even under similar ecological conditions, are adopted first in areas closer to the market which have higher land values.

Fattening Systems

Based on four years experimental results reported in the Pasture Utilization section, a 1000-hectare fattening farm in Region A of the Colombian Llanos was simulated. As in the previous cases, the economic analysis was carried out over a 25-year period. Prices of 1976 were used and were assumed constant over time and expressed in real terms. The net income flow was used to calculate the internal rate of return using the discounted-cash-flow method.

Three fattening systems were evaluated: (A) grazing molasses grass during 270 days with a stocking rate of 0.44 A.U./ha; (B) same as above but with a stocking rate of 0.88 A.U./ha; and, (C) grazing *B.*

Table 62. **Percentage rates of return[1] of System 11: sensitivity analysis with respect to land values and percent financing of initial investment[2] under subsidy conditions.**

Land value:		Percent financing of initial investment				
Col.$/ha	US$/ha	0	20	40	60	80
0	0	8.5	9.6	11.0	13.1	16.8
500	14	6.5	7.0	7.0	8.5	9.5
1000	28	5.4	5.8	6.2	6.7	7.2
1500	42	4.8	5.1	5.3	5.7	6.0
2000	56	4.3	4.6	4.8	5.0	5.2

1 Rates of return on producer's own capital and on total investment including value of land.
2 Financing of initial investment excluding land.

Table 63. **Rates of return from finishing cattle on improved pastures.**

System	Pasture	Stocking rate	Production		Rate of return
			per-head	per-ha	
		(A.U./ha)	(kg/270 days)		(%)
A	*M. minutiflora*	0.44	114	50	7.2
B	*M. minutiflora*	0.88	76	67	4.8
C	*B. decumbens*	1.30	103	134	12.1
D	*B. decumbens*	1.70	80	136	8.0

decumbens during a similar period, fertilized with 200 kilograms of basic slag every two years, at a stocking rate of 1.3 A.U./ha. Results for the three systems are reported in Table 63. Using return on capital (excluding value of land) as the criterion, although System B yields more output per hectare, it is less profitable than System A which has a lower stocking rate. Only in areas with high land values would System B become more profitable than A.

System C is significantly more profitable than the other two systems. This result tends to support the ones obtained in the simulation of System 11 with the breeding herd grazing *Brachiaria*.

Table 64 is included to illustrate the type of economic results that could be expected from different pastures needing different levels of inputs with different frequencies.

Each value in the table represents a different pasture needing application of a given amount of fertilizer (worth the amount indicated in the respective column), with a given frequency (as indicated in the row), in order to yield the same output per hectare with the same stocking rate as in System C (Table 63). In the Carimagua region and at 1976 prices, the amounts indicated in Table 64 would buy the volumes of nitrogen P_2O_5 indicated below:

Kgs of	in form of:	US$28	US$42	US$59
N	urea	50	75	100
P_2O_5	basic slag	67	101	135
P_2O_5	TSP	39	58	78

Other things being equal, pastures needing frequent fertilization (even low levels) are markedly less profitable than those needing only low establishment rates. Pastures needing the same fertilization with higher frequency are also substantially less profitable. In order to compensate for such differences in returns, animal response to fertilization of the pasture needs to be rather high. Thus, it seems logical that, in the case of the Carimagua region, pastures needing frequent fertilization could become economic alternatives perhaps only in cases of strategic grazing by those animals with high response capacity.

Alternatively, for systems grazing the bulk of the herd on improved pasture

Table 64. **Percentage rates of return on investment[1] of simulated fattening systems having identical carrying capacity and animal performance, applying inputs at different frequencies.**

Input application every:	Value of inputs (US$/ha)			
	0	28	42	56
year	12.1	4.6	1.0	[2]
2 years	12.1	8.5	6.7	5.0
3 years	12.1	10.2	8.7	7.6
4 years	12.1	10.4	9.7	8.9

[1] Excluding land value

[2] Negative return.

(fattening farms or grazing the entire breeding herd), the above results clearly indicate the appropriateness of selecting species and varieties based on minimum input and maximum carrying capacity criteria, reinforcing the need for seeking legume-based pastures.

ECONOMICS OF FOOT-AND-MOUTH DISEASE

During 1977, the foot-and-mouth disease (FMD) control study in endemic areas was completed with the sensitivity analysis of vaccination and the study of the eradication strategy.

Sensitivity analyses on both the private and social optimum vaccination strategies were done with respect to the main parameters in the model: results are shown in Table 65. The first 12 cases correspond to changes in one variable at a time. It may be observed that the private optimum level fluctuates between 60 and 80 percent of vaccination coverage, and the social optimum varies between 70 and 90 percent. The gap between private and social optimum is present in all cases, and increases with a lower vaccine effectiveness as shown in Table 65.

In Case 13, 20 percent lower attack rates and outbreak probabilities together with a lower vaccine effectiveness were considered. Results indicate that even in the case of a possible overestimation of these parameters, the private and social op-

Table 65. **Summary of results from sensitivity analysis of vaccination strategies for foot-and-mouth disease in an endemic area.**

Case No.	Variables changed	Change assumed	Optimum strategy	
			Private	Social
1	Outbreak probabilities	20% lower	60	80
2	Same as 1	20% higher	80	90
3	Mortality rates	20% higher	70	90
4	Same as 3	20% lower	70	90
5	Attack rates	20% lower	60	80
6	Same as 5	20% higher	80	90
7	Vaccine effectiveness	From 85% down to 60%	60	90
8	Weight losses from FMD	20% higher	70	90
9	Same as 8	20% lower	70	80
10	Milk loss from FMD	20% higher	70	90
11	Same as 10	20% lower	70	90
12	Vaccination costs	100% higher	60	70
13	Combination of runs No. 1, 5, 7		60	70
14	Same as 13 plus vacination costs	20% higher	50	80
15	Same as 13 plus vaccination costs	50% higher	0	70

timum levels of vaccination would be only 10 percent lower, indicating stability of results. On the other hand, if, in addition, vaccination costs were underestimated, the private optimum solution changes drastically (Cases 14 and 15).

The eradication strategy was defined as a sequence of massive vaccinations for a period of four years, followed by two years of vaccination combined with slaughter. Also, to ensure the continued disease-free status of the region, a permanent epidemiological surveillance was considered as an essential component of this strategy.

The rationale for this sequence is that after four years of vaccination, the full effect of this activity would be realized; after that, all animals becoming sick plus those in contact with them are slaughtered, while preventive vaccination continues. It is expected that after two years of slaughtering sick animals, outbreaks will terminate as will the vaccination and slaughter activities. However, efficient epidemiological vigilance continues indefinitely so that further widespread episodes of the disease are avoided.

The benefits from eradication are two-fold: (1) the economic losses from the disease are eliminated; and, (2) additional foreign-exchange earnings are gained due to the price differential favoring exporting areas (countries) "without FMD", if access is gained to markets in disease-free countries. A 30-percent increase in beef export prices was estimated for Colombia, based on the long-run FOB price paid by the United States to Costa Rica, which exports a similar quality of beef. This second benefit is another type of externality, that can only be captured by a farm (or exporter) if all farms carry out the eradication strategy simultaneously. Therefore, two different cases were considered: one with and the other without access to the market in FMD-free countries. Alternative vaccination coverages of 60, 70, 80 and 90 percent were considered as part of an eradication program. As shown in Table 66 the optimum vaccination level for an eradication program is 90 percent.

Net benefits from shifting to eradication were compared with those resulting from continuing to vaccinate at 90 percent coverage indefinitely (which was reported in the 1976 Annual Report to constitute the social optimum vaccination strategy). Inspection of Table 67 indicates that, if the area is accorded a disease-free status by importing nations, FMD eradication is preferable. When there is no guarantee of access to the disease-free market once the slaughter cycle has terminated and eradication achieved, at the current opportunity cost of capital of 10 percent, the social optimum control strategy is still 90 percent vaccination coverage in the region. This result would hold even more for higher opportunity costs of capital. In this latter case, only in a situation with capital abundance and opportunity costs of less than 5 percent, would eradication be the optimum strategy.

A collaborative project with ICA was carried out during 1977, to obtain direct

Table 66. **Social net present benefits from shifting to eradication versus continuing with vaccination, in relation to level of initial vaccination[1] (in millions of Col.$, 1975 prices).**

	Level of vaccination (% coverage)			
Strategy	60	70	80	90
Continuous vaccination	2,545	3,063	3,124	3,126
Eradication[2]	-11,425	582	3,857	6,368

[1] Net benefits are discounted up to year 5, when the alternative of shifting to eradication arises, with a 10 percent discount rate.

[2] This is Case A, of access to the market "without FMD". Values indicate net present value of benefits from year 5 onwards, if the first phase consists of the vaccination coverage shown above in corresponding column.

Table 67. Net present value of the social benefits expected from shifting to eradication versus continuing with vaccination[1] (in millions of Col.$, 1975 prices).

	Social discount rate (%)		
Control strategy	5	10	15
Vaccination (90% coverage)	6,252	3,126	2,084
Eradication			
Case A[2]	16,206	6,368	3,289
Case B[3]	6,316	2,241	966

1 Net benefits are discounted up to year 5, when the alternative of shifting to eradicatin or continuing with vaccination arises.

2 This case assumes access to the FMD-free market. Results are based on conservative estimates, assuming a price-elasticity of supply equal to zero.

3 This case assumes no access to the FMD-free market.

field information from the Urabá region (North Coast of Colombia), in order to validate the simulation results described above. This collaborative project was partially financed by the Ford Foundation. A survey was done on all cattle farms experiencing FMD outbreaks during one year. The group consisted of 49 cattle farms, equivalent to 1.24 percent of all farms in the area, at a time when an average vaccination coverage of 90 percent was achieved in the region. Data were obtained for epidemiological parameters, physical losses and vaccination costs. Information from the survey plus that collected from the ICA-USDA program in charge of the campaign against FMD in the area, provided the following results.

(1) The annual outbreak probability at 90 percent vaccination coverage was considerably lower than expected. However, data obtained correspond only to reported outbreaks. It is suspected that at high vaccination levels, many outbreaks are so mild as to go undetected. This information was used to recalculate disease incidence for all levels of vaccination coverage.

(2) Attack rates observed were higher than those expected at high levels of vaccination, but this may be explained by the fact that 90 percent coverage had only been in effect in the area for one year. Thus, the corresponding parameters in the semi-Markov model were not altered in the new calculations.

(3) Weight losses of only 15 kg/animal for steers older than 2 years of age were reported by the farmers, as compared with average losses of 35 kg/animal observed in areas with low levels of vaccination. Therefore, new estimates have been obtained with physical losses expressed as a continuous decreasing function of regional vaccination coverage.

(4) Finally, although the private costs of vaccination per head were very similar to previous estimates, the public cost in the area turned out to be considerably higher. During the one year, the average annual public cost per head vaccinated was Col.$40.50, which gave a total unit cost per head of Col.$60, at 1976 prices.

Table 68 presents the costs and benefits from all vaccination intensities estimated for the Urabá region. In spite of the higher vaccination costs, and lower outbreak probabilities, the optimum vaccination coverage from the social standpoint is 80 percent, versus 90 percent projected previously. This is within the range of results predicted with the sensitivity analysis described above.

A comparison between the on-going vaccination strategy in Urabá and alternative control programs, including eradication, is being completed and will appear in a separate report.

The study on the economics of animal health, through the case of FMD in Northern Colombia, ended during the year. The methodology developed at CIAT was transferred to ICA, the national institution in charge of disease control.

Table 68. **Social annual costs and benefits from foot-and-mouth disease vaccination in the region of Urabá,[1] Colombia, (in millions of Col.$, 1976 prices)**

Regional vaccination coverage (%)	Economic losses	Gross benefits	Vaccination costs[2]	Net benefits
0	44.2	0	0	0
10	36.8	7.5	1.8	5.7
20	30.4	13.9	3.6	10.3
30	25.5	18.7	5.3	13.4
40	19.9	24.3	7.1	17.2
50	13.7	30.5	8.9	21.6
60	7.3	36.9	10.6	26.2
70	3.9	40.3	12.4	27.9
80	1.6	42.6	14.2	28.4
90	0.7	43.5	16.0	27.5
100	0.6	43.6	17.7	25.9

1 Estimates based on a stabilized regional herd of 295.8 thousand head.
2 Annual unit cost of Col.$60 per head vaccinated.

Training and Regional Trials

In mid-1977 a senior scientist arrived to coordinate the Program's transfer of technology activities which include training, regional trials and seminars. Establishment of this section implemented the policy of integrating the development and the transfer of technology within the Beef Program. As with other new sections, a considerable part of available time was spent in developing a strategy.

STRATEGY

The objectives of the section are: (1) To develop and strengthen a network of scientists working on research and production of forages to validate, adopt, and transfer new technology developed by the Beef Program and other institutions to the impact area. (2) To establish cooperative links with national institutions for all the activities of the Program, especially on regional trials. In this fashion the principal functions of training and regional trials form a continuum. Training activities will be followed up by regional trials in cooperation with the CIAT staff to assure continuity and guarantee the feed-back of information to the research program. Figure 65 illustrates the strategy

TRAINING

In 1977, 31 postgraduate interns received individual training in pastures and forages, animal management and animal health. Trainees were selected from national institutions in Latin America for advanced training to better prepare them for research responsibilities in their countries.

Six visiting research associates are conducting dissertation research projects in the various disciplines of the Beef Program, in collaboration with the univer-

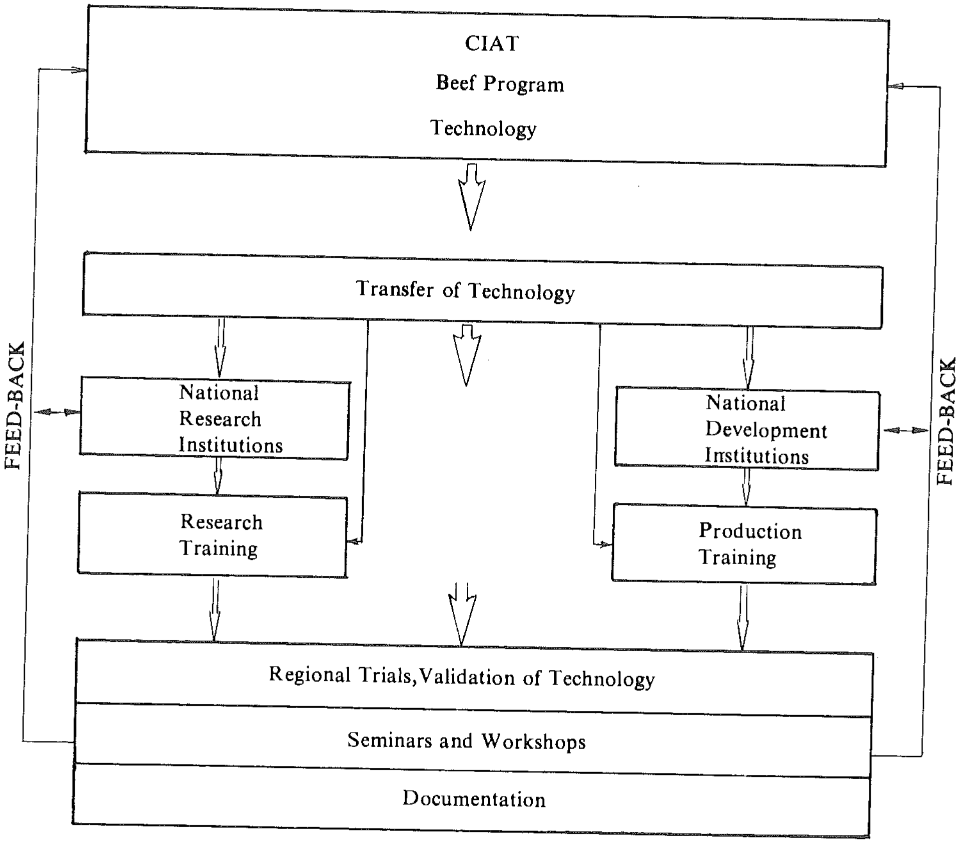


Figure 65. **Integration of research, transfer of technology and training in the Beef Production Program.**

sities where they have completed their academic requirements.

The Fifth Livestock Production Specialist Training Program began January 1977 for a group of 18 participants, 13 from Guatemala, 2 from Bolivia and 1 each from Colombia, Honduras and Panama. The trainees spent three months at CIAT (theory phase) after which 16 went to Guatemala for a ranch phase of an additional seven months under the supervision of two training assistants from CIAT. The Programa de Desarrollo Ganadero (PRODEGA) supported the training program in Guatemala.

The main emphasis in the ranch phase was on establishing and managing improved pastures, since the most critical problems associated with the development of the local cattle industry were related to lack of adequate nutrition during the dry season because of lack of forage, lack of persistence of improved pastures under grazing, and weed competition during establishment. Alternatives considered were the establishment of grass species that could compete fairly well with weeds, improved grazing management, weed control, and the use of sugar cane and green-chopped grasses for fodder supplementation during the dry season.

REGIONAL TRIALS

Eight priority countries —Brazil, Colombia, Venezuela, Perú, Panamá, Bolivia, Nicaragua and Ecuador— were identified within the impact area of the Program, with the possibilities of including Honduras, Paraguay, Trinidad, the Guyanas and other sections of the Caribbean region. Selection was based on the relative extent of their territory covered with acid infertile soils (Oxisols and Ultisols) and the relative importance of the beef cattle industry in relation to national agricultural development projects.

The first eight countries were visited during the year with four objectives. (1) To become acquainted with forage production conditions in relation to the development of the cattle industry. (2) To establish contacts for future collaboration with national institutions working on research and development of the beef cattle industry, especially for regional trials to evaluate the adaptation and productivity of forage germplasm developed by the Program. (3) To evaluate the training needs of national institutions and possibilities of participating in training at CIAT.

The first regional trials in cooperation with national institutions have been designed to evaluate the adaptation and productivity of promising germplasm.

Table 69. **Southern hemisphere sites selected for CIAT Beef Program regional trials of forages.**

Country	Institution		Sites
Brazil	1	Centro de Pesquisa Agropecuária dos Cerrados (CPAC)	Brasilia, D.F.
	2	EMGOPA	Goiania, Go.
	3	Centro Nacional de Pesquisa de Gado de Corte (CNPGC)	Campo Grande, M.T.
	4	Centro de Pesquisa Agropecuária do Trópico Umido (CPATU)	Belem, Pa.
	5	CPATU-UEPAE	Manaus, Am.
Perú	6	Centro Regional de Investigación III Ministerio de Alimentación/Proyecto Cooperholta	Tarapoto
	7	Universidad Estatal Carolina del Norte/Ministerio de Alimentación	Yurimaguas
Bolivia	8	Centro de Investigaciones de Agricultura Tropical/Misión Británica	San Ignacio
Ecuador	9	Instituto Nacional de Investigaciones Agropecuarias (INIAP)	Santo Domingo
	10	Instituto Nacional de Investigaciones Agropecuarias (INIAP)	Coca

Table 69 lists sites where these trials will begin during the present southern hemisphere rainy season.

Plans are being developed to include sites in other countries of the impact area beginning with the next northern hemisphere rainy season, in May 1978.

CONFERENCES

A Workshop on "Collection, Preservation and Evaluation of Tropical Legume Germplasm Resources" was organized in collaboration with the University of Florida (USA) and sponsored by the United States Agency for International Development, (USAID), be held at CIAT in April 1978. The objectives are: (1) To develop procedures for collecting, preserving and evaluating tropical legumes which may have agriculture potential. (2) To prepare a manual which would provide guidelines for a coordinated system of collection, classification, preservation, distribution, and evaluation of legume germplasm.

A Seminar on "Forage Production and Utilization on Acid Infertile Soils of the Tropics" was also organized by CIAT to follow the workshop above. Seminar objectives are: (1) To review the state of knowledge on production, management and utilization of forages under acid infertile soil conditions (Oxisols and Ultisols) in the Latin American tropics and related areas of the world. (2) To discuss the possibilities of exchanging information and technology between CIAT and national institutions and to establish the mechanisms to transfer this technology to beef cattle producers.

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