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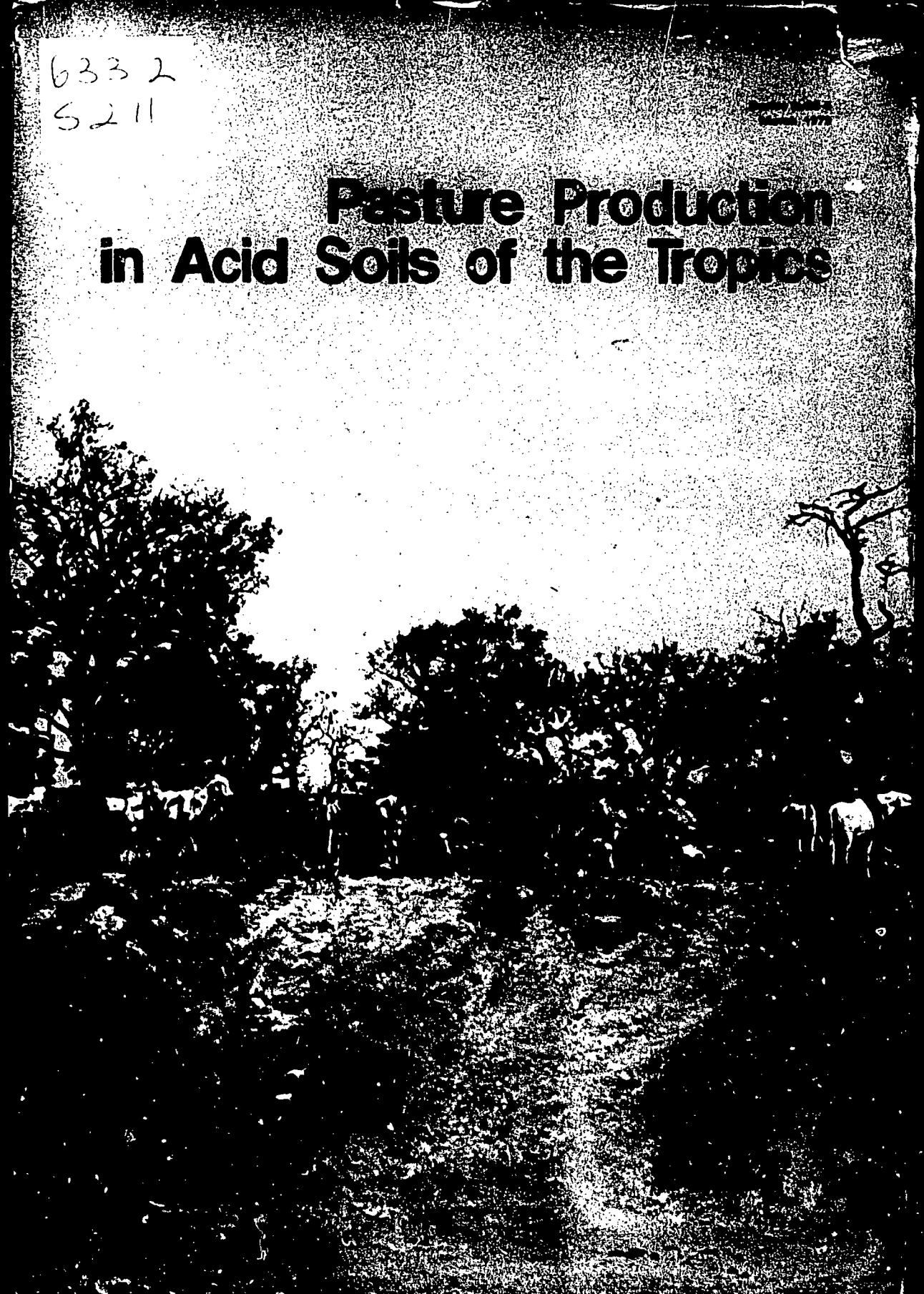
Pasture Production in Acid Soils of the Tropics



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PASTURE PRODUCTION IN ACID SOILS OF THE TROPICS

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PREFACE

Pasture-based beef production is one of the most important food production activities in lowland tropical Latin America, where beef is a major component of the diets of families of all income levels. Tropical Latin America is the continent with the largest possibilities of expanding its agricultural frontier into its vast hinterlands of 850 million hectares of tropical savannas and humid forests. Many of these regions are rapidly being settled, but progress is limited by the low native fertility of the main soils classified as Oxisols or Ultisols and poor infrastructure. Under these conditions beef production is usually the most effective initial activity but it is largely limited by forage availability during part or all the year.

The purpose of the Seminar was to review the present state of knowledge on the production, management and utilization of forages under acid infertile soil conditions in the tropics, with emphasis in Latin America, but taking advantage of relevant experiences gained in other parts of the world. An additional objective was to establish mechanisms among the interested institutions in the development and transfer of improved pasture production technology to beef producers.

A total of 189 scientists, development officials, and producers representing 69 institutions from 23 countries participated actively in many discussions sharing experiences and making useful suggestions. The countries represented were: Antigua, Australia, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Guyana, Honduras, Italy, Kenya, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad, United Kingdom, United States and Venezuela.

This book consists of 31 papers 30 of which were presented at the Seminar and one which summarizes its conclusions. They are grouped into seven parts. Part I describes the nature of the area and its production potential. Part II concentrates on soil-pasture relationships emphasizing nutrient requirements and nitrogen fixation. Part III describes experiences on pasture establishment and management techniques in different regions, and Part IV analyses such practices in terms of beef production and economic implication. Part V covers the important subject of pasture seed production, a common bottleneck preventing the application of new forage technology. Finally Part VI describes experiences on technology transfer to beef producers and Part VII the conclusions of the different work groups.

The Organizing Committee wishes to acknowledge the efforts of the 48 authors and coauthors of the papers in compiling a body of new and relevant information and their cooperation during the editing process. It is also grateful for the session chairmen: Horacio Ayala (Colombia), Walter Couto (Brazil), Antonio Leone (Venezuela), Luis Frómeta (Venezuela), Rudi Stein (Colombia), José A. de Toledo (Nicaragua), and Fernando Riveros (FAO-Rome), and the chairmen of the work groups on research (Alexander Grobman, CIAT), technology transfer (José A. de Toledo, Nicaragua), training (Fernando Riveros, FAO-Rome) and regional trials (Enrique Alarcón, Colombia). They were extremely helpful in summarizing the discussions and developing the conclusions of the seminar. Finally the Organizing Committee is grateful to the Managing Editor, Mrs. Stellia Sardi de Salcedo, for her excellent work in preparing the final manuscripts in two languages.

Luis E. Tergas, Chairman
Pedro A. Sánchez, Vice-chairman
Fritz Kramer
David Evans

Cali, March 1979

ABBREVIATIONS

AAR	average annual rainfall
ADWG	average daily weight gain(s)
an	animal(s)
AU	animal unit(s)
CEC	cation exchange capacity
cm	centimeter(s)
CPC	crude protein content(s)
cv.	cultivar(s)
DM	dry matter
e.g.	for example
FM	fresh matter
ha	hectare(s)
i.e.	that is
IHE	initial head emergence
LSD	least significant difference
m	meter(s)
meq	milleqiuvalents
mg	milligram(s)
mm	millimeter(s)
no.	number(s)
OM	organic matter
pH	hydrogen ion concentration
PLS	pure live seed
ppm	parts per million
SSF	simple superphosphate
t	ton(s)
TSP	triple superphosphate
var.	variety(s)
yr	year(s)
%	percent, percentage
>	more than, greater than
<	less than
≥	equal to or greater than
≤	equal to or less than
±	plus or minus

PART I

THE PASTURE POTENTIAL OF OXISOL-ULTISOL REGIONS

AN ONGOING APPRAISAL OF THE SAVANNA ECOSYSTEMS OF TROPICAL AMERICA FOR BEEF CATTLE PRODUCTION

Thomas T. Cochrane*

ABSTRACT

As human population pressures build up, the vast areas of the acid, infertile Oxisol and Ultisol soils of tropical America will play a more important role in beef cattle production. Consequently, there is an increasing interest in these lands. In order to obtain a clearer idea of the problems involved in beef cattle production in these regions, it was decided to carry out a land systems survey, using satellite imagery as a base for collating and extending existing knowledge into a common geographical context. The survey was started in June 1977, and in seven months some 188 million ha of land have been mapped. Some highlights of the findings of the survey in central-west Brazil are: (1) The use of total wet season estimated evapotranspiration as a climatic criteria for the zonation of native vegetation. (2) The subdivision on the savanna lands into two completely different categories for beef cattle production according to soil drainage characteristics: 97 million ha classify as well-drained "cerrado" lands, 28 million ha, as poorly drained savannas and the remainder as other formations. (3) Whilst one soil type often predominates in any one land system, there are invariably significant minor soil intrusions that are different both in terms of moisture relationships and native fertility. (4) The lack of soil moisture during the dry season on the well-drained lands would indicate a need for a more vigorous search for deep rooting grazing plants to help alleviate stress during the period. (5) It is clear that poor soil nutrient status in terms of both mineral deficiencies and toxicities is common throughout the region.

The Oxisol and Ultisol lands of tropical America as shown by the FAO-UNESCO Soil Maps of the World extend from southern Mexico to northern Paraguay. Table 1 (3) provides a ranking of the extent of these lands in tropical Latin America. There is no doubt of their importance in the context of individual countries. They occupy about 850 million ha, or about half of tropical America's land surface and are characterized by high annual rainfall with a dry season of varying intensity and very low native fertility. Approximately 300 million ha are covered by savannas and the remainder by forest.

The savanna lands are mainly used for very extensive cattle grazing because of the severely limiting soil chemical and, or, physical factors. It is estimated that beef cattle production on these lands and the neighboring forested lands will increase as human population pressures build up, as beef production on the fertile high base soils of tropical America will be unable to compete with food production. Consequently, there is an increasing interest in these lands.

The published information relating to the climate, landscape, vegetation and soils of these lands is far from comprehensive, and has not been reduced to a common base. Therefore CIAT formulated a project to

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Table 1. **Distribution of Oxisols and Ultisols by country in Latin America. (Calculated from 6, 7)[a]**

Country	Million of ha	% of country	Importance [b]
1. Brazil	572.71	68	***
2. Colombia	67.45	57	***
3. Peru	56.01	44	**
4. Venezuela	51.64	58	***
5. Bolivia	39.54	57	**
6. Guyana	12.25	62	***
7. Surinam	11.43	62	***
8. Paraguay	9.55	24	*
9. Ecuador	8.61	23	*
10. French Guyana	8.61	94	***
11. Mexico	4.42	2	
12. Panama	3.59	63	***
13. Honduras	3.13	29	**
14. Nicaragua	2.92	30	**
15. Cuba	2.42	21	*
16. Chile	1.37	2	
17. Argentina	1.28	0.4	
18. Guatemala	0.96	9	
19. Costa Rica	0.70	14	*
20. Haiti	0.52	19	*
21. Jamaica	0.45	41	**
22. Trinidad	0.42	84	***
23. Dominican Republic	0.42	9	
24. Belize	0.40	18	*
25. Puerto Rico	0.16	18	*
26. Guadalupe	0.09	47	**
27. Martinique	0.05	43	**
Totals: [c]			
Latin America	851.10	42	**
Tropical America	848.45	51	***
Tropical South America	828.21	59	***
Central America and Caribbean	15.80	23	*

[a] Prepared by P. A. Sánchez

[b] * More than 10% of the country

** More than 25% of the country

*** More than 50% of the county

[c] Includes the following countries where Oxisols and Ultisols are not present: Uruguay, El Salvador, Antigua, Bahamas, Barbados Curação and other minor Antilles.

collate the existing studies and carry out survey work as a means of checking and extending information, in order to provide a more comprehensive common base to identify geographical areas for technological endeavour. Economical considerations, as related to the developmental aspirations of individual nations will be considered in determining priorities.

The objectives of the survey are: (a) To classify and map the land resources of the Oxisols and Ultisols area as a basis for the CIAT Beef Program's technological develop-

ment and transfer strategy; and (b) To identify geographical priority areas for technological innovation through economic appraisal.

The products of the survey will be:

1) The compilation of a data bank containing:

   a) Maps and/or satellite photography at a scale of 1:1,000,000 in minimal geographical units of approximately 3,300,000 ha showing land systems.

   b) Information related to individual land systems in terms of climate, landscape and soils.

   c) Information on selected grasses and legumes prevalent or thought suitable for cultivation in any one land system.

   d) Information on animal management and disease problems and control measures for any one land system.

   e) Bibliographical references and abstracts.

2) Reports summarizing the land information and the geographically oriented appraisal of priority areas for beef cattle work on a national basis according to the economic studies.

METHODOLOGY

In order to provide a geographical summary of the land resources, it was decided to modify the land systems approach developed by Christian and Stewart (4) in their study of the land resources of the Katherine-Darwin region of northern Australia.

For this study, 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. These environmental parameters classify in the following categorical order to form a true land classification.

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

The climatic analysis is being carried out using Hargreaves' (12) method. Utah State University has been subcontracted to carry out the climatic work using data sorted from over 1000 meteorological stations in the survey area. A sample of the preliminary analyses of climatic information is shown in Table 2.

Satellite imagery (ERTS and LANDSAT) with aerial and land reconnaissance is being used in the definition of landscape patterns.

Soil physical properties are being categorized using a modification of the technique described by Mansfield (16), to facilitate computer comparison of data. Soil fertility is being described according to the Soil Fertility Capability Classification system developed by Buol and his co-workers (2) in North Carolina, modified for the low fertility circumstance.

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 with forage introduction and consequent management recommendations. This aspect is most important, as clearly, some plants are better adapted to specific climatic and fertility conditions than others.

As disease control is one of the major costs affecting cattle production, an attempt will be made to locate approximate geographical boundaries of the major endemic cattle diseases.

Table 2. **An example of Hargreaves provisional water balance analysis at the meteorological station of Porto Nacional Goias (lat. 10°31', long. 48°43', alt. 237 m.a.s.l.).**

	Temp Med[a]	H.R. Med[b]	PCT Sol[c]	RS Med[d]	Prec[e]	Et Pot[f]	Def Prec[g]	Dep Prec[h]	MAI[i]
January	25.3	84	42	471	274	146	-128	182	1.24
February	25.3	85	40	452	229	127	-103	151	1.19
March	25.4	85	40	435	272	135	-137	181	1.33
April	26.0	81	57	474	150	145	- 5	95	0.66
May	25.8	75	77	497	36	156	119	15	0.10
June	24.8	67	85	489	1	145	144	9	-0.05
July	24.8	62	89	513	2	157	155	- 8	-0.04
August	26.4	53	87	559	3	178	175	- 8	-0.04
September	27.9	57	66	540	35	172	137	14	0.08
October	27.0	73	52	510	142	164	23	89	0.54
November	25.9	81	42	468	233	142	- 91	153	1.08
December	25.5	84	38	447	284	139	-144	189	1.35
Annual	25.8	74	60	448	1663	1808	145		

a Mean temperature in degrees Celcius
b Mean relative humidity in percent
c Mean percentage of possible sunshine
d Incident solar radiation estimated from PCT SOL
e Mean precipitation in mm
f Estimated potential evapotranspiration
g ET POT Minus PREC
h (0.70 x PREC) minus 10
i Moisture availability index (DEP PREC/ET POT).

Following the 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 will be complemented by field studies of managemental practices of specific areas to help with the identification of production problems.

The survey, as it crosses international boundaries, is being carried out with the cooperation of national agencies. In Brazil it is being carried out as a joint venture with EMBRAPA's Cerrado Center, and in Bolivia with the Ministry of Agriculture of that country.

The survey was started in June 1977 and is scheduled to run for two years.

RESULTS AS OF JANUARY 1978

In-field checking of the preliminary interpretation of the satellite imagery of approximately 188 million ha of land has been carried out over the major savanna region of tropical South America, the central-west of Brazil and a part of eastern Bolivia between latitudes 10°S and 20°S (Fig. 1). This represents about 22% of the project area as a whole and was given priority, as the generalized vegetation maps of the FAO-UNESCO Soil maps of the World (6, 7) indicated that about 60% of the savanna regions to be studied were found in this region. The preliminary satellite image interpretation has been revised in the light of the field studies, and data compilation is well under way for eventual storage as a data bank prior to report publication.

Climate

Data from 83 meteorological stations east of the Bolivian border have been provisionally analyzed and mapped. It was seen that the savanna region is associated with a strong, five month dry season which increases

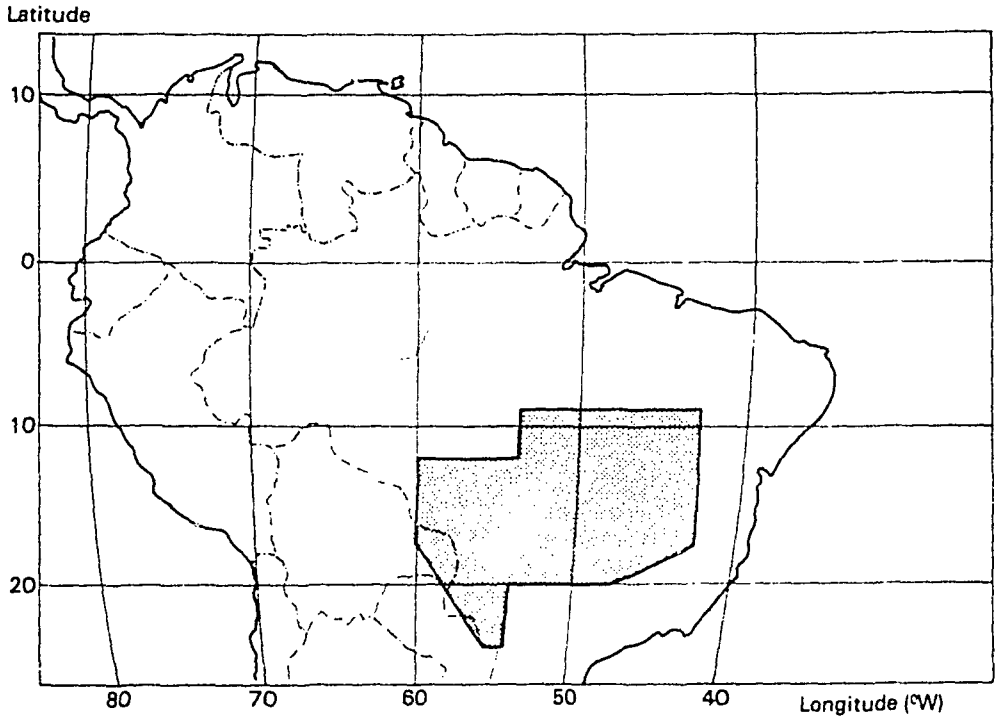

Figure 1. Central-west region of Brazil and part of eastern Bolivia.

towards the northeast. Of particular interest was the observation that the total wet season (months with a Moisture Availability Index* greater than 0.33) potential evapotranspiration throughout these areas is remarkably constant. Table 3 summarizes this information for the 25 meteorological stations found in the dry land savanna region. Potential evapotranspiration ranges from 923 to 1 112 mm, with a mean of 1001 mm and a standard deviation of 56 mm. It is logical that the potential evapotranspiration during the wet season of the year, which in effect is a measure of the energy available for plant growth or the multiplicant of solar radiation and temperatures, should correlate with natural vegetation cover, providing other factors affecting the ecosystem such as soil fertility are relatively constant.

It was interesting to note, that throughout the study region, the average wet season monthly potential evapotranspiration was considerably higher than the average monthly dry season potential evapotranspiration, whereas the reverse is true above a line approximately coinciding with the 8°S parallel.

The meteorological analyses to date have been termed provisional as an attempt is being made to obtain more accurate measurements of solar radiation received, through an analysis of the cloud cover data as shown on the satellite imagery.

Landscape

There are two completely different land circumstances for cattle production on the Oxisol and Ultisol savannas mapped.

* The Moisture Availability Index (MAI) is a term defined by Hargreaves (12) as a moisture adequacy index at the 75% probability level of precipitation occurrence (or dependable precipitation, DP). It is defined as dependable precipitation divided by potential evapotranspiration, PET. The equation is $MAI = \frac{DP}{PET}$.

Table 3. **Potential evapotranspiration - Cerrado region, Brazil.**

Stations	States	Latitude	Longitude	Potential evapotranspiration
		S	W	mm
Carolina	Maranhão	7°20'	47°28'	1058
Imperatriz	Maranhão	5°32'	47°30'	1110
Belo Horizonte	Minas Gerais	19°56'	43°56'	954
Curvelo	Minas Gerais	18°46'	44°26'	929
Frutal	Minas Gerais	20° 2'	48°56'	1098
Itabira	Minas Gerais	19°37'	43°13'	984
Monte Alegre	Minas Gerais	18°52'	48°52'	1024
Muriae	Minas Gerais	21° 8'	42°22'	1050
Oliveira	Minas Gerais	20°41'	44°49'	997
Paracatu	Minas Gerais	17°13'	46°52'	940
Pedra Azul	Minas Gerais	16° 0'	41°17'	952
Catalão	Goiás	18°10'	47°58'	987
Formosa	Goiás	15°32'	47°18'	935
Goiania	Goiás	16°41'	49°17'	989
Luziania	Goiás	16°15'	47°56'	995
Pirenopolis	Goiás	15°51'	48°58'	934
Porto Nacional	Goiás	10° 3'	48°43'	998
Taguatinga	Goiás	12°16'	45°54'	1112
Caceres	Mato Grosso	16° 3'	57°41'	1028
Cuiaba	Mato Grosso	15°36'	56° 6'	1058
Meruri	Mato Grosso	15°43'	51°44'	1024
Pres. Murtinho	Mato Grosso	15°38'	53°55'	965
Goias	Goiás	15°56'	50° 8'	989
Paraná	Goiás	12°33'	47°47'	923
Franca	São Paulo	20°33'	47°26'	1002
Minimum				923
Maximum				1112
Mean				1001.4
Standard deviation				55.9

The first is characterized by cattle production on well-drained lands, principally Oxisols, where the major limiting factor to production is lack of palatable fodder during the dry season.

The second land circumstance is characterized by cattle production on poorly drained lands with mainly Ultisols on flat topography. These soils have a heavy textured subsoil horizon that impedes drainage under a lighter textured topsoil. With the onset of the wet season, the topsoil very quickly becomes saturated with water and the land generally inundates to the extent that cattle must be shifted to higher lands. Often the availability of higher lands within reasonable walking distance is limited and a shortage of wet season fodder results. Nevertheless, at the present time,

such lands appear to be carrying more stock per unit area than the well-drained lands, and are well thought of by cattle producers.

Over the area studied to date, approximately 43% or 80 million ha would classify as well-drained (mainly Oxisol) savannas, 15% or 28 million ha as seasonally flooded (mainly Ultisol) savannas and the remaining lands as other formations including 17 million ha of Entisol savannas.

Vegetation

The literature review indicates that considerable time and effort has been spent studying the Brazilian savanna lands. Nevertheless, even recent vegetation maps have failed to depict the area of poorly drained savannas along the Araguaia River in central Brazil.

There is a varying vegetation gradient throughout the dry land savannas, or "Cerrados". The locally recognized physiognomic forms are usually described as "Campo Limpo" (grassland), "Campo Sujo" (grassland with occasional shrubs), "Campo Cerrado" (open savanna), "Cerrado" (closed savanna with low, open tree forms) and "Cerradão" (closed savanna with higher, more closed tree forms).

Terminology and specific descriptions vary from author to author, and only a few workers such as Goodland (9) have described the physiognomic types in quantitative terms such as percent canopy cover, component numbers and heights. Figure 2 is a photo of the type of cerrado vegetation showing the typically distorted semi-deciduous, xeromorphic shrubs and small trees.

An excellent account of the cerrado vegetation has been given by Eiten (5) who summarized existing knowledge and notes that "within its own climatic region, the cerrado is adapted to poor, well-drained, senile soils". Notwithstanding, there is a considerable controversy as to the origin of cerrados vegetation, the background of

Figure 2. **The campos cerrados vegetation.**

which is provided by Goodland (10). Hill (13) summarized various authors' opinions according to their general bias in terms of climatic, pedologic or edaphic, geomorphic and biotic, and anthropic or combinations of these. The controversy will undoubtedly continue until adequate yardsticks are used to measure the interdependent components of the savanna ecosystems.

An important feature common to the well-drained savannas is that many tree and shrub species stay green even during the last month of the dry season. Rawitsher *et al.* (19) and Ferri (8), have shown that these plants transpire normally during the dry season. However, neither they nor subsequent workers on this subject made estimates of total leaf area transpiring as a percentage of complete vegetative cover; further their findings on soil moisture and water table heights are clearly site specific. Certainly, the underbrush of grasses and herbs dries out soon after the start of the dry season, due to the first meter or so of the soil drying out almost completely.

It was interesting to observe that beef cattle actively browse cerrado shrubs and trees especially during the dry season. The only work on this aspect reported in the Brazilian literature (18), would indicate that at the height of the dry season (September) over 60% of animal intake comes from shrub and tree browsing. From a cattle production point of view, the supply of protein-adequate forage during the dry season is critical on the well-drained lands, and the use of deep rooting grasses, legumes, shrubs and trees should receive more attention. In this context, perhaps a grass such as the *Andropogon gayanus* Kunth cultivar described by Bowden (1) with a specialized deep root system, might profitably be tried.

Soils

Cerrado landscape shows exciting contrasts between flat tablelands, hills and valleys and lowland plains. These major formations have been summarized on a small scale physiographic map (Fig. 3). Within these units, land systems have been mapped. Many systems are well-watered with perennial streams dissecting the countryside at regular intervals. All contain areas of contrasting soils. This variability of soils within landscape units has been illustrated by Lepsch *et al.* (14) in their study of the Occidental Plateau, São Paulo.

Water-table depths vary in the well-drained savannas, but as indicated by Eiten (5) are generally deep, ranging from 10 to 30 m. Moisture holding capacities of the Oxisols, as reported by the same author, are also generally quite low, in spite of relatively high clay contents. However, within any one area of landscape, there are often significant areas of soil, such as that following along streams, with completely different physical and chemical characteristics which might be used to help alleviate dry season water stress. The reverse is true for the areas of poorly drained landscape.

As a general trend, there is a fertility gradient between the savannas and adjacent forest vegetation. The same is true within the savannas; those with a higher biomass generally have a higher fertility status. This was first shown by Goodland (9, 11) and is clearly illustrated by Table 4.

Table 4 also indicates that levels of Al and Mn in some soils might be toxic for plants sensitive to high levels of these elements, and that Ca, P, Mg, and Zn levels are often low. S levels are not shown, but S has been reported as being deficient in comparable soils by McClung and de Freitas (17), and other authors. From other data, it has been seen that soil Na levels are often very low, which is probably of significance to animal production.

CONCLUSIONS

The methodology adopted for the survey—the classification of land into land systems according to climate, landscape and soils—is proving to be an effective method of

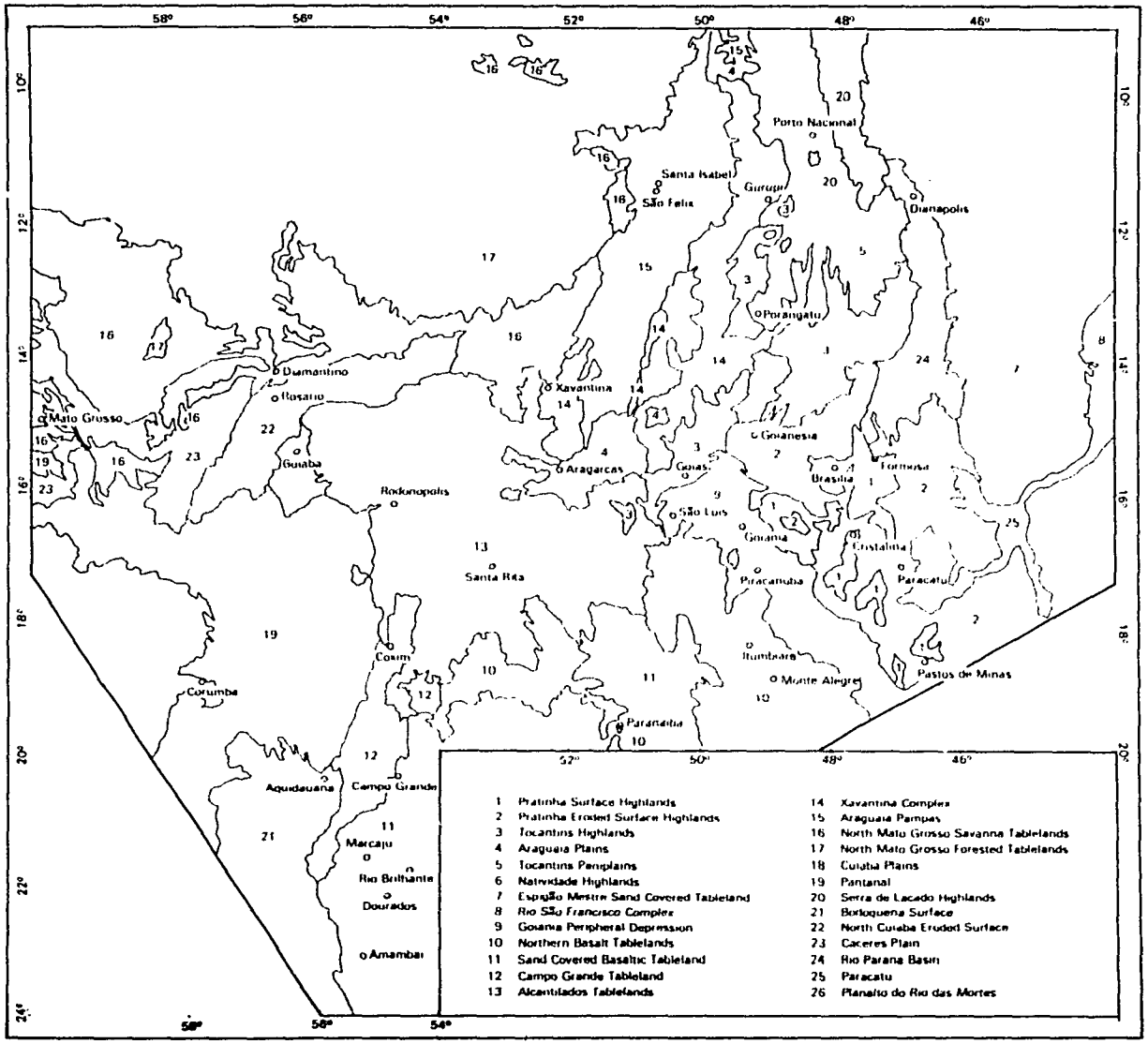

Figure 3. Major physiographic units, central-west Brazil.

Table 4. **Relationship between types of native Cerrado vegetation in central Brazil and average topsoil characteristics. (15)***

Soil property	Campo Limpo (64)**	Campo Cerrado (148)	Cerrado (255)	Cerradão (45)	Forest (16)
pH (H_2O)	4.87a	4.94ab	5.00b	5.14b	5.28c
pH (KCl)	4.16a	4.25b	4.25b	4.32b	4.35b
Δ pH	-0.71ab	-0.69a	-0.76bc	-0.82dc	-0.93d
OM (%)	2.21a	2.33a	2.35a	2.32a	3.14b
Exch. Ca (meq/100 cc)	0.20a	0.33ab	0.45b	0.69c	1.50d
Exch. Mg (meq/100 cc)	0.06a	0.13a	0.21b	0.38c	0.55d
Extr. K (meq/100 cc)***	0.08a	0.10ab	0.11b	0.13b	0.17c
Exch. Al (meq/100 cc)	0.74a	0.63a	0.66a	0.61a	0.78a
Eff. CEC (meq/100 cc)	1.08a	1.19a	1.43b	1.81c	3.00d
Al saturation (%)	66a	58b	54b	44c	40c
Extr. P (ppm)***	0.5a	0.5a	0.9b	2.1c	1.4bc
Extr. Zn (ppm)***	0.58a	0.61a	0.66b	0.67b	1.11c
Extr. Cu (ppm)***	0.60a	0.79ab	0.94b	1.32c	0.95b
Extr. Mn (ppm)***	5.4a	10.3b	15.9c	22.9d	24.1d
Extr. Fe (ppm)***	35.7a	33.9a	33.0a	27.1b	37.2c
Clay (%)	33a	36a	34a	32a	37a
Silt (%)	20a	16b	15b	16b	16b
Sand (%)	46a	48a	51a	53a	47a
Hue	7.3YRa	6.7YRA	5.4YRb	4.4YRc	4.4YRc
Value	4.3a	4.2a	3.8b	3.5c	3.6bc
Chroma	4.5a	4.7a	4.9a	4.7a	5.7a

* Means for each line not followed by the same letter are significantly different at the 0.05 probability level

** Number of samples

*** Extracted by 0.05 *N* HCl + 0.025 *N* H_2SO_4

mapping and describing land as a basis for CIAT's strategy of development and transfer of beef production technology.

The climate of the upland savannas of the Cerrado of central-western Brazil appears to be remarkably constant when described as "an area with five or more dry months and a total wet season evapotranspiration of approximately 950 to 1050 mm". The use of the wet season evapotranspiration totals clearly equates with the period of most active plant growth. Hargreaves's (12) Moisture Availability Index, facilitated the practical definition of a "dry month".

The systematic appraisal of landscape using the satellite imagery with in-field checking, has enabled a rapid, reasonably accurate estimation of the extent of the major landscapes. It has been seen that the savanna regions can be broadly classified into well-drained and poorly drained lands. The management of the well-drained versus the poorly drained circumstances would involve the development of two diametrically opposite strategies for improving cattle production in the region.

The characterization of land systems gives a certain emphasis on minor soil areas within any one region in which a particular type of soil predominates. These minor areas of land may be very important in the context

of practical farming during periods of stress, and forage plants might be selected for these circumstances.

On the well-drained Oxisol savannas, water-tables are low and soils have a low moisture holding capacity. The solum completely dries out to a depth of one or more meters during the dry season; the need for deep rooting forage plants is clearly indicated.

The nutrient status of the Oxisols and Ultisols is very low particularly with respect to Ca, P, Zn and probably S. Other elements may also be deficient either for forage and, or, animal production, including Na.

Al and Mn levels appear high in many soils, and toxicities could be significant limiting factors to forage production.

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AGRICULTURAL PRODUCTION POTENTIAL OF THE AMAZON REGION

Paulo de T. Alvim*

ABSTRACT

The low fertility of the Amazon soils has been an obstacle for introducing conventional agriculture practiced in other traditional agricultural regions. Because of torrential rains as well as the scarcity of nutrients, these soils show a high concentration of exchangeable Al and a high fixation of P. For these reasons farming on the soils of Amazonia has been essentially of a shifting type, in which the native vegetation is felled and burned to correct soil mineral deficiencies. Then the land is cultivated for a few years and abandoned so it may recover its fertility. If the value of agricultural production in this region is not sufficiently high to justify purchasing fertilizers, farming will continue being of the shifting type. Some examples are cited to illustrate that intensive agriculture, utilizing modern inputs, is economically viable. Nevertheless, the low technological level and the high cost of inputs in this region dictate, for the moment, reduction of fertilizer applications to the minimum. Based on these premises and considering principally the problem of food production, three alternatives are suggested: (a) To utilize first the small fertile soil areas found in the Amazonia, at least during the initial phases of programs oriented to increasing food production. (b) To establish systems of cattle production in appropriate areas. Pasture establishment on relatively poor soils of good topography could be a rational and economic method of exploiting these regions Pastures in Amazonia can be considered a variant of shifting agriculture as the duration of the cropping period depends on the fertility of the soil, when it is not economically feasible to fertilize it. (c) To develop efficient, self-sustaining food production systems, based on cultivating tropical trees that produce edible fruits, like breadfruit and certain palms. Shifting agriculture always will continue being a subsistence system, incapable of improving appreciably the level of living of the farmer. Agricultural research can contribute to perfecting self-sustaining systems so that they raise the level of commercial exploitation.

Agricultural problems in the humid tropics have led to several controversial opinions based more on theoretical considerations than on research data. In the past few years, as an outcome of campaigns aimed at preserving the environment, these problems have been analyzed by a greater number of naturalists and environmental experts than by agricultural experts. Consequently, some exaggerated concepts have become popular regarding substitution of the native forest for other vegetative covers more productive for man. This has given rise to what can be called a "catastrophic" viewpoint characterized by its alarming thesis of the formation of real deserts or the total disappearance of rivers, the decrease of oxygen in the atmosppere, and other

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ecological disasters. For example, some of the most critical conservationists defend the viewpoint that Amazonia, from the ecological sense, shoul be considered a "desert covered with trees" and if felling and clearing are practiced, the region will become a "red desert" (9). With this reasoning, posibilities for making full use of the Amazonian soils for agricultural purposes without causing serious environmental changes appear very remote.

In previously published studies (1, 2, 3), the potential and limitations of agriculture in the Amazonian region were analyzed and some examples were given of land uses which offer no risk of serious ecological changes. In this report attempts will be made to establish some ecological guidelines for the rational utilization of the region's potentially cultivable soils in terms of food crops, pastures and agro-forestry.

LAND RESOURCES

There is no accurate information regarding the extent of potentially cultivable land in the Amazonian region. Table 1 gives some preliminary information compiled by the United States Department of Agriculture (14) on percentage distribution of land under cultivation and potentially cultivable in countries of Latin America. In the United States nearly 80% of potentially cultivable lands are cultivated, while in Latin America only about 16% of the theoretically suitable land is under cultivation, with the lowest indices being in the tropical regions.

A preliminary study (15) on soil resources in the tropics gives an approximate idea of the extent of lands with potential for cultivation. It is estimated that 2.3 million ha in Central America have possibilities for cropping, 5.2 million are suitable for pastures and tree crops, and 18.5 million are suited for wood reserves and forestry.

As is evident in Table 2, in South America the total area with agricultural possibilitites amounts to 362.2 million ha distributed as follows: 11.3 million ha of alluvial soils (várzeas) with good fertility although subject to periodic flooding; 56.6 million ha of hydromorphic soils with drainage problems; 35.5 million ha of well-drained soils on stabilized land with medium- to high-fertility; and, 258.8 million ha of well-drained soils with low fertility (Oxisols and

Table 1. **Land poter.. al and land under cultivation in the United States and Latin American countries. (Adapted from 14).**

Countries or regions	Area under cultivation with			Area with potential use		
	Crops	Pastures	Forests	Crops	Pastures, forests	Reserves
	%					
United States	16	30	32	20	58	22
Mexico	14	36	17	22	45	33
Central America	9	17	50	42	34	24
Venezuela	6	15	50	51	20	29
Andean countries	4	19	41	34	30	36
Brazil	4	12	63	40	39	21
Southern Latin American countries	9	51	25	26	59	15
Latin America	6	23	46	35	40	25

Table 2. **Soils with possibilities for crops in the wet tropical regions of Latin America (Adapted from 15).**

Countries	Alluvial soils	Hydromorphic soils	Fertile, well drained soils	Acid, infertile well drained soils	Total
	Millions of ha				
Argentina	2.7	2.3	3.1	5.7	13.8
Bolivia	0.7	10.8	0.6	12.3	24.4
Brazil	3.2	25.4	21.8	174.4	224.8
Colombia	3.6	6.3	1.5	20.2	31.6
Ecuador	0.1	0.6	0.4	4.8	5.9
Paraguay	0.7	2.8	4.2	7.1	14.8
Peru	0.1	2.7	1.6	17.2	21.6
Venezuela	0.2	5.7	2.3	17.1	25.3
Total	11.3	56.6	35.5	258.8	362.2

Ultisols) which have possibilities for growing less demanding crops with the use of fertilizers.

The Amazon Basin countries contain nearly 20% of the world's land available for agricultural purposes. It is important to point out that this immense land reserve is located in the Earth's ecological belt where biological processes are most intense and where the ecosystem's primary productivity reaches its highest level (2, 11). Naturally, this productivity is due to the abundance of solar radiation and lack of cold seasons and prolonged droughts. The region shows great promise for expansion of the agricultural frontier, both because of the land area involved and its potential for biological productivity. However, it is important to remember that the secret is yet to be discovered for transforming this tremendous biological potential into agricultural or economic productivity. If this were not so, how could we explain the fact that this region continues to be one of the most backward in the world in terms of agricultural development? More specifically, although the entire South American continent was colonized at about the same time, why does agricultural development in the Amazon continue to be behind that of other regions of the continent? What are the factors that constrain agriculture in the humid tropics of Latin America, particularly in Amazonia?

ADVERSE FACTORS

It appears that it has not been possible to identify the principal ecological factors characterizing the tropical environment. This fact has hindered the utilization of Amazon soils for agricultural purposes. Actually, the two most important obstacles (low native soil fertility in well drained areas and the impossibility of draining wet lands) are related to the climatic conditions of the region, and more specifically, to the excessive rainfall that characterizes it. The rainy or excessively humid climate also favors the incidence of insects and diseases, hinders mechanized tillage and accelerates the wear of agricultural machines and implements. However, the soil chemical properties are the most serious impediments to introducing conventional agriculture of a type traditionally practiced in cold or temperate climates. Because of the very heavy rainfall and the low content of essential nutrients, these soils show a high concentration of exchangeable Al and a marked deficiency and fixation of P. These

unfavorable characteristics for conventional agriculture do not limit the luxuriant growth of native vegetation which is undoubtedly well-adapted to poor soils. It must be remembered, however, that plants traditionally cultivated for food production were selected over time precisely for their rapid growth and efficient storage capacity of assimilates and these properties exert increasing demands on the soil fertility. If these plants are to demonstrate their production potential on poor lands like those that predominate in heavy rainfall regions, applications of chemical or organic fertilizers are indispensable.

Ancient peoples, who knew nothing of fertilization, discovered empirically a method of correcting mineral deficiencies in tropical soils by felling and burning the native vegetation. Farmers not only utilize this method to "prepare the field for seeding", as is generally said, but also to incorporate into the soil, through the ashes and decomposed organic residues, the minerals found in the vegetative biomass. Unfortunately, this method of fertilizing the soil is transitory and cannot be repeated indefinitely.

When land is cultivated with plants that do not completely protect the soil, as with the majority of short-cycle crops, leaching or erosion easily wash out nutrients added by burning. Within a few years, the soil fertility decreases to a level even lower than originally. This is how shifting agriculture, based on felling and burning the native forest emerged. Food crops were cultivated for a few years—generally, two or three, or at most, four—then, the cultivated areas were abandoned for several years and even decades to let the land regain its fertility. Throughout the years this has been the primary system of cultivating food plants in humid tropical regions of the world. It is estimated that today this method is still employed by more than 200 million persons distributed over an area of almost 30 million km^2, approximately one-quarter of the world (6).

Although it is considered a relatively efficient system to avoid excessive soil impoverishment, shifting agriculture should be carefully practiced and then only in regions of low population density where each family can have a relatively large area that permits using this system without causing irreversible damage to the soil. When demographic pressure increases in areas where only shifting agriculture is practiced, there is a natural tendency to prolong cultivation periods and shorten fallow periods, with disastrous effects, both in terms of soil fertility and crop yields. This situation produces a series of economic problems in some regions of the Brazilian Amazonia such as in Bragantina, near Belém. In view of the low economic profits, shifting agriculture, in general terms, only meets the minimum needs of the farmer and his family. There is no reason to believe that this system is capable of improving the standard of living of rural populations.

Because of their high native fertility, alluvial soils have always been utilized more intensively for food production in the Amazon region. Periodic overflows of the rivers, which last three to four months, generally between May and August, are the main limiting factor of these soils in the Brazilian Amazon. Drainage systems and water control gates and dikes can contribute considerably to increasing the production potential of these soils, although these practices still are almost unknown to the great majority of farmers in the region.

The above factor—low fertility of the soils and drainage problems—are unquestionably the most restrictive for the utilization of the soils of the Amazonia. Naturally, other important factors could be mentioned, such as lack of adequate transportation, marketing, technical assistance, credit, storage, land tenure, financial incentives, etc. The purely agronomic aspects, however, deserve special attention since our real interest lies in knowing, first, how we should handle the relatively poor soils prevailing in the region,

and then, what production systems would be most appropriate for these soils from the ecological and economic point of view.

PROMISING LAND USE SYSTEMS

Various methods have already been discussed for using some types of soils of the Amazon (3); from that work comes the following observation: "The greatest challenge for scientists working on agriculture in the humid tropics is undoubtedly to find new production systems ecologically suited to the region. In time, this will lead man to a new state of equilibrium with the environment and without a doubt, will require the substitution of native forests for other vegetative communities in selected areas. Unfortunately, some time will pass before these new production systems, developed through research, can be extensively utilized to promote agricultural development in the humid tropics. However, this does not mean we should completely ignore what can be done today in some selected areas of the tropics, without causing ecological disasters".

To illustrate this viewpoint, in the work cited above, some agricultural projects were reviewed that are under way in the Brazilian Amazon. Some examples are: irrigated rice on alluvial areas, tree crops like cocoa (*Theobroma cacao*), rubber (*Hevea brasiliensis* and *Hevea pauciflora*), African oil palm (*Elaeis guineensis*), Brazil nut (*Bertholletia excelsa*), fast growing forestry species (*Gmelina arborea* and *Pinus caribea*) and the establishment of improved pastures in regions of lower rainfall with flat or slightly undulating topography.

Among the main cereals, rice is certainly the one which seems to offer the best possibility of expansion in the Amazon region. In the Amazon River delta area alone, for example, it is estimated that more than 1.5 million ha of level land are suited for growing irrigated rice (12). In one 2000 ha plantation along the Jari River, an average yield of 12-14 t/ha/yr was recorded from two harvests. Other food crops such as cowpea (*Vigna* spp.) and pigeon pea (*Cajanus cajan*) are well-adapted to the climatic conditions and to certain types of soils found in the region. Other productive plants for the tropical regions are mentioned by Alvim and Kozlowsky in their recent book (5).

Logically, the cultivation of any plant species by conventional methods lowers the soil's native fertility. The application of fertilizers is essential to obtain reasonable harvests for several consecutive years in relatively poor soils. If fertilizers are too expensive, the only solution is to return to the old system of shifting agriculture, that is, to abandon the field for a few years and establish new plantings in new areas by burning the native vegetation. Thus, the inevitable conclusion is reached that if agricultural production is not sufficiently high to justify purchasing fertilizers and other corrective materials, agriculture on relatively poor tropical soils will continue to be of the shifting type, offering no possibilities for becoming a productive enterprise capable of improving the farmer's standard of living. Nevertheless, this situation can be altered in any region, at any time, when changes occur in price relationships between inputs and agricultural products. For example, one can mention what is occurring today in the Brazilian Amazon with some high-demand market crops such as black pepper (*Piper nigrum*) and vegetables.

Black pepper, introduced by Japanese settlers in the 1930's, is cultivated extensively today on poor Oxisols using heavy rates of fertilizers. Nearly 70% of production costs consist of inputs and labor. Nevertheless, cultivation of black pepper is one of the most profitable activities in the Amazonia. Another interesting example is the production of vegetables, principally tomato, using highly advanced technology in greenhouses covered with transparent plastic. The system was successfully introduced at a commercial scale (about 100

greenhouses 8 x 30 m) by the Adventist Agricultural Institute, near Manaus, a city where the scarcity of vegetables helps raise their price to a sufficiently high level to cover production costs and yield a good profit to the company.

Naturally, although these examples are not general for all tropical regions, they serve to illustrate that intensive utilization of modern inputs can not be ignored in tropical regions. In other words one cannot discard, *a priori*, the hypothesis that in the future the utilization of fertilizers in the tropics will reach the same levels as in the temperate regions, but will depend, as usual, upon costs/profits relationships. Given the low level of agricultural technology presently found in the Amazon and considering the high cost of modern inputs in this region, it is preferable to explore the possibilities for expanding the agricultural frontier without intensive use of fertilizers. Based on this idea and considering food production as the *primary standard, there are three main* alternatives.

Preferential use of fertile lands

Edaphological studies of the Amazon region are still relatively scarce; nevertheless, those already done reveal a great variability of soil according to their *native fertility and relief. The variability* in terms of native fertility is presented in Figure 1, with a graphic system proposed by Alvim and Cabala (4), using nine soils representing different tropical regions of Brazil. Emphasis is placed on soils with a high native fertility (Terra Roxa or Alfisols) which are found not only in the cocoa region of Bahia but also in other areas of Amazonia such as Rondônia, Santarém and Altamira (Fig. 1A, 1B, 1C and 1D). Alluvial soils are equally as fertile (Fig. 1E). Nevertheless, the soils found most frequently, covering probably more than 70% of the Amazon, are the Oxisols and Ultisols of very low native fertility (Fig. 1F and 1H).

According to topographic reconnaissance done by the Radam Project and the Brazilian Ministry of Agriculture, there are between to 8 to 10 million ha of relatively fertile soils in the Brazilian Amazon, including alluvial soils (Inceptisols) and highland ones (Altisols). These are the only lands on which the conventional type of agriculture can be practiced without major inputs of fertilizers, a reason why they ought to be preferentially reserved for that purpose. By all means, their utilization for pasture establishment and reforestation should be very limited.

Cattle raising in low fertility areas

One of the most controversial topics in tropical regions are the ecological consequences encountered when forests are converted into pastures for cattle production. Because this system is precisely the one being expanded most easily and rapidly, cattle raising is generally considered as a most serious threat to the tropical environment, with the capacity of causing changes in the courses of rivers resulting in increased flooding during the rainy season and diminished flows during the dry season. Some authors also speak of climatic alterations (i.e. diminished rains) as a consequence of pasture formation, but no data or other scientific proof exists that these phenomena have occurred anywhere in the past.

Investigations done in Brazil have shown that it is possible to use correct grazing management practices on certain types of soils that contribute in a real way to improve the original soil characteristics from the agronomic viewpoint and that offer reasonable protection against losses caused by leaching or erosion. The principal defender of this point of view in Brazil is Falesi (7, 8). Figure 2 shows some results of Falesi's work indicating that after burning the forest, soil fertility improves appreciably, in terms of availability of P, exchangeable bases and lowering of Al saturation. After 10 or 11 years of improved pastures on these soils, their fertility level is still higher than the soils under virgin rainforest. Based on these results, Falesi (7) tentatively con-

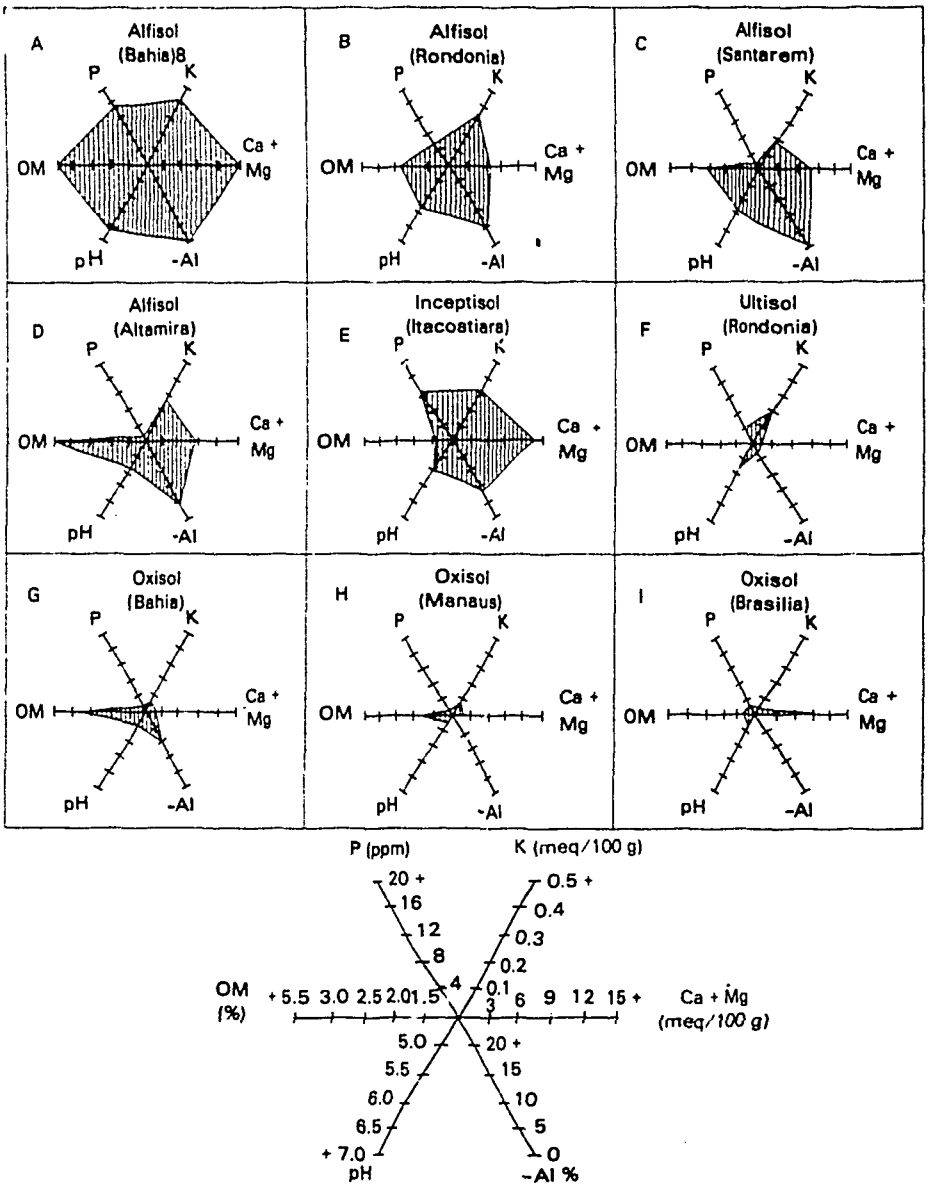

Figure 1. **Different types of soil fertility found in the Brazilian tropical regions in terms of pH (water), percentage of OM (wet combustion), P concentration (Mehlich method), K concentration (Mehlich method), Ca + Mg concentration (extracted with KCl), Al saturation percentage (extraction with KCl). The last diagram represents the scale for the different parameters according to Alvim and Cabala (4).**

cludes that "establishment of improved pastures on low-fertility Oxisols and Ultisols is a rational and economic method of occupying and upgrading these extensive areas". However, he warns of the necessity of using correct management practices to prevent the natural tendency of the tropical forest to re-establish itself, and feels

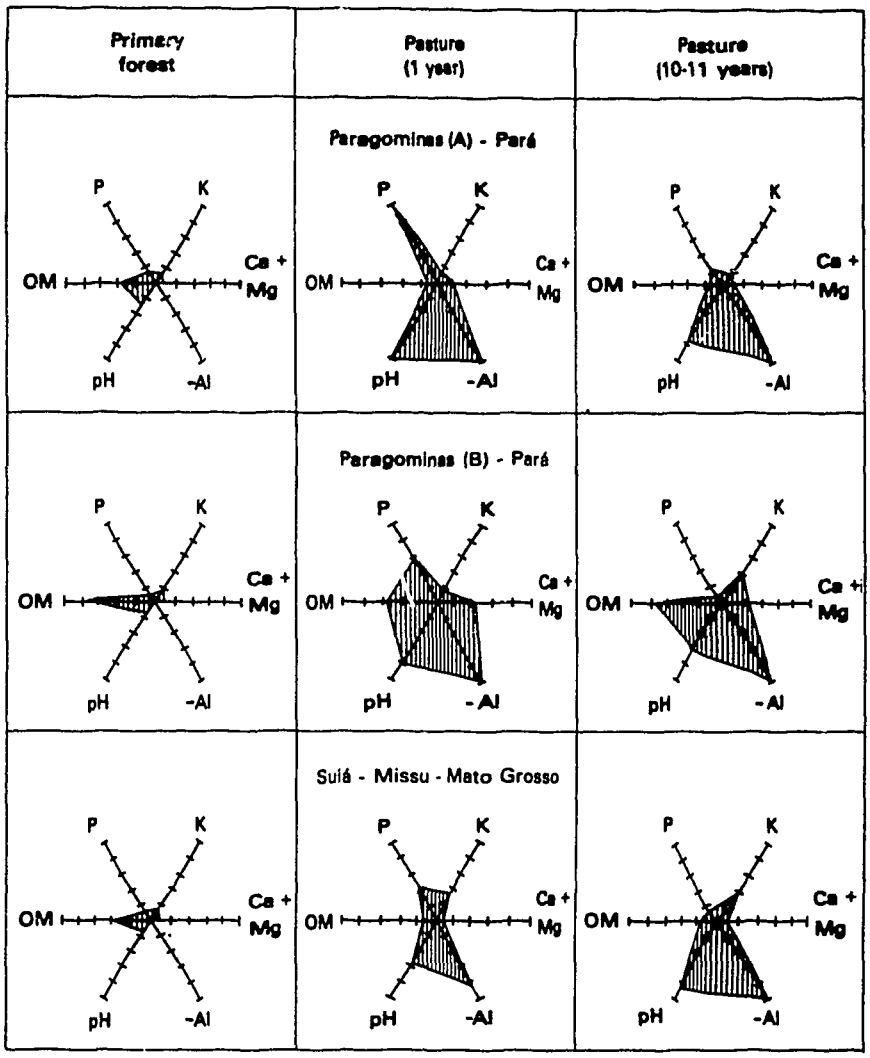

Figure 2. Changes in Oxisol fertility resulting from burning techniques and establishment of pasture lands in three different areas of the Amazon region according to analytical data obtained by Falesi (8). For interpretation of values please refer to scale in Figure 1.

that it is necessary to control with special care the stocking rate in order to prevent overgrazing. Falesi also includes that "the alluvial plains areas are excellent for extensive raising of buffalos and constitutes an immediate solution for the problem of protein scarcity that the world is suffering".

The problem of pasture establishment in tropical zones of Central America was reviewed recently (13), and it was observed that maintenance and productivity of pastures in tropical climates will require fertilizers as well as intensive management practices. As these fertilizers are not generally applied in jungle areas because of their high costs, pastures established there may have a relatively short useful life that logically depends on the native fertility of the soil. Pasture establishment in the forest

climate appears to be a variation of shifting agriculture, in which the cultivation period can be prolonged for several years when soils are relatively fertile or reduced to only a few years when soils are poorer.

Self-sustained systems

According to the ecological viewpoint, a self-sustained system is one that is in perfect equilibrium with the environment, maintaining itself practically unchanged over the years. From the agronomic viewpoint, it is one capable of completing two basic functions: providing more production to man than nature produces and preventing degradation of the soil. The functions for preventing soil degradation ought to fulfill three specific ends: prevent erosion, maintain the recycling of nutrients and prevent leaching.

The tropical forest is a self-sustaining system perfectly adapted to the edaphic and climatic conditions of the humid tropics (Fig. 3). Countless products useful to man are extracted from the forest, and some are of great commercial interest such as the Brazil

1. a. Less rainfall impact
   b. Botanic diversity
   c. Recycling of nutrients
   d. Incorporation of nutrients

2. a. Minimum reduction of rainfall impact
   b. Weed competition
   c. Nutrient loss due to leaching
   d. Soil loss due to erosion
   e. Nutrients extracted by the crops

3. a. Less rainfall impact
   b. Nutrient extracted by the crop
   c. Shade
   d. Recycling of nutrients
   e. Incorporation of nutrients

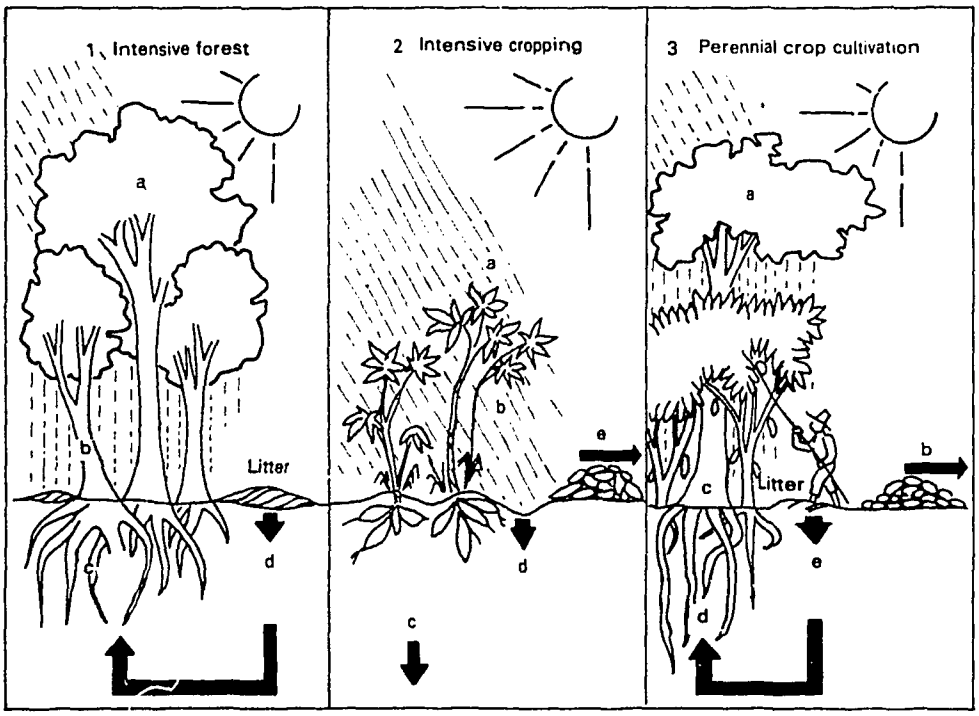

Figure 3. Effect of vegetative cover on preserving soil fertility in a natural forest, intensive cropping (cassava) and perennial crops (cacao).

nut (*B. excelsa*), rubber (*Hevea* spp.) and an infinite number of forest essences. Obviously, the utilization of these forest products only by extraction can never contribute to promote development of tropical regions. In the case of wood extraction the possibility does exist for developing utilization systems for the native forest using selective cutting, obeying the principle of self-sustained production; however, the economic viability of the system almost always depends on transport costs. Silviculture and tree crops (rubber, African oil palm, cocoa, etc.) are systems that mimic the native forest, but they can not be considered completely self-sustaining, as they invariably demand, at least over the long term, the replacement of nutrients extracted by the harvests (Fig. 3).

In the area of food production, it appears that good possibilites exist for developing efficient systems based on the cultivation of trees that produce edible fruits, of which innumerable species are found in the tropics. These include some palms which are not only producers of fruits but also of palmito, like *Guilielma* spp., *Euterpe oleracea, Eterpe edulis,* etc. The creation of home gardens with food trees like breadfruit, avocado, mango, cassava, etc. is, on the other hand, a tradition in all tropical regions. Undoubtedly, agricultural research will contribute enormously to perfecting these systems, making them viable for a commercial type of agriculture. Emphasis must be placed on a recent review of the advantages and possibilities of these non-conventional forms of producing foods in the tropics (10).

Shifting agriculture could also be improved through research and in this manner transform it into the character of self-sustained agriculture (6). As is evident in Figure 4, when intervals between cultivation periods are very short, soil fertility decreases rapidly, reaching a point where the system becomes completely unproductive after a few years shifting. When, however, intervals between cultivation periods are long, the always-low economic return of the system is changed to almost nothing. Theoretically, research could define the cropping interval which accomplishes most effectively the double function of maintaining constant levels of productivity and soil fertility. Although shifting agriculture can be transformed into a self-sustaining system, it can be expected that it will remain, as it always has, basically a subsistence form of agriculture incapable of improving substantially the standard of living of farmers.

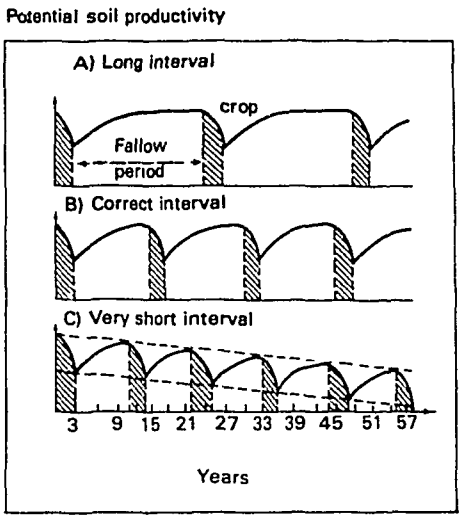

Figure 4. **Soil's productive potential altered by the influence of fallow periods in shifting agriculture. (Adapted from 6).**

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A COMPARISON OF THE SOILS OF TROPICAL LATIN AMERICA AND TROPICAL AUSTRALIA

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Ray F. Isbell**

ABSTRACT

This paper describes the contrasting soil properties between the areas concerned with improved tropical pastures in Australia and its counterparts in Latin America. In Australia the predominant soils are Alfisols and Vertisols, with smaller proportion of Entisols, Aridisols, Ultisols and Oxisols. In Latin America, Oxisols and Ultisols predominate; smaller areas of Alfisols, Inceptisols and Entisols also occur. Climate in Australia is characterized by six to eight months of dry season, with cool temperatures including common frosts as far north as 17°S. In Latin America the savanna regions have four to six months of dry season, no frosts, while the upper Amazon basin and other regions have no significant dry season. The predominant vegetation in the Australian tropics with 500 mm annual rainfall is woodland savannas. Soil pH values in the Alfisol and Vertisol regions of Australia range from 5.5 to 9.0. These soils do not present Al toxicity problems and their supply of exchangeable bases is generally high. High levels of exchangeable Na are common in some subsoils. The P fixation capacity of these soils as well as many Australian Ultisols is low. Nevertheless P and S deficiencies are widespread and Mo and Zn deficiencies are important in many areas. In the savannas and jungles of Latin America, soil pH ranges from 3.8 to 5.5, with higher exchangeable Al saturation and common Al toxicity. Exchangeable base status is low and no exchangeable Na is present. P fixation is high in Oxisols and Ultisols, except those with sandy topsoil texture. In addition to P, Ca and Mg, K and S deficiencies are widespread, and micronutrient deficiencies common but less well characterized. N deficiency is acute in both Australia and Latin America. In general, Australian Alfisols and Vertisols present more serious physical limitations than chemical ones, while in Latin America the dominant Oxisols and Ultisols present more serious limitations related to acid soil infertility. Direct extrapolation from one continent to another is therefore limited. Tropical legume species adapted to Australian conditions are not likely to be successful in most Oxisols and Ultisols of Latin America, and viceversa.

The tropical portions of Australia and Latin America contain the largest areas in the world devoted to extensive beef cattle production. These areas are characterized by their vastness, low population density, soils of low native fertility, and considerable distance from main markets. These limitations make pasture-based beef production the main agricultural activity, unless relatively high investments in fer-

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tilizers and infrastructure permit profitable crop production. In Latin America the largest expanses occur in the savannas of the Llanos of Colombia and Venezuela, and the Cerrado of Brazil; also in the Amazon basin and other rain forests which have been cleared for agriculture, and on many hillsides on the lower slopes of the Andes. In Australia, the region capable of supporting improved tropical pastures is usually defined as that receiving more than 500 mm annual rainfall, and this paper will concentrate on this area. Tropical Latin America has large areas of more fertile soils devoted primarily to crop production, and coastal desert strips. Tropical Australia has small high rainfall areas devoted to sugar cane production and other crops, and a vast interior desert area.

The two continents have been closely linked in terms of tropical pasture development. The growth of the beef industry in tropical Australia is relying on the introduction, adaptation and widespread use of pasture legume species collected from Latin America and grasses mainly from Africa. Likewise, more recent efforts in tropical Latin America are based on the Australian experience, either in terms of research strategy or by attempts to directly adapt Australian cultivars to Latin America. This relationship suggests the need for quantifying the physical similarities and differences between these two continents in order to gain a better understanding of the kind and degree of possible extrapolation. The purpose of this paper is to compare the soil environment of tropical Latin America and tropical Australia with particular reference to their role in pasture production for cattle. For uniformity, soil taxonomy terminology (60) is used in this paper. The main definitions appear in Appendix 1 and the translation of Australian terminology to soil taxonomy equivalents is shown in Appendix 2.

CLIMATE

Australia

The Australian tropics comprise approximately 227 million ha, about 32% of the country. The most striking feature is their general aridity. About 44% of tropical Australia has annual rainfall greater than 500 mm; only 12% receives more than 1 000 mm (Fig. 1). Areas receiving more than 1 500 mm are confined to far northern Cape York Peninsula and a narrow zone fringing the northeast coast where a few small areas receive as much as 4000 mm. This "wet coast" area occupies less than 1 million ha.

Annual rainfall decreases with increasing distance from the coast. Figure 2 shows a transect from Townsville on the coast, southwestwards to Charters Towers (125 km inland) and Hughenden (300 km inland) near the arid limit. Figure 2 also shows an example of the wet coastal area at Innisfail.

More important than total rainfall is its seasonal distribution and variability. All areas have a strongly summer-dominant rainfall pattern. In general, areas with mean annual rainfall of about 1500 mm or more have a plant growing season of more than six months. With the exception of the wet coast which has a udic soil moisture regime (<three montns dry season), all areas above the 500 mm isohyet can be classified as ustic. Towards this lower limit, the length of season during which useful pasture growth occurs is three months or even less, denoting an aridic soil moisture regime. However, variability of rainfall is high over all except the northern extremities, and the irregular incidence of tropical cyclones and rain depressions may lead to extreme intensities being registered in near-coastal regions.

Mean annual temperatures in tropical Australia are above 22°C with sufficiently low variability in northern near-coastal areas to classify the soil temperature regime as isohyperthermic. Most areas in the inland portions of tropical Australia have a hyperthermic soil temperature regime. In the eastern parts, frosts may occur over inland regions as far north as about 17°S; hence the growing period of tropical pasture species may be restricted by low night temperatures.

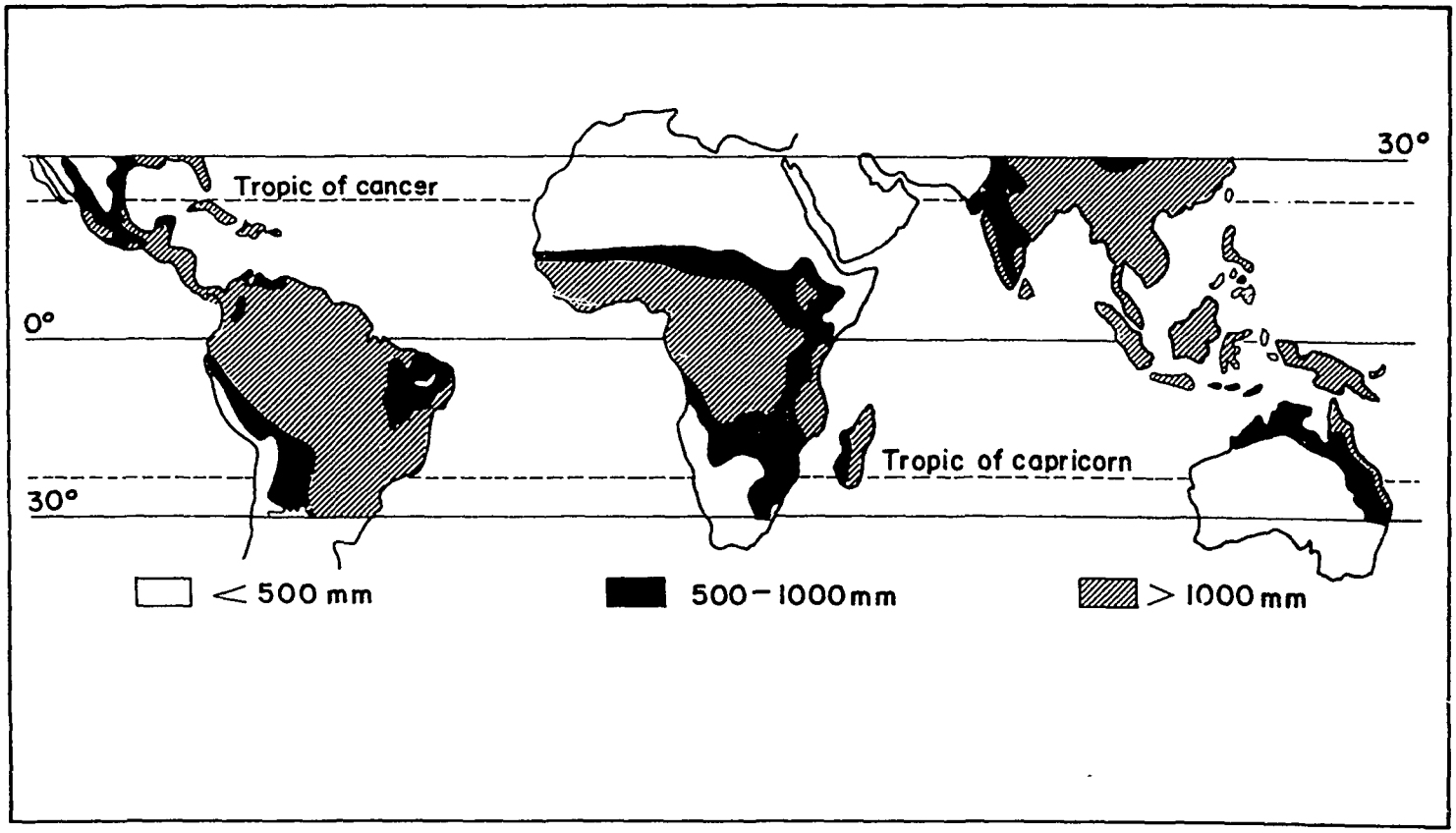


Figure 1. Annual rainfall regimes of tropical and subtropical regions of the world (25).

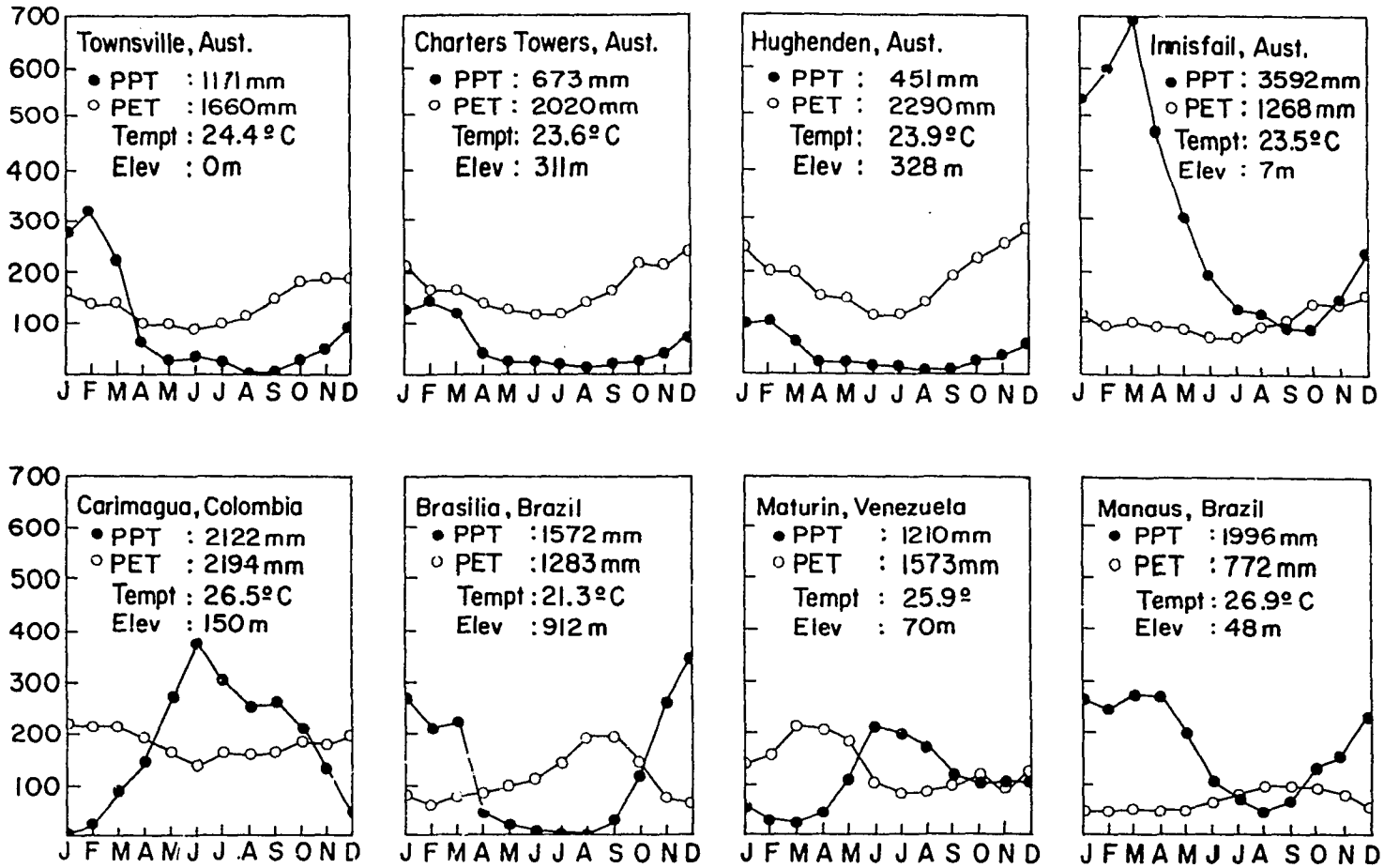


Figure 2. Climatic summary of four locations of tropical Australia and tropical Latin America.

Latin America

Tropical Latin America covers about 1514 million ha, or 77% of the land of the countries south of the U.S. border. Climatically, it is more complex than tropical Australia, and in general more humid. Over 90% of tropical America receives more than 500 mm annual rainfall and more than 70% receives in excess of 1000 mm. Vast areas in the Amazon basin have annual rainfall in excess of 2000 mm.

Much of the land area lies in equatorial latitudes, and in fact the region has the earth's greatest continental extent of humid tropical climates, areas in which plant growth is restricted by moisture stress only for very short periods of the year. These areas have a udic soil moisture regime and encompass about 42% of tropical America. Another 43% has an ustic soil moisture regime which can be divided into two broad groups: (1) Areas with more than 1000 mm/yr with a four to six month-long dry season when pastures suffer serious water stress; this includes most of the savannas, the eastern Amazon, and most of Central America. (2) Sub-humid regions (<1000 mm) with strongly seasonal and highly variable rainfall. This includes northeast Brazil, southern Bolivia-northern Paraguay and central Mexico, with smaller areas in Venezuela, Colombia and sub-coastal Peru (Fig. 1). Here, plant growing seasons are always less than about six months and may be as little as three months. About 7% of the region consists of seasonally flooded plains with a strong dry season as well. Examples of these are the Llanos of Casanare-Apure in Colombia and Venezuela, the Pantanal of Brazil and Paraguay, and the Guayas basin in Ecuador. The remaining 7% are deserts, the principal one in northern Mexico, followed by the coast of Peru, and the Guajira Peninsula in Colombia and Venezuela, all with aridic soil moisture regimes.

Although there are a few areas in lowland Latin America where low temperatures may inhibit plant growth (chiefly in temperate southern Brazil), low temperatures induced by high altitudes are common in much of the Andean region and to a lesser extent in parts of Central America and the Caribbean.

Figure 2 shows climatic summaries of four stations representing three savanna regions and one jungle region where pasture production is important. Unlike the Australian data in the same figure, these stations are not representative of the entire Latin American tropics because of the wide variety of climatic regimes in this continent.

VEGETATION

There are a number of differences between the vegetation of tropical Latin America and tropical Australia. Some of these are to be expected in view of the marked climatic differences just described. Thus in Latin America there are vast areas of tropical rain forests (550 million ha) whereas in tropical Australia the wet coast rain forest area comprises less than 1 million ha.

The greater part of the Australian tropics is covered by savannas (Eucalypt woodlands) which decrease in tree density with decreasing rainfall. A characteristic feature of these woodlands is their prominent grass canopy, consisting of species of genera *Heteropogon, Themeda, Sorghum* and others. Some of the more open woodlands, particularly those on very infertile or poorly drained soils, bear resemblance to the widespread Cerrado formations of Brazil. Australia has no counterparts to the Latin American dry thorn scrubs with their prominent cacti, such as the widespread Caatingas of northeast Brazil. Nor does it have any equivalent of grassland areas such as the Llanos. The extensive treeless grassland areas of tropical Australia are mostly located below 500 mm of annual rainfall, although small areas do occur on Vertisols in the sub-humid lands of central Queensland and adjacent to the southern part of the Gulf of Carpentaria. Finally, it may be noted that nearly all the Australian communities are evergreen or

semievergreen, and there are no counterparts of the subalpine communities such as the Páramos of the Andean region or the pine forests of Mexico and Central America.

GEOMORPHOLOGY

Although the two continents have some common features, there are a number of strongly contrasting geomorphic aspects. Tropical Australia is largely dominated by lowlands; areas exceeding 600 m in elevation are largely confined to parts of northeast Queensland and those exceeding 1000 m occur only as a narrow and irregular subcoastal zone in the same region. Elsewhere, extensive plains interrupted only by low-elevation ranges, tablelands or their dissected remnants are the characteristic feature of the landscape.

In contrast, while much of tropical Latin America consists of vast depositional plains or little-disturbed old erosion surfaces, there are also the spectacular mountain chains of the Andes and their continuation in Central America and Mexico. There is no active vulcanism in tropical Australia, nor are there any widespread recent pyroclastic deposits, nor any evidence of Pleistocene glacial or periglacial features. Volcanic activity is prominent in southern Mexico, throughout Central America, and in parts of Colombia, Ecuador, Peru, Bolivia and the Caribbean.

Widespread old erosion surfaces occupy vast areas in parts of Latin America, particularly on tectonically stable or uplifted areas such as the Brazilian and Guayana shields. The oldest of these surfaces are Mesozoic and the more recent, late Tertiary (34). Similar old surfaces are present in many parts of tropical Australia (21, 67) although their present extent is not on such a grand scale as in Brazil. In contrast, the much more active Tertiary and Quaternary geologic history of Central America and the Andean Region has produced youthful and often extremely unstable landscapes which have no counterparts in tropical Australia.

Within tropical Australia the chief physiographic contrasts are afforded by the uplifted, relatively youthful, dissected lands adjacent to the northeast coast, and to a lesser extent the lower but strongly dissected sandstone plateaux of the northeast part of the Northern Territory and the Kimberley region of northern Western Australia.

SOIL FORMATION

In both regions the main soil determinants are climate, geomorphic history, and parent material. Although in most instances these closely interact, in some circumstances one or other of these factors may assume dominance. From a consideration of the climatic factor alone it might be expected that Latin America would possess a much greater area of leached, highly weathered soils, and this is true. The main exceptions occur in those high rainfall areas that possess youthful, unstable slopes where erosion has not permitted deep weathered soils to accumulate, and those areas of relatively recent deposition where time has been insufficient for the formation of highly leached and weathered profiles.

Differences in geomorphic history between various parts of the two regions have had a marked impact on soil formation. This is particularly evident in parts of tropical Australia where many soils are relict and obviously formed under vastly different environmental conditions than those of today. The most striking examples are the occurrences of deep oxic Alfisols that are now found in present rainfall regimes of 700 mm or less. Similar examples are present in the drier areas of northeast Brazil (28). The effect of paleoclimates is more difficult to evaluate in those large areas of Latin America that presently have a humid climate. In particular this applies to vast areas of Brazil with old stable landscapes and a seasonally humid climate; there it is difficult to know if the deep, highly weathered soils owe their character to present environmental conditions or to more extreme leaching conditions of the past. Probably the best example of geomorphic history influencing soil formation is to be

found in Central America where the youthful nature of much of the landscape, brought about largely by its active or recent volcanic history, has lead to the widespread occurrence of relatively juvenile soils that are to at least some degree independent of present climate.

The role of parent material assumes major importance in many areas of both regions, irrespective of climate. The more striking examples are usually afforded by more extreme kinds of parent materials. Thus soils formed from basalt in both continents tend to have distinctive characteristics but which may vary depending on the rainfall regime (24). Soil formed from volcanic ash in Andean South America and in Central America have characteristics not found in Australia. At the other end of the parent material spectrum the widespread occurrence of siliceous sandstones in subhumid tropical Australia has given rise to a characteristic suite of soils (mostly Entisols), as have siliceous sand deposits (e.g. old beach ridges and coastal dunes) in humid climates given rise to Spodosols in tropical Queensland and eastern Brazil.

Between these parent material extremes, there are many other soil parent materials that tend to produce characteristic soils in any given climatic environment. This is particularly evident in the subhumid, seasonal climates. Examples are many Alfisols in tropical Australia and eastern Brazil formed on intermediate igneous and metamorphic rocks, and the widespread Vertisols formed on more basic and often calcareous parent materials in subhumid tropical Australia, Mexico and Central America.

SOIL DISTRIBUTION

Sufficient information is now available to compare soil occurrence and distribution between the two continents in a generalized way. Table 1 shows the distribution of soil orders between the Tropics of Cancer and Capricorn in both continents, calculated from the FAO World Soil Map sheets (15, 16, 17), the Soil Map of Australia (61), with modifications by the authors, and converted to soil taxonomy equivalents.

Table 1 shows a major contrast between

Table 1. **Comparative distribution of soil orders in tropical America and Australia (23° N-23° S). Calculated from the World Soil Maps of South America, Mexico and Central America and Australia (15, 16, 17) with author's modifications and converted to soil taxonomy equivalents.**

	Tropical America		Tropical Australia	
Order	Million ha.	%	Million ha.	%
Oxisols	513	34	0.2	-
Ultisols	371	24	7.5	3
Alfisols	192	13	54.9	25
Inceptisols	168	11	2.6	1
Entisols	130	9	93.1	42
Mollisols	82	6	-	-
Aridisols	35	2	33.4	15
Vertisols	20	1	31.4	14
Histosols	3	-	-	-
Spodosols	-	-	0.8	-
Total	1514	100	224	99

the two continents. Oxisols and Ultisols cover by far the largest areas of tropical Latin America, followed by Alfisols, Inceptisols, Entisols and Mollisols, with minor occurrences of the other soil orders. In tropical Australia, Entisols, Aridisols and Vertisols are the dominant soils of the huge interior desert while in the region with more than 500 mm annual rainfall Alfisols predominate, followed by Entisols, Vertisols, Ultisols and Inceptisols, with very much smaller areas of Aridisols, Spodosols and Oxisols.

Figure 3 shows the geographical distribution of soil orders in tropical Australia and Figure 4 is its counterpart for tropical Latin America. The definition of soil taxonomic terms appears in Appendix 1 and the conversion to Australian soil terminology is shown in Appendix 2.

Oxisols and Ultisols

For several reasons it is appropriate that these two orders be considered together. Firstly, it is becoming increasingly apparent that in many tropical areas it is often difficult to distinguish between them (23). The second reason concerns the fact that most Oxisols and Ultisols are chemically and mineralogically similar, presenting similar problems of soil acidity and low nutrient availability.

Figure 3 shows that Oxisols are of very minor occurrence in tropical Australia (0.2 million ha), the chief forms being those formed on basalt under moderate to high rainfall in north Queensland, locally known as Krasnozems (24). Small areas of Oxisols also occur associated with Ultisols and Inceptisols on other parent materials in the higher rainfall areas of north Queensland, and some near the lower rainfall limit of 500 mm. The later are probably relict soils, product of a previous climate.

In tropical South America Oxisols are the dominant well drained soils of the areas affected by the Guayanan and Brazilian shields, including the Cerrado, the Llanos and the eastern Amazon basin. Calculations from the FAO-UNESCO (15) map show a total of 609 million ha of Oxisols. However, Sánchez and Buol (53) have claimed that large areas of the upper Amazon basin of Peru consist of Ultisols rather than Oxisols as presently shown in the FAO maps. Ultisols and acid Inceptisols are also extensive in the Amazon of Colombia (3). The revised Oxisol area of tropical America is thus reduced to 513 million ha. Oxisols of tropical South America occur on many of the widespread old erosion surfaces, although they have also been identified as occupying large areas on more recent depositional plains. Few of these soils have any counterparts in tropical Australia. A widespread soil formed on basalt in Brazil —the Latosol Roxo— is morphologically unlike any present in north Queensland. In contrast to South America, Oxisols are scarce in Mexico, Central America and the Caribbean, covering only 0.6 million ha, slightly more than tropical Australia.

Ultisols in tropical Australia are confined to the higher rainfall areas near the coast. Although most are highly weathered soils with oxic chemistry and mineralogy, they possess a characteristic clay increase with depth, which separate them from the Oxisols. Most are formed on acidic parent materials on landscapes that range from youthful to very old. The most common forms are Red and Yellow Podzolic soils and Xanthozems on acid igneous rocks, and Red and Yellow Earths on sedimentary rocks and sediments.

Ultisols are extensive in tropical Latin America, covering 371 million ha. They are fairly common in the higher rainfall areas of Central America (about 20 million ha) but are more widespread on gently sloping outwash plains of the Amazon and Orinoco basins, and on more dissected parts of the Brazilian and Guayanan shields. Most Ultisols of tropical South America bear a close morphological similarity to those of northeast Australia.

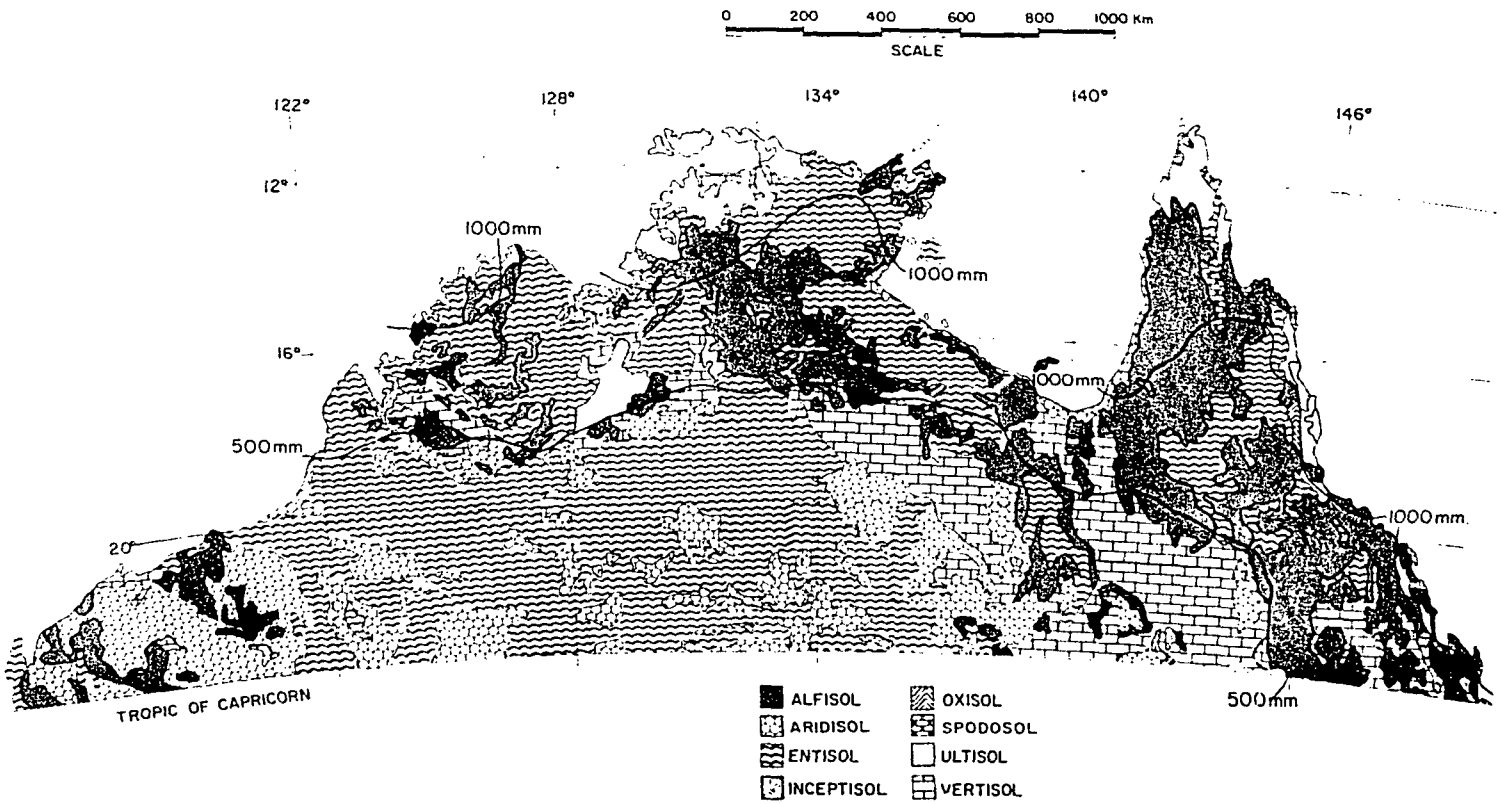
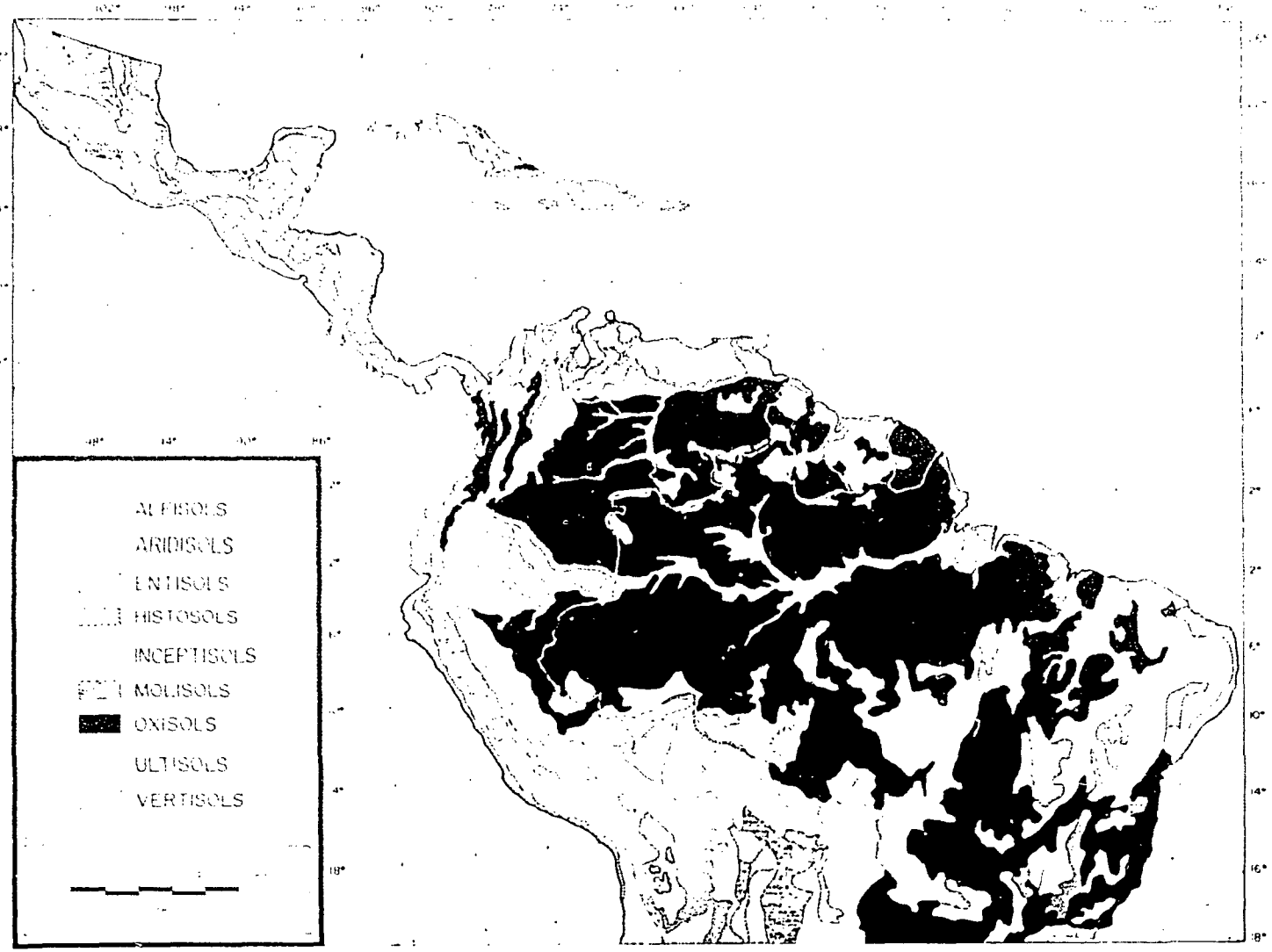


Figure 3. Soil map of tropical Australia


ALFISOLS
ARIDISOLS
ENTISOLS
HISTOSOLS
INCEPTISOLS
MOLISOLS
OXISOLS
ULTISOLS
VERTISOLS

Alfisols

The most characteristic feature of the Australian tropics is the dominance of Alfisols, particularly in Queensland. Nearly all occur in ustic climates with a pronounced seasonal rainfall. Alfisols occur on an extremely wide variety of landforms which may range from mid or late Tertiary surfaces to recent alluvial plains and dissected hilly areas. The majority of the soils are locally known as Red, Yellow and Grey Earths (many of these have oxic properties), Solodics, Non-Calcic Brown soils, Euchrozems, and some Red and Yellow Podzolics.

Perhaps the most striking feature of the Australian Alfisols is the widespread occurrence of sodic forms (Natrustalfs) which are particularly prominent in the subhumid areas of Queensland. These are locally known as Solidized Solonetz and Solodic soils, occasionally Soloths. In total, Alfisols occupy about 55 million ha in the Australian tropics.

Alfisols are also common in the lower rainfall areas of tropical Mexico, Central America and the Caribbean (32 million ha), derived from generally basic parent materials, but in tropical South America they occupy 160 million ha, mostly in the less-humid regions, such as in northeast Brazil, the north coast of Colombia and western Venezuela. In northeast Brazil they occur on a wide range of land forms and parent materials. In more dissected areas of igneous rocks they often resemble their Australian counterparts. On the more basic gneisses and metasediments of the Brazilian shields, islands of Alfisols are found in oceans of Oxisols. These are the Non-Calcic Brown soils which are morphologically very similar to those in Australia.

Mention must also be made of the Terra Roxa Estruturada (Rhodic subgroups of Peleustalfs, Paleudalfs or Paleudults) which although occupying only relatively small areas in the south of Brazil, is a most important agricultural soil. Formed mostly on basalt, these soils bear a close morphological resemblance to the eutrophic Krasnozems of north Queensland. Finally, it is noteworthy that in some less humid parts of northeast Brazil (Bahia, Pernambuco and Ceará) sodic Alfisols (Natrustalfs) occur that are very similar to those in tropical Australia.

Vertisols

Vertisols are an important and characteristic feature of the soil landscapes of tropical Australia, particularly in the subhumid regions where they occur widely on basic igneous rocks such as basalt, on felspathic or calcareous sedimentary rocks, and on alluvial deposits derived from base-rich parent rocks.

Some Vertisols occur in regions with as much as 1500 mm rainfall but all areas are characterized by extremely seasonal rainfall conditions. The darker forms are known as Black Earths and those with higher chroma, Grey, Brown or Red Clays. In Central Queensland vast areas of Vertisols occur immediately below the 500 mm rainfall limit adopted for this study.

In Mexico and Central America Vertisols are also common in the less humid regions where they occur mainly on calcareous and volcanic rocks or derived alluvial material. In sharp contrast, Vertisols are only sparingly present in South America, and almost all are in lower rainfall regions. The chief occurrences are in coastal Ecuador and adjacent northern Peru, western Venezuela and small areas in Colombia.

Entisols

Large areas of tropical Australia are occupied by Entisols, mostly sandy soils of the suborder Psamments. They are found on dissected upland areas of sandstone, quartzite and other mainly siliceous rocks. Most soils in these situations are shallow. Elsewhere on old outwash fans deeper

Entisols are locally prominent (called Earthy and Siliceous Sands). At the 500 mm rainfall limit, old wind modified sand sheets and occasional dunes occur (e.g. near Broome in Western Australia). Small areas of Entisols formed on low terraces of streams (the classic alluvial soils of the suborder Fluvents) occur widely throughout the region.

Many of the large areas of Entisols in Latin America are very different to those occurring in tropical Australia. Thus in central and eastern Brazil where Entisols are widespread the chief forms are deep Oxic Quartzipsamments (Areias Quartzisosas). These are deep red or yellowish sands formed from siliceous parent materials on old erosion surfaces. In stark contrast, considerable areas of shallow gravelly Entisols occur throughout the steeper parts of the Andean system and other mountainous areas. Finally, extensive areas (in aggregate) of Fluvents are associated with many of the major river systems.

Entisols do not occupy large areas in Mexico, Central America and the Caribbean, although shallow gravelly kinds are probably common on the lower-rainfall mountainous areas and Fluvents are locally important associated with major streams.

Inceptisols

In tropical Australia Inceptisols are only common in two localities. In the high rainfall areas of northeast Queensland they occur associated with Oxisols and Ultisols on metamorphic rocks. The chief forms are Dystropepts (acid young tropical soils). The other main area of occurrence is in some lower rainfall parts of northern Australia where they occur as shallow soils formed on basalt and are associated with Alfisols. These forms are mostly Ustropepts (non-acid Inceptisols).

In contrast, Inceptisols are widespread soils in Andean South America and the mountainous areas of Mexico, Central America and the Caribbean. Andepts (volcanic ash soils) are of particular importance in the latter area, and also in parts of Colombia, Ecuador, Peru and Bolivia. Other Inceptisols (mainly Dystropepts) are common in these mountainous areas, as well as on the more hilly areas of eastern Brazil. Finnaly it is likely that large areas of Aquepts (wet Inceptisols) occur in the extensive seasonally flooded areas areas of the Llanos, the Guayas basin, the Pantanal and along the major river systems.

Aridisols

The small areas of Aridisols in tropical Australia above the 500 mm isohyet shown in Figure 3 all consist of highly saline soils (Salorthids) that occur on coastal saltpans and estuarine flats that are occasionally flooded by tidal waters. Elsewhere in tropical Australia below the 500 mm rainfall limits Aridisols are extensive in the desert areas.

In South America similar saline soils occur fringing parts of the coastline in eastern Venezuela, the Guayanas and northern Brazil. Elsewhere in tropical Latin America, Aridisols are limited to the Mexican, Peruvian and Guajira deserts.

Spodosols

Small areas of these soils occur in the wetter areas of Queensland, mainly adjacent to the coast where they have formed in sand sheets, old beach ridges and modified dunes. These are the classic tropical Podzols. However, many are giant forms similar to those described by Thompson and Hubble (66). Similar soils occur as narrow fringes to a number of parts of the coast of Brazil. Spodosols are also known to occur on coarse-textured alluvial materials in parts of the Amazon basin (35, 53).

Mollisols

Although these very fertile soils are rare in tropical Australia, they are locally important in subhumid parts of tropical Latin America,

where they cover 82 million ha. Particular examples are in Central Mexico and the Yucatan Peninsula, in some drier inter-andean valleys of Peru and Colombia (including the Cauca Valley), in northwest Argentina and in northern Paraguay.

Histosols

The organic soils occur in small localized areas of both continents, none of them large enough to appear at the 1:5 million scale used in the FAO maps.

SOIL PHYSICAL PROPERTIES

The remainder of this paper confines the comparison to the tropical pasture areas of Australia with > 500 mm annual rainfall with the savannas and jungle areas of tropical America. Thus, the desert interior of tropical Australia, the Andean region, northeast Brazil, and most of Central America and the Caribbean are excluded from this discussion.

Water stress

Although in both regions water is a limiting factor during parts of the year, the magnitude of seasonal water stress is more pronounced in Australia, due to the generally longer dry season as shown in Figure 2. This is particularly acute in the Alfisol and Vertisol regions, where yearly variability in duration and intensity of drought stress is probably greater than in the savannas and jungles of Latin America.

Paradoxically, Vertisols and many Alfisols have a higher water holding capacity than Oxisols and Ultisols at the same clay content, because in the Oxisols in particular the kaolinitic clay particles are often bound by iron oxides and hydroxides into sand-sized granules, which gives them excellent structural properties, but lower water retention (52). Table 2 shows the available water ranges observed in Oxisols of Brazil and oxic Alfisols in North Queensland. In contrast, data for Australian Vertisols and those from other areas of the world are in the order of 10 to 25%. Consequently the predominant non-oxic Alfisols and Vertisols of tropical Australia store more water than the Latin American Oxisols and Ultisols, but the availability of water from rainfall is more restricted in Australia.

Table 2. **Available soil water ranges (0.1 - 15 bars, by weight) of Oxisols of the Cerrado of Brazil and oxic Alfisols from Australia (Red Earths and Yellow Earths) (38 and J. Williams, unpublished data).**

Order	% Clay	% available H_2O
Oxisols (Brazil):		
(44 topsoils)		
	<18	4.9
	18-35	8.5
	35-60	8.8
	>60	9.1
Alfisols (Australia):		
(18 topsoils)		
	5-15	11.9
	15-30	8.1
(14 subsoils, 90-120 cm)	22-55	8.1

In the highly variable rainfall environment of the subhumid Australian tropics there is extreme variation in pasture production among years. McCown (42) has shown that differences among soils in available soil water storage capacity have a substantial influence on growing season length. McCown *et al.*, (43) suggested that examination of the salt profile affords a simple means to define the depth limits to wetting. No such problems occur to a significant extent in the acid soil regions of tropical America.

Soil structure

Oxisols, because of their strong degree of granulation have excellent physical proper-

ties, which favor air and water movement, makes tillage possible soon after a heavy rain, and the uniform texture and structure with depth allows uniform percolation which makes them more tolerant (but not immune) to erosion than most other soils. Similar properties apply to some oxic subgroups of Alfisols and Ultisols, including those Krasnozems and Euchrozems in Australia which are Alfisols. These are the ultimate soils in terms of desirable physical properties.

Ultisols, particularly those with sandy topsoils are subject to soil compaction and erosion in both continents, but these limitations are minor compared with the difficult physical properties of two abundant groups of soils in Australia: the sodic Alfisols (Natrustalfs) and the Vertisols.

Alfisols known in Australia as Solodics, Solidized Solonetz and Soloths have massive sandy A horizons underlain by extremely dense clayey subsoils. When these subsoils are high in exchangeable Na content they have low permeability to water and hence plant rooting depth is inhibited. In spite of this limitation, tropical legumes of the genus *Stylosanthes* can persist in such soils.

Vertisols present even more severe physical limitations to pasture growth. Because of their shrink-swell properties and the hot dry environment where they occur, Vertisols with more than about 60% clay dry very rapidly at the surface, and form crusts and a loose mulch below this which impede seedling emergence of pasture species with small seeds (37). In all Vertisols, nearly all legume species currently used in tropical Australia simply do not persist (5). The reasons are not well understood but salinity may be a factor since many Australian Vertisols contain appreciable amounts of salts at relatively shallow depths, and there is evidence that many tropical pasture legumes have low tolerance to salinity (51).

Laterization

The specter of laterization of tropical soils is still a concern in the minds of many agricultural scientists and administrators. The fallacy of this argument has been documented previously (52, 53). It should be pointed out that in both tropical Australia and Latin America, laterite formation poses no threat to development since they occur in a minor proportion of the areas, usually in predictable topographic positions (at the break of slopes) which protects slopes against further erosion and provides valuable low-cost road building materials widely used in both continents.

Consequently, it can be generalized that the soil physical properties of the savannas and jungle areas of Latin America are far superior to those of most of tropical Australia in terms of rainfall supply and distribution, soil structure, and lack of physical restrictions to plant growth.

SOIL FERTILITY

Just as one can generalize that soils in tropical America are superior in physical properties, the opposite situation occurs in terms of soil chemical properties. In general, soils of tropical Australia are chemically more desirable than those of tropical Latin America. Evidence for this is provided in Tables 3 and 4 which show some properties of representative soils from both regions. The following discussion is largely based on these tables.

Soil acidity and aluminum toxicity

The most striking soil fertility contrast between the two regions is in terms of soil acidity. Tropical Australia generally lacks highly acid soils. The vast majority of surface soil pH values range between 5.5 and 6.5, with higher values present in calcareous Vertisols. At these pH ranges exchangeable Al is absent or very low and thus there is no danger of Al toxicity (30). Table 3 shows the

Table 3. **Selected topsoil chemical properties of representative soils of the tropical pasture area of Queensland, Australia.**

Soil & No.	Location	pH	Org. C	Clay	Exchangeable cations Al	Ca	Mg	K	ECEC	Al sat.	Reference
			— % —		— meq/100 g —					%	
ALFISOLS:											
Solodic (T30)	Lansdown Sta.	5.3	1.6	9	0.2	1.4	0.7	0.11	2.7	9	*
Red Earth (T256)	Redlands Sta.	6.3	0.5	16	0.1	1.4	0.6	0.10	2.1	2	*
Yellow Earth (T255)	Redlands Sta.	6.0	0.4	10	0.1	0.4	0.2	0.04	0.7	14	*
Euchrozem (T93)	Talaver	6.6	2.5	40	0.0	16.3	7.3	1.75	25.8	0	9,10
VERTISOLS:											
Grey Clay (T13)	Hughenden	7.6	0.4	56	0.0	35.0	5.5	1.80	45.3	0	9,10
Grey Clay (B297)	Mt. Coolon	8.6	1.6	32	0.0	22.0	5.6	1.50	29.5	0	9,10
ENTISOLS:											
Siliceous Sand (T76)	Wenlock	5.9	0.4	2	0.0	0.7	0.3	0.02	1.0	0	26
ULTISOLS:											
Yellow Earth (T137)	McDonnell	4.9	1,3	10	0.9	0.1	0.1	0.02	1.1	77	*
Red Earth (T241)	Tully	4.6	3.6	22	1.4	0.6	0.5	0.13	3.3	42	9,10
OXISOLS:											
Krasnozem (T62)	Malanda	5.4	8.0	66	0.8	1.3	1.6	0.26	4.0	20	9,10
Krasnozem (T84)	Gregory Falls	5.5	6.7	63	0.04	2.5	1.4	0.17	4.1	1	9,10
Xanthozem (248)	Lake Tinaroo	5.2	3.6	19	0.5	2.1	1.4	0.18	4.2	11	9,10

* Analyzed at CIAT except for Org. C and clay which were done in Australia.

Table 4. **Selected topsoil* chemical properties of representative soils of savannas and jungle areas of tropical Latin America.**

Soil & No.	Location	pH	Org. C	Clay	Exchangeable cations Al	Ca	Mg	K	ECEC	Al sat.	Reference
			—%—		——meq/100g——					%	
OXISOLS:											
Haplustox	Carimagua, Colombia	4.5	3.2	35	3.5	0.5	0.3	0.08	4.5	78	58
Haplustox (LVE)	Brasilia, Brazil	4.9	1.8	45	1.9	0.2	0.2	0.10	2.4	79	12
Yellow Latosol (28)	Paragominas, Brazil	4.4	1.3	74	1.4	0.7	0.3	0.07	2.4	58	14
Acrustox (C)	Caicara, Venezuela	4.5	0.4	24	1.0	0.3	0.1	0.10	1.6	63	56
Haplorthox (T.A.)	La Libertad, Colombia	4.4	2.7	25	2.2	0.4	0.4	0.06	3.1	71	19
Eutrustox (1)	Capinópolis, Brazil	5.4	2.8	40	0.6	7.5	2.1	0.53	10.7	25	44
ULTISOLS:											
Paleustult	Jusepín, Venezuela	4.7	0.9	24	0.5	0.5	0.1	0.01	1.1	43	13
Paleudult (Y-13)	Yurimaguas, Peru	4.0	1.2	9	2.3	0.2	0.2	0.10	2.9	79	57
Paleudult (P-2)	Pucallpa, Peru	4.4	1.6	42	3.4	2.5	1.3	0.41	4.2	81	45
Palehumult (F-3)	Quilichao, Colombia	4.1	4.1	71	2.7	0.7	0.5	0.36	4.2	64	8
Paleudult (2)	Echaporã, Brazil	4.9	0.5	16	0.4	1.0	0.1	0.10	1.6	62	36
Paleustult (1)	Pres Murtinho, Brazil	4.7	1.0	18	0.8	0.2	0.2	0.06	1.3	63	14
ALFISOLS:											
Paleustalf (4)	Maracaibo, Venezuela	5.7	0.8	7	0.1	1.7	0.7	0.33	7.9	1	47
Tropaqualf (Y-7)	Yurimaguas, Peru	5.0	1.2	53	7.4	11.4	6.3	0.67	25.8	29	53

* When first horizon was <10 cm, data was weighed with second horizon to depth of no less than 20 cm.

generally high pH values, low exchangeable Al and low Al saturation levels of Australian Alfisols, Vertisols, Entisols and even some Oxisols. It also includes an important exception, the Ultisols from the better watered regions, which present chemical properties very similar to their Latin American counterparts (Table 4). Even in these truly acid Australian Ultisols, no major deleterious effects of Al toxicity on pasture growth have been detected (63, 64), and the lime responses that have been recorded have been attributed to overcoming Ca deficiency (27, 62, 63, 64).

In contrast, tropical Latin America is dominated by highly acid soils with pH ranging from 3.8 to 5.5 with Al saturation values commonly over 60%, a generally accepted critical level for Al toxicity (30). In these soils, acidity adversely affects plant growth because of Al or Mn toxicity as well as Ca and Mg deficiencies.

These differences also apply to subsoil properties, which perhaps are more critical since it is very difficult to correct them by management. Figure 5 shows the dramatic contrast in pH and Al saturation with depth at two experiment stations of each continent. Soil pH is uniformly low and Al saturation high with depth in the Oxisol and Ultisol of Latin America, almost ideal in the Alfisol of the Redlands Station in Australia, and undesirably alkaline in the subsoil of the Alfisol at Lansdown.

In both continents, liming tropical pastures has to be minimized because of its high cost in relation to beef production. The accepted strategy is to select and utilize pasture species tolerant to the major soil stresses (59, 68). Australian scientists have successfully developed cultivars of species such as *Stylosanthes humilis* (Aubl.) Sw., *Stylosanthes hamata* (L.) Taub., *Stylosanthes scabra* Vog. and *Macroptilium atropurpureum* (DC.) Urb. for their soils which range, as stated, from pH 5.5 to 6.5 (1, 22). Latin American scientists have found that commercial cultivars of these species are not always well adapted to Oxisols and Ultisols with pH lower than 5.5. Pasture legume species more tolerant to stronger Al

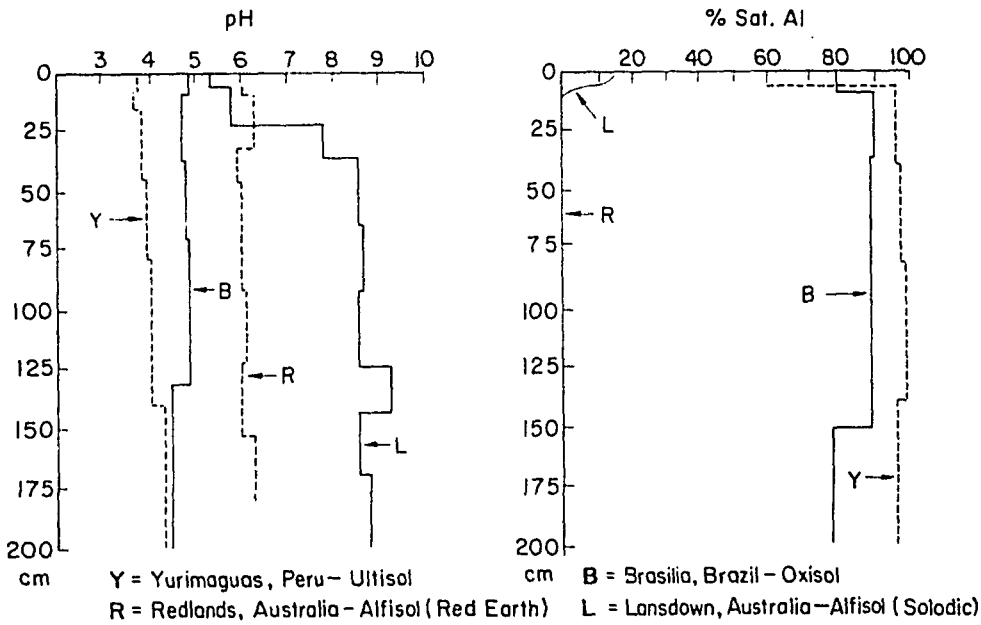


Figure 5. Soil acidity profile of two Australian Alfisols and an Ultisol and Oxisol from Latin America (9, 12, 45).

toxicity include *Stylosanthes capitata* Vog. *Zornia* spp., *Desmodium ovalifolium* Vahl. and some *Centrosemas* (8).

Exchangeable bases

The supply of Ca and Mg is generally higher in the Australian than Latin American soils as shown in Tables 3 and 4. Straightforward Ca and Mg deficiencies are common in Oxisols and Ultisols of Latin America, and are readily corrected by applying 0.1 to 0.5 t/ha of dolomitic lime (58). These rates are sufficient to overcome Ca and Mg deficiencies without altering significantly the pH and Al saturation of the soil. Mg deficiencies can be directly overcome by Mg fertilization. In Australia, Ca deficiencies have been reported in Ultisols of high rainfall areas, where apparently the response to lime could be attributed to Ca fertilization or increased Mo availability in the case of legumes. Mg deficiencies are rare in tropical Australia, but are very common in the savannas and jungles of tropical America.

Figure 6 shows the distribution of exchangeable bases with depth in four characteristic soils. The uniformly low Ca, Mg and K status of the Oxisol and Ultisol is in sharp contrast to the ample levels found in many Australian Alfisols. The Natrustalf from Lansdown depicts an inversion of the Ca:Mg ratio in the subsoil, which may negatively affect plant growth, as well as the previously mentioned increase in Na with depth.

Comparison of K status between the continents is less straightforward. Considering a generally accepted critical level of 0.2 meq K/100 g many, but not all, Alfisols, Ultisols, Oxisols and Entisols of both continents are K deficient, in contrast with the high levels observed in the Vertisols. K responses by tropical pastures in Australia have been commonly recorded on the high rainfall Ultisols and Oxisols (33), but responses on Alfisols have been much more variable. In some soils there may be plant uptake from nonexchangeable sources, but in other Alfisols this does not occur (4) and significant pasture responses have been recorded (20).

In tropical America, K is often a neglected element in pasture fertilization, particularly in Ultisols and Oxisols. Successful production of species adapted to high soil acidity has been possible when K deficiencies have been corrected, usually by modest applications (8, 45).

Organic carbon and nitrogen

There are no major differences between tropical Australia and Latin America in these two parameters. Data in Tables 3 and 4 show that the main soils in both continents have low to medium OM contents, in predictable amounts as a function of climate, vegetation and soil texture. In general, soils of both continents are severely deficient in N, except for some Vertisols and virgin rain forest soils.

Phosphorus

Australian soils are generally very deficient in P, and so are the soils from the savanna and jungle regions of tropical America. Direct comparison of available P levels between the two continents is not possible, because the extraction methods are different. Australian scientist use 0.01 *N* H_2SO_4 extractant and they consider 15-20 ppm P as the critical level for most tropical pasture legumes. Data show that P deficiency is acute in all tropical Australian soils except for most Vertisols and soils derived from basalt (Euchrozems and some Krasnozems) which can be Alfisols or Oxisols (4). Latin American scientists use a wide range of soil extractants such as the Olsen bicarbonate method, the North Carolina dilute double acid, and Bray I and II. The only well established critical levels are related to cereal crops, such as 15 ppm P for Olsen in Peru, 10 ppm P for the North Carolina method in Brazil and 15 ppm P for Bray II in Colombia. The critical levels for tropical pasture species are likely to be

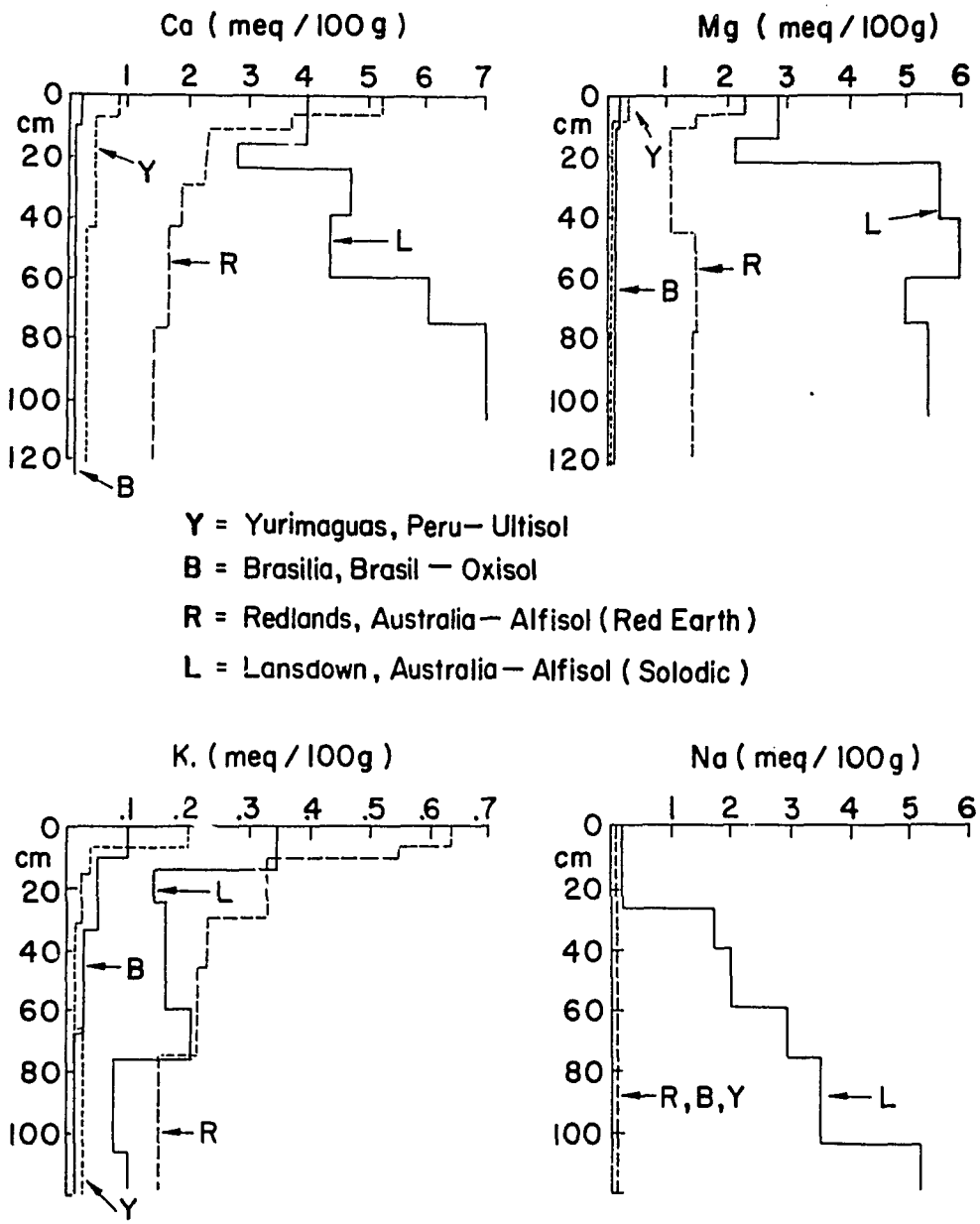


Figure 6. Profile of exchangeable bases in two Australian Alfisols and two Latin American acid soils (9, 12, 45).

lower. Preliminary data show that the Bray II critical levels for adapted tropical pasture legumes is in the order of 3 to 7 ppm P (8). Soil test summaries such as those of the Cerrado of Brazil (39), Colombia (40) and Peru (6) show that the Oxisol and Ultisol regions are extremely deficient in available P.

The big difference between the two continents is the capacity of the soils to fix P, that is to make P applications largely

unavailable to plants. Figures 7 and 8 show P fixation curves of representative topsoil samples analyzed according to the Fox and Kamprath (18) method. From Figure 7 it appears that all except one of the samples (which represent common tropical Australian soils) have low fixation capacities, requiring less than 70 ppm P to reach a level in the soil solution of 0.05 ppm P, which is probably adequate for pasture growth. In contrast, most of the Oxisols and Ultisols of Latin America require 3 to 5 times more P to reach a similar level (Fig. 8). The important exception in Australia is also an Oxisol (Gregory Falls Krasnozem). It is derived from basalt and has a high oxide content.

In soils high in Fe and Al oxides such as some Oxisols, Ultisols and oxic Alfisols, P fixation generally increases with increasing clay content (48, 38, 55). This can be observed in Figure 8 where the Brasilia and

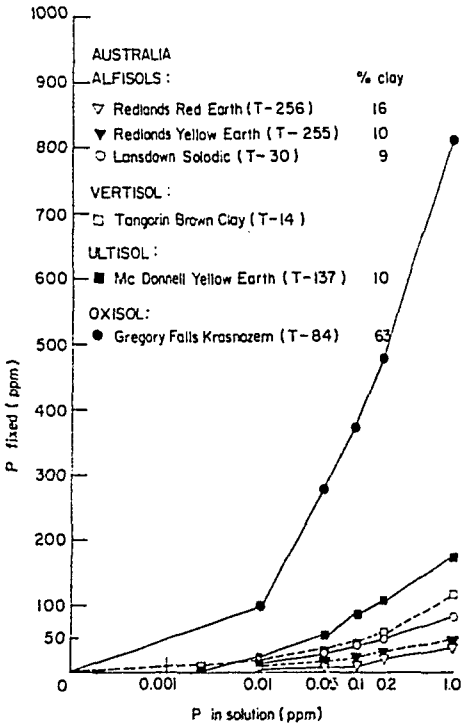


Figure 7. **Examples of P sorption isotherms of representative soils in tropical Australia.**

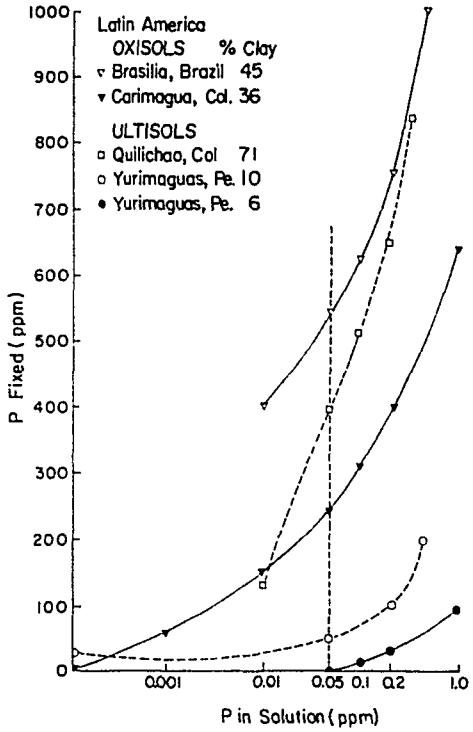


Figure 8. **Examples of P sorption isotherms of representative soils in Tropical America (7, 45).**

Carimagua Oxisols and the Quilichao and Yurimaguas Ultisols have totally different P fixation curves and clay contents. Soils low in Fe and Al hydroxides such as the Lansdown Solodic generally have low P fixation capacity.

It can be concluded therefore, that while both regions suffer from acute P deficiency in most of their soils, the amounts of fertilizer P needed to overcome the deficiencies are likely to be higher in Latin America because of the generally higher P fixation capacity of the widespread Oxisols and Ultisols (except the sandy ones).

Sulfur

S deficiencies are considered widespread in both the Australian and Latin American tropics (29, 30). This is an important reason why SSP and not TSP is the main form of P used in Australia.

The evidence in tropical Australia suggests that S deficiencies are more frequent on soils with limited capacity to sorb, and hence retain S, and where seasonal leaching occurs. Even though input of S from rainfall may be low, in some soils (e.g. Oxisols and some Ultisols) high levels of sorbed sulfate can occur in subsoils (49). Recent studies (50) suggest a critical level of 4 ppm of SO_4-S (extracted by the phosphate method) in the entire profile for tropical pastures.

S deficiencies are widespread but not universal in Oxisols and Ultisols of Latin America, with significant responses observed in tropical pastures (7, 41, 65). There is also evidence of sulfate accumulation in subsoils with relatively high S sorption capacity, typical of some Oxisols, Ultisols and oxic Alfisols (32).

Micronutrients

Information on micronutrients is less well defined in both regions, apart from the fact that deficiencies of Zn, Cu, B, and Mo have been reported in both tropical Australia and tropical America (4, 11).

In tropical Australia molybdenized simple superphosphate has been widely used to correct possible Mo deficiencies (22) but responses have not been well documented. They are more acute in high P fixing soils (Oxisols and some Ultisols) since they also fix the molybdate anion by the same mechanism (33). However, there are important species differences. For example there are no known field responses to Mo recorded for the genus *Stylosanthes* in Australia (33). In Latin America Mo deficiencies occur in Oxisols and Ultisols (11, 46) but the response data are very limited.

Deficiencies of Zn, Cu and B are poorly characterized in terms of geographical distribution and economic importance. Of these Zn is probably the most important in Ultisol and Oxisol regions of Latin America (11). Mn deficiency as well as toxicities are also known to occur. The same applies to Fe deficiency both in calcareous and extremely acid soils. Cu and Zn deficiencies have been recorded in the high rainfall Ultisols and Entisols of tropical Australia (33). There is much need for establishing critical levels both in soil and pasture tissue in order to better characterize the micronutrient limitations of tropical Australia and Latin America.

CONCLUSION

Soils of tropical Australia and tropical Latin America share the common problem of low native fertility, but for different reasons. The most widespread Australian soils have more severe water stress but enjoy a higher base status than their Latin American counterparts. Although N, P and S deficiencies are widespread in both continents, the generally higher P fixation, lower K status and Al toxicity of Oxisols and Ultisols intensifies the acuteness of low fertility in Latin America. There is nothing unique about the differences described in this paper that cannot be inferred by soil taxonomy, supplemented by rather simple soil fertility analyses. Alfisols, Ultisols or Oxisols are similar, regardless of where they occur. There are strong similarities between the small region of high rainfall Oxisols and Ultisols of North Queensland with the vast areas of the same soils in Latin America, and likewise between the dominant Alfisols and Vertisols of Australia with their less widespread counterparts in tropical Latin America.

The adaptation of tropical legumes to low input management is very much soil and climate dependent. Some of the most important tropical pasture legumes in Australia today are *M. atropurpureum, Centrosema pubescens* Benth., *S. guianensis, S. humilis* and *S. hamata*. The latter two *Stylosanthes* species are well adapted to Alfisols with severe water stress, low P status and low Al stress. They are likely to be adapted to similar conditions in tropical America, but less likely to Oxisols and

Ultisols with their higher Al stress. On the other hand *C. pubescens* and *S. guianensis* adapted to more acid rain forest Ultisol and Oxisol conditions in North Queensland may have a strong potential for the Amazon Jungle. However *M. atropurpureum* cv. Siratro is well adapted to higher pH Oxisol areas of the Brazilian Cerrado.

These statements are limited to edaphic adaptation, which includes climate to a certain extent. Many other factors affect species adaptation, particularly pest and diseases, seed production potential, etc. They must also be included when considering the transfer of technology from one region to another. For example, lack of persistence of Australian cultivars of *S. guianensis* in tropical America is primarily due to their susceptibility to anthracnose (caused by *Colletotrichum gloeosporoides*), rather than lack of adaptation to acid soil stresses.

In conclusion, it can be generalized that soil conditions for tropical pasture production in Australia and Latin America are different enough to preclude direct extrapolation of results from one continent to another. However, each continent also has small areas of soils which are very similar to vast areas of the other.

ACKNOWLEDGEMENTS

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Appendix 1. **Simplified definition of Soil Taxonomy terminology used in this paper, as applied to the tropics (52).**

SOIL ORDERS:

Oxisols: Soils with an oxic horizon of low activity clays (<16 meq/100 g clay), consisting of mixtures of kaolinite, iron oxides and quartz, low in weatherable minerals. Usually deep, well drained, red or yellow soils, excellent granular structure, acid, very low fertility, uniform properties with depth. Formerly known as Latosols, Lateritic soils.

Ultisols: Soils with an argillic horizon (20% increase in clay content) with less than 35% base saturation in the control section. Usually deep, well drained red or yellow soils, higher in weatherable minerals than Oxisols, with less desirable physical properties, but still acid and low in native fertility. Formerly known as Red Yellow Podzolic soils, and some Latosols and Lateritic soils.

Alfisols: Soils with an argillic horizon with more than 35% base saturation. Similar to Ultisols except for considerably higher native fertility. Formerly known as: Eutrophic Red Yellow Podzolics, Non Calcic Browns, Planosols, Terra Roxa Estruturada, Red Earths, Yellow Earths, Solodics.

Aridisols: Soils of aridic soil moisture regimes, with horizon differentiation. Generally high native fertility.

Entisols: Soils with such slight or recent development that only an ochric (yellowish) epipedon or simple man-made horizons have formed.

Vertisols: Heavy, cracking clayey soils with more than 35% clay and >50% of 2:1 clay minerals. Usually shrink and swell with changes in moisture content, have gilgai microrelief and slickensides on peds. Generally high native fertility.

Inceptisols: Young soils with a cambic horizon but no other diagnostic horizon. Native fertility variable.

Mollisols: Soils with a mollic epipedon (high in organic matter, soft when dry and >50% base saturation). Very high native fertility. Known as Chernozems, Rendzinas, Brunizems.

Spodosols: Soils with a spodic horizon (of Fe and organic matter accumulation) usually developed from sandy materials. Very low native fertility. Known as Podzols.

Histosols: Organic soils (>20% OM).

SOIL MOISTURE REGIMES:

Udic: The subsoil is dry (>15 bars) for less than 90 cumulative days during the year.

Ustic: The subsoil is dry for more than 90 cumulative days but less than 180 cumulative days or 90 consecutive days.

Aridic: The subsoil is dry for more than 180 cumulative days and moist for less than 90 consecutive days during the year.

Aquic: The subsoil is saturated with water long enough to cause soil reduction.

SOIL TEMPERATURE REGIMES:

Isohyperthermic: The mean annual temperature of the soil at 50 cm is > 22°C with less than 5°C variation between the three warmest and the three coldest months.

Hyperthermic: Same as above but with more than 5°C variation between the three warmest and three coldest months.

Appendix 2. **Approximate correlation between some Australian great soil groups (61), Soil Taxonomy orders and great groups, and FAO mapping units (25).**

Australian Great Groups	Soil Taxonomy		FAO World Soil Map
	Order	Great Group	
Siliceous Sands	Entisols:	Quartzipsamment	Eutric Regosol, Cambic Arenosol
Earthy Sands	Entisols:	Quartzipsamment	Cambic Arenosol
Grey, Brown and Red Clays	Vertisols:	Chromustert	Chromic Vertisol
Solodized Solonetz and Solodic soils	Alfisols:	Natrustalf, Paleustalf, Haplustalf	Orthic Solonetz, Albic Luvisol
Soloths	Alfisols:	Paleustalf, Natrustalf, Haplustalf	Albic Luvisol, Orthic Solonetz, Solodic Planosol
Red Earths	Alfisols & Ultisols:	Paleustalf, Haplustalf Paleustult, Paleudult	Eutric Nitosol, Ferric Luvisol, Dystric Nitosol
Yellow Earth	Alfisols & Ultisols:	Haplustalf, Paleustalf, Paleustult, Plinthustalf	Ferric, Albic and Plinthic Luvisols, Ferric Acrisol
Grey Earths	Alfisols:	Paleustalf, Tropaqualf	Albic Luvisol, Gleyic Luvisol
Euchrozems	Alfisols & Inceptisols:	Rhodustalf, Paleustalf, Ustochrept, Ustropept	Chromic Luvisol, Eutric Nitosol Chromic Cambisol

Appendix 2. Continued

Australian Great Groups	Soil Taxonomy		FAO World Soil Map
	Order	Great Group	
Xanthosems	Oxisols & Ultisols:	Haplorthox, Haplustox, Palehumult, Acrohumox	Xanthic Ferralsol, Humic Ferralsol, Humic Acrisol
Krasnozems	Oxisols & Alfisols:	Acrohumox, Acrorthox, Eutrustox, Paleustalf	Humic Ferralsol, Rhodic Ferralsol, Eutric Nitosol
Red Podzolic soils	Alfisols & Ultisols:	Paleustalf, Paleudult, Haplustult, Tropudult	Albic Luvisol, Ferric and Orthic Acrisols, Dystric Nitosol
Yellow Podzolic soils	Alfisols & Ultisols:	Haplustalf, Haplustult, Paleustalf	Albic Luvisol, Orthic and Ferric Acrisol
Gleyed Podzolic soils	Ultisols:	Paleaquult, Albaquult	Gleyic Acrisol, Dystric Planosol
Podzols	Spodosols:	Tropohumod, Troporthod Haplohumod	Humic and Orthic Podzols
Humic gleys	Ultisols & Inceptisols:	Paleaquult, Albaquult, Haplaquept	Gleyic Acrisol, Dystric Gleysol

GENETIC RESOURCES OF FORAGE LEGUMES FOR THE ACID, INFERTILE SAVANNAS OF TROPICAL AMERICA

Rainer Schultze-Kraft*
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ABSTRACT

Observations made during collecting expeditions, in introduction plots and under grazing conditions indicate that the following main genera and species demonstrate clear potentials as forage legumes for savannas with acid, infertile soils in tropical America: *Stylosanthes (S. capitata); Desmodium (D. ovalifolium, D. barbatum* and others); *Zornia* (from the group of species with bifoliate leaves) *Aeschynomene (A. histrix* and *A. brasiliana); Centrosema; Macroptilium/Vigna;* and *Galactia*. However, these genera, along with others that appear adapted to acid infertile soils, still require considerable research attention with respect to systematic collections and evaluations.

Until about 40 years ago the importance of tropical legumes was limited to their use as cover crops on oil palm or rubber plantations (12). Although in earlier literature there were some indications of the great potential of tropical legumes as forage plants (4, 5, 9) it was only during the 1940's that research on using legumes as forage began in Australia. These early efforts consisted of various trips to collect germplasm throughout the tropics (1, 7, 8), followed by systematic evaluations and, occassionally, some plant breeding efforts. The work done by Australian scientists resulted in a series of cultivars of tropical forage legumes that were released during the last 15 years.

Interest in forage legumes for tropical America dawned during the last decade. In most cases, research was limited to maintaining a few plots of Australian cultivars in introduction gardens and collecting data on fresh matter production. This situation was problematic as well as paradoxical: the importance that forage legumes would eventually have in research projects of individual institutions depended on the behavior of a few commercial cultivars selected in Australia for specific climatic and edaphic conditions of that country; meanwhile, no attention was being given to native genetic resources.

Brazil was one of the first Latin American countries to become interested in developing its own forage legume genetic resources. The Ministry of Agriculture began to study them in 1941 (9), and between 1961 and 1965, the IBEC Research Institute (IRI) made a series of surveys from

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which an important collection was assembled, consisting of a wide range of genera, species and ecotypes of native Brazilian legumes (3).

Only more recently Latin American and international institutions have begun to carry out systematic collection trips in tropical America, and to show interest in preserving and evaluating the collected germplasm. At present there are approximately 10,000 ecotypes of many genera and species of tropical legumes available from the following institutions:

1. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) through its Centro Nacional de Recursos Genéticos (CENARGEN), Brasilia, D.F., Brazil.

2. Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), Belo Horizonte, Minas Gerais, Brazil.

3. Empresa Goiana de Pesquisa Agropecuária (EMGOPA), Goiânia, Goiás, Brazil.

4. Instituto de Pesquisas IRI, Matão, São Paulo, Brazil.

5. Instituto de Zootecnia, Secretaria de Agricultura do Estado de São Paulo, Nova Odessa, São Paulo, Brazil.

6. University of Florida, Fort Pierce, Florida, U.S.A.

7. University of the West Indies/International Development Research Centre, Antigua and Belize.

8. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Major international efforts were consolidated during a recent Workshop on Collection, Preservation, and Characterization of Genetic Resources of Tropical Forage Plants, held April 10-15, 1978 at CIAT, and attended by the world's leading scientists in tropical forage germplasm (6). An important result of this workshop was an agreement for free exchange of all available germplasm. This agreement includes the institutions listed above, and others in Latin America which keep smaller collections of native germplasm (i.e. in Cuba, Ecuador and Panama). Also participating will be institutions outside of Latin America which have important collections comprising species native to tropical America and of exotic origin (i.e. the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia; and the Food and Agriculture Organization (FAO) Forage Collection and Evaluation Project, in Kenya).

In tropical America, CIAT—in an intensive way— and EMBRAPA—in a partial way—have concentrated their work on collecting, introducing and evaluating tropical forage legumes for acid, infertile soils (Oxisols and Ultisols). EMBRAPA works through CENARGEN and its Active Germplasm Banks in the Centros de Pesquisa Agropecuaria dos Cerrados (CPAC) near Brasilia, dos Trópicos Umidos in Belém and de Gado de Corte (CNPGC) in Campo Grande.

The final objective of efforts at CIAT and EMBRAPA is the identification of genetic material adapted to the edaphic and climatic conditions of approximately 300 million ha of tropical savannas and 550 million ha of humid tropics in Latin America with acid, infertile soils. Legumes adapted to these conditions must combine the following characteristics, collectively known as "persistence under grazing": (a) tolerance to low pH values (including high concentrations of Al and Mn); (b) low requirements for P and other elements; (c) effective nodulation with *Rhizobium;* (d) compatibility with grasses (vigorous growth and regrowth and adequate growth habits); (e) tolerance to diseases and insect attacks; (f) adequate palatability (absence of toxic factors and of excessive palatability); and (e) tolerance to drought and flood stress.

MAJOR GENERA—COLLECTION AND EVALUATION

The following notes about the most important genera summarize CIAT's and EMBRAPA's collection and evaluation experiences up to the present.

Stylosanthes Sw.

Among all the tropical legumes, researchers have given their greatest attention to the genus *Stylosanthes* and its several interesting characteristics. *Stylosanthes guianensis* (Aubl.) Sw. (Fig. 1) is the species with the greatest genetic diversity, a fact reflected in the recent attempts to establish new botanical species and varieties (2, 10). Geographically, it is found from Mexico to Argentina and from Ecuador to Bahia, Brazil. Although *S. guianensis* is an indicator plant for acid (but not necessarily infertile) soils, some ecotypes have been found in alkaline soils.

Other important *Stylosanthes* species that are also indicator plants for acid soils include: *Stylosanthes scabra* Vog., *Stylosanthes viscosa* Sw., *Stylosanthes humilis* H.B.K. and *Stylosanthes capitata* Vog. (Fig. 2). All of these are well-adapted to the Oxisols and Ultisols of the South American tropical savannas. Moreover, *S. capitata* needs a low pH and low fertility and has been observed to not grow well on fertile soils. Geographic distribution of these species is more limited than that of *S. guianensis*. For example, in Colombia it has been impossible to find *S. scabra, S. viscosa* or *S. capitata*. Existence of *S. humilis* in that country seems limited to acid soils in regions bordering Venezuela.

With the exception of *S. humilis*, all the species mentioned above show the advantages of vigorous growth, high DM production and good resistance to drought. Averaging the combined observations of Colombian and Brazilian experiences, the species could be ranked according to their productivity as follows (highest to lowest): *(S. guianensis* $\geq$ *S. scabra* $>$ *S. viscosa* $\geq$ *S. capitata.*

S. capitata appears to be native only in

Figure 1. *Stylosanthes guianensis* **CIAT 136.**

Figure 2 *Stylosanthes capitata* **CIAT 1019.**

Brazil and certain regions of Venezuela. Three markedly different types have been identified in this species:

A. Early flowering: germplasm native to central Brazil; with high seed production and relatively low DM production.

B. Intermedia flowering: germplasm native to the states of Maranhão and Piaui, Brazil; lower seed production and higher DM production than (A).

C. Late flowering: plants morphologically different from (A) and (B); germplasm native to Bahia, Brazil; apparently smaller seed production but high DM production, especially during the dry season.

To these we could add a fourth ecotype of *S. capitata* collected in the states of Anzoátequi, Bolívar and Monagas, Venezuela. Morphologically, it should be classed as late-flowering although it flowers earlier. Plants of this type, along with some of those of ecotypes (A), (B) and (C), apparently are resistant to burning.

Productivity of the species *S. humilis* is restricted by its annual growth habit. Its best potential is in regions with acid soils where average annual rainfall (AAR) is less than 1000 mm/yr and the dry season is long. However, in the jungle area of the state of Maranhão, Brazil, some very vigorous ecotypes have been collected whose productivity in environments having an AAR of 2000 mm/yr (at Carimagua, in the Colombian Llanos) equals that of many *S. guianensis* ecotypes.

Stylosanthes hamata (L.) Taub. deserves mention because one cultivar of this species has replaced large areas of *S. humilis* in Australia. All of the CIAT germplasm of *S. hamata* is native to the Caribbean area and was collected in areas of low AAR from fertile soils having a slightly acid to alkaline pH. One ecotype, however, shows some adaptation to infertile soils of very low pH in contrast to the rest of the *S. hamata*

germplasm. The ecotype appears to be native to the Calabozo region of Venezuela (state of Guárico) where the vegetation is typical savanna on an acid soil of medium fertility.

Stylosanthes angustifolia Vog. and *Stylosanthes bracteata* Vog. are other indicator plants for acid, infertile soils. Although not enough work has been done yet with germplasm of these species, the productivity of *S. angustifolia* seems to be very low.

Despite the several positive characteristics of *S. guianensis, S. scabra* and *S. viscosa,* their potential is seriously limited by their lack of resistance to anthracnose (*Colletotrichum gloeosporioides* Penz.) and to a stem borer (*Caloptilia* sp.). A rather wide range of susceptibility has been found in the germplasm evaluated in the greenhouse and observations of materials in introduction plots and under grazing. Many materials of a determinant type of *S. guianensis,* distinguished by their fine stems, abundant pubescence and late flowering, apparently are more tolerant to attacks of both the disease and the insect. This tolerance is not sufficiently great, however, to assure persistence of plants under grazing.

S. capitata is the only *Stylosanthes* species that up to now appears sufficiently tolerant to anthracnose as well as to stem borer attacks. Therefore, this species is considered of very high priority for further work, including additional germplasm collections to widen the available genetic variability as much as possible.

Desmodium Desv.

The potential of this genus, which includes approximately 200 species, has not been sufficiently explored. *Desmodium barbatum* (L.) Benth. and *Desmodium cajanifolium* (H.B.K.) DC. are the two species found most frequently on collection trips to regions of acid, infertile soils.

Preliminary observations indicate that *D. barbatum* includes ecotypes with a surprisingly wide range of growth habits, foliage densities and productivities. From observations at many collection sites, a group of ecotypes is evidently well-adapted to high rainfall conditions.

D. cajanifolium is part of a group of very erect species that reach heights of up to 3 m with little branching and very little foliage, but which produce abundant seed. *Desmodium distortum* (Aubl.) MacBr. and *Desmodium discolor* Vog. also belong to this group but they require more fertile soils. The main potential of these plants is in their eventual use for browsing.

Few species of *Desmodium* native to southeast Asia have been tested on Oxisols and Ultisols of tropical America. The most promising of these few is a subspecies of *Desmodium heterocarpon* (L.) DC. that is commonly known by its older name *Desmodium ovalifolium* Wall. (Fig. 3). Little is known about its genetic variability. The only material available is a commercial variety marketed in Singapore which is well-adapted to Oxisols of the Colombian Llanos. The very vigorous stoloniferous growth of *D. ovalifolium* permits its successful establishment with a grass as aggressive as *Brachiaria decumbens* Stapf. It apparently has good drought tolerance and, up to now, has shown no specific problems caused by diseases or insects.

Zornia J. F. Gmel.

This genus, which includes some 60 species, was, until a short time ago, completely unknown to tropical forage plant researchers. CIAT's experience with this genus began two years ago and can be summarized as follows:

1. All de *Zornia* species and ecotypes collected so far are indicator species for acid, and very often infertile, soils. Materials evaluated do not have adaptation problems on Oxisols and Ultisols.

Figure 3 *Desmodium ovalifolium* CIAT 350.

2 Apparently, the most promising germplasm comes from species with compound leaves of two leaflets (i.e. *Zornia* aff. *latifolia)* (Fig 4). Very extensive genetic variability has been observed in DM production, flowering date and foliage density. Many of the ecotypes are more than annuals under grazing. They also appear resistant to burning.

3 The few *Zornia* ecotypes with compounds leaves of four wide leaflets that have been studied (i.e. *Zornia* aff. *brasiliensis* Vog.) show little productivity and seem markedly annuals.

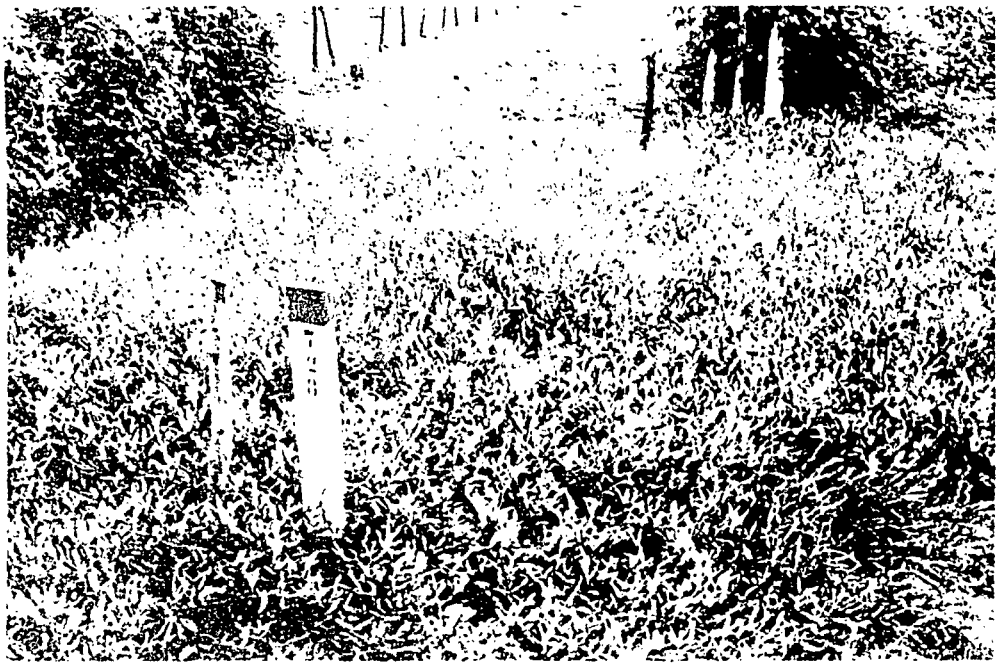
Aeschynomene L.

Although the genus *Aeschynomene* L. is known to scientists studying tropical forage legumes, only recently has research been initiated to identify germplasm adapted to acid, infertile soils. Among the most interesting species is *Aeschynomene paniculata* Willd. ex. Vogel, and material of other species having procumbent to prostrate growth habits, fine stems, many branches and, frequently, heavy pubescence (i.e. *Aeschynomene histrix* Poir. and *Aeschynomene brasiliana* (Poir.) DC.

Several observations made during collection trips and from introduction plots on an Ultisol of pH 4.0 suggested further evaluation. Ecotypes of the above-mentioned species are frequently found in savanna regions with acid, infertile soils, vary widely in their productivity, flowering date and persistence, show good drought resistance, produce considerable quantities of seed, and up to now have not shown problems of diseases or insect attacks.

Centrosema (DC.) Benth.

The genus *Centrosema*, like *S. guianensis*, has a very wide geographic distribution. However, unlike that species, *Centrosema* is not a genus of indicator plants for acid soils. Most *Centrosema* species are native to regions with rather high soil fertility. Conse-



[illegible] CIAT 728

[illegible]

[illegible] observed [illegible] species [illegible] *Centrosema* [illegible] rather [illegible] a climbing habit. [illegible] attributed to the frequent burning practices in these areas. For the same reason it has been found that some species, especially *C. venosum*, have the ability to produce fruits underground in sandy soils. In savanna areas protected from fire and burnings, i.e. around the borders of gallery forests and in regions where vegetation is jungle-like, *Centrosema* species with climbing growth habits do occur, among them *Centrosema pubescens* Benth., *Centrosema macrocarpum* Benth. and *Centrosema angustifolium* (H.B.K.) Benth. The latter species is very typical of the plains of Colombia and Venezuela.

Because species with creeping growth habit have rather low productivity, collection and evaluation of germplasm from the climbing group have been intensified. Some plants of this group have been found vigorous, growth prostrate, well adapted to acid infertile soils.

Macroptilium (Benth.) Urb. and *Vigna* Savi

Like *Centrosema*, these genera have a very wide geographic distribution. And also like *Centrosema*, their potential for acid infertile soils, has not been sufficiently explored. From travels through savanna regions as well as other Oxisol and Ultisol zones, a considerable quantity of germplasm of these genera has been collected, and very wide ranges of productivity and phenotypes have been found. Some of the extraordinary characteristics encountered include unfoliate leaves, tuberous roots and underground fruiting. Much of this material is probably annual. In the systematic evaluation of this germplasm, which has only

begun recently, special attention will have to be given to resistance to *Rhizoctonia*, an especially important criterion for selecting material in these genera.

Galactia P. Browne

Up to the present, agronomic studies of this genus have been directed to just one commercial variety of *Galactia striata* (Jacq.) Urb. (IRI 1220). This variety has the desirable characteristics of good adaptation to acid, infertile soils, high productivity and considerable resistance to drought. However, under the more humid conditions of the climate of the Colombian Llanos, this species is seriously affected by anthracnose (*Colletotrichum* spp.).

Like *Centrosema, Macroptilium* and *Vigna* genera, *Galactia* species with climbing growth habits (i.e. *G. striata)* have very wide geographic distribution and are more frequently found in regions with fertile soils. However, a series of ecotypes of this genus has also been collected from unburned savanna regions and other acid soil regions of the South American tropics.

It is important to mention two other *Galactia* species very frequently found in tropical South American savannas where bushy vegetation is scant and frequent burnings occur. The first is *Galactia glaucescens* H.B.K., a species with unifoliate to trifoliate leaves and an erect growth habit up to 1 m in height. The other is *Galactia jussiaeana* H.B.K., a species with semi-erect to procumbent growth habits. The potential of both species as forage plants is still unknown. Both have a rather rough appearance and do not seem to be very productive, but they share the very special trait of being extraordinarily resistant to burning. It has often been observed that the initial growth of *G. jussiaeana* after burning is much more vigorous than the growth of other surrounding plants on the savanna. This resistance to burning is due to a rather common characteristic among typical savanna plants: the pressence of tuberous roots (xylopodia) as special organs for food reserves as well as for regrowth points.

Xylopodia have also been found very frequently in other leguminous savanna species such as *Erinosema* spp., *Clitoria guianensis* and *Vigna* sp., and sporadically in some types of *S. guianensis, S. bracteata, Stylosanthes* sp., *Zornia* sp. and *Alysicarpus* aff. *vaginalis*.

Other genera

The genera *Pueraria, Calopogonium* and *Rhynchosia* have also shown potential as forage species for the tropical savanna regions of South America.

Another group of genera deserving future attention include *Cassia, Mimosa* and *Tephrosia*. Within these genera have been found some species of very vigorous growth and excellent adaptation to acid, infertile soils. However, preliminary studies are needed to determine the presence of toxic factors that undoubtedly exist in most species within these genera.

Finally, it is important to stress the need to investigate the potential that might be found in bushy and shruby species, either because of their fruits or their possible use as browsing plants on acid, infertile soil savannas in the dry season. Some of the better known genera of this kind are *Leucaena, Prosopis* and *Piptadena*. However, their geographical distribution is limited to regions with long dry seasons and relatively high pH soils.

CONCLUSIONS

Experiences in CIAT, EMBRAPA and at other institutions indicate that the genetic resources of tropical forage legumes have been explored only superficially. The eight genera or groups of genera mentioned in this paper represent a great germplasm potential for tropical savannas with acid, infertile soils. The variability of the genetic

material seems to be ample enough to justify no major efforts in hybridization projects at this time. It appears more convenient to continue increasing the genetic variability in these promising genera by further collections. Special emphasis sould continue to be placed on collecting in regions with acid soils, since it is much more likely that germplasm native to these areas will also be adapted to the edaphic conditions of the tropical savannas.

There are two important reasons for continuing germplasm collections: (a) the need to obtain the maximum possible genetic variability, in order to proceed with the selection of the most promising materials; and (b) the need to guarantee the preservation of the available genetic resources, **while they still exist.** An important reason to stress the latter need is the very clear evidence that genes of tropical legumes are being lost. On more than one occasion, upon returning to a collection site of especially promising genetic material, it has been found the material no longer exists. The area has often been cleared for agricultural cultivation, and because agricultural development is accelerating in many tropical regions, the need to collect existing germplasm material is urgent.

The collection of germplasm to guarantee the preservation of available genetic resources is only a first step. The second step would be the characterization and evaluation of the germplasm collected, that is, to identify its potential as a forage. This stage—already utilized in selecting the most promising material—is too important to restrict evaluation of the most interesting characteristics to overvations of periodic fresh matter yields on introduction plots. It is well-known that some of the most important characteristics of a forage plant, especially those determining persistence depend on the way plants are utilized. Since the product being developed is a plant for grazing, beef cattle, as the eventual consumers, should enter the evaluation process as soon as possible.

Stylosanthes is the most intensively collected genus up to now. In spite of the problems of disease and insect attacks, species with capacity for high productivity still deserve major attention. According to the Law of Homologous Series (11), the resistance shown by *S. capitata* to anthracnose and to stem borer attacks offer good reason to expect some other resistant ecotypes might also be found among related species such as *S. guianensis.*

It is worthwhile to stress again the need to continue collecting and increasing the germplasm of those other major genera having potentials— so far insufficiently explored—for use on the tropical savannas of South America. Experience with *D. ovalifolium* indicates that efforts should not be limited to germplasm native to the American tropics, the diversification center for most of the tropical legume species. Rather, collections should extend to tropical Asia and Africa. In the case of *D. ovalifolium,* special efforts should be made to increase the germplasm collection.

Since vigorous growth is one of the most important characteristics of a forage plant, it is necessary to emphasize the importance of an effective legume/*Rhizobium* symbiosis. The *Rhizobium* strains found in association with the plants being collected as germplasm should also be considered as genetic resources. The potential that a legume might have as a forage plant for acid, infertile soils could be much greater if the *Rhizobia* occurring at the collection site are utilized when possible.

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SPONTANEOUS LEGUMES OF DEVELOPED PASTURES OF THE AMAZON AND THEIR FORAGE POTENTIAL

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ABSTRACT

Amazonian brush communities are a serious management problem and have received little attention from researchers. These communities include at least 60 families and over 500 species. The Leguminoseae are an important constituent of the pasture invader flora, contributing at least 74 species. Several brush legumes are browsed by bovines, and species were selected and tested for macro and micronutrients, and compared with *Panicum maximum* from the same site. Shrub legumes had significantly higher N contents, and some species had higher levels of Ca and P. Differences in Mg levels in grass and brush were not significant. Grass K contents were higher than those of brush. Shrub legumes appear to be excellent micronutrient accumulators. Brush legumes have an important ecological role in grasslands, and may contribute to pasture stability by increasing biological diversity and tightening biogeochemical mineral cycles.

Plant species that invade formed pastures in Amazonia are of great economic importance to ranching. Brush control can consume between 10-20% of a given ranch's operating costs. Although brush invasion is generally perceived as undesirable, and is certainly an important factor in the decline of pasture productivity, it has been largely ignored by pasture scientists, agronomists, botanists and ecologists. Species composition, community description, autecology, synecology, role in soil dynamics and response to management are virtually unstudied. The basic succession data for Amazonia does not yet exist in the literature, and although a few studies of succession in tropical rainforest areas are available (8, 9, 26, 27, 48), they can give only general ideas of trend. There is also information on the behavior of woody and weedy tropical pasture species (7, 57, 58), including response to herbicide applications (2, 33, 42, 43). This research, unfortunately, has only limited applicability in eastern Amazonia, where species, climate and soils differ from the areas studied.

The omnipresence of brush in Amazonian pastures under every possible management option suggests that it fills an important ecological function. This paper analyses one important family in the brush community, the Leguminoseae in terms of (a) frequency, (b) growth habits, (c) source communities, (d) nutritive value, and (e) potential role in nutrient recovery. It is hoped that with a

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better understanding of the dynamics and the potential of the pasture invaders that reasonable management strategies can be evolved since obliteration of brush is unlikely.

SITE INFORMATION

The research area is a series of ranches in the municipality of Paragominas in Pará State. The region was rainforest, until the development of the Belém-Brasilia highway in 1960, when the area was converted to pasture.

Located near 3°S and near the 48th meridian, the climate of the sites falls into Koppen's Af climate. Areas located near rivers have a slightly more humid microclimate. Mean rainfall recorded at the ranches varies between 2300 and 3000 mm on a five-year average. The driest months are August and September with less than 20 mm of rain. Temperatures hover around 25°C with little seasonal variation. Extremes of 36°C have been recorded during the dry season.

Dominant soil types are the Yellow Latosols (Typic Haplorthox) of varying textural classes, concretionary Red-Yellow Podzols (Plinthic Paleudults) both of which intergrade fairly frequently with ground water laterites (Plithaquults and Plinthaquox). The relief is gently undulating with occasional lateritic scarps. The parent material on which these soils developed is thought to be of Tertiary age (44, 54, 59).

Soil fertility is low. Nutrient ranges taken from the literature (12, 54, 59) and unpublished field data give the following values: pH 4.3 - 6.2; available P, 0-6 ppm; Ca^{++} and Mg^{++}, 0.2-5.1 meq/100 g; K, 16-207 ppm; Al^{+++}, 0-5.0 meq/100 g. Micronutrient deficiencies are common.

Pasture areas were cleared by the "broca" technique. Small diameter trees are cut first, then larger trees are felled. After drying for two to four months, the slash is burned. Seeding was generally done aerially, at an average rate of between 15 and 25 kg/ha. The most commonly planted grass is *Panicum maximum* Jacq. very occasionally consorciated with *Pueraria phaseoloides* Roxb. Benth. var. Javanica (Benth.) Bak and *Centrosema pubescens* Benth. Pastures are generally burned after the first year of establishment, and thereafter whenever brush or grass conditions are thought to warrant fire. Animal management has tended to overstocking at the rate of 2-4 AU/ha/yr. The optimal stocking is considered to be around 1 AU/ha/yr. The Paragominas area has been in decline and today about 80% of the ranches there are nonproductive.

P. maximum does not persist well in nutrient poor soils (49). Declines in grass productivity are caused by factors such as continuous insect attack (16), infection of seeds by *Blissus* sp. (49) and soil nutrient changes (12). The bunch grass morphology of *P. maximum* provides open areas between individual grass plants which are invaded by other plant species. Not surprisingly, brush becomes an important component of the pasture ecosystem and subsequently of interest to pasture management and animal nutrition.

SPONTANEOUS LEGUMES OF THE BRUSH COMMUNITY

The brush community is very complex, consisting of at least 60 plant families comprising well over 500 species. Of these, 150 are relatively common. A complete discussion of the botanical composition and community structure is inappropriate for this paper but one family, the Leguminoseae, is of special interest to pasture scientists for several reasons. First, and most obviously, the nitrogen (N) fixing capacity of legumes is a central theme in tropical pasture and soil management (see for example 10), and animal nutrition (24). Legumes provide food for people and animals, and many valuable tropical hardwoods are also members of this family. The Leguminoseae also have their disadvantages: they can be serious pasture pests,

such as some species of *Cassia* and *Mimosa*, or toxic plants such as some *Crotalarias*.

The relative frequency of legumes in formed Amazonian pastures as determined by the step-point method of Evans and Love (11) varies between 0.02 and 17% (Hecht, field data) depending on a number of factors:

1. Initial legume composition of the original forest
2. Proximity to forest
3. Soil types
4. Soil drainage properties
5. Quality of initial fire
6. Intensity and frequency of subsequent fires
7. Agricultural history of the area
8. Proximity to major roads
9. Source areas of grazing animals
10. Contamination of grass seed with weed seed
11. Grazing management
12. Herbicide usage
13. Method of herbicide application
14. Frequency of hand clearing
15. Dominant legume growth forms

In the study area, 34 genera including 66 species have been collected and identified at the herbaria of the Museu Paraense Emilio Goeldi and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA). The species were then classified into growth form and source communities (Table 1). Growth form classification is as follows:

Table 1. **Spontaneous legumes of formed upland pastures in the municipality of Paragominas, Pará, with their growth forms and usual source communities.**

Species	Growth form	Source community	Additional observations
Abrus			
A. tenuiflorus L.	Creeper	C	Common roadside weed
Acacia			
A. farensiana Willd.	Shrub	C	
Bauhinia			
B. glabra Jacqu.	Liana	A B C	
B. macrostachya Bth.	Shrub	A B C	
B. rufa L.	Liana	A B C	
Cassia			
C. alata L.	Small tree	B C	
C. bicapsularis L.	Shrub	C	Inundated areas
C. diphylla L.	Herb	C D	Sandy, open areas
C. fastuosa Willd.	Small tree	B C	
C. latifolia Ducke	Shrub	C	
C. occidentales L.	Shrub	C	Roadside and agricultural weed
C. tenuisepala Bth.	Creeper	C D	Roadside weed
C. tora L.	Woody herb	C	Roadside and agricultural weed

Table 1. Continued.

Species	Growth form	Source community	Additional observation
Centrosema			
C. plumieri Juss.	Creeper	D C	Roadside weed
C. brasilianum Bth.	Creeper	D C	Roadside weed
Clitoria			
C. glycinoides DC.	Herb	D C	
Crotalaria			
C. nitens H.B.K.	Herb	C	Roadside weed
C. incana L.	Herb	C	Cosmopolitan agricultural weed
C. spectabilis Roth.	Herb	D	Campos of Marajo
C. maypurensis H.B.K.	Shrub	D C	Weed of abandoned land
Cratylia			
C. floribunda Bth.	Liana	B C	
Calopogonium			
C. mucunoides Desv.	Creeper	D C	Possible seed contaminant; Campos of Marajo
Desmodium			
D. axillare Sw.	Herb	C D	
D. adsendens Sw.	Herb	D C	Roadside weed
D. barbatum Bth.	Herb	C D	Roadside and agricultural weed
D. canum			
Dioclea			
D. bicolor Bth.	Liana	C D	
D. glabra Bth.	Liana	D	Dry campos
D. guianensis Bth.	Liana	C D	Dry campos
D. virgata Rich.	Liana	C D	Dry campos
Diplotropis			
D. purpureum Rich.	Tree	A	Often near open formations
Dinizia			
D. excelsa Ducke	Tree	A	
Derris			
D. floribunda Bth.	Liana	A B C D	
D. urucu Killip and Smith	Liana	A B C D	
Enterolobium			
E. contortisquum Vell	Tree	A B	
E. sthombergkii Bth.	Tree	A	
Hymenea			
H. coubaril L.	Tree	A	
Hymenolobium			
H. sp. indet	Tree	A	

Table 1. Continued.

Species	Growth form	Source community	Additional observation
Galactria			
G. jussianea H.B K.	Shrub	D	Marajo
Inga			
I. edulis L.	Small tree	A B C	Widely cultivated
I. longifolia	Small tree	A B	
I. heterophylla Willd.	Small tree	B	
Indigofera			
C. anil	Shrub	C	
Machaerium			
M. microphyllum May	Liana	A B	
M. froesi Bth.	Shrub	A B	
Mimosa			
M. pudica L.	Viney shrub	C	
M. sensitiva L.	Creeper	C	
M. pigra Bth.	Viney shrub	C	Roadside weed
M. invisa Mart.	Creeper	C	Roadside weed
M. myriadena Bth.	Shrub	C	
Macrolobium			
M. gracile	Shrub	B C	Flooded areas
Parkia			
P. multigua L.	Tree	A	
Pithecolobium			
P. jupunba Willd.	Tree	A	Forest margins
P. racemosun Bth.	Shrub	A	
Phaseolus			
P. truvillensis H.B.K.	Creeper	D	Flooded grasslands of Marajo
P. peducularis H.B.K.	Creeper	C D	Grasslands of Marajo
P. reptans Ducke	Herb	C D	
Rhynchosia			
R. minima L.	Herb-creeper	D C	
Sesbania			
S. exalta Raf	Herb	C	
Stryphnodendron			
S. pulcherrimin Willd.	Liana	A B	
S. guianensis Aubl.	Shrub	A B	
Stylosanthes			
S. gracilis	Herb	D	
Teramnus			
T. volubilis Sw.	Creeper	C	Agricultural weed

Table 1. Continued.

Species	Growth form	Source community	Additional observation
Tephrosia			
T. nitens Bth.	Herb	D C	Grasslands of Marajo
T. candida L.	Shrub	D	Grasslands of Marajo
Vigna			
V. rexillata L.	Creeper	D C	Grasslands of Marajo
Zornia			
Z. dyphylla L.	Herb	C D	Roadside weed

A=Climax forest, B=Old second growth, C=Young second growth, D=Climax grassland

Trees - woody vegetation greater than five meters in height

Shrubs - woody vegetation to five meters

Herbs - non-woody vegetation less than one meter

Lianas - climbing vines

Creepers - scandent vines

In analyzing the growth-form percentages of spontaneous legumes (Fig. 1), lianas and creepers were lumped together because the habit of lianas in open situations is that of a decumbent ground cover. The tolerance of these plants to variable light conditions and water stress almost preadapts them for pasture conditions. Creepers and lianas account for one-third of the volunteer legume flora, shrubs, for 31%, herbs contribute 20%, and trees, 16%.

Spontaneous legumes in formed pastures are derived from several source communities (Fig. 2). Plants from early successional stages comprise 24 genera and 45 species. This group consists of many cosmopolitan weeds and some grassland species which have become agricultural and roadside weeds. Old second growth, defined as forests of 10 years and older, contributes least to the pasture flora, partly because light conditions in grasslands are not suitable for these species and also because at the time of clearing only relatively small and widely scattered areas of secondary forest existed near the study sites. Rainforest species (such as *Hymenea, Dizinia* and *Parkia*, as well as some liana species) are the result of resprouting stumps, seed survival after fire and seed reintroduction by forest animals. Most of the rainforest species found in pastures are characteristic of the forest canopy, and their presence in formed grasslands suggests further use of

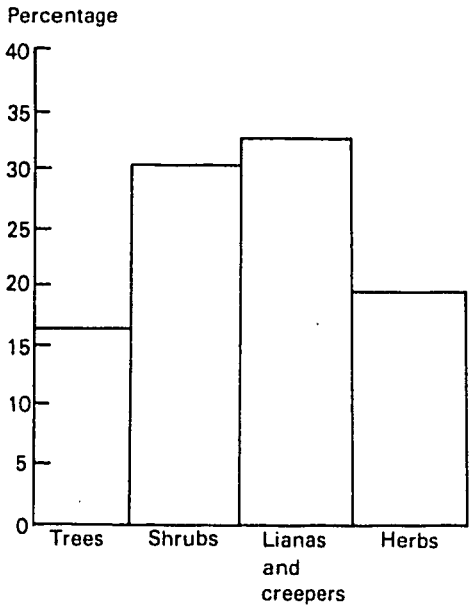

Figure 1. **Growth form percentages of spontaneous legumes in some Amazonian pastures.**

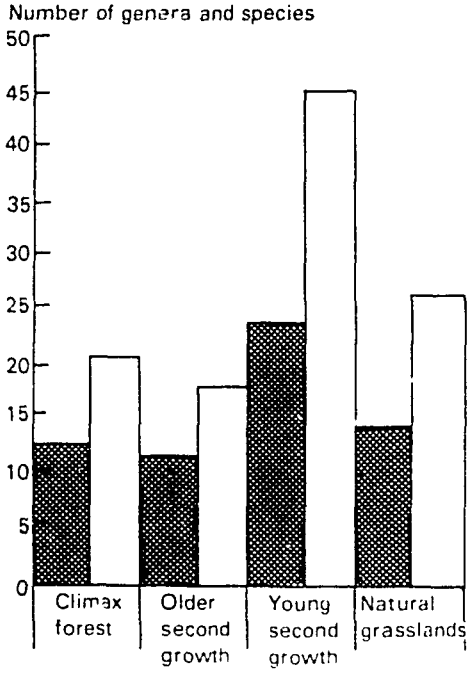

Figure 2 Number of genera and species contributed by different source communities (Shaded area = genera)

these species in mixed plantations Natural grasslands, especially those from the island of Marajó, have contributed 26 species. Some of these plants were introduced by cattle brought from Marajó, while others, such as *Zornia*, are found in climax grasslands, but are also common weeds.

FORAGE UTILIZATION OF BRUSH SPECIES

In spite of the prevalence of serious brush invasion throughout the humid tropics, even with fertilization (7), the forage value of browse has traditionally been of greater interest to wildlife managers than to cattle producers (61). Existing studies that deal with brush species in animal diets have focused on plants in natural grasslands located in areas with a pronounced dry season. Workers in Africa (5, 6), have noted that brush constitutes an important auxiliary fodder in the dry season. McLeod (32), working in Australia, performed bromatological tests on shrub species known to be browsed by cattle, and showed that brush had adequate levels of N and relatively low values of P. Andrade *et al.* (1) studying *Trema micanthra* Blume (Ulmaceae), in Mato Grosso, a common secondary succession species in the tropics, found that it had 20% crude protein levels, twice the protein of *P. maximum* from the same site.

Simão Neto *et al.* (50) and Rodriges *et al.* (46) worked with fistulated heifers in the Cerrado of Minas Gerais, Brazil, in a situation where brush biomass varies between 42 and 60%. Their results show that during the driest months, brush contributed between 45.5 and 63.8% of the animal diet, and as much as 50% of the protein consumed by the heifers. Even during the wet season brush supplied over 4% of the animal intake All these studies emphasize the importance of native species to the animal diet

NUTRIENT VALUE OF SHRUB LEGUMES

Several species of brush in the study area which are browsed by cattle were analyzed for macro and micronutrients in foliar samples The top leaves of the brush samples were taken, since these are the parts generally eaten by animals, and the younger leaves of grass were clipped and compared. The brush and grass were sampled at the initiation of the dry season. It should be mentioned that *P. maximum* seeds all year long in the study area, and that the grass samples represent a diversity of phenological states

The methods used for determination of the nutrient levels were the micro-Kjeldahl technique for N, and the Bray II technique for P All the other nutrients were analyzed by atomic absorption. The means of these analyses are presented in Table 2. These data were lumped and compared with *P. maximum* samples from the same site, and evaluated with Student's t-test (53). The results are presented in Table 3.

Table 2. **Mean nutrient content of 10 species of spontaneous legumes, taken from a five year old pasture, which are browsed by animals.**

Species	Crude protein	P	Ca	Mg	K	Mn	Cu	Fe	Zn
	%		ppm						
Stryphnodendron guianensis Aubl.	6.75	0.13	3515	1429	2600	113	62	227	166
Enterolobium Schomberkii Bth.	6.88	0.18	16,970	1270	4525	75	83	227	111
Pithecolobium jupunga Willd.	6.85	0.20	8364	1667	3475	226	83	221	111
Tephrosia candide L.	10.81	0.23	10,093	2222	4375	150	62	277	111
Bauhinia glabra Aubl.	4.25	0.10	1333	1137	1800	75	75	200	55
Inga edulis L.	5.18	0.16	8606	1270	3025	75	110	277	75
Dioclea guianensis Bth.	7.00	0.18	16,485	3920	4875	133	82	277	166
Cassia alata L.	6.75	0.16	3879	952	2525	75	42	221	55
Inga sp.	7.01	0.18	5879	1192	3625	113	62	332	120
Enterolobium spp.	5.97	0.10	6303	879	3735	56	83	332	67

The mean levels for macronutrients of brush are practically double those of grass. The standard deviations are higher among the volunteer species due to the heterogeneous nature of the group. N levels are significantly different between grass and brush, but if some individual species are compared (for example *Tephrosia)* the contrast would be marked. Mg levels in groups are not statistically different. Grass species are significantly higher in K, a phenomenon already noted by Teitzel and Bruce (56). Native brush species are rather spectacular mobilizers of micronutrients. Caution should be used in interpreting these results, since the digestibility data is not yet available.

DISCUSSION

The brush flora is a virtually untapped source of potential forage species, (in the Leguminoseae as well as other plant families), but invader species should be of interest to pasture managers for other reasons.

In clearing tropical rainforest for pasture one replaces a high biomass (28, 34), species rich (39, 40, 45, 47), ecologically complex (3, 17, 31) ecosystem with a functional though temporary monoculture. The existence of rainforest on nutrient poor soils is dependent on a variety of nutrient cycling systems still not yet fully understood

Table 3. **Nutrient levels and t-tests comparing *P. maximum* and brush species from a five year old pasture.**

		P. maximum		Brush		P
Crude	$\bar{x}$	3.95	x	6.82	22.923	0.001 ***
Protein (%)	sd	0.648	sd	1.539		
P (%)	$\bar{x}$	0.085	x	0.169	1.812	0.10 n.s.
	sd	0.039	sd	0.196		
Ca^{++} (ppm)	$\bar{x}$	3994	x	8397	2.729	0.02 *
	sd	815.69	sd	5036		
Mg^{++} (ppm)	$\bar{x}$	2213	x	2989	0.9304	0.4 n.s.
	sd	496.86	sd	2591.37		
K^{+} (ppm)	$\bar{x}$	8355	x	3476	10.068	0.001 ***
	sd	1231	sd	912.62		
Mn (ppm)	$\bar{x}$	64	x	96	2.53	0.02 *
	sd	26.34	sd	30.09		
Cu (ppm)	$\bar{x}$	8.2	x	73.7	15.30	0.001 ***
	sd	2.68	sd	13.28		
Fe (ppm)	$\bar{x}$	126	x	255.5	7.617	0.001 ***
	sd	20.99	sd	49.9		
Zn (ppm)	$\bar{x}$	33	x	96.9	6.264	0.001 ***
	sd	18.26	sd	26.6		

*** Highly significant
* Significant
n.s. Not significant

(19, 38) including structural modifications for nutrient capture (see for example 4, 22, 28) and symbiotic relations between higher plants and micro-organisms (35, 55).

Among numerous possible effects, substitution of pasture for rainforest results in (a) a decline in biomass and transfer of nutrients previously tied up in the biomass to soil nutrient storage where they are more vulnerable to leaching; (b) decline in species diversity; (c) destruction of some nutrient conserving mechanisms (29); and (d) opening of large areas for heliophilic and fire tolerant species which have restricted niches in rainforest areas. The brush community is a response to environmental modification and the beginning of secondary succession back to forest. Pasture stability, defined as the area proportion of a pasture which remains botanically unchanged from the end of one wet season to the end of the next (60), is virtually nonexistent in eastern Amazonia, due to intense invasion by successional species.

Two aspects of succession which may have implications for the long term stability and productivity of formed pastures are the increase in biological diversity and the "tightening" of biogeochemical cycles (37). The axiom that diversity increases stability is not universally applicable (30), but the idea does have merit in much of the humid tropics (23). Increased species diversity can provide buffers against insect attack (16) by supplying habitat and alternate prey items for insectivorous animals. More species may also generate a more balanced diet for bovines. Grass monocultures do not maintain themselves in eastern Amazonia without large economic and energy inputs; but by augmenting species diversity through selective protection of legumes during manual brush clearing, it may be possible to competitively exclude or reduce less desirable plant species. More research along these lines is necessary.

The data presented in this paper suggest that brush species are good nutrient accumulators, particularly for micronutrients. Kellman (25) has indicated that successional species may cycle nutrients in higher amounts than climax species. Nye and Groenland (36), and Snedaker (51) show that close to 80% of the initial nutrient store is recovered within 12 years after clearing, if successional processes are allowed to progress. The diversity of rooting depths of brush and the nutrient quality of grass underneath some brush species (Hecht in prep.) imply better nutrient cycling than the 20 cm rooting depth of *P. maximum* would allow. In the rainfall regimes of Amazonia where the leaching of nutrients is a problem (12), the role of brush in mineral cycling could be of importance for sustained production, particularly in areas where fertilizer applications are not economically viable.

It is unlikely that the system of implanting monoculture grasslands will be abandoned, but, as was pointed out in Farnworth and Golley (13), some compromises should be discovered whereby ecosystem diversity can be enhanced without major reductions in productivity. It would seem that modification and more efficient utilization of secondary vegetation in conjunction with planted grass species could be an alternative.

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PART II

SOIL FERTILITY RELATIONSHIPS

PROBLEMS AND SUCCESSES OF LEGUME-GRASS PASTURES, ESPECIALLY IN TROPICAL LATIN AMERICA

E. Mark Hutton*

ABSTRACT

Successes and failures of improved legume-grass pastures, mainly in Australia, Brazil and Central America are discussed. Current technology used in pasture improvement is inadequate in a number of tropical areas. Further research is needed to develop new techniques which farmers will be prepared to adopt for increasing their pasture and cattle production. Some of the main problems include: lack of knowledge of soil nutrient deficiencies, lack of well adapted legumes with pest resistance and tolerance to highly acid soils, legume seed inoculation, selection of grasses, dry-season forage, reducing pasture establishment costs, and adequate seed supplies of legume and grass cultivars.

It has been estimated by CIAT (7) that tropical America has 850 million ha of acid, infertile Oxisols and Ultisols where pasture and cattle productivity can be increased markedly when all regions have dependable legume-grass systems. The major part of this vast area is in Brazil, but other countries especially Colombia, Peru and Venezuela have significant tracts of these infertile acid soils awaiting improvement. With increasing population pressure in most countries, any Oxisols and Ultisols suitable for cultivation will be cropped, often in rotation with short or long-term pastures. For example in Goias State, Brazil, where extensive areas of upland rice are grown on poor acid soils, a pasture phase is initiated on a number of farms by planting the rice with a small amount of *Brachiaria decumbens* Stapf. seed; this vigorous grass gives a relatively high producing pasture following the rice crop.

Even when suitable tropical pasture technology is available for all the acid soil regions, the proportion of improved pasture to unimproved savanna, grassland and forest will probably remain quite low for many years due to economic, political and other reasons. Thus it is necessary to find how to integrate improved and unimproved pasture to maximize production from cattle herds.

The main aim of tropical pasture technology must be to stimulate production of low cost, good quality beef so that meat remains a significant part of the diet of the large numbers of lower income people in tropical America. Improved pastures and their management on a large, rather than small scale is more likely to keep beef prices down. This is because of increased efficiency of larger scale operations from their greatly increased throughput of cattle per unit of resources including land, breeding herd, equipment and improvements, finance and labor. The Banco de Mexico has

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encouraged and financed large scale pasture improvement and cropping among peasants by its ejido or cooperative scheme in areas of the Mexican tropics.

SUCCESSES AND FAILURES OF CURRENT TROPICAL LEGUME-GRASS TECHNOLOGY

Existing tropical pasture technology (10, 11, 25, 28) has resulted in a number of successful improved pasture developments in Australia, Africa, Brazil, Mexico and other tropical regions. However, for various reasons there have also been a number of failures. There is a lot of research still to be done, particularly in the acid soil areas of tropical America. The pasture problems facing organizations like CIAT, ICA, EMBRAPA, FONAIAP, IVITA and INIAP are urgent and challenging. Where improved legume-grass pastures have persisted there has often been no attempt to monitor the increased profitability and animal productivity.

In this brief review it is impossible to include all my field observations on tropical pasture improvement. Colombia is covered by other seminar speakers. After a short introduction on Australian experience most of my comments will concern Latin American countries like Brazil and Mexico where substantial areas of tropical pastures have been sown. A number of countries including Venezuela have not yet made systematic attempts to capitalize on their potential for increasing pasture and cattle productivity.

Australia

In Australia there have been a number of reports of increased cattle productivity from improved pastures. The long-term pasture experiments of Mannetje (18) at the CSIRO Narayen Research Station on poor acid granitic soils (Alfisols) with a summer rainfall of 700 mm and 7 to 7.5 months dry season exemplifies what can be achieved in the extensive *Heteropogon contortus* (L.) Beauv. ex Roem. & Schult. region of central Queensland, which is the most important beef cattle area in eastern Australia. Mannetje (18) found that unimproved native *H. contortus* pasture will carry 0.27 steers/ha and give a liveweight gain of 25 kg/ha. Fertilizing the native pasture with 125 kg/ha of molybdenized superphosphate did not improve stocking rate and only increased liveweight gain to 34 kg/ha. However replacement of the native pasture with the legume *Macroptilium atropurpureum* (D.C.) Urb. cv. Siratro and *Cenchrus ciliaris* L. in conjunction with 125 kg/ha of molybdenized superphosphate, raised the stocking rate to 1.09 steers/ha and gave a mean liveweight gain of 147 kg/ha. The Belmont Red and Hereford steers were marketed at about 24 months of age and gave first quality carcasses of 250 kg. This is a very substantial increase in productivity compared to that from unimproved native pasture: 4 times the stocking rate and almost 6 times the meat yield. Of considerable importance is the fact that the legume *M. atropurpureum* cv. Siratro has persisted and multiplied in Mannetje's (18) pastures which have improved their productivity over 10 years. Similar results have been achieved on commercial farms.

On the wet tropical coast of north Queensland where rainfall is 2000-4000 mm/yr, mixed pastures of the legumes *Centrosema pubescens* Benth., *Pueraria phaseoloides* (Roxb.) Benth. var. javanica (Benth.) Bak. and *Stylosanthes guianensis* (Aubl.) Sw. with *Panicum maximum* Jacq. have been very successful for beef production. With applications of 250 kg/ha/yr of superphosphate and correction of Mo, Zn and Cu deficiencies, these pastures will carry 3 to 4 steers/ha/yr and give liveweight gains up to 900 kg/ha/yr (29).

Brazil

Brazilian farmers with encouragement from government, and state scientists, and the banks have made an impressive attack on tropical pasture development over the

last 7 to 8 years. Extensive areas of improved pasture have been planted in the Cerrado, Amazonia and other regions. Even though failures have occurred, enough successes have given confidence in the future of improved pastures in Brazil, and a high level of new plantings has been maintained. Brazil has planted much larger areas than any other country of the vigorous stoloniferous grass *B. decumbens,* tolerant of poor acid soils with high Al saturation. In spite of serious doubts over the last few years about *B. decumbens* because of outbreaks of photosensitization in cattle grazing it, farmers have found this to be a relatively minor problem and are planting increasing areas of the grass. *B. decumbens* usually without an associate legume, is spreading like a "flood" over lowland tropical Latin America, and farmers and scientists will have to learn to live with it. There is no doubt that *B. decumbens* establishes readily over a wide range of conditions, including very acid Oxisols and Ultisols, and gives a marked increase in animal productivity over native pastures. CIAT (7) has shown that *B. decumbens* pastures at stocking rates of 1-2 steers/ha/yr will give liveweight gains of about 200 kg/ha/yr, but in the dry season weight losses can occur if stocking rates are too high. The problems associated with *B. decumbens* will be discussed later.

The legume-grass mixtures which have been sown widely in Brazil include *P. phaseoloides-C. pubescens-P. maximum* cv. Colonião (Amazonia), *M. atropurpureum-C. pubescens-P. maximum* cv. Colonião (Cerrado, etc. of São Paulo, Goias, Minas Gerais, southern half of Mato Grosso), and *M. atropurpureum* or *S. guianensis* with one among several grasses, especially *C. ciliaris* and *P. maximum* cv. Colonião (Northeast e.g. Maranhão, Ceara). *S. guianensis* has usually been included in most pasture mixtures, but has often failed after a few years so there is now less interest in this legume. Other legumes have been grown to some extent, such as *Glycine wightii* (R. Grah. ex Wight & Arn) Verdcourt and *Desmodium intortum* Mill. (Urb.) in better soils, and *Calopogonium mucunoides* Desv. and *Galactia striata* (Jacq.) Urb. over a range of soils. Definite interest is developing in Brazil in the tree legume *Leucaena leucocephala* (Lam.) De Wit which has grown well in limited areas of the Cerrado and other regions such as the Northeast.

A wide range of grasses have been tried, and confusion exists concerning which one should be planted in each of the many different ecological niches. However *B. decumbens* is the only grass seriously challenging the dominant position held by *P. maximum* cv. Colonião in Brazilian agriculture. Because of the spittle bug problem in *B. decumbens,* there is now interest in the more resistant *Brachiaria humidicola* (Rendle) Schweickt. *Melinis minutiflora* Beauv. is naturalized widely in the Minas Gerais hills and other areas such as Goias. Increased plantings of the various types of *C. ciliaris* are being made in the drier, less acid zones, including the Northeast. Other grasses being grown to some extent include Guianeazihno, Green Panic, Gatton Panic (cultivars of *P. maximum),* Nandi and Kazungula, (cultivars of *Setaria anceps* Stapf. ex Massey), *Digitaria decumbens* Stent., *Cynodon dactylon* (L.) Pers. and *Brachiaria radicans* Napper.

Allowing for its size, Brazil has done more pasture improvement than any other country in tropical America and will continue to dominate the scene. It needs more meat from its 100 million head of cattle to feed a rapidly increasing population of over 110 million people and for export. It is difficult to obtain definitive results on increased productivity of farms from pasture improvement. Farmers agree that after clearing, pasture sowing and fertilizing, their cattle production at least trebled, because stocking and calving rates were increased and slaughter age of steers significantly reduced. In the Cerrado, improved legume-grass pastures enabled a number of farmers to market Nellore steers of 450 kg liveweight at 2 to 2.5 years of age. Lack of persistence of

the legume in a proportion of the pastures, due especially to overgrazing and soil deficiencies in some essential plant nutrients, has resulted in loss of pasture vigor and weed invasion with markedly reduced cattle production. Similar, but more severe problems have occurred with a number of legume-grass pastures sown in the Amazonian region after clearing heavy rainforest. Here loss of humus and nutrient leaching are at a fast rate. Unless adequate levels of essential nutrients like P, S, Mo and Zn are maintained in the soil the legume is lost, and once vigorous Amazonian pastures rapidly decline with invasion of woody regrowth, and spectacular decreases in cattle productivity. Poorly fertilized *B. decumbens* pastures, in spite of considerable initial vigor, also decline eventually because of P, S and other deficiencies.

Central America and Caribbean

Farmers and scientists in several Central American and Caribbean countries have been active in tropical pasture development.

In the Mexican Tropics, several national institutions (e.g. Instituto Nacional de Investigaciones Pecuarias (INIP), Palo Alto) have active pasture research programs. The Banco de Mexico and its staff of agronomists have promoted substantial pasture improvement projects among peasants and ranchers. These have been in sandy acid soil areas along the Southeast and Southwest coasts bordering the Gulf of Mexico and Pacific Ocean, respectively, and also in alkaline soil regions as in the Northeast around Tampico, the northwest of the State of Guerrero around Altamirano, and on the extensive marine limestone areas of the Yucatán Peninsula. **On the slightly acid** (about pH 5.5) **granitic soils** of the southern coasts 1-2 Brahman steers per ha can be fattened to slaughter weight at an age of about 30 months or less. Successful pastures on the slightly acid soils comprise the legumes *M. atropurpureum* and *C. pubescens* with *P. maximum* and fertilized with SSP (100-200 kg/ha) containing added Mo and Zn; in low lying wet areas close to the coast, *C. pubescens* is the best legume with grasses like *S. anceps* cv. Kazungula, *D. decumbens* and *C. dactylon*, the latter two often being too aggressive for the legume. The value of their widely spread indigenous *L. leucocephala* is now realized by Mexican scientists and farmers who are using it increasingly in both their acid and alkaline soils in combination with grasses like *D. decumbens, C. dactylon* and *P. maximum*. **On the alkaline soils** (pH 7.5) of the Yucatán Peninsula, clearing and burning the native scrub results in an almost pure stand of *L. leucocephala* which is then often interplanted with grasses like *C. ciliaris* and *P. maximum; M. atropurpureum* and *G. wightii* are other legumes used successfully on the Yucatán Peninsula. *L. leucocephala, M. atropurpureum* and *G. wigthii* have also proved to be the best pasture legumes for the alkaline, dry tropical areas of northwest Guerrero. **On the flat moist near neutral loams** around Villahermosa and Cárdenas, pastures of *C. dactylon* with *L. leucocephala* or *C. pubescens* and of *S. anceps* cv. Kazungula with *G. wightii* and *D. intortum* have been successful.

Among Caribbean countries, **Cuba** has one of the largest and most active research programs in pasture and animal production. Because of short-falls in domestic milk and meat production, the government gives considerable support to pasture and animal research. Many pasture areas are nearly neutral (pH 6.5) and the most promising legumes include *G. wightii, M. atropurpureum, C. pubescens* and *L. leucocephala*. *P. maximum* is favored for extensive use, and Cuba has one of the best ecotype collections of this species in Latin America. *D. decumbens*, usually under irrigation and with N fertilization, is used for intensive milk production.

CATTLE PRODUCTIVITY RELATIVE TO PASTURE FEEDING VALUE

In the various regions it is essential to know the main factors limiting animal

production. It is now clear that improved tropical pastures need to supply the grazing animal with adequate digestible energy, protein and minerals for high levels of growth and reproduction. For most tropical American pasture development, nitrogenous fertilizers are too costly, and vigorous persistent legumes are the key to pasture and animal productivity. With legume-based pastures, adequate P, S, Ca, K, Mo, Zn and Cu, in particular are necessary and all these, except Mo, are essential for animal nutrition, as well as elements like Na, Co, and I. Poorly fertilized legume-grass pastures become deficient in legume and feed protein, and often have to be supplemented with licks containing several of the elements mentioned if a moderate level of animal production is to be maintained. It is not uncommon for animals to receive insufficient Na (22) from improved tropical pastures, and at times they do not provide the requisite Co and Cu (19, 31).

A well balanced tropical legume-grass pasture gives best results under continuous grazing, as young grass is selectively eaten early in the season and legumes mostly later in the season when grasses become fibrous and low in protein. Rigid rotational grazing reduces animal selectivity, overstresses and reduces the legume in the pasture, and so results in decreased liveweight gain per ha. There is a direct relationship between legume content of pasture and cattle liveweight gains (8). A relatively small proportion of legume (particularly if green) in dry season pastures maintains good levels of ruminal activity and intake of dry fibrous grass (20).

If improved tropical pastures supply all essential nutrient needs of animals as outlined, steers should reach slaughter weight (450-500 kg) at 30 months of age or younger. This needs to be the main aim of research and development in tropical America to ensure higher productivity on farms and raise the overall quality of the meat sold. The tough meat from 4-5 year old steers is not appetizing. The main objective with breeding cows is a high calving rate, and to achieve this they could probably spend a large proportion of their time on the poorest pastures, and only relatively short periods at critical stages (e.g. mating and calving) on improved legume-grass pastures, often a scarce resource. Growing steers, the highest revenue producers, need if possible to be given improved legume-grass pastures, all the year.

CURRENT PROBLEMS IN TROPICAL PASTURE IMPROVEMENT

Soil nutrient deficiencies

Correction of soil nutrient deficiencies affecting legume-grass growth is the most neglected aspect of pasture improvement in the Latin American Tropics. In these areas most acid soils are deficient in N, P, S, Ca, Mo and Zn and marginal in K and Cu, and sometimes in Mg. Often it is not realized that P and S are of equal importance in legume and grass growth. Also the almost universal deficiencies of Mo and Zn in many tropical Oxisols and Ultisols are overlooked. Heavy lime (and phosphate) applications aggravate Zn deficiency. In the Brazilian Cerrado and Amazonian areas it is difficult to find *C. pubescens* without the chlorosis associated with Zn deficiency. Both Mo and Zn are essential for legume growth, Mo being a vital metallic co-enzyme for N fixation in legumes (6). A number of progressive farmers using either SSP (9.6% P, 10% S, 20% Ca), TSP (without S) or rock phosphate on their legume-grass pastures often become dispirited when their legumes fail. It appears that legume failures are often due to unsuspected Mo and Zn deficiencies, although S deficiency could be significant where TSP or rock phosphates were applied.

Superphosphate with added minor elements, like Mo and Zn, are usually unavailable in Latin America. However, legume seed can be pelleted at planting with 175 g MoO_3/ha (= 100 g Mo/ha) or more to correct Mo deficiency (17) without inhibiting initial nodulation. It would be a big advance if

Zn could also be added to the pellet, but unlike MoO_3, ZnO is a very toxic to *Rhizobium*. Perhaps use of finely divided Zn metal would overcome the problem.

The world is richly endowed with phosphate resources (23) but transport, treatment and application costs are a problem in Latin America. Large phosphate deposits have been found in some countries, including Venezuela, Colombia, Perú and Brazil, but vigorous exploration is necessary to identify further deposits, especially in Brazil. For pastures, the cheaper rock phosphate (untreated or thermally modified) is usually satisfactory for legume-grass growth on acid P deficient Oxisols and Ultisols. Apart from price, it is also advantageous because of the high P fixation capacities of these soils (24). Rock phosphate, as well as TSP often need supplementation with S or SSP because of widespread S deficiency in Oxisols and Ultisols. Subsoil S accumulation occurs in some of these (e.g. Malaysian Rengam) and S deficiency in early growth disappears with deeper root penetration (24). It is economically important to determine the S status of the extensive regions of Oxisols and Ultisols considered for pasture improvement. The presence of subsoil S would mean that most P requirements could be supplied cheaply by rock phosphate. Forgetting cost, SSP is the best balanced P nutrient, but high fixation could be a problem in acid soils. However it appears that some legumes and grasses are able to utilize a relatively high proportion of the aluminum phosphate formed.

TSP is often preferred, because its high available P content reduces transport costs per unit of P. On this basis rock phosphate is costly to apply. This is a consideration in aerial phosphate applications in newly cleared areas (e.g. Amazon jungle) with stumps, partially burned logs, etc. There is no evidence that surface phosphate applications (ground or aerial methods) are less efficient than drilling phosphate into the soil.

Legume-grass vigor relative to soil nutrients

As discussed in the previous section, legume growth and that of the grass, are dependent on the supply of essential elements in the soil. Legumes are much more sensitive to nutrient deficiencies than grasses. It is unrealistic to consider improvement of pasture and cattle productivity in poor acid Oxisol and Ultisol regions without some inputs of any deficient essential elements. If farmers are not prepared to do this they should forget about pasture improvement and make best use of native pastures with low-cost mineral licks, etc.

Monitoring essential mineral elements in just mature legume leaves at peak pasture growth is the best index of available nutrients in the soil-pasture system, and indicates any deficiencies which need correction. For optimum growth and N fixation, legume DM should contain 0.18-0.20% P, 3.0% N, 0.14-0.18% S, 1.0% K, 1.0% Ca, 0.5% Mg, 1 ppm Mo, 35-40ppm Zn and 7-10 ppm Cu (4, 5). In tropical Latin America it is important to institute mineral monitoring of legume leaves in improved pastures to find minimal percentages of essential elements in DM necessary to maintain good growth and persistence. Fertilizing with major elements for maximum legume growth would probably be uneconomic. Scientists need to find economic fertilizer rates, which maintain good legume yield and persistence. This is essential if improved pastures are to expand and have real impact on cattle production. Deficiencies of the minor elements Mo, Zn and Cu must be corrected for legumes to persist, but their addition to the system is not costly if seed pelleting or pasture spraying with dilute solutions is used. About 0.5 kg/ha of a Mo compound and 5-8 kg/ha of zinc sulphate or copper sulphate (or both) are usually sufficient to correct any of these deficiencies for five years or more.

Johansen *et al.* (16) have found that the Mo requirement of legumes is influenced by

a number of factors including site, soil pH and species. For example at one site, an initial application of 200 g/ha of Mo gave maximum growth of *G. wightii* for only two years, of *D. decumbens* for three years, and of *M. atropurpureum* for five years. At other sites, *M. atropurpureum* required much less Mo for maximum growth. The biggest responses to Mo were obtained at the sites with the lowest pH.

Reapplication of essential minor elements is best done with dilute sprays (ground or aerial) as indicated. Also there appears to be scope for maintenance applications of major elements as colloidal sprays during peak pasture growth. This could significantly reduce fertilizer costs.

A high level of grass production is primarily dependent on a vigorous legume component in the pasture, ideally up to 40% at the peak of the season. Legumes are unable to provide enough N for maximum grass growth, but this is not disadvantageous as protein rather than digestible energy is usually the main feed deficiency for animals in tropical pastures. Deficiencies of P, S or K often affect grass growth, but deficiencies of the essential minor elements Zn and Cu, do not appear to be so critical. In Brazilian Amazonia, three year old plantings of *P. maximum* cv. Colonião without phosphate fertilization, often become stunted with severe P deficiency (small plants, purple leaves) and chlorotic with S and N deficiencies. Any legumes planted with *P. maximum* cv. Colonião do not persist. Without vigorous competitive growth of *P. maximum* cv. Colonião, there is invasion of woody unpalatable species with pasture deterioration and significant loss of cattle productivity. *P. maximum* (and its ecotypes) is more sensitive to S deficiency than other grass species such as *B. decumbens* and *Andropogon gayanus* Kunth. With *B. decumbens* it is now common to see older unfertilized plantings, about six years old, in the Cerrado and Amazonia with deficiencies of N, P and S.

Selecting and breeding persistent adapted legumes

As stressed in previous sections, correction of soil nutrient deficiencies especially P, S, Ca, Mo and Zn is essential before it is possible to evaluate adaptation and persistence of any legume in grazed pastures of different regions. At some research centers, there is a tendency to keep legume introductions too long at the "museum plot stage" under periodic cutting. The sooner the range of legume plots are put under periodic grazing with a common associate grass (pregrazing quadrat cuts for DM yield, etc.), the sooner a few promising ecotypes can be selected and promoted to regular grazing trials. Scientists criticize this approach on the basis that species are differentially grazed, but is there a better system? Post grazing assessment is essential for proper evaluation. Very palatable legumes may not persist, but palatability is relative. For example, *Stylosanthes scabra* Vog. is often overlooked and considered undesirable because of coarseness and unpalatability at the peak of the season. However it is drought resistant and provides valuable green forage well eaten in the dry season. *S. scabra* is an important indigenous legume in drier regions, including the Cerrado and northeast Brazil, and bigger collections should be made and evaluated.

Persistent adapted legumes have not yet been commercialized for some important areas of tropical Latin American, such as the Colombian Llanos. In some areas, as already indicated, lack of persistence of current legume cultivars can be due to lack of attention to soil nutrient deficiencies. To be persistent, legumes (adequately fertilized) need to withstand grass competition, mismanagement (overgrazing, etc.) and periodic attack by a variety of insects and fungi, and have the ability to regenerate from crowns, rooted stolons and fallen seed. In spite of considerable research, only a few regions have persistent *Stylosanthes* cultivars. For example *Stylosanthes humilis* H.B.K. has been successful over a long-period with

native *H. contortus*, especially in Central Queensland (26). Its place is being taken by *M. atropurpureum* and *Stylosanthes hamata* (L.) Taub., while *S. scabra* is proving valuable in hot monsoonal regions of the far north in Australia. *S. scabra* appears to have ability to compete with vigorous grasses like *P. maximum*, and is also resistant to the Australian biotypes of anthracnose *(Colletotrichum gloeosporioides)*. Failure of *S. guianensis* in Brazilian pastures could be due to inability to compete with the vigorous *P. maximum* cv. Colonião, as well to attack by anthracnose. CIAT's (7) research at Carimagua and Santander de Quilichao has clearly shown the anthracnose and insect problems (especially stemborer) which are making it difficult to select persistent *Stylosanthes* cultivars for the Latin American tropics. These problems are a real challenge to scientists introducing, selecting and breeding *Stylosanthes* species.

Selecting and breeding legumes for tolerance to soil conditions (12) including low pH (low Ca, high Mn), low levels of P and other mineral nutrients, and waterlogging are very important aspects in development of legume cultivars for tropical Oxisols and Ultisols. Nodulation and growth at low pH (4.0) and low Ca are unaffected in some tropical legumes (e.g. *Macroptilium lathyroides* (L.) Urb. and *Lotononis bainesii* Baker) but severely inhibited in others (e.g. *Desmodium uncinatum* (Jacq.) D.C. and *G. wightii)* (1). In *M. atropurpureum* it was found possible to breed high yielding lines with a high degree of tolerance to high Al and Mn levels at pH as low as 4.2 (13, 15). This indicates scope for selecting and breeding vigorous lines from other legumes such as *C. pubescens*, and even *L. leucocephala*, for poor acid Oxisols and Ultisols. Ecotypes of several *Stylosanthes* species, *S. guianensis*, *S. scabra* and *S. capitata* are already well adapted to acid soils. When selecting and breeding legumes for acid soils, toxicities of both Al and Mn should be considered, as Mn toxicity could be more widespread than realized.

Some scientists consider that certain *Stylosanthes* species need almost no P and other nutrients because they occur naturally as scattered populations on very poor soils. However no legume can thrive in relatively dense legume-grass pastures without adequate inputs of essential nutrients. The protein levels in all legumes, including *Stylosanthes* species, is directly correlated to their P contents (4, 5). In several legumes, soluble Al in the substrate restricts uptake of P and Ca and reduces efficiency of translocation of P from roots to tops (2, 3). Legumes selected and bred for tolerance to low pH and excess Al could also possess increased efficiency in P utilization (13). Because of increasing fertilizer costs greater effort is required in selecting and breeding legume lines more efficient in utilization of all essential nutrients, including P.

Because of substantial areas of waterlogged soils in some regions, e.g. Pantanal of Brazil, legumes tolerant to these conditions are needed. Species with some flood tolerance include *M. lathyroides*, *Vigna luteola* (Jacq.) Benth., *Clitoria ternatea* L. and *C. macunoides*. *Desmodium* is a widespread genus which appears to contain some flood tolerant species. One of the most promising water tolerant legumes observed is the northeastern Argentinian native *Phaseolus adenanthus*, first collected and studied at Corrientes by an INTA scientist. It is vigorous and stoloniferous and thrives in soils waterlogged for long periods.

Should legume seed be inoculated at planting?

In tropical Latin America there is a wide range of native legumes and a high and variable native *Rhizobium* population in the soil. Thus the question is often asked, why increase pasture establishment costs by inoculating seed? Where seed inoculation is used, the applied *Rhizobium* could soon be replaced by the abundant native *Rhizobium*. A lot of farmers have planted various legumes without inoculation and nodulation has been quite satisfactory. Why inoculate, is a very important question and needs an answer without delay in the Latin American

Tropics. Fortunately CIAT's (7) recent soundly based *Rhizobium* research has already shown in various legumes, marked differences in efficiency between inoculant strains, efficacy of rock phosphate pelleting (lime pelleting in *Macroptilium* sp.), and a distinct growth advantage from inoculation in the establishment phase of about two months. Inoculation could also be especially advantageous in legume-grass establishment following clearing of heavily forested areas like Amazonia, and with legumes not native to the area (e.g. *Leucaena* spp.) when grown in much of South America.

Which grass?

In improved pastures, grasses provide much of the digestible energy requirements but need to be compatible with legumes (unless N fertilizer used) to ensure a sufficiency of N and protein. The important grasses in the Latin American Tropics are African in origin. The main three at present are *P. maximum* and *B. decumbens*, with *C. ciliaris* for drier tropical areas. *M. minutiflora* and *Hyparrhenia rufa* (Nees) Stapf. are still planted and are naturalized over large areas, especially in Brazil. As discussed earlier, a number of other grasses are being tried, and of these *C. dactylon* ecotypes are probably the most important for particular conditions such as heavier soils. There is considerable scope for further selection in the main grasses, particularly *P. maximum*, (aided by the Tifton, Gainesville or African sexual types) for tolerance to lower P and S in acid soils and in *C. ciliaris* (aided by Bashaw's sexual type) for tolerance to low pH, Ca and P. It is of interest that *C. ciliaris* is unable to tolerate high soluble Mn levels, while *P. maximum* var. trichoglume has medium tolerance, and *Paspalum dilatatum* Poir. and *S. anceps* have high Mn tolerance (27).

Due to the considerable interest in *B. decumbens* and other *Brachiaria* species, there is an urgent need for scientists to compare the steer liveweight gain potentials of the *Brachiaria* species in suitable replicated trials, using *P. maximum* as a control. It may be possible to increase the variation for selection in *B. decumbens* through crosses with the sexual diploid, *Brachiaria ruziziensis* Germain & Evrard. The selection and promotion from germplasm banks of new and widely successful grass species will be difficult, although CIAT's (7) research with African *A. gayanus* selections has distinct promise.

Selection of grasses for waterlogged conditions is important for low-lying areas throughout the Tropics. Species with potential include *Echinochloa polystachya* (H.B.K.) Hitchc., *Brachiaria mutica* (Forsk.) Stapf., *Paspalum plicatulum* Michx., *S. anceps* and *Hemarthria altissima* (Poir.) Stapf. & Hubbard.

Tufted grasses are usually compatible with the main legumes, but strongly stoloniferous grasses often prevent the growth of associate legumes. The stoloniferous, aggressive *B. decumbens* widely grown without legumes now presents scientists with one of the most difficult pasture improvement problems in the Latin American Tropics. Eventually the *B. decumbens* pastures will become deficient in N, P, S, etc. and lose productivity, but cultivation and fertilization with introduction of legumes will only reinvigorate the *B. decumbens* and inhibit legume development. A stable pasture can be developed by first establishing spaced rows of *L. leucocephala*, and then planting the *B. decumbens* between. On the infertile Carimagua Oxisols, CIAT's (7) research has shown a promising compatibility between *B. decumbens* and the rather unpalatable *Desmodium ovalifolium* Vahl. (similar results were obtained on the poor coastal bris soils of east Malaysia). Vigorous ecotypes of *S. scabra* could also be compatible with *B. decumbens*.

In the last two to three years, as mentioned earlier, photosensitization in young cattle (up to about 15 months old) grazing *B. decumbens* was considered a major and serious problem, especially in Brazil.

Farmers now realize it is a management problem, and that they need alternate pastures, e.g. *P. maximum*, for the younger cattle as soon as symptoms appear. It is significant that last season in Brazil *B. decumbens* was the grass seed in shortest supply, because of a resurgence in demand. Photosensitization of sheep and cattle (e.g. facial eczema) is from impaired liver function caused in New Zealand by a phytotoxin in *Pithomyces chartarum (Sporidesmium bakeri)*, a saprophytic fungus on the litter of *Lolium perenne* L. and other pasture species (9). In New Zealand it has now been shown that high Zn intakes in cattle and sheep protect against the phytotoxin and photosensitivity (30). The fungus is world-wide and occurs in Brazil and other Latin American countries, so it could be involved in photosensitization of cattle eating *B. decumbens*. Widespread Zn deficiency in poor tropical Oxisols and Ultisols, where much of the *B. decumbens* is grown, could be a predisposing factor (Zn is essential to maintenance of liver function). Other possible factors in young cattle include lower liver activity and partial development of the dark skin pigmentation of mature cattle. Also *B. decumbens* could contain a compound which has its greatest effect on young rapidly growing cattle.

Dry season problems and the role of legumes, including shrub types

If pastures have not been overgrazed in the wet season there is usually ample DM of variable to low quality available in the dry season. Some scientists and farmers advocate the costly procedure of cutting surplus summer forage for hay which is fed back in the dry season. As mentioned earlier, a small proportion of green legume in dry season pasture will maintain good ruminal activity and intake of fibrous grass, so that weight losses do not occur.

A number of the herbaceous legumes including *Stylosanthes* species, *M. atropurpureum* and *C. pubescens* are drought resistant and will produce some green leaf in the dry season. However the deep-rooting shrub and tree legumes, especially *L. leucocephala* (21), have the ability to produce significant amounts of valuable high protein leaf and shoots in the dry season for supplementing low quality fibrous grass. If *L. leucocephala* could be adapted to the acid Oxisols and Ultisols of the Latin American Tropics, it could if properly managed, obviate dry season feed problems in a number of regions. It is probably not practical to establish large areas of *L. leucocephala* in spaced rows with grasses planted between. However closely planted "protein banks" of *L. leucocephala* fenced and rotational grazed in conjunction with native or improved pasture (10 ha *L. leucocephala* per 100 ha of ordinary pasture) would not only improve summer liveweight gains but significantly increase dry season performance of cattle (11). The high and undesirable mimosine level in *L. leucocephala* cultivars will eventually be significantly reduced by crossing with other *Leucaena* species, including *Leucaena pulverulenta*. A study of the comparative effects of $CaCO_3$ on growth, nodulation and chemical composition of four *L. leucocephala* lines (3 bred) has indicated important factors (e.g. Ca and Al uptakes) involved in the adaptation of *L. leucocephala* to acid soils (14).

Low cost pasture development

Considerable research is needed in all important tropical regions to determine the cheapest methods of pasture establishment and maintenance, so that farmers will be encouraged to improve their pasture and cattle productivity. CIAT (7) is already devising low cost methods for the Colombian Llanos at Carimagua.

Wherever possible the existing grassland and savanna should not be destroyed during pasture improvement. This would not only lower costs but also provide cattle forage during the improvement phase. The Empresa de Pesquisa Agropecuaria de Minas Gerais, (EPAMIG of Belo Horizonte, Brazil) is studying the feeding value throughout the

year of the low Cerrado scrub at Felixandia by means of oesophageal fistulated steers. It has been found that the Cerrado during a portion of the year provides good quality forage for grazing cattle. EPAMIG is considering methods of establishing suitable legumes (e.g. *S. scabra* and *M. atropurpureum)* with SSP, Mo and Zn in strips between the scrub using a simple but heavy drill. In the central Queensland *H. contortus* zone similar methods have been used but in some cases most of the larger Eucalyptus are poisoned individually with Tordon.

Seed production and supplies

There will be no significant increases in pasture improvement directly related to the development of new technology and promising new legume and grass cultivars in tropical Latin America, unless ample quantities of good quality seed of the cultivars are available commercially at reasonable prices. For some years Australia has been an important supplier of tropical pasture seed, but with the increasing tempo of tropical pasture improvement based on Australian cultivars, has not been able to produce the quantities of seed required. Fortunately CIAT (7) has been active for some years in the development of seed production methods for a number of new legume and grass cultivars. Also several commercial firms, notably in Brazil, have been producing increasing quantities of seed of important pasture cultivars. Scientists and governments need to give all the support possible to organizations producing relatively low cost pasture seed of good quality. Without this vital seed, the substantial increases in large scale pasture improvement needed for production of lower cost meat for lower income people will not be possible.

CONCLUSIONS

There have been enough successes with tropical pasture improvement in various countries to be confident that suitable low cost pasture technologies will be developed for the extensive areas of acid Oxisols and Ultisols with high Al saturation. The key is the selection and breeding of legumes adapted to soils of low pH, and which form stable persistent combinations with tufted grasses (e.g. *P. maximum)* under grazing which is sometimes too severe. The legumes need to be tolerant of relatively low nutrient levels, but are unable to form vigorous associations with grasses without inputs of essential elements including P, S, Ca, K, Mo, Zn and Cu. Grasses require much more study, and especially the problem of associating a legume with *B. decumbens.*

Soil nutrient deficiencies in the different acid soil regions need intensive study so that economic fertilizer practices can be devised. The dry season forage problem could be solved by the selection and breeding of drought resistant legumes able to produce green leaf in the dry season e.g. the valuable tree legume *L. leucocephala.* Low cost pasture improvement methods are required which cause minimal disturbance of the native forages. Without adequate commercial seed supplies of legume and grass cultivars, pasture improvement in tropical Latin America will be severely retarded.

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FORMULATION OF PASTURE FERTILIZER PROGRAMS FOR THE WET TROPICAL COAST OF AUSTRALIA

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ABSTRACT

Progress with a research program designed to determine the mineral nutritional requirements for establishing and maintaining productive grass/legume pastures is described. A variety of experimental techniques including soil and plant chemistry, nutritional screening pot and field trials, fertilizer rates field trials, test fertilizer strips, maintenance fertilizer grazing trial and commercial fertilizer monitoring were used. Addition of P, K Ca, S, Cu, Zn, Mo and B increased plant growth on certain land units. Responses were grouped in an easily recognizable ecological framework based on soil parent material and natural vegetation. Natural vegetation was found to be a good indicator of the general level of fertility and the soil parent rock to be a fairly reliable guide to the specific elements needed. Fertilizer recommendations were formulated within such guidelines. These are seen as the minimum amount of fertilizer required to establish productive pastures with any degree of certainty on a given land unit. Work on maintenance fertilizer strategies has progressed to the formulation of a broad set of recommendations which, if implemented, prevent pasture degradation and allow economically viable beef production levels. Continuing research is aimed at minimizing fertilizer input and maximizing animal output while maintaining pasture stability.

The wet tropical coast is a narrow coastal plain up to 60 km wide between the Pacific Ocean and Great Dividing Range stretching from approximately latitude 16° to 19°S in North Queensland, Australia.

Rainfall is the dominant climatic feature. Within the region average annual rainfall ranges from 1500 to 5000 mm with some 75% of this falling in the hottest six months of the year (November to April). Probability analysis shows that the months of September and October have the lowest and least reliable rainfall. Plant growth is often restricted by available moisture at this time of the year but severe drought stress is rarely encountered. Conversely, the next most severe climatic limitation on plant growth occurs most frequently in the two midwet season months of February and March when radiant energy is reduced by excessive cloud cover. Average monthly maximum temperatures for the South Johnstone Research Station (at about the center of the region) range from 23.6°C in July to 30.8°C in December, while the minimum range is from 13.7°C in July to 21.8°C in February. Pasture growth rates in mid winter are commonly 80% lower than those measured in mid summer.

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Beef production is the major grazing industry and pasture research programs have placed emphasis on the maintenance of rapid and economic fat cattle turnoff and pasture stability. A small cattle fattening industry has been based on the more fertile rain forest soils of the area for about 40 years and experienced few problems. The situation changed drastically in the 1960's, when large tracts of very infertile sclerophyll forest country were released by the Government for development. Attempts to develop this class of country failed dismally. Early experiments (4, 7) recorded extreme P deficiency. These were followed by a major research program designed to determine the mineral nutritional requirements for establishing and maintaining productive pastures. Progress with this program and associated commercial experience are described in this paper.

EXPERIMENTAL METHODS

Objectives

It was recognized that grass/legume pastures would form the basis of commercial beef production enterprises in the Australian wet tropics. Certain grass-only pastures which receive N fertilizer dressings of at least 200 kg N/ha/yr (grass/bag N pastures) give higher levels of production but are much less attractive financially. The most important pasture mixtures consisted of *Panicum maximum* Jacq. cv. Riversdale or cv. Hamil growing with one or a mixture of *Centrosema pubescens,* Benth., *Pueraria phaseoloides* Roxb (Benth.) var Javanica (Benth.) Bak. and *Stylosanthes guianensis* (Aubl.) Sw. Experience had show that legumes and in particular the legume/*Rhizobium* symbiosis were more sensitive than the grasses to most mineral nutritional disorders. Determination of the fertilizer requirements for optimum legume N fixation on all areas available for pasture improvement became the prime objective of the research program.

Regional Survey

No prior surveys had been undertaken so the first step was to examine all land likely to be developed for cattle fattening for potential differences in fertility status. Preliminary ecological groupings were made in the laboratory after studying all maps and aerial mosaics together with existing data on soils, vegetation, topography, climate and geology. Field trips were used to check the initial grouping and to record more detailed site characteristics. Where available, local residents were asked to relate any experiences with plant or animal growth. Any available records were examined. As experimental work progressed, attempts were made to simplify the great diversity of information from the preliminary surveys by associating readily observable ecological features with suggestions and actual measurements of mineral nutritional disorders.

Soil and plant chemistry

Soil samples were taken from representatives of all land units and analyzed for pH, available P (0.01N H_2SO_4 ext.), exchangeable K, organic C, total N and cation exchange capacity.

Plant samples were taken from plant growth experiments and district pastures and analyzed for N, P, K and occasionally Ca content.

Nutritional screening experiments

The regional survey isolated a large number of land units with different ecological features. Representatives of each of these were screened for deficiencies of P, K, Ca, Mg, S, Cu, Zn, B, Mn and Mo.

Screening experiments were either field trials on a site representative of a particular land unit, or glasshouse pot trials using soil from at least 12 random positions within the boundary of a land unit. Techniques used were essentially similar to those described

by Andrew and Fergus (1) except that larger volumes of soil were used. Particular attention was paid to water purity in the glasshouse, acid washing of apparatus, purity of chemical treatments and procedural operations likely to cause mineral contamination.

Small plot fertilizer rate trials

Minerals isolated by the screening studies were studied in field trials where different rates of the elements were applied to commercial pasture mixtures. Early experiments were Latin squares with five rates of superphosphate. More recent examples paid more attention to interactions between a range of known deficient elements than to isolating the optimum application rate of any one fertilizer. A typical example would be a 3P x 3K x 2Ca x 2 (Cu Zn Mo) factorial array in two completely randomized blocks.

Test strips

Farm machinery was used to apply fertilizer grades of potentially deficient elements in strips to grazed pastures.

Maintenance fertilizer grazing trials

One grazing trial designed specifically to study maintenance fertilizer requirements of grazed pastures is in progress. At establishment, the experiment consisted of a uniform pasture fertilized to sufficiency on soil known to be low in P, K, Ca and S. Fertilizer use was then discontinued on certain treatments. Attempts are being made to measure differences in requirements, depletion rates and recycling patterns of the above elements at stocking rates of 5, 6.25 and 7.5 animals/ha.

Commercial fertilizer monitoring

The objective is to measure the rates of change in nutritional levels in the range of land classes with known differences in natural fertility. Initially, most emphasis was placed on the depletion rates of soil P and K levels once levels have been adjusted to approximately 30 ppm available P and 120 ppm exchangeable K by fertilizer addition. Forty soil cores (10 cm) are taken from two fixed transects in paddocks representative of certain soil/vegetation units in June-July each year. The present project design consists of a factorial array of 3 rainfall situations x 5 soil fertility classes as indicated by natural vegetation type x 4 replicates.

RESULTS

Regional survey

After attempting a number of groupings, Teitzel and Bruce (10) found that soil parent material and natural vegetation provided a natural framework for presenting and extrapolating the results of the soil fertility research program. Seven major soil groups and 11 major vegetation units were recognized and described. Some vegetation associations were not found on certain soil types and only 48 soil vegetation units were listed.

Vegetation groupings were selected to represent points on a continuium from dense mesophyll vine forest to sparse sclerophyll woodland. Mesophyll is used to describe dicotyledonous halophobic trees with nonsclerophyllous leaves. Australian ecological literature uses the term sclerophyll to describe forests and woodlands dominated by acacias, eucalypts, tristanias, melaleucas, casuarinas, etc. which have hard xeromorphic leaves. The term is used in the same context in the above vegetation units with the exception that the tea trees *(Melaleuca* spp.) are grouped separately.

Soil groupings are largely based on geological information from de Keyser (5) and may be listed in declining order of their importance as pasture soils: Granites, Metamorphics, Basalts, Beach Sands, Mixed Alluvials and Organic Soils. Sugar

and banana industries occupy the more fertile alluvial and less rugged residual basaltic soils. As a result, the grazing industries are largely based on shallow, light textured soils of granitic or metamorphic origin. Groupings with more conventional systems of soil classification do not coincide with the above. Krasnozems are restricted to the basalts but representatives of soloths, podzolics and podzols occur on a number of parent material groupings, as do the following groups of the Factual Key (6): Um4, Um5, Um6, Gn2, Gn3, Dy2, Dy3, Uc4 and Uc5. Using the U.S.D.A. Taxonomy, the Basaltic soils are Oxisols, the Alluviums are mainly Inceptisols with some Entisols, the Beach Sands are Entisols, the Metamorphics are mainly Inceptisols with some Ultisols, the Granitic grouping has both Ultisols and Inceptisols, and the Organic soils are Histosols.

Nutritional screening for pasture establishment

Teitzel and Bruce (10, 11, 12) grouped the results of 54 screening experiments on the basis of soil parent material. These are presented in greatly summarized form in Table 1. Their outstanding feature is large and general P response. Additional Cu brought about large plant growth increases on a high proportion of soils derived from granite and beach sand. Zn deficiency was largely confined to granitic sites and Mo to soils derived from metamorphic rocks. Responses to K were generally smaller and confined to certain metamorphics, granites and beach sands. Ca and S responses were not restricted to particular soil types. The only other elements to bring about significant plant growth increases were B and Mg in one experiment each. Responses

Table 1. **Distribution and average yield response from mineral additions.***

	*Average yield ratios***				
Element added	Basalts	Metamorphics	Granites	Beach Sands	Mixed Alluvials
P	4.44(9)***	2.75(9)	9.50(14)	6.39(12)	9.41(10)
K		1.17(4)	1.24(8)	1.49(4)	
Ca	1.25(4)	1.87(7)	1.60(5)	1.32(3)	3.06(4)
S	1.30(2)	1.15(4)	1.34(2)	1.16(2)	
Cu			1.67(8)	2.08(11)	1.75(1)
Zn			1.28(9)	2.19(1)	
Mo	1.15(1)	1.43(6)		1.18(2)	1.25(2)
B				1.13(1)	
Mg		1.29(1)			
Bulk		1.34(1)	1.26(2)	1.13(3)	1.76(2)
Total no. of sites studied	9	9	14	12	10

* Indicator species included *Macroptilium lathyroides* (L.) Urb., *M. atropurpureum* and *S. guianensis*

** $\textit{Yield ratio} = \frac{\text{yield with element}}{\text{yield without element}}$

Except for those used in calculating the yield ratio for P, all plants received a basal application of 60 kg P/ha

*** Brackets indicate number of responsive sites

to 'bulk' treatments and element interactions were measured but are not considered further in this paper.

Nutritional screening for pasture maintenance

This work is continuing. Interim results suggest that with time, Mo deficiency becomes more important on basaltic soils. A further response to Mo has also been measured on a basaltic soil two years after a commercial application of 0.5 kg sodium molybdate per ha. On other soil types, trace element deficiencies have yet to reappear four years after commercial application, but only a relatively small number of sites have been studied to date. In a major departure from the trends shown in Table 1, responses to Mo have been measured in granitic soils some four to five years after pasture establishment. So far no other results have suggested that the pattern of responses in Table 1 will not be a useful guide to planning maintenance fertilizer programs.

Fertilizer rate trials

Results from these have agreed closely with the qualitative responses shown in Table 1. In quantitative terms, a multitude of different plant growth response curves and interactions were recorded (2, 3, 8, 10, 11, 12; Teitzel and Standley, unpublished data).

As a general rule, grasses and legumes were least responsive to fertilizer on former rain forest sites, particularly on basaltic soils. On these it was possible to observe an outstanding early response to applied P, but after about 10 weeks many of these P treatment differences were not significant. This contrasted markedly with trials on sclerophyll forest and woodland country on soils derived from metamorphic, granitic, mixed alluvial and beach sand material. Unless P fertilizers were applied to these sites, improved pasture species failed to establish. However, on sandy soils (some granites and beach sands) the range from extreme P deficiency to P toxicity is very narrow. Legume yields have been drastically depressed by 60 and 80 kg P/ha treatments and surviving plants have contained 2 to 3% P instead of a more normal 0.2% P. When the trial contained a Ca treatment in factorial array, the growth depression and plant P content were generally reduced by 500 kg $CaCO_3$/ha or by an equivalent amount of $CaCl_2$. The 500 kg $CaCO_3$ treatment functioned in different ways in different sites, viz. overcoming an Al imbalance, Mo release and Ca deficiency. Limited experience with higher rates (2000 kg/ha) of $CaCO_3$ suggests that they will depress legume growth. Responses to K, Cu, Zn and Mo were more straightforward and simply additive to the P response. Their relative importance and the sequence of the additive effect varied between sites. The grasses appeared to require larger amounts of K and the legumes were more sensitive to trace element deficiencies. Growth depressions were sometimes recorded at rates higher than 150 kg KCl/ha.

Soil and plant chemistry

Good pasture establishment proved to be very difficult on soils which contained less than 15 ppm available P, except those derived from basalt. Pasture establishment benefits from applied P on soils with a higher available P level and on basaltic soils, were extremely variable but plant growth was always increased in the short term at least. A response to Ca can confidently be expected on soils where the pH is below 5.0 and an Al saturation level greater than 40%. Soil chemical tests for K, Cu and Zn were unreliable indicators of the requirements of these elements for pasture establishment.

A data bank of *ad hoc* analyses of district soils has steadily accumulated at South Johnstone. From these, levels of 30 ppm available P and 120 ppm exchangeable K have tentatively been established as desirable optima for the maintenance of productive grass/legume pastures on granitic, metamorphic and mixed alluvial soils in the area. Visual estimates of pasture

composition and growth rate were the only criteria to establish these levels: i.e. from local experience, really good pastures were not found when P and K levels were below these. This observation does not hold for the basalts and beach sands.

Plant chemical content varied dramatically with addition of the element under study, changes in the status of other elements, age, season and severity of plant defoliation as well as between species and varieties. There was often a greater variation between the same treatment on different experimental sites than between different treatments with highly significant yield differences in the one experiment. Some of these variations would not be a factor when using standardized procedures in determining 'critical levels'. However, the problem of multiple sequential deficiencies and their dynamic influence on plant chemical content remains. Another weakness is that critical values are normally standardized on terminal parts of the plants which are difficult to find in grazed pastures. Despite this poor performance in fertilizer prediction, plant chemistry has played a valuable interpretive role: e.g. K dilution caused by P addition; and increase in legume N content caused by Mo release through $CaCO_3$ addition.

Test strips

Test strips have not been reliable indicators of a fertilizer requirements.

Maintenance fertilizer grazing trial

This trial is still in progress. The effects of fertilizer treatments are still only minimal when compared to those from different stocking rates. After almost three years, additional P has yet to have a significant effect. Associated tests have suggested that a positive response to 500 kg $CaCO_3$/ha and a depression to higher rates could be expected. In the grazing trial, the 500 kg $CaCO_3$/ha treatment has had a slight but consistent depressing effect on both pasture and animal production.

Commercial fertilizer monitoring

Exchangeable K levels remained surprisingly stable on all transects when soil levels were up around 120 ppm. No real need for additional fertilizer K is apparent some four years after KCl application to such transects. On the other hand, soil available P levels have declined steadily. Data suggest that the most rapid rates of decline on granitic and metamorphic soils may be halted by the application of 300 kg SSP/ha every second year. Soil P data were however extremely variable, with variation occurring along a transect as well as between transects on the one land unit. Consequently, it has not yet been possible to measure consistent differences in depletion rates between land classes representative of different levels of natural fertility.

Available evidence gathered to date, indicates that the main cause of variable P data is inaccurate commercial fertilizer application. There is strong evidence that operators avoid difficult areas (boggy or rough) and make little effort to mark out "runs" in a paddock. Poor operator performance was compounded by poor physical standards of superphosphate. It was found that particles of superphosphate range in size from 0.1 mm to about 1 cm and the proportion of different particle sizes varies between bags and batches. In bulk lots, large particle sizes tend to rise to the surface of the load during transport. Accurate calibration of any machine is therefore impossible. The most common machines in use are spinner type broadcasters which are notoriously inaccurate in spreading material of variable particle size. Problems were compounded with superphosphate/trace element mixes which were discovered to be only a rough dry blend of commercial superphosphate and very fine trace element compounds. It was generally a case of poor operators using poor machines to apply a poor product.

Relationships between results of different types of experiments on similar land classification units

As an example, data contrasts are made from experiments on two sites representative of the open sclerophyll forest/granite land unit. Data was extracted from Teitzel (8), Teitzel and Bruce (10) and Teitzel unpublished. Experiments on site 1 were a pot screening trial, a field screening trial and a fertilizer rate field trial. On site 2 there was a pot screening trial and a production systems grazing trial.

Results of the nutritional screening experiments are presented in Table 2. Plant growth was increased by P, K, Cu in all experiments, by Zn in the two pot experiments and Ca in the pot experiment in site 1. The field trial on site 1 had basal Ca in the form of $Ca(H_2PO_4)_2$.

The magnitude of *Macroptilium atropurpureum* (DC.) Urb. yield (kg DM/ha) in the field screening trial on site 1 is shown below.

	K_0	K_1
Cu_0	265	229
Cu_1	543	712
LSD (5%)	132; (1%)	178

The follow-up fertilizer rates field trial was planted to a mixture of *P. maximum* and *S. guianensis*. Plant DM yields and some chemical analyses are summarized in Tables 3 and 4. These reveal different degrees of responsiveness and the operation of plant competition factors following the addition of different rates and combinations of P, K and Cu. Plant chemical data help with the interpretation of the yield data and highlight the importance of interactions and dilution effects which can be operative.

One combination of treatments in the production systems grazing trial allows an assessment of the importance of the above elements in terms of animal production. With an input of 30 kg P/ha every three years, a stocking rate of 1.5 an/ha seems the maximum attainable. With an initial input of 50 kg P, 100 kg KCl, 10 kg $CuSO_4$, 10 kg $ZnSO_4$/ha and reapplication of 30 kg P every two years and 10 kg $CuSO_4$, 10 kg $ZnSO_4$ and 0.4 kg sodium molybdate every four years, stocking rates have been increased to 3 an/ha. Pot experiments not described in this paper had shown the site to be Mo responsive about four years after pasture establishment.

Similar series of complementary results were obtained from other sites. Probably the most important feature is the reliability and sensitivity of the glasshouse pot trial as a screening technique.

Table 2. **Nutritional screening experiments from two granitic soil sites***

	Significant yield ratios				
	P	K	Ca	Cu	Zn
Site 1					
Pot trial	2.74	1.32	1.37	2.25	1.31
Field trial	4.07	1.31	–	2.41	–
Site 2					
Pot trial	7.70	1.24	–	1.51	1.37

* Indicator species were: pot trials, *M. lathyroides*; field trial, *M. atropurpureum*.

Table 3. **Mean effects of P, K and Cu on DM yield and chemical composition of pasture components in the fertilizer rates field trial.**

Treatment	Yield		P		K	
	*P. maximum**	*S. guianensis***	*P. maximum*	*S. guianensis*	*P. maximum*	*S. guianensis*
	kg D M/ha		%			
P_0	578	511	0.11	0.15	2.36	1.77
P_{300}	1615	533	0.12	0.20	2.01	1.52
P_{600}	2084	523	0.15	0.23	1.79	1.34
L.S.D. 5%	479	174	0.02	0.02	0.23	0.16
Cu_0	1260	344	0.13	0.20	2.05	1.66
Cu_{10}	1478	641	0.12	0.19	2.01	1.47
Cu_{40}	1541	582	0.13	0.19	2.10	1.49
L.S.D. 5%	479	174	0.02	0.02	0.23	0.16
K_0	1048	419	0.13	0.20	1.73	1.10
K_{50}	1517	526	0.12	0.18	1.96	1.43
K_{100}	1448	565	0.12	0.20	2.18	1.63
K_{200}	1701	579	0.14	0.20	2.36	2.00
L.S.D. 5%	553	199	0.03	0.03	0.27	0.18

* *P. maximum* cv. Riversdale

** *S. guianensis* cv. Schofield

Table 4. **The effect of some P, K, and Cu fertilizer combinations on yield and K concentration in pasture from the fertilizer rates field trial.**

Treatment		*S. guianensis**		*P. maximum***	
		Cu_0	Cu_1	Cu_0	Cu_1
		K concentration (%)			
	P_0	1.35	1.48	1.95	2.34
K_0	P_1	1.39	1.26	1.30	1.74
	P_2	1.23	0.59	1.53	1.20
	P_0	1.87	1.97	2.64	2.73
K_2	P_1	1.75	1.37	2.32	1.88
	P_2	1.51	1.21	1.77	1.87
		Yield (Kg DM /ha)			
	P_0	313	522	262	270
K_0	P_1	358	531	425	1996
	P_2	213	426	948	1861
	P_0	437	354	435	288
K_2	P_1	342	677	1359	1438
	P_2	423	568	2949	2677

* *S. guianensis* cv. Schofield ** *P. maximum* cv. Riversdale

FERTILIZER RECOMMENDATIONS

Pasture establishment

The problem was to simplify the diversity found in the wide range of land units so that an agricultural adviser could make a good estimate of the amounts and types of fertilizer required to establish a particular type of pasture in a particular area.

Natural vegetation cover was found to be a good guide to the general level of fertility. Experimental results agreed with commercial experience in showing that soils supporting dense rain forest required little fertilizer for pasture establishment. As the proportion of sclerophyll species increased, the plant growth responses became more dramatic and the amount of fertilizer required for optimum establishment increased. Within the pure sclerophyll vegetation groups, the most infertile areas were indicated by stunted, fairly sparse trees with a well-developed grass layer. Between the two extremes of rain forest and grassy sclerophyll woodland was a continuium of natural vegetation classes ranging from the most to the least luxuriant. Trial results also showed that it was important to separate well-drained and poorly-drained areas. This information is summarized in Table 5.

Soil chemical analyses give further support to a fertility series based on natural vegetation groupings. Teitzel and Bruce (9) reported a strong positive correlation between organic carbon and cation exchange capacity ($r = 0.90^{**}$ $n = 60$) but little correlation between clay content, which ranges from 6 to 44%, and cation exchange capacity ($R = 0.18$ n.s. $n = 60$). Soil organic carbon is greater under the more luxuriant vegetation types; as the vegetation becomes less luxuriant when moving down the series it follows that organic carbon and cation exchange capacity decreases also.

A relationship between soil parent material and natural vegetation classes also become apparent very early in the study. Only rain forest vegetation types were found on basaltic soils and only sclerophyll vegetation types were found on soils derived from beach sands.

It was considered that basaltic soils were fertile enough for rain forest and beach sands too poor. Yet on soils derived from granite, usually thought of as infertile, the whole range of vegetation classes occurs. A wide range was also found on soils derived from metamorphic rocks, but on these and other non-basaltic soils the rain forest vegetation groups are found only in areas of

Table 5. **Vegetation groupings indicative of soil fertility status. (Arrows indicate declining fertility).**

Well drained areas	Poorly drained areas
Rain forest (Mesophyll vine forest)	Palm forest (Mesophyll palm vine forest)
Bastard scrub (Sclerophyll-Mesophyll vine forest)	Narrow-leaf tea-tree (Tall Melaleuca forest)
Open forest (Open sclerophyll forest)	Broad-leaf tea-tree (Melaleuca woodland)
Grassy woodland (Grassy sclerophyll woodland)	

nutrient accumulation such as the levee banks of streams and the foothills of ranges.

Apparently, local enrichment through nutrient accumulation can, to some extent, make up for soil parent material differences. However, with beach sands as the most outstanding example, it is obvious that nutrient accumulation is unable to overcome soil parent material differences completely.

Soil parent material was shown in Table 1 to be a fairly reliable guide to the specific elements likely to be needed. A two way classification based on soil parent material and natural vegetation presents itself. Fertilizers recommended for the various soil-vegetation units found in the area are shown in Table 6. This illustrates a unique situation on the beach sands in that less fertilizer is recommended on areas of lower natural fertility. This is because plants growing on such poor areas could not utilize large quantities of fertilizer in their establishment year. There are two main reasons for this, both related to water. First, because they are so sandy, the soils dry out quickly and moisture deficiency becomes more important than mineral deficiency. Second, there is very little clay or humus to hold the fertilizers in the soil, and most of a large dressing is washed through the soil. Another apparent anomaly exists with the recommended fertilizer application to rain forest sites on basaltic soils where only a short term response had been observed in field trials. This short term response has been found important in practice because it provides the pasture plants with a competitive advantage over weeds and regrowth.

Pasture maintenance

Under prevailing poor economic conditions in the beef industry, the basic objective of the maintenance fertilizer program is to apply the minimum amount of fertilizer necessary to maintain the pasture at a set stocking rate. The critical factor in this is adequate N fixation by legumes, which then boosts associated grass growth to give a competitive advantage over weeds and regrowth. Research therefore concentrated on finding the minimum mineral requirements for optimum legume growth and N fixation. Fortunately, this also seems to satisfy the requirements of the grass; there has been no cause to modify fertilizer applications to alter grass-legume balance. Any tendency to grass dominance brought about by heavy P application has been overcome by grazing management. The work is continuing but available results indicate that fertilizer programs satisfying the above requirements also give peak animal production. Surprisingly, therefore, no dichotomy in objectives exists.

Present trends suggest that the soil parent material/natural vegetation classification system described earlier may also be the most useful framework for basing maintenance fertilizer strategies. There will however, be continuing attempts to force the steadily accumulating pile of data into a more meaningful classification system. For the present it is only possible to give broad maintenance fertilizer recommendations for the major soil parent material groupings.

Granitic soils

Excellent pastures have been found where soil available P is about 30 ppm and exchangeable K about 120 ppm. Different paddocks require different quantities of fertilizer to reach these levels, so soil sampling is a necessary preliminary to fertilizer program planning. Each soil sample submitted for chemical analysis should consist of a thorough mix of about 30 cores taken with a soil sampling auger. Core sampling depth has been standardized at 10 cm.

Exchangeable K has shown little change in three years and, once pasture establishment requirements have been met, little KCl should be needed for several years. Soil P levels, however, gradually declined and it was found that approximately 300 kg

superphosphate/ha is required every two years to maintain soil P at 30 ppm.

Granitic soils also require fertilizer inputs of S, Cu, Zn and Mo. So far, superphosphate containing 10% S has satisfied the requirement for S. For the trace elements, the present recommendation is to re-apply 10 kg $CuSO_4$, 10 kg $ZnSO_4$ and 0.5 kg sodium molybdate every four years. Mo is applied generally but Cu and Zn only on those areas where they were recommended for pasture establishment (Table 6).

Metamorphic soils

The P, K, Mo and S recommendations for granitics also apply to metamorphics for the

Table 6. **Recommended fertilizers for pasture establishment on the range of soil-vegetation units found in the tropical wet coast of Australia.**

	Basalt	Metamorphic	Granite	Mixed Alluvial	Beach Sands
Rain forest	250 P	250 P	250 P	250 P	-
Palm forest	0.5 Mo	0.5 Mo		0.5 Mo	-
Bastard scrub	-	250 P 50 K 0.5 Mo	250 P 50 K	250 P 50 K 0.5 Mo	-
Open forest	-	500 P 100 K 0.5 Mo	500 P 50-100 K 10 Zn 10 Cu	500 P 50-100 K 0.5 Mo 10 Cu	500 P 150 K 10 Cu 10 Zn
Grassy woodland	-	-	500 P 100 K 10 Zn 10 Cu	500 P 100 K 0.5 mo 10 Cu	250 P 10 Cu 10 Zn
Palm forest	-	250 P 0.5 Mo	250 P	250 P 0.5 Mo	-
Narrow-leaf tea-tree	-	500 P 100 K 0.5 Mo	500 P 50-100 K 10 Zn	500 P 50-100 K 0.5 Mo	N.D.
Broad-leaf tea-tree	-	500 P 100 K 0.5 Mo	500 P 100 K 10 Zn	500 P 100 K 0.5 Mo	N.D.

N.D. indicates development of these soils is not recommended

P = kg/ha superphosphate

Mo = kg/ha sodium molybdate

K = kg/ha KCl

Cu = kg/ha $CuSO_4$

Zn = kg/ha $ZnSO_4$

time being. Cu and Zn deficiencies have not been discovered. The only other fertilizer likely to be required is a single dressing of 500 kg $CaCO_3$/ha on soils with a pH below 5.0 and an Al saturation ratio greater than 40%.

Soils derived from beach sand

These soils are extremely infertile and the golden rule is to add "little and often". Exchangeable K rarely exceeds 60 ppm. Annual application of 150 kg superphosphate and 50 kg KCl/ha at the end of the wet season are recommended; 10 kg $CuSO_4$, 10 kg $ZnSO_4$ and 0.5 kg sodium molybdate/ha every fourth year seems to suffice. High fertilizer rates are wasteful and may even be toxic on these sands.

Basaltic soils

Deficiencies of P, Mo and S have been recorded. Available chemical tests were found to be unreliable on these soils. Experiments have shown that application rates of 200-400 kg superphosphate/ha are insufficient to produce marked increases in pasture growth on old pasture sites. If the pasture has not received fertilizer for five years or more, the standard recommendation is 500 kg superphosphate and 0.5 kg sodium molybdate/ha to be followed by 200 kg superphosphate/ha annually sodium molybdate every second year.

Mixed alluvial soils

The variation within this broad grouping makes it very difficult to delineate where each element is deficient. Fortunately for the pasture scientist, only small areas are available for grazing and improved pastures. Where they are in use, the normal practice is to follow the recommendations for the dominant parent material.

ECONOMICS

Some seven to 10 years follow-up commercial experience has demonstrated the relevance and reliability of the above fertilizer recommendations for pasture establishment. Unless the major mineral deficiencies were corrected, productive pasture development proved to be impossible. Recommended fertilizer programs account for only a relatively small proportion of the cost of land clearing and pasture establishment and probably because of this, they have been adopted by most producers.

Maintenance fertilizer recommendations have not been so well accepted. Following the crash in beef prices in 1974, most producers ceased fertilizer application altogether. This had very severe consequences. Many pastures became so heavily infested with weeds and regrowth that they lost their ability to fatten cattle. Regrowth problems on some sclerophyll forest country were such that it was difficult to believe that the areas were once cleared, let alone capable of feeding cattle.

Subsequent commercial experience and grazing trials have shown that provided there is sufficient legume in the pasture (1 to 2% dry weight seems adequate) correction of existing mineral deficiencies and the implementation of the above maintenance fertilizer strategies will reverse the pasture degradation process. In the rehabilitation process, it was found that six to nine months after fertilizer application, stocking rates could be increased to about 3 an/ha.

It can be argued that the substantial capital investment in existing good grass/legume pastures should be protected by implementing the recommended maintenance fertilizer programs. If not, the capital already invested will be lost and a substantial infusion of more capital for re-development purposes will be required to take advantage of any improvement in the beef market. Cash returns from a market improvement will also be delayed if a re-development program is necessary.

Local costs of 300 kg superphosphate/ha

Table 7. **A comparison of annual costs and returns of alternative systems of fattening on grass/legume pastures (Assuming a store steer purchase price of A$50 and a sale nine months later for A$100, i.e. A$ 50/head margin).***

Stocking rate	Material inputs	Cost of inputs	Returns	Profit
(AU/ha)		$ A/ha		
1.25	Nil (pasture degradation proceeding)	0	83	83
1.25	Low fertilizer (300 kg superphosphate/ha for 4 yr)	6	83	77
1.25	Low fertilizer + molasses (3.5 kg molasses/head/day for 6 months)	23	83	60
2.5	Low fertilizer + molasses supplementation (degradation)	40	166	126
2.5	Recommended fertilizer (e.g. P, Cu, Zn, Mo)	15	166	151
3.0	Recommended fertilizer	15	200	185

* *Approximate mid 1978 exchange rate: A$1= US$1.17*

every two years and 10 kg $CuSO_4$ + 10 kg $ZnSO_4$ + 0.5 kg sodium molybdate every four years, are about A$60/ha per four-year period (A$15/ha/yr)*. Unpublished grazing trial results have shown that good grass/legume pastures receiving the recommended maintenance fertilizer dressing were capable of carrying somewhere between 2.5 and 3.75 an/ha. Weight gains were such that 18-month-old store steers were fattened in nine months. This contrasts with a commercial situation where a stocking rate of 1.25 an/ha and a 12 to 18-month fattening period is considered normal.

As it has been possible to purchase store steers for about A$50 and sell them nine months later for about A$100, it can be argued that the implementation of recommended fertilizer strategies is a highly desirable economic proposition even with prevailing market conditions. It is certainly the most attractive of the alternatives listed in Table 7.

* Approximate (mid 1978) exchange rate A$1 = US$1 17

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MANAGEMENT OF PHOSPHORUS FERTILIZATION IN ESTABLISHING AND MAINTAINING IMPROVED PASTURES ON ACID, INFERTILE SOILS OF TROPICAL AMERICA

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ABSTRACT

One of the major problems in establishing and maintaining improved pastures, in the Oxisols and Ultisols of tropical Latin America, is the extremely low levels of both total and available P. In addition, these soils generally have a high P fixation capacity so substantial amounts of P must be added to satisfy both the plant and the soil requirements. Because of these constraints, along with the high unit cost of P fertilizers, alternative methods of managing improved pastures must be considered. This paper considers four economical methods of improving forage production while still satisfying the P requirements of the plant. These are: (1) selection of plant species that will tolerate relatively low levels of available soil P; (2) determining rates and placement of P fertilizers to increase their efficiency, both initially and residually; (3) use of cheaper and less soluble forms of P carriers; and (4) use of soil amendments to enhance the availability of soil applied P.

Phosphorus is generally considered the most limiting element in the acid, infertile soils of tropical Latin America. Total P will range from only about 200 to 600 ppm and available P, determined by the Bray II method, from 1 to 5 ppm. It is quite obvious that to increase forage production phosphate fertilizer must be added to these soils and plant species that are efficient P users must be selected. These soils are acid (pH 4.0-5.5), and often high in free Fe and Al oxides and hydroxides which tend to rapidly fix large amounts of P, especially when it is applied in soluble forms such as simple (SSP) or triple (TSP) superphosphate.

Although P is highlighted in this paper on forage production, it must also be remembered that these soils are generally deficient in all of the primary and secondary nutrients as well as Zn, B, Mo, and Cu (12). In addition, there are also many instances of Mn and Al toxicities affecting a number of the forage species.

From a physical properties standpoint Oxisols and Ultisols present few management problems. With the exception of some of the sandy Ultisols, which are susceptible to mechanized compaction and erosion, these soils have excellent structure, are generally well drained, and have good water infiltration capacity. Sánchez (11) states that, "the excellent structure of these soils is caused by primary particles being aggregated in very stable sand-sized

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granules. Their high stability is associated with high clay content and cementing or coating of amorphous iron and aluminum oxides". Because of the stable sand-sized particles, the water holding capacity of these soils is relatively low and even during short periods of drought, plant water stress can be a problem.

In order to determine a sound, economic P management strategy for forages grown on the acid, infertile Oxisols and Ultisols of tropical Latin America, several factors must be taken into consideration. These would include but not necessarily be limited to: (1) selection of plant species that will tolerate relatively low levels of available soil P, (2) determining rates and placements of P fertilizer to increase its efficiency, both initially and residually, (3) use of cheaper, less soluble forms of P such as phosphate rock (PR) or partially acidulated PR, and (4) use of soil amendments to enhance the availability of soil applied P (12).

USE OF EFFICIENT FORAGE SPECIES AT LOW LEVELS OF AVAILABLE SOIL PHOSPHORUS

Muller (2) conducted a greenhouse experiment on a Carimagua Oxisol with several forage species to determine the critical P soil test level for obtaining 60 to 80% of maximum yield, according to the Cate-Nelson method. Levels of soil applied P ranged from 0 to 240 kg/ha and dry matter (DM) yields were correlated with soil test P values (Bray II) to estimate external P requirement. The results indicate that the external P requirement varied markedly between the forage species and ecotypes tested (Fig. 1). The range was from 2.5 ppm P for ecotypes of *Stylosanthes guianensis* (Aubl.) Sw. and *Stylosanthes capitata* Vog. to 11.4 ppm P for *Desmodium leonii*. Unpublished data by León indicate that rates of applied P would vary from approximately 50 to 300 kg P_2O_5/ha, to accommodate this range of plant requirements in an Oxisol from Carimagua and an Ultisol from Quilichao, in Colombia (Fig. 2).

Sánchez, León and Ayarza (unpublished data) working with several legume species planted on the Quilichao Ultisol in the greenhouse, show a wide variety of yield responses to added P. In general *Centrosema plumieri* (Pers.) Benth., *Zornia* 728, and *S. capitata* did not respond to added P, whereas *S. guianensis* 136, *Desmodium ovalifolium* Vahl. and *Centrosema* 1733 responded to levels of 50, 100 and 400 kg P_2O_5/ha, respectively (Fig. 3). These data appear to correlate well with those of Muller and of León (Figs. 1 and 2).

When taking into consideration the minimum input philosophy it is significant that only 50 kg P_2O_5/ha is needed to achieve the lowest critical soil test level of 2.5 ppm P (Bray II) for *S. capitata* in Carimagua. It is also important to realize that this minimum input level will probably have very little residual value so consideration should be given to either applying a higher rate of P initially or annual applications later. In order to sustain even the most P efficient species it would appear that substantial amounts of fertilizer P are required.

Another aspect to consider in selecting forage species with relatively low P requirements is the amount of P needed to establish the pasture versus the amount needed to sustain it at near maximum yield levels. Ozanne *et al.*, (10) conducted a pot experiment with eight different legume and grass species, adapted to Australian conditions, in which they determined the P requirements at different stages of growth. The minimum amount of P required for 90% of maximum growth varied markedly with stage of growth within species and between the various species (Table 1). In general, however, with the exception of one legume (*Trifolium cherleri* L.), the minimum P requirements for near maximum growth at maturity were equal to or less than the initial plant requirements.

In selecting a low P tolerant forage the ideal situation would be a plant species that has both low initial and maintenance P

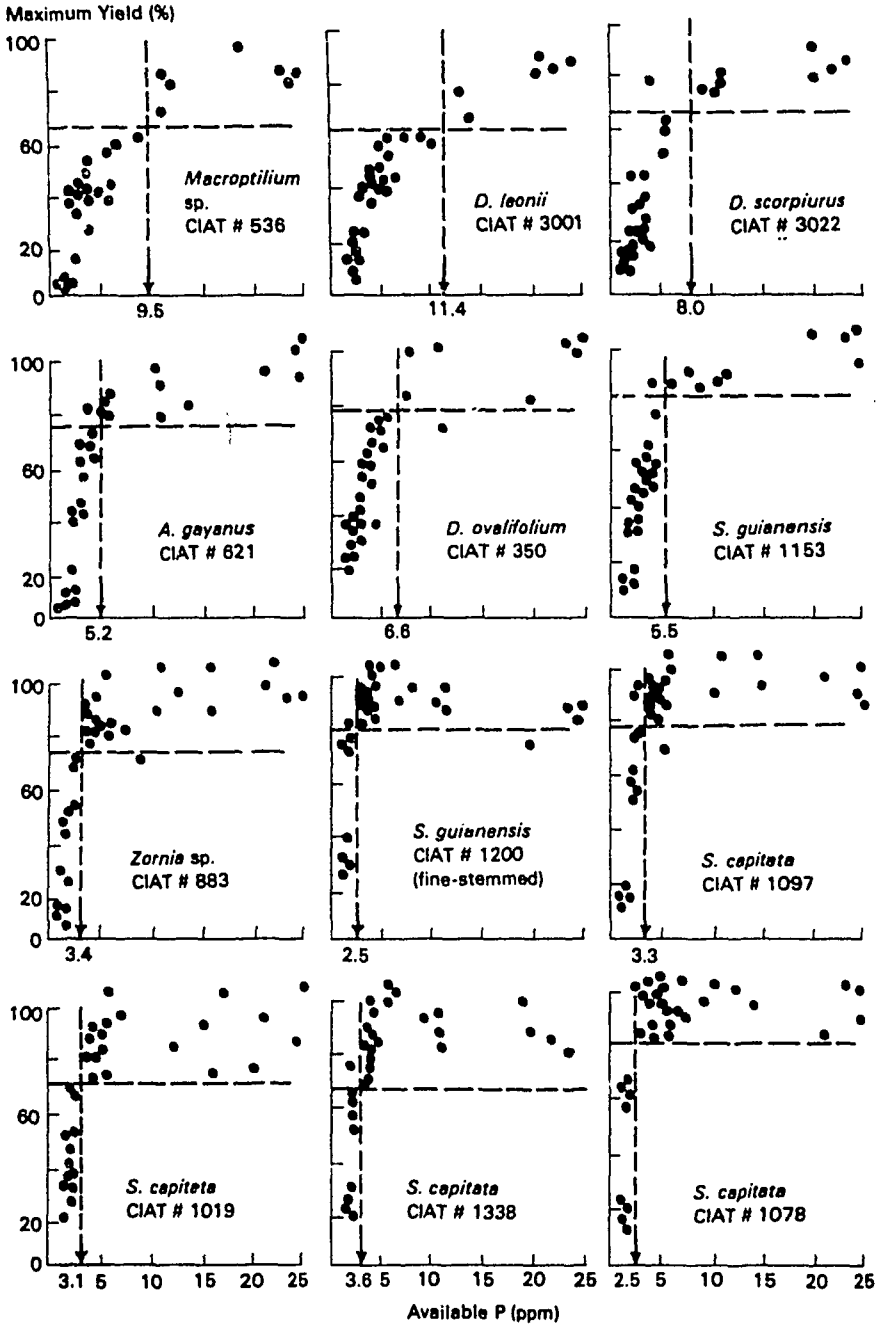

Figure 1. External P requirements of 12 CIAT accessions grown on a Carimagua Oxisol, in the greenhouse (3).

requirements. In the absence of this, however, a reasonable alternative would be to select a forage that may require somewhat higher amounts of P in establishment but only minimal amounts for maintenance.

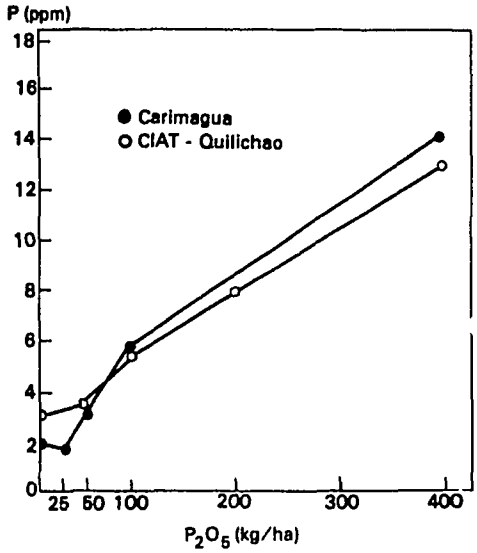

Figure 2. **Effect of phosphate (TSP) additions on soil test phosphorus (Bray II) from two locations in Colombia.**

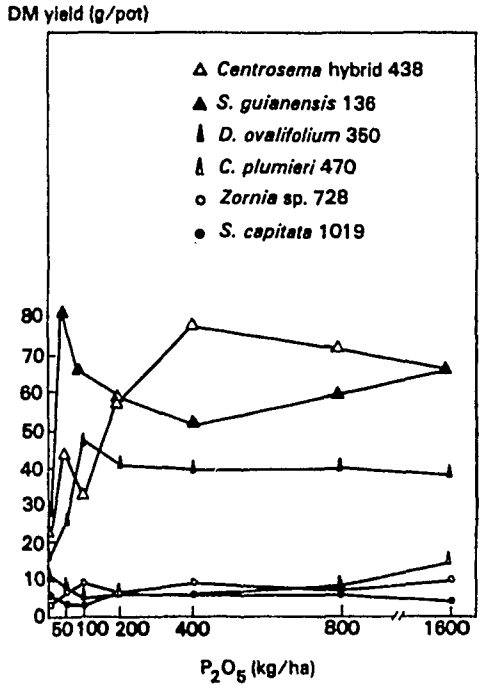

Figure 3. **Effect of varying levels of P (TSP) on DM yields of several forage legumes grown in the greenhouse on a CIAT-Quilichao Ultisol. (Unpublished data by Sánchez *et al*).**

Table 1. **Phosphorus required for 90% of maximum yield of tops at two harvest times in Australia. (Adapted from 10).**

Species	P applied ppm	
	Day 29	Day 92*
Trifolium c ierleri	140	302
Trifolium hirtum	128	124
Trifolium subterraneum	137	87
Lupinus pilosus	49	57
Cryptostemma calendulacea	242	43
Erodium botrys	124	43
Lolium rigidum	80	26
Festuca myuros	87	21

* Full flowering

DETERMINING MOST EFFICIENT PLACEMENT METHODS AND RATES

Placement

In tropical Latin America P fertilization of pastures has generally followed the classical approach of broadcast and incorporation of superphosphate during establishment, followed by periodic top-dressings. Recently, however, some research has been conducted to ascertain the effect of P placement on pasture establishment and the results have varied markedly.

Spain and Ayarza (2), using basic slag as the P source, compared broadcast versus band applications on three grass-legume mixtures in a field experiment at Carimagua, Colombia. The comparison also included levels of 10, 40 and 70 kg P_2O_5/ha and the seeds were mixed with the fertilizer, so in effect seeding was also banded or broadcast. They concluded that there was a definite advantage to banding the seed and fertilizer application (Fig. 4). Band placement also appeared to benefit the legume more than the associated grass. They concluded that, "band seeding and fertilizer applications

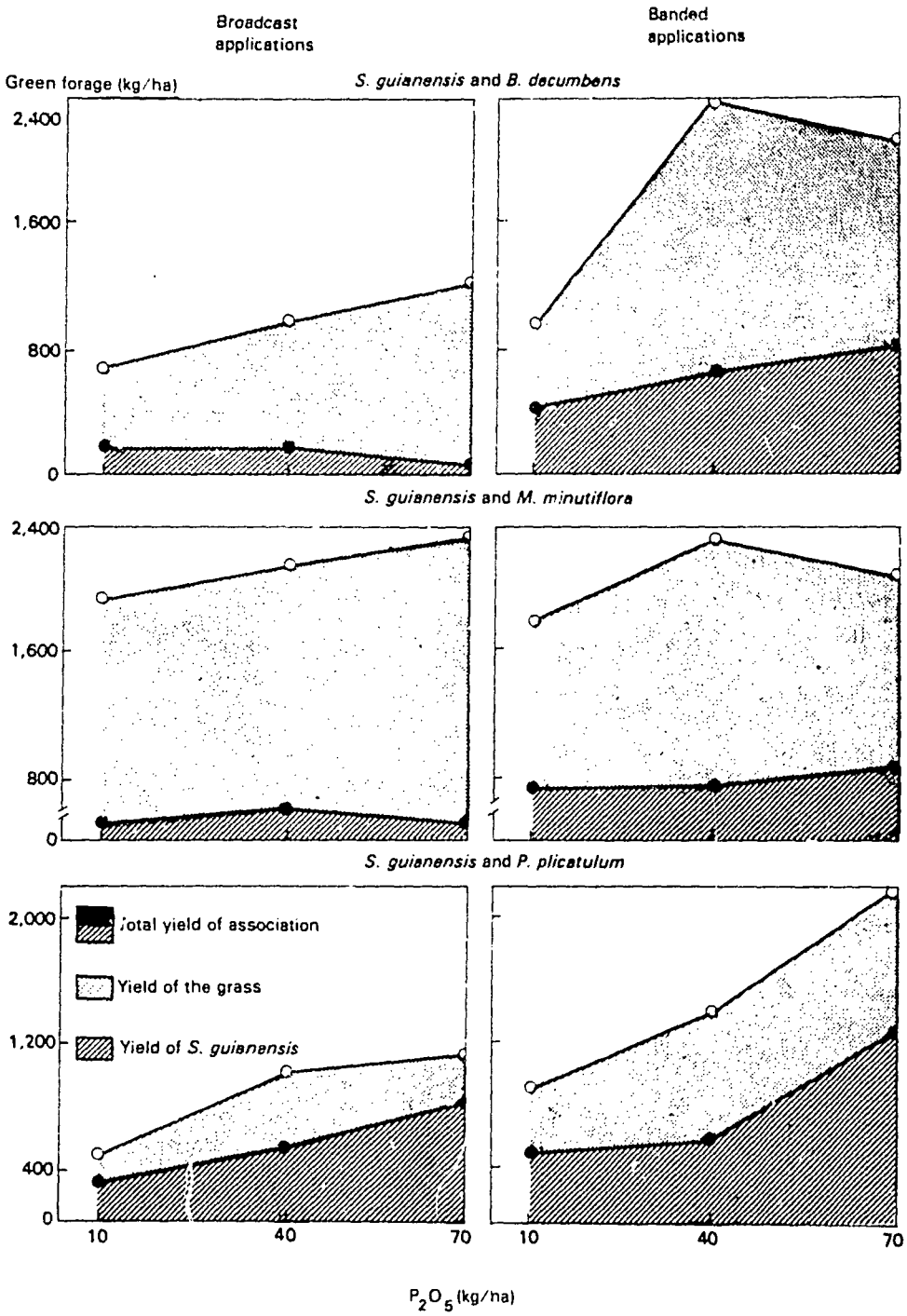

Figure 4. **Effect of three levels of P and method of application on yields of three forage associations on a Carimagua Oxisol (2).**

apparently create a more favorable fertility environment for the developing seedling than do broadcast applications. The fertilizer is concentrated in the seedling zone and phosphorus availability is greater during the seedling stage when it appears to be especially critical for small-seeded forage species".

Preliminary results from a continuing experiment being conducted by Sánchez, Ayarza and León, at the Quilichao experiment station in Colombia, indicate that broadcasting P is superior to banding in establishing *Panicum maximum* Jacq. and *Andropogon gayanus* Kunth. Results of selected TSP treatments on yields of these two grasses are illustrated in Figure 5. In this same experiment broadcast plus band application of P gave the highest yields. These preliminary data would suggest that banding is important in establishing the forage but broadcast treatments are necessary for maintenance.

It is also probable in these very low P supplying soils that when only banded P is applied, root growth is restricted to the band area, thus the plants are susceptible to drought, even during short periods when it does not rain (7, 8, 9). Short periods of drought are common in many of these Oxisols and Ultisols because of the very stable sand-sized aggregates at the surface (7, 8, 9).

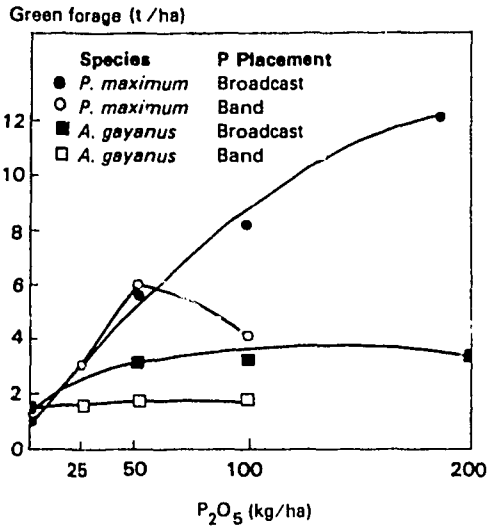

Figure 5. **Effect of rates and method of application of P (TSP) on two grasses grown on a CIAT-Quilichao Ultisol. (Unpublished data by Sánchez *et al.*, 1978).**

It is obvious that more research is needed to ascertain the merits of P placement in pasture production. These experiments should be relatively long-term so residual values of the P placement can also be studied. Long-term experiments by Yost *et al.* (7, 8, 9) with corn at the Cerrado Center in Brazil, indicate that a combination of broadcast plus banded P is the most promising strategy.

Rates of phosphorus

Several experiments have been conducted in tropical Latin America with a number of forage grass and legume species to determine the P rates necessary to maximize pasture production. Although many of these experiments have included several P carriers, only SSP and TSP will be discussed in this section.

In the Cerrado of Brazil, North Carolina State University and Cornell (7) initiated a long-term P experiment with *Brachiaria decumbens* Stapf. using 86, 345 and 1380 kg P_2O_5/ha as SSP as basal rates. Although the 1380 kg/ha treatment yielded somewhat higher the first two cuttings, the 345 kg P_2O_5/ha treatment was giving comparable results after the third harvest (Fig. 6). Hammond, León and Gualdrón (3) established a similar experiment on a Carimagua Oxisol in Colombia with *B. decumbens* using 25, 50, 100, and 400 kg P_2O_5/ha as TSP. In this instance it would appear that the 100 kg P_2O_5/ha treatment, is comparing favorably with the 400 kg/ha treatment (Fig. 6).

These two continuing experiments are a good illustration of why it is so difficult to make generalized phosphate recommen-

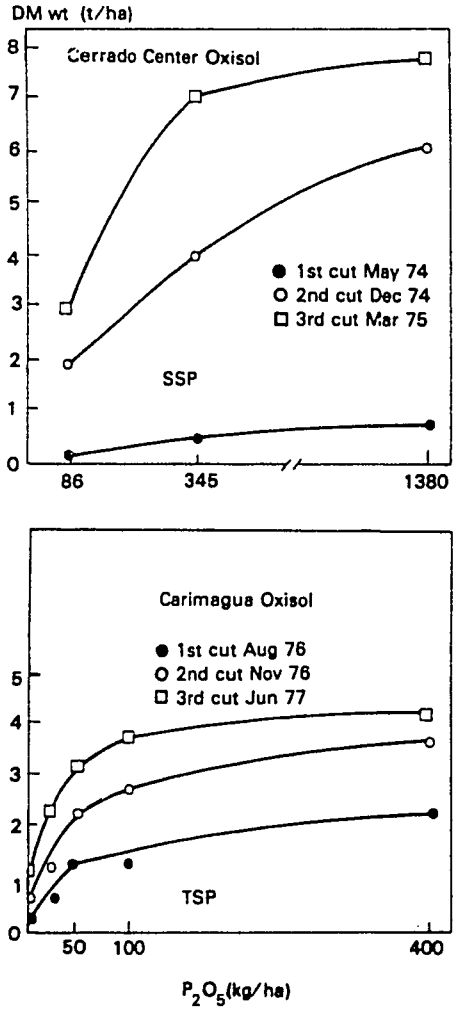

Figure 6. **Effect of varying rates of P on DM yield of *B. decumbens* at two locations. (Adapted from 3 and 8).**

dations on forages of tropical Latin America. Here is a situation where the same grass species was grown on two different P deficient Oxisols and the P requirements for maximizing production differ by approximately three orders of magnitude. León and Sánchez (3) found the P fixation capacity of these two soils to vary quite markedly. It took additions of 350 and 750 ppm P for the Carimagua and Cerrados soils, respectively, to reach a level of 0.2 ppm P in the soil solution (Fig. 7). The differences in the P fixation capacities of these two soils probably explain, to a large degree, why the P requirements for forages vary so markedly from place to place. This also emphasizes the point that both the plant requirements and the soil chemical characteristics must be understood in order to make reasonably accurate fertilizer recommendations.

Spain (3), in another pasture experiment at Carimagua with four grass species and varying rates of P_2O_5, found significant yield responses to all levels of applied P. The biggest response, however, was noted at the 50 kg P_2O_5/ha rate for all species except *Hyparrhenia rufa* (Nees) Stapf. which responded linearly up to 100 kg P_2O_5/ha (Fig. 8). These results are an average of three or four harvests during the first year after establishment. Similar results have been observed by Sánchez, León and Ayarza (3) in a greenhouse trial with *P. maximum* and a *Centrosema* hybrid 1733, on a Quilichao Ultisol. The first inflection point on the response curve was at about 40 kg P_2O_5/ha for the *Centrosema* hybrid and 60 kg/ha for *P. maximum* (Fig. 9).

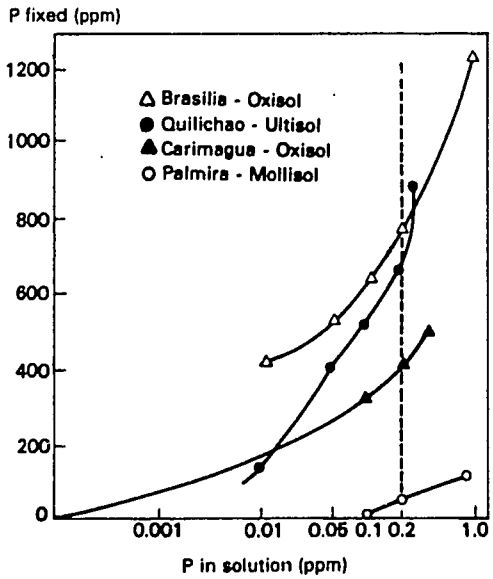

Figure 7. **P fixation isotherms of CPAC-Brasilia, CIAT-Quilichao, CNIA-Carimagua, and CIAT-Palmira (3).**

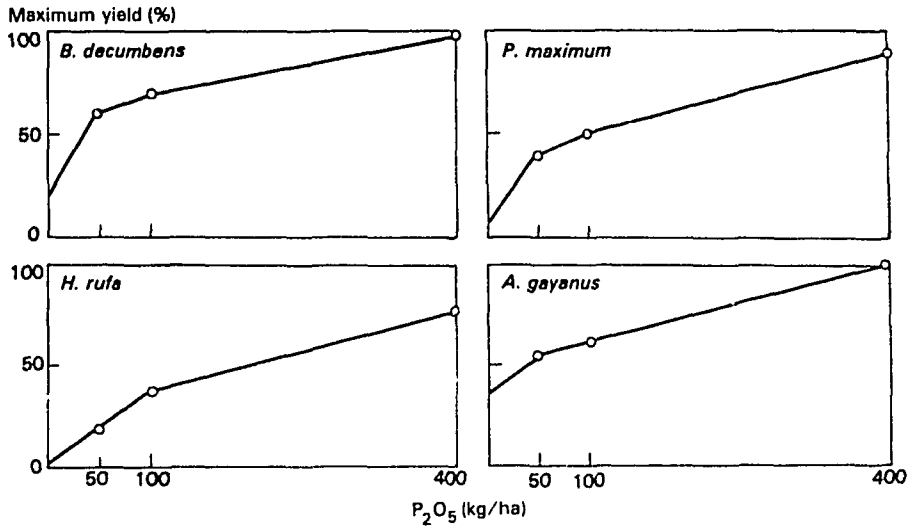

Figure 8. **The relative yield response of four grasses, grown on a Carimagua Oxisol, to varying levels of P. Average of three to four harvests one year after establishment.(Adapted from 3).**

It is imperative that growth response curves with P be run on all of the promising grass and legume pasture species under a variety of soil conditions, in order that a higher degree of confidence can be established in making fertilizer P recommendations in tropical Latin America.

USE OF CHEAPER SOURCES OF PHOSPHORUS

The use of PR as a P source for pasture production appears both economically and agronomically attractive. Not only is the unit cost of the P much cheaper, one-third to one-fifth that of TSP or SSP (12), but the residual value of the product is likely to be greater than the more soluble P carriers. Since the soil P deficient Oxisols and Ultisols of tropical Latin America generally fix large quantities of P (Fig. 7), PR is often more effective than SSP or TSP (4). Also, since PRs are more reactive in acid soils than in neutral or calcareous soils it is likely that release of available P is more in unison with the growing forages needs, thus possibly reducing the incidence of P fixation by the soil. Other factors related to the effectiveness of the PRs would be their solubility and fineness of particle size.

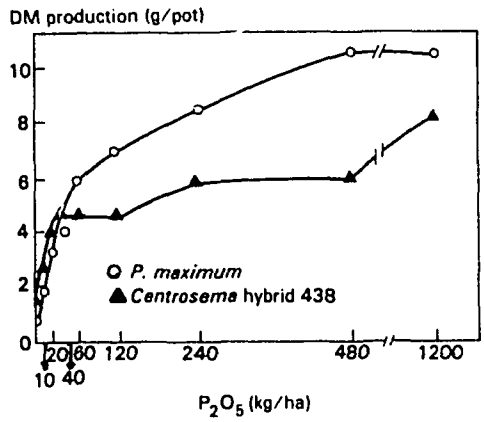

Figure 9. **Effect of varying levels of P on yield of two forage species (two cuttings), grown in a greenhouse on a CIAT-Quilichao Ultisol (3).**

The reactivity or relative agronomic effectiveness (RAE) of the PRs in Latin America (Fig. 10) are generally low to medium (5). With time, however, these PRs appear to be an effective source of P in forage production (3, 7, 8, 9).

A number of forage production experiments have been conducted in tropical Latin America using the direct application of PR. Recent works in Brazil and Peru by North Carolina State University (7, 8, 9) and in Colombia by the International Fertilizer

Figure 10. Rock phosphate deposits in tropical South America, 1977.

Development Center (IFDC) and CIAT (3, 5) have shown very encouraging results.

In the Cerrado of Brazil, North Carolina State University and Cornell (7, 8, 9) initiated a long-term experiment with various P carriers on pasture production to determine the effect of using cheaper sources of P. Initially, the highly soluble Hiperfosfato (Morocco) PR performed about as well as SSP. The low reactive Araxá PR from Brazil was ineffective at first, however, after two cuts the availability was increased significantly and yields were comparable to other P carriers (Fig. 11). Rates of P used were 86, 345 and 1380 kg P_2O_5/ha. In the Amazon Jungle of Peru, North Carolina State University (7, 8, 9), in another series of pasture experiments, also showed that Hiperfosfato, Florida, North Carolina, and Fosbayovar (Peru) PRs were comparable to SSP in forage production with *P. maximum.* These two experiments are being continued to further assess the residual values of the P carriers.

In a long-term field experiment at Carimagua, using *B. decumbens* and comparing six PR sources with TSP at P rates of from 0 to 400 kg P_2O_5/ha, Hammond and León (3) conclude that TSP was only superior to PR sources of P at the first harvest. Thereafter, all PRs increased their effectiveness with time and in most instances surpassed the yields of the TSP treatments by the third harvest. After five cuttings, taken over an 18-month period, it would appear that 50 to 100 kg P_2O_5/ha are adequate for near maximum production of *B. decumbens,* regardless of the P carrier used (Fig. 12).

From the previously described experiments, it is apparent that the medium and low reactivity PRs, although they perform well with time, are initially inferior to the more soluble P carriers. The works by McLean and Wheeler (6) would indicate that partially acidulating these PRs to levels of 10 to 20% could overcome this problem. The partially acidulated PR would provide a soluble source of P initially while still maintaining the desirable characteristics of low cost and residual value of the PR. The soluble P in the partially acidulated PR might stimulate the plants initially so they can make more efficient use of the unreacted PR

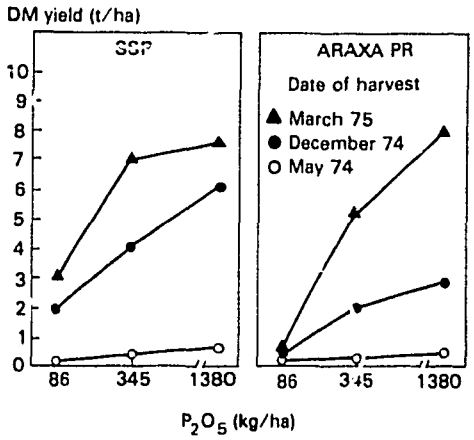

Figure 11. **Effect of time, and source and rate of P on yield of *B. decumbens* grown on a Cerrado Oxisol. (Adapted from 8).**

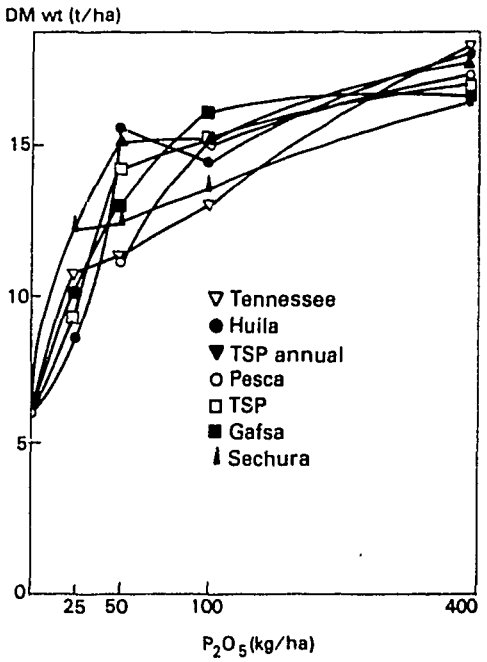

Figure 12. **Effect of P carrier and rate on yield of *B. decumbens* (five cuttings) grown on Carimagua Oxisol. (Adapted from 3 and unpublished data).**

when the soluble P is exhausted. Furthermore, since the P in the unreacted PR is probably becoming available over a period of time, thus providing a continuous supply to the plants, perhaps the adverse common ion effect of the Fe and Al will be somewhat overcome. Although no work has been published in tropical Latin America on the use of partially acidulated PR in pasture production, some research with beans (1) has shown very encouraging results.

USE OF SOIL AMENDMENTS TO ENHANCE THE AVAILABILITY OF APPLIED PHOSPHORUS

One of the main problems encountered with the acid, P deficient Oxisols and Ultisols of tropical Latin America is their fixation capacity (Fig. 7). In order to decrease this fixation capacity, soil amendments such as lime or Ca silicates are sometimes applied to neutralize the exchangeable Al. It is important here to note that the concept of adding lime to make the native P in the soil more available is probably erroneous in the acid, P deficient soils of tropical Latin America. Since the total amount of P in these soils is so low, it is unlikely that adding lime would appreciably increase its availability. The concept of adding lime to increase or maintain the availability of applied P, however, has merit.

North Carolina State University conducted a lime-P pasture experiment with *P. maximum* in the Amazon Jungle of Peru (7, 8, 9). In this experiment lime levels varied from 0 to 3.5 t/ha and P, as SSP, from 0 to 200 kg P/ha. The researchers conclude that, "there was a strong response to superphosphate, a lesser one to lime applications, and an interaction between the two. Without lime, an annual application of 50 kg P/ha seems to be the optimum, with a total DM production of 20 t/ha/yr. When lime was applied in the absence of superphosphate, DM production increased to 19 t/ha/yr. When lime was applied at either 2 or 3.5 t/ha and superphosphate at 25 kg P/ha, maximum DM production of 25 t/ha/yr was reached" (Fig. 13). The researchers further indicated

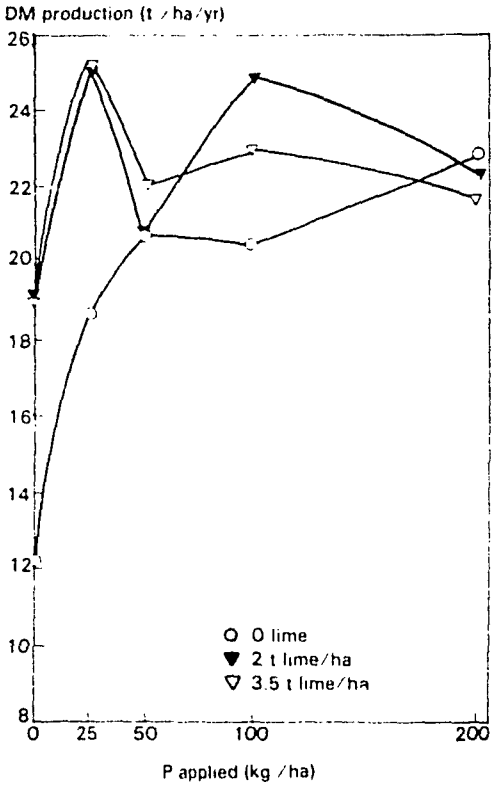

Figure 13. **Effect of P (SSP) and lime on yield of *P. maximum* (six cuttings) grown on a Yurimaguas Ultisol. (Adapted from 8).**

that although the Al saturation was fairly high (64%), only 4 t/ha of $Ca(OH)_2$ was needed to completely neutralize the exchangeable Al. This was because of the sandy texture of the surface horizon of this soil. Nevertheless, this experiment is very important as these sandy textured Ultisols cover large areas of the Amazon Jungle, and other parts of Latin America.

In another pasture experiment, conducted by North Carolina State University (7) at the Cerrado Center in Brazil, varying lime and P rates were applied using *B. decumbens* and *Stylosanthes humilis* H.B.K. as test crops. After two cuttings the *B. decumbens* appeared to respond to the 4.5 t lime/ha at P rates of 86 and 345 kg P_2O_5/ha (Fig. 14). The yield increase from the lime was about 1

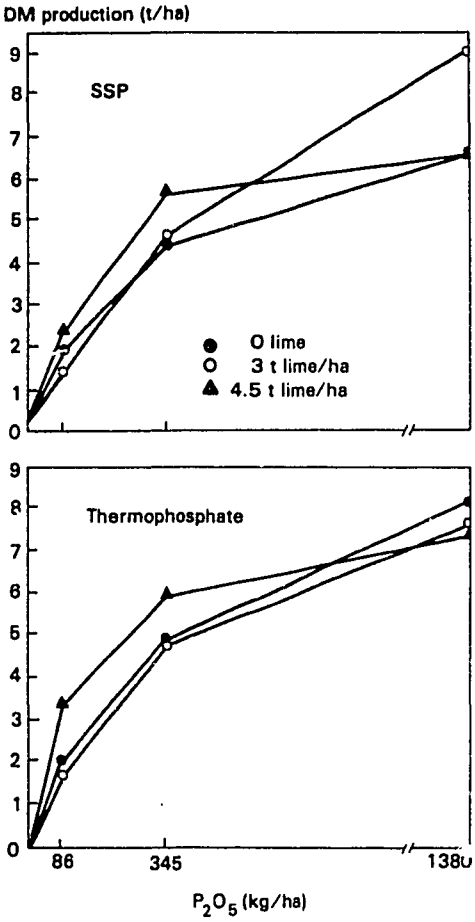

Figure 14. **Effect of P and lime on yield of *B. decumbens* (two cuttings) grown on a Cerrado Oxisol. (Adapted from 8).**

t/ha for both SSP and thermophosphate. When PR was used as a P source, lime tended to depress the yields.

With *S. humilis* the researchers obtained significant yield responses to lime (Fig. 15). They state, "this is of interest since other workers have shown that this and other *Stylosanthes* species favor only moderate Ca levels. This response was particularly apparent at the rate of 345 kg P_2O_5/ha with ordinary superphosphate and thermophosphate, where yields more than tripled with increasing rates of 0, 1.5 and 4.5 t lime/ha".

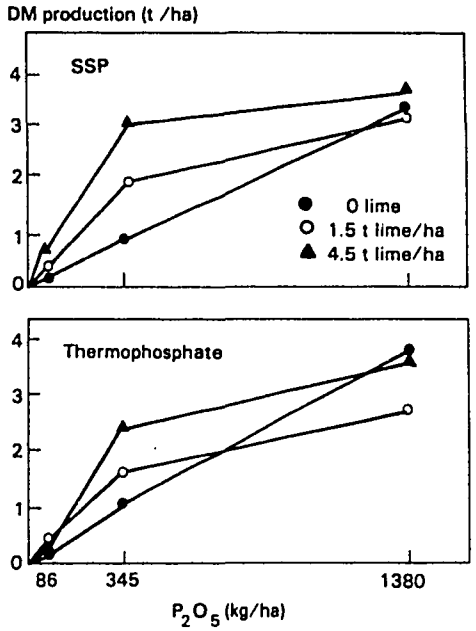

Figure 15. **Effects of P and lime on yield of *S. humillis* (one cutting) grown on a Cerrado Oxisol. (Adapted from 8).**

León (3) conducted a greenhouse experiment, using a Carimagua Oxisol, in which varying rates of P were applied with combinations of Ca silicate, lime and Mg oxide. In all cases the addition of one or more of the amendments significantly increased the yield of *Stylosanthes guianensis* (Aubl.) Sw. (two cuttings) over that of TSP applied alone (Fig. 16). The highest yield was obtained with TSP plus additions of Mg oxide and Ca silicate.

The main problem encountered with many of the P-amendment experiments is determining if the lime or Ca silicate is enhancing the availability of the applied P or whether there is an additional nutrient response. On these acid soils Ca and Mg deficiencies are common, so the additions of amendments may very well be responses to these cations. Research by Smith (13) in Brazil would indicate, however, that there is definitely an amendment effect of neutralizing the exchangeable Al from both the lime and Ca silicate (Table 2).

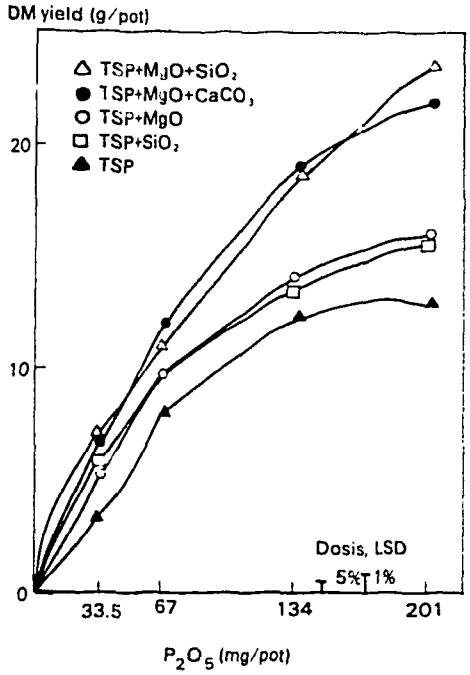

Figure 16. **Effect of TSP, alone and in combination with soils amendments, on yield of *S. guianensis* 136 (two cuttings) grown in the greenhouse on a Carimagua Oxisol. (Adapted from 3).**

CONCLUSIONS

Although there has been a considerable amount of research done on improving pasture production on the acid, P deficient soils of tropical Latin America, it is clear that many problems must still be solved from a P management standpoint. Selecting forage species that utilize limited amounts of P most efficiently must be given top priority. This is very important since most of the soils are not only P deficient but also tend to fix appreciable amounts of fertilizer applied P.

Based on the previously discussed experimental results, it would appear that even the low P requiring plants need substantial amounts of fertilizer P. It is therefore important that cheaper forms of P carriers be used to accommodate these needs. Since PR is the cheapest form of P available it is important that long-term, comparative studies be conducted with the various rocks and their low-cost altered products to ascertain if it is feasible to use them in deference to the more soluble, costly P carriers. Further research is also needed to determine the effect of added amendments on the availability of applied P.

When these problems have been further researched, it should then be possible to make relatively accurate P fertilizer recommendations for any given pasture management scheme. This will only be accomplished when both the plant and soil P needs are better understood and related to the animal's own nutritional requirements.

Table 2. **Decrease in P fixation by lime and silicate applications sufficient to neutralize exchangeable Al in a clayey Oxisol from the Cerrado of Brazil with an original pH of 4.6, 1.45 meq Al/100 g and 80% Al saturation. (Adapted by Sánchez (12) from Smith (13)).**

Amendment applied	P fixed to give 0.03 ppm P in solution	0.10	0.20	Decrease in P fixed 0.03 ppm P in solution	0.10	0.20
	ppm			%		
None	230	325	415	-	-	-
Lime (1.5 t/ha)	135	275	370	41	15	11
Calcium silicate (1.8 t/ha)	125	265	355	46	18	14

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FIELD RESPONSES BY TROPICAL FORAGE LEGUMES TO INOCULATION WITH *RHIZOBIUM*

Jake Halliday*

ABSTRACT

A large collection of strains of *Rhizobium* has been assembled and is under evaluation in symbiotic association with tropical forage legumes adapted to acid, infertile soils. First the strains are assessed for genetic compatibility with the host plant. Then their symbiotic N fixation potential under optimal conditions is determined. The strains with greatest potential are tested for ability to nodulate their host and fix N under acid-soil stress in pot culture. Peat inoculants incorporating selected strains were applied to the seeds of promising tropical forage legumes sown into acid soils under field conditions. Seed pelleting with calcium carbonate or rock phosphate was compared with a simple non-pelleting procedure. Data are reported for *Stylosanthes guianensis; S. scabra; S. viscosa; S. capitata; S. humilis; S. hamata; Desmodium heterophyllum; D. heterocarpon; D. distortum; Centrosema* hybrid *brasilianum x virginianum; Galactia striata; Macroptilium* sp.; *Pueraria phaseoloides;* and *Zornia* sp. Forage yield responses were obtained in the field at two sites with the majority of the legumes tested. With some species it was advantageous to lime-pellet inoculated seed sown into acid soil. The inoculation response, which was as high as 100% in some cases during early establishment, tended to diminish over time.

It is still widely believed that many tropical forage legumes do not need to be inoculated because firstly they are not specific in their *Rhizobium* requirement (1,13) and secondly effective "cowpea-type" strains are abundant in tropical soils (13,14). A review of pertinent literature reveals that this view is not well-founded. Some species and accessions from genera previously considered promiscuous (1) require specific strains of *Rhizobium* (2,6,10) or form highly effective symbioses with only a few out of the wide array of strains with which they nodulate (4,5,8,17). Site differences in the size of (12,16) and range of strains (16,19) in soil populations of *Rhizobium* are common. It is therefore impossible to predict whether a tropical pasture legume introduced to a particular site will require inoculation. The only valid basis for such a decision is a "need-to-inoculate" trial (3,7). This paper reports the results of laboratory, growth room, greenhouse and field trials to develop *Rhizobium* strain and technology recommendations for inoculation of forage legumes in Oxisols and Ultisols of the Latin American tropics.

MATERIALS AND METHODS

Strains of *Rhizobium* used in these trials were collected, isolated, characterized, and are preserved using the methods described

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by Date and Halliday (9). Details of the origin, cultural characteristics, and effectiveness responses of the strains have been catalogued (11). Methodologies employed in the five stages of the strain selection program are outlined in Table 1.

RESULTS

Stylosanthes

The reaction of six of the 35 strains of *Rhizobium* tested in Stage I against five *Stylosanthes guianensis* (Aubl.) Sw. accessions and one *Stylosanthes scabra* Vog. accession are given in Table 2. Certain strains which were highly effective in N fixation in the Stage II assessment with some accessions failed to nodulate others (Table 2). CIAT 71 was frequently high in the effectiveness ranking but did not nodulate one of the *S. guianensis* accessions. CB756 (CIAT 79), the wide spectrum, cowpea-type strain often used to inoculate *Stylosanthes* performed poorly in these tests, averaging only 17th in effectiveness order. CIAT 630 failed to nodulate any of the *S. guianensis* accessions but was one of the most effective strains in symbiosis with *S. scabra*.

Table 1. **Procedure for *Rhizobium* strain selection.**

Stage	To assess	Method
I	Genetic compatibility	Inoculation of plants cultured aseptically in agar deeps of Jensen's medium in 150 x 25 mm tubes (18). Five replicates. Data: + or - nodulation.
II	Nitrogen fixation	Inoculation of plants cultured in Leonard jar assemblies using washed river sand as rooting medium and Norris and Date's nutrient solution (15). Five replicates. Data: DM and N content.
III	Symbiotic effectiveness under acid soil stresses	Inoculation of plants cultured in pots of site soils. Five replicates. Data: DM and N content.
IV	Expression of N-fixing potential under field conditions*	Field trial of three best strains from III inoculated by three techniques (simple inoculation, lime pelleting and rock phosphate pelleting). Randomized complete block design (three replicates) using 4 x 2 m plots with 1 m drainage canals around each. Data: DM 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 N fertilized plots. Three replicates. Data: DM and N content; % nodulation due to inoculant strain.

* At two acid soil sites, Quilichao and Carimagua, in Colombia (5).

Table 2. **Relative symbiotic N fixation effectiveness[a] of *Rhizobium* strains with *Stylosanthes* accessions.**

	Stylosanthes accession[c]					
Strain[b]	184	136	107	64A	1152	1053
CIAT 71	1	4	6	4	NN[d]	4
CIAT 301	6	5	5	22	NN	NN
CB 756	12	14	24	23	16	13
CIAT 308	3	8	7	13	2	1
CIAT 693	11	1	8	6	11	26
CIAT 530	NN	NN	NN	NN	NN	3

[a] Value is place of strain in list of 35 strains ranked in order of effectiveness (Stage II)

[b] Only six out of the 35 strains are included

[c] All *S. guianensis* except 1053 which is *S. scabra*

[d] No nodulation.

Strains CIAT 71, CIAT 301 and CB 756 (CIAT 79) were tested with *S. guianensis* (two accessions), *S. scabra* (two), *Stylosanthes capitata* Vog. (one), *Stylosanthes humilis* H.B.K. (one), *Stylosanthes hamata* (L.) Taub. (two), and *Stylosanthes viscosa* Sw. (two) at Stage III in an acid soil (pH 4.2). All of the accessions responded markedly to inoculation. CB 756 was the most effective strain only in the case of *S. scabra* (CIAT accession 1074). CIAT 71 gave the biggest response in seven of the nine remaining accessions and CIAT 301 in the other two (Fig. 1).

In Stage IV trials at Quilichao with *S. guianensis* accession 136, inoculation with *Rhizobium* and pelleting with rock phosphate increased the forage yield by 75% in the best treatment at the first cut (four months after sowing). At the second cut (seven months) the response was 28% and in the third cut (10 months) it was 50%. The accumulative yield from the three cuts representing 10 months of growth was higher in all of the inoculation treatments than in the uninoculated control (Table 3). Inoculation with *Rhizobium* had no significant effect on the Kjeldahl N content of the foliage at the first cut but increased it marginally over the level in uninoculated plots at the second cut (Table 3).

S. capitata (accession 1078) responded to inoculation at Carimagua, giving an 18% increase in dry matter (DM) yield at the first cut (Table 3). At the second cut however, there was no significant difference between treatments.

Desmodium

Table 4 gives the contrasting compatibility ranges of *Desmodium heterophyllum* DC. and *Desmodium heterocarpon* (L.) DC. when tested at Stage I with 39 strains originally isolated from *Desmodium* species. *D. heterophyllum* nodulated with only 10 of the 39 isolates whereas *D. heterocarpon* nodulated with 34.

The N-fixation effectiveness ranking of strains tested with *D. heterophyllum* and *Desmodium distortum* (Aubl.) MacBr. is given in Figures 2 and 3, respectively. It is noteworthy that the most effective strain for *D. distortum* (CIAT 512) was the only strain in the test that had been isolated from *D. distortum*. Plants inoculated with CIAT 512 gave 33% more DM than those inoculated

Figure 1. Response of three *Stylosanthes* species to inoculation with *Rhizobium* isolates 71 and 301 compared with CB 756 (CIAT 79) and uninoculated control plants. Accession 1009 is *S. scabra;* 1011 is *S. viscosa*, and 136 is *S. guianensis.*

Table 3. **Results of field trials of *Rhizobium* strains and inoculation technologies for *Stylosanthes*.**

Treatment		*S. guianensis* #136 at Quilichao							*S. capitata* #1078 at Carimagua		
No.	Technology	*Rhizobium* strain	Yield I	N in foliage	Yield II	N in foliage	Yield III	Accumulated I+II+III	*Rhizobium* strain	Yield I	Yield II
			kg/ha	%	kg/ha	%	kg/ha	t/ha		kg/ha	
1	zero input*	none	400	3.08	2,852	3.04	2,095	5.35	none	618	2,919
2	uninoculated	none	1,007	3.17	2,810	2.99	2,425	6.24	none	3,567	4,655
3	simple	CB 756	1,142	2.98	3,274	3.16	2,144	6.55	CB 756	2,818	4,560
4	lime pellet	CB 756	1,536	2.98	3,604	3.14	3,475	8.62	CB 756	3.298	3,705
5	RP pellet	CB 756	1,705	2.88	2,726	3.20	2,822	7.26	CB 756	2,760	4,541
6	simple	CIAT 71	1,435	3.17	2,998	3.29	2,349	6.79	CIAT 71	4,108	3,684
7	lime pellet	CIAT 71	1,256	3.09	2,906	3.15	3,242	7.41	CIAT 71	3,773	4,918
8	RP pellet	CIAT 71	1,332	2.75	2,189	3.15	2,878	6.40	CIAT 71	3,574	4,344
9	simple	CIAT 702	1,768	2.87	2,821	3.11	2,660	7.25	CIAT 301	3,482	4,493
10	lime pellet	CIAT 702	1,021	2.92	3,250	3.14	3,000	7.27	CIAT 301	4,142	4,236
11	RP pellet	CIAT 702	1,506	2.99	2,717	3.26	3,382	8.05	CIAT 301	4,200	4,370
12	100 kg N/ha	none	1,308	3.08	2,885	2.98	2,505	6.69	none	3,632	4,734

* All other plots received low inputs of P, K, Ca, Mg, Zn, B, Cu, and Mo.

Table 4. **Contrasting compatibility ranges of *D. heterophyllum* (CIAT 349) and *D. heterocarpon* (CIAT 350) with *Rhizobium* strains.**

CIAT Strain No.*	*D. heterophyllum*	*D. heterocarpon*	CIAT Strain No.*	*D. heterophyllum*	*D. heterocarpon*
13	-	+	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

** + = Nodulated (two or more of the five replicates nodulated).

with CB 627 (CIAT 109), a strain recommended in Australia for *D. intortum.* (Mill.) Urb. Strains used in Australia and the USA to inoculate *D. heterophyllum* CB 2085 (CIAT 80) and 41Z3 (CIAT 31), respectively—were among the best strains in this trial.

Results of Stage III evaluation of strains selected for *D. distortum* and *D. heterophyllum* emphasize the important modifying role played by the soil component in soil/plant/*Rhizobium* interactions. Only one of the strains (CIAT 13) which had shown high N fixation potential with *D. distortum* under optimal conditions in the Leonard jar test was fully effective with this host in a pot trial in site soil with a pH of 4.2. In the case of *D. heterophyllum* only two (CIAT 31 and CIAT 80) out of 10 strains that had formed effective associations in Leonard jars were effective in pots of site soil. CIAT 31, provided by J. C. Burton, the Nitragin Company, was by far the most effective strain.

In a field trial at Quilichao *D. distortum* produced significantly more yield in plots inoculated with a selected *Rhizobium* strain than in uninoculated plots (Table 5). At the first cut the response was 30% and at the second, 18%. The N content and digestibility of foliage in inoculation treatments was not significantly different from the uninoculated controls. *D. heterocarpon* produced 100% more forage in an inoculation treatment (*Rhizobium* strain CIAT 299, lime pelleted) than in the uninoculated control. At Carimagua visual assessments indicate a

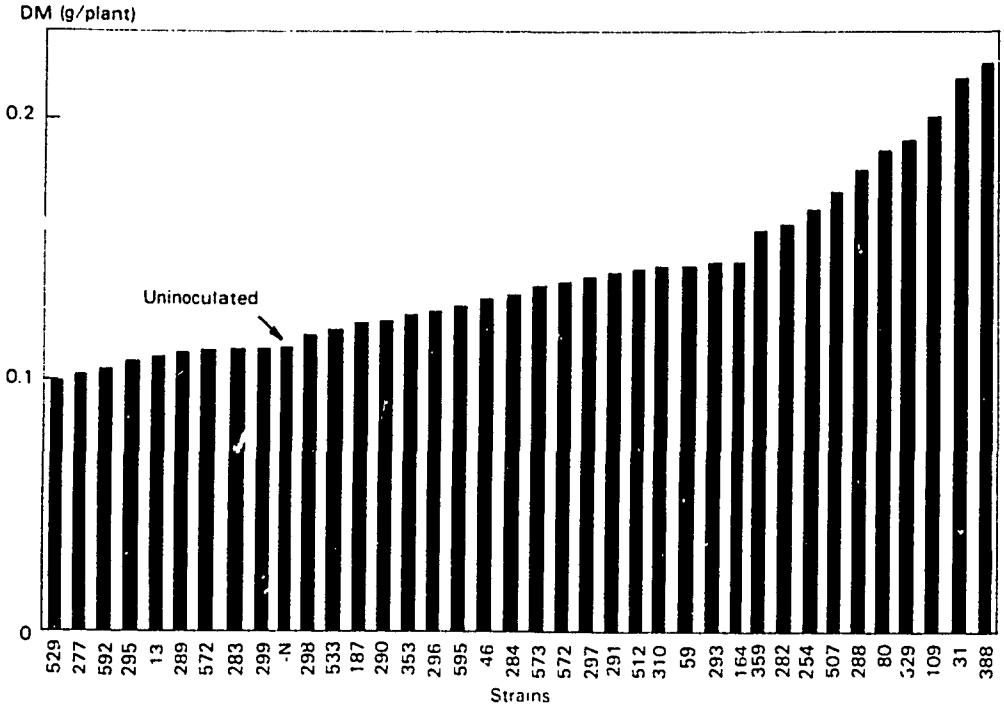

Figure 2. **Effectiveness ranking of strains of *Rhizobium* with *D. heterophyllum*.**

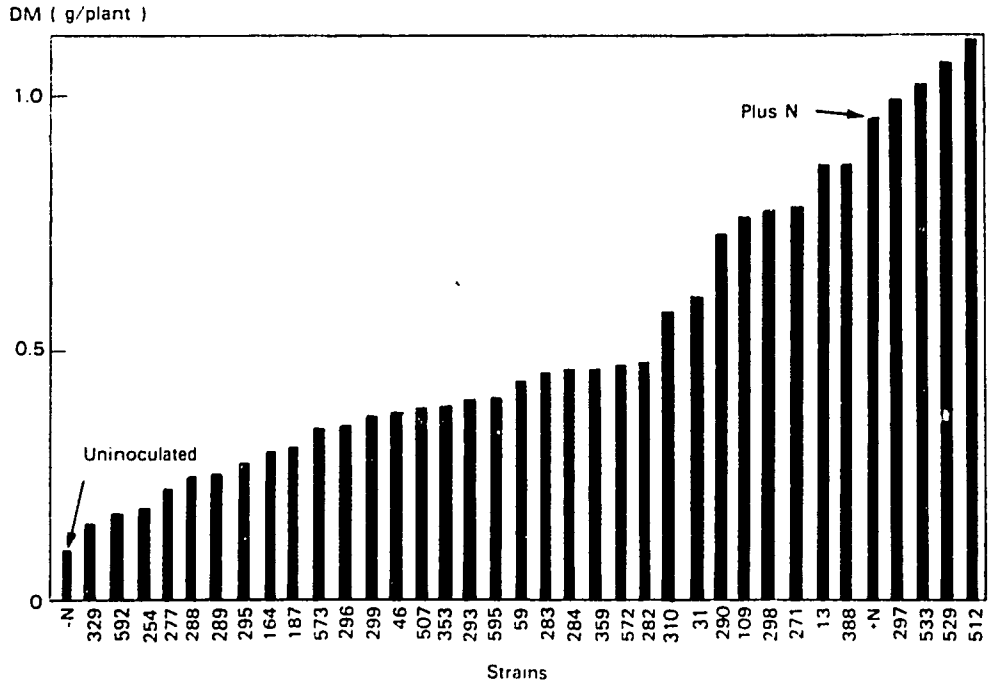

Figure 3. **Effectiveness ranking of strains of *Rhizobium* with *D. distortum*.**

Table 5. **Results of field trials of *Rhizobium* strains and inoculation technologies for *Desmodium*.**

Treatment		*D. distortum* at Quilichao					*D. heterocarpon* at Carimagua		*D. heterocarpon* at Quilichao	
No.	Technology	*Rhizobium* strain	Yield I	N in foliage	Yield II	N in foliage	*Rhizobium* strain	Yield I	*Rhizobiun* strain	Growth*
			kg/ha	%	kg/ha	%		kg/ha		
1	zero input*	none	83	3.96	973	3.85	none	90	none	1.4
2	uninoculated	none	1,440	3.58	2,348	3.61	none	1,034	none	3.8
3	simple	CIAT 529	1,387	3.66	1,705	3.56	CIAT 529	1,887	SU 462	7.0
4	lime pellet	CIAT 529	1,353	4.14	2,331	3.46	CIAT 529	671	SU 462	7.2
5	RP pellet	CIAT 529	1,987	3.83	2,416	3.37	CIAT 529	1,630	SU 462	10.6
6	simple	CB 627	1,802	3.77	2,345	3.40	CB 627	2,034	CB 2085	6.8
7	lime pellet	CB 627	1,862	3.73	2,290	3.62	CB 627	1,104	CB 2085	7.2
8	RP pellet	CB 627	1,967	3.50	2,120	3.39	CB 627	1,274	CB 2085	5.0
9	simple	CIAT 299	1,931	3.80	2,823	3.35	CIAT 299	1,373	CIAT 299	6.8
10	lime pellet	CIAT 299	1,309	3.84	2,461	3.38	CIAT 299	2,067	CIAT 299	7.0
11	RP pellet	CIAT 299	1,381	3.71	2,299	3.45	CIAT 299	958	CIAT 299	5.6
12	100 kg N/ha	none	2,181	3.99	1,963	3.42	none	232	none	9.0

* *All other plots received low inputs of P, K, Ca, Mg, S, Zn, B, and Mo.*

** Plots not cut. Average rating in 5 visual observations. Maximum value possible is 15.

similar response to inoculation of *D. heterocarpon*. *D. heterophyllum* responded markedly to inoculation with CB 2085 (CIAT 80) during establishment at Quilichao but the effect was lost over time.

Centrosema

The symbiotic effectiveness rating of 50 isolates of *Rhizobium* from *Centrosema* species in association with the *Centrosema* hybrid *brasilianum x virginianum* (CIAT accession 438) is given in Figure 4. The commercial strain for *Centrosema pubescens* Benth. (CIAT 48) was only partially effective whereas several local isolates (CIAT 193, 221, 224, 227, 590 and 602) were outstanding, giving higher DM yields than plants grown with combined N. The best two strains (CIAT 583, CIAT 584) were isolated at CIAT using dessicated nodules collected in Mexico from *Centrosema brasilianum* (L.) Benth., one of the parents in the cross. The black nodule strain C 101a (CIAT 49) was among the most effective strains. Crude protein content (Kjeldahl N x 6.25) of shoots of plants with fully effective symbioses averaged 20.7% as against 6% in non-nodulated plants, 11.3% in plants with N available in the rooting medium and 12% in ineffective symbioses.

The results of pot trials in acid soil confirmed CIAT 590 and CIAT 594 as very effective symbionts for this host (Table 6).

Table 6. **Dry matter production by three legume species inoculated with *Rhizobium* in pots of acid soil.**

D. distortum		*D. heterophyllum*		*Centrosema* hybrid *brasilianum x virginianum*	
Rhizobium strain	DM	*Rhizobium* strain	DM	*Rhizobium* strain	DM
CIAT No.	g/plant	CIAT No.	g/plant	CIAT No.	g/plant
13	3.94 (23)*	31	4.80 (139)*	178**	2.25 (3)*
31	3.42 (12)	80	3.14 (62)	193	3.37 (80)
80	2.42	109	1.12 (53)	221	2.26 (1)
109	2.87 (3)	254	2.70 (3)	224	2.95 (27)
271	2.93	282	2.55	227	3.95 (135)
290	2.23 (3)	288	2.20 (26)	314	3.68 (73)
297	2.50 (8)	329	1.19 (31)	583	2.51 (64)
298	2.83	359	2.23	584	3.60 (139)
310	2.34	388	0.87 (3)	590	3.66 (164)
329**	2.61	507	3.61 (4)	810	2.78 (17)
388	2.27	529**	2.37		
512	2.81 (9)				
529	3.27 (20)				
533	2.99 (4)				
592**	2.78 (5)				
Uninoculated	2.37		2.34		3.13 (21)
+ N control	2.22		3.41		3.74 (14)

* mg dry weight of nodules (mg/plant) given in parenthesis

** Ineffective strains from Stage II included for reference.

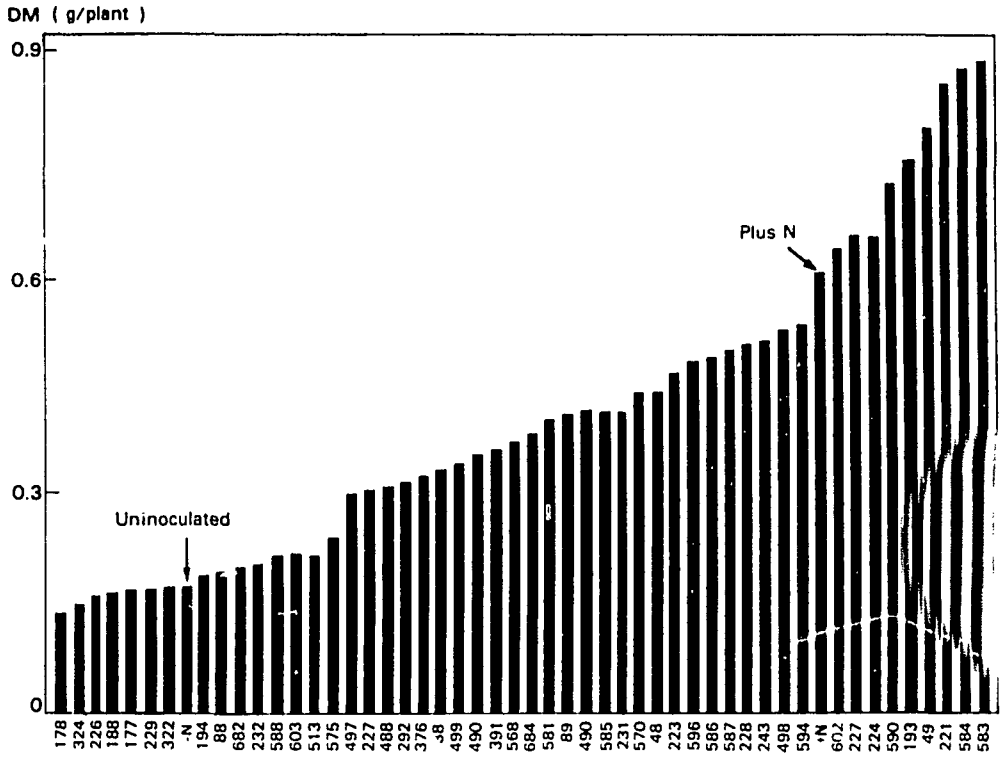

Figure 4. **Effectiveness ranking of strains of** *Rhizobium* **with** *Centrosema* **hybrid** *brasilianum x virginianum*.

Both these strains produced yield responses in a field trial at Quilichao. At the first cut (3.5 months after sowing) inoculation with CIAT 594 boosted yield by 60%. At the second cut (seven months) however, there was no significant difference between treatments (Table 7).

Galactia

Galactia striata (Jacq.) Urb. responded to inoculation with *Rhizobium* strain CIAT 378 pelleted with rock phosphate (Table 7). At the second cut there was no significant difference between treatments.

Macroptilium

A *Macroptilium* species native to the Llanos Orientales of Colombia did not nodulate at Stage I with four out of nine isolates originating from nodules of this genus commonly considered to be promiscuous. In Stage II evaluation all five strains capable of nodulating this host were fully effective in N fixation. In a field trial at Carimagua yield was increased dramatically (98%) by inoculation with *Rhizobium*. Lime pelleting was consistently the best treatment (Table 8). The inoculation response, though less, was still appreciable (41%) at the second cut (Table 8). The very low yield and inconsistent result from the third cut reflects non-adaptation by this species to the stresses of the region, principally in this case *Rhizoctonia*. The same *Macroptilium* sp. gave an 87% response to inoculation at the first cut and 82% at the second in an unreplicated trial at Quilichao (Table 9). The N content of foliage from inoculated and N fertilized plots was higher than in the uninoculated controls.

Table 7. **Results of field trials of *Rhizobium* strains and technologies for inoculation of *Centrosema* and *Galactia* at Quilichao.**

Treatment		*Centrosema* hybrid *brasilianum* x *virginianum*					*G. striata*						
No.	Technology	*Rhizobium* strain	Yield I	N in foliage	Yield II	N in foliage	*Rhizobium* strain	Yield I	N in foliage	Yield II	N in foliage	Yield III	N in foliage
			kg/ha	%	kg/ha	%		kg/ha	%	kg/ha	%	kg/ha	%
1	zero input*	none	647	3.83	5,556	4.32	none	309	4.29	1,303	3.41	3,942	3.62
2	uninoculated	none	1,482	3.57	6,628	4.76	none	766	3.77	2,252	3.46	4,042	3.87
3	simple	SU 634	1,186	3.02	5,962	4.62	CIAT 426	613	4.14	1,981	3.60	4,672	3.62
4	lime pellet	SU 634	1,212	3.40	5,244	4.60	CIAT 426	681	3.87	1,927	3.50	3,789	3.62
5	RP pellet	SU 634	1,264	3.36	6,118	4.52	CIAT 426	696	4.30	1,849	3.52	4,280	3.31
6	simple	CIAT 590	1,467	2.97	5,914	4.49	SMS 2	648	3.96	1,701	3.47	4,036	3.53
7	lime pellet	CIAT 590	1,740	2.86	5,100	4.60	SMS 2	654	3.94	1,610	3.66	4,883	3.99
8	RP pellet	CIAT 590	1,402	3.37	5,314	4.62	SMS 2	628	3.57	1,958	3.67	4,541	3.69
9	simple	CIAT 594	1,839	2.93	5,802	4.75	CIAT 378	738	4.19	1,971	3.69	4,055	3.43
10	lime pellet	CIAT 594	1,769	3,24	6,034	4.58	CIAT 378	743	4.15	1,974	3.06	3,361	3.57
11	RP pellet	CIAT 594	1,553	3.24	5,904	4.55	CIAT 378	917	4.47	1,893	3.67	4,056	3.59
12	100 kg N/ha	none	1,050	3.12	5,662	4.47	none	457	4.47	2,002	2.97	4,331	3.73

* All other plots received low inputs of P, K, Ca, Mg, S, Zn, B, and Mo.

Table 8. **Results of field trial of *Rhizobium* strains and inoculation technologies for *Macroptilium*.**

Treatment		*Macroptilium* sp. at Carimagua				*Macroptilium* sp. at Quilichao	
No.	Technology	*Rhizobium* strain	Yield I	Yield II	Yield III	*Rhizobium* strain	Yield I
				kg/ha			kg/ha
1	zero input*	none	20	335	506	none	770
2	uninoculated	none	383	1,274	1,337	none	1,232
3	simple	CB 756	275	1,489	1,184	CB 756	1,561
4	lime pellet	CB 756	526	1,450	813	CB 756	1,739
5	RP pellet	CB 756	506	1,568	942	CB 756	1,738
6	simple	CIAT 318	333	1,168	860	CIAT 318	1,329
7	lime pellet	CIAT 318	760	1,800	1,358	CIAT 318	1,733
8	RP pellet	CIAT 318	526	1,347	1,163	CIAT 318	863
9	simple	CIAT 319	419	1,345	1,021	CIAT 319	2,073
10	lime pellet	CIAT 319	514	1,525	1,205	CIAT 319	2,106
11	RP pellet	CIAT 319	392	1,373	1,187	CIAT 319	1,051
12	190 kg N/ha	none	235	1,489	1,057	none	753

* All other plots received low inputs of P, K, Ca, Mg, Zn, B, Cu and Mo.

Pueraria

In an unreplicated trial *Pueraria phaseoloides* (Roxb.) Benth. var Javanica (Benth.) Bak. yielded 61% more DM when inoculated with CB 756 (CIAT 79) after three months, but by five months there was no real difference between treatments (Table 9). The N content of foliage was higher in inoculated plants than in uninoculated controls.

Zornia

Zornia sp. CIAT accession 9069 did not respond to inoculation in a three plot trial at Carimagua (Table 9).

Table 9. **Results of three plot inoculation trials with *Macroptilium, Pueraria,* and *Zornia***

Treatment	*Macroptilium* sp. # 535 at Quilichac		*P. phaseoloides* at Quilichao		*Zornia* sp. # 9069 at Carimagua	
	Yield I	Yield II	Yield I	Yield II	Yield I	Yield II
	kg/ha					
Inoculated	984	849 (4.64)*	1,259	2,505 (5.39)*	133	876
Uninoculated	528	467 (4.30)	781	2,425 (4.58)	130	789
+ N Control	590	858 (4.61)	724	1,975 (5.18)	371	1,208

* % N in foliage.

DISCUSSION

Yield responses in tropical forage legumes to inoculation with *Rhizobium* proved to be the rule rather than the exception. To some extent this result can be considered a "special case" in view of the extreme soil acidity of the experimental sites and the use

Table 10. **Recommendations for inoculating promising forage legumes in acid, infertile soils (current March, 1978)**

Species	CIAT No.	Strain of *Rhizobium*	Technology*	Basis for recommendation**
Desmodium heterocarpon	350	CIAT 299	B	II, III, IV
Pueraria phaseoloides	9900	CIAT 79	C	IV
Stylosanthes capitata	1019	CIAT 71	B	I, IV, V
Stylosanthes capitata	1078	CIAT 71	B	IV
Stylosanthes capitata	1315	CIAT 71	B	
Zornia sp.	728	CIAT 79	C	I
Centrosema sp.	1733	CIAT 590	B	II, III, IV
Centrosema sp.	1787	CIAT 590	B	
Centrosema sp.	845	CIAT 590	B	
Desmodium distortum	335	CIAT 299	A	II, III, IV
Desmodium heterophyllum	349	CIAT 80 + 31	C	I, II III, IV
Desmodium leonii	3001	CIAT 299	C	
Desmodium sp.	336	CIAT 299	C	
Glycine wightii	201	CIAT 79	C	C
Stylosanthes capitata	1097	CIAT 71	B	III
Stylosanthes capitata	1405	CIAT 71	B	III
Stylosanthes hamata	118	CIAT 71	B	III
Stylosanthes hamata	147	CIAT 71	B	III
Desmodium barbatum	3063	CIAT 299	B	
Desmodium heterocarpon	365	CIAT 299	B	
Desmodium scorpiurus	3022	CIAT 299	B	
Desmodium sp.	3019	CIAT 299	B	
Galactia striata	964	CIAT 378	C	IV
Macroptilium sp.	535	CIAT 318	B	IV
Stylosanthes sympodialis	1044	CIAT 71	B	III
Teramnus uncinatus	508	CIAT 79	C	C
Aeschynomene sp.	9666	CIAT 79	C	C
Aeschynomene sp.	9681	CIAT 79	C	C
Aeschynomene sp.	9690	CIAT 79	C	C
Alysicarpus sp.	706	CIAT 503	C	S
Centrosema pubescens	5122	CIAT 590	B	
Centrosema pubescens	5124	CIAT 590	B	
Macroptilium atropurpureum	4085	CIAT 79		
Stylosanthes humilis	1304	CIAT 71	B	
Vigna sp.	4016	CIAT 71	C	
Zornia sp.	9179	CIAT 71	C	

* A=not pelleted
B=pelleted with CaCO
C=pelleted with rock phosphate

** Strain selection stages
I=Tube culture
II=Leonard jar
III=Pot trial
IV=Field experiment
V=Regional trial

C=Commercial strain
S=*Strain isolated from same species.*

of unique CIAT forage germplasm lines. However, even commercial cultivars of relatively common tropical forage legumes *(D. heterophyllum* and *P. phaseoloides)* responded to inoculation. Nor can the result be attributed entirely to the refined selection of strains of *Rhizobium* since in the case of *D. heterophyllum* and *P. phaseoloides* yield responses were obtained with the commercially recommended strains from Australia.

On the basis of the results reported here inoculation of tropical forage legumes with selected strains of *Rhizobium* using appropriate inoculation technology is well justified as a strategy to impart early vigor and thereby enhance the legume's competitive ability during establishment in mixtures with grasses. Current inoculation recommendations for promising legume lines and the basis for offering them are given in Table 10. It is encouraging that *D. heterocarpon* and *S. capitata* respond well to inoculation since both are notoriously slow to establish but are otherwise well adapted to the soil and edaphic conditions into which CIAT aspires to introduce them.

The inoculation response tended to diminish over time in some species. This is a cause for concern and raises the question of whether there is a long-term N fixation benefit from inoculation of perennial legumes. Possible reasons for the loss of response are currently under investigation. Although it is suspected that the inoculant strain is being displaced over time by competitive native strains, preliminary results (Belalcázar, personal communication) indicate that, in the case of *S. guianensis* at least, the introduced strain is still dominant in the nodule population at the end of the first year. The possibility that the success of highly effective introduced strains in forming the primary nodule population was attributable to the protection (against soil stresses) afforded by the seed inoculation technology cannot be ruled out. On death of the primary nodules the introduced *rhizobia* are subjected to acid soil stresses and unless they are capable of multiplying to high numbers as free-living members of the soil microflora they will be unlikely to reinfect the roots of their host. For this reason a screening procedure that will ensure that all strains of *Rhizobium* entering the strain selection program can multiply at low pH is considered essential.

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THE POTENTIAL OF ASSOCIATIVE SYMBIOSES BETWEEN NITROGEN FIXING BACTERIA AND FORAGE GRASSES

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ABSTRACT

The biological nature of the "association" of free-living N-fixing bacteria with the roots of grasses is briefly reviewed. There appears to be no appreciable development of a close physiological relationship between the two organisms which could result in a highly efficient transfer of energy source to the bacteria and, subsequently, an efficient transfer of fixed N to the plant. Preliminary evidence indicates that both N fixation and plant growth hormone production by the bacteria may contribute to observed crop response to inoculation with the bacteria. The potential for exploitation of these systems, as currently understood, appears to be minimal. It is suggested, however, that the potential for exploitation of these associations may be realized in the future as a result of plant breeding programs directed toward selection of plants possessing traits favoring the establishment of these associations.

The explotation of biological N-fixing plant/bacteria systems (BNFS) in agronomic practice is not a new idea. Farmers throughout the world have included legumes in their crop rotations for many hundreds of years. This traditional practice was based on the empirical observation that legumes restored, maintained or enhanced soil fertility. It was less than a hundred years ago that scientists explained this phenomenon. They established that a common soil bacterium, *Rhizobium*, could infect and form nodules on the roots of leguminous plants. These bacteria, concentrated in the nodules, formed an association with the plant which was capable of reducing or "fixing" atmospheric N in combined forms which could then be utilized to satisfy the growth requirements for this element by the bacteria, the host plant and, ultimately, by animals and man. A good legume crop could therefore produce a significant N gain in the soil-plant system. The advantage of this is obvious since N is the mineral element most frequently found limiting to crop production. N fixation rates in agronomic legumes commonly range from 50-150 kg N/ha/yr and rates as high as 300 kg N/ha/yr are not uncommon in certain systems (e.g., *Medicago sativa* L.) under favorable conditions.

Once the biological nature of the phenomenon was clarified the potential for agronomic exploitation of legumes on a

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greatly expanded scale was immediately recognized. Agronomists, microbiologists and scientists from many other disciplines collaborated to develop a simple, inexpensive technology permitting the successful establishment of legumes in a wide variety of cropping situations. This involves the practice of inoculation, the placement of large numbers of live *Rhizobium* cells in the soil or on the seeds of a legume at the time of planting, thereby creating a situation favorable for plant infection, nodulation and N fixation soon after seed germination. The methods for selecting *Rhizobium*-legume combinations which will result in maximum N fixation are well established and the procedure is easily applied on a field scale. This methodology may be of particular importance to subsistence farmers and those concerned with forage production, for whom use of N fertilizer is often impossible or impractical. Increased efforts to extend existing inoculation technology will help the subsistence farmer in years to come.

Nevertheless, the use of legumes is frequently impossible for forage producers in the tropics. This may be due to the large land areas involved and the prevalent sub-optimal soil and climate conditions which cannot be altered to favor growth of desired legumes. An ideal solution to the forage producer's dilemma would be the discovery of BNFS in forage grasses which could be manipulated or managed in such a way as to fully exploit their N-fixing potential on an agronomic scale. Such N-fixing grass/bacteria systems are now known to exist. The critical questions which must be asked are concerned with (a) the magnitude of fixation and (b) the potential for agronomic exploitation of these systems. The purpose of this paper is to briefly review the existing information and on that basis provide a critical evaluation of their potential for exploitation.

BIOLOGICAL N-FIXING GRASS/BACTERIA SYSTEMS

Within recent years there have been numerous reports of the association of free-living N-fixing soil bacteria with the roots of different grasses. Most of this work has been reviewed (5). Excitement and interest increased dramatically following the report of Dobereiner and Day (4) of N fixation in an association of *Spirillum* bacteria with the roots of *Digitaria decumbens* Stent. cv. Transvala in Brazil. This report, the result of several years of pioneering work by Dr. Dobereiner and co-workers, was the most detailed evidence for the existence and significance of such systems. This work provided the stimulus for initiation of much-needed research throughout the world.

I wish to review now what we know of the nature of these systems. The bacterium originally implicated by Dr. Dobereiner was tentatively identified as *Spirillum lipoferum*. Subsequent studies have shown the organism to be related but sufficiently different to merit proposal of a new genus, *Azospirillum*, containing two species, *A. lipoferum* and *A. brasiliensis* (9). It has also been shown that representatives of several other genera of free-living N fixing soil bacteria are commonly found associated with the roots of various grasses (10). These reports come from Africa, North America and South America, indicating an apparent widespread distribution of such associations under diverse natural conditions. Several reports (10) confirm the existence of genotype specificity in at least some of the grasses.

The biological nature of these associations varies significantly from the legume-*Rhizobium* system. In legumes, bacteria infect the roots and ultimately penetrate **intracellularly** in the root cortex. A distinctive morphologically differentiated nodule structure is formed, and the bacteria achieve a highly concentrated population within the protective confines of the nodule. This population is linked directly to an energy supply since the vascular system of the root penetrates and ramifies in the nodular tissue. This is a critical consideration. Biological N fixation is inefficient and therefore energetically expensive (11). A large quantity of carbohydrate (energy

source) is required to reduce or "fix" a molecule of N. Bacteria must receive a generous supply of this carbohydrate (photosynthate) in order to achieve significant fixation. The connecting vascular strands perform an additional critical function in the transport of "fixed" N from the nodule to other parts of the plant.

This situation is quite different in the grasses. Evidence which is admittedly restricted in scope indicates a very limited invasion of the root by the bacteria (4,8). The microorganisms penetrate only **intercellularly** in the outer cortical layers of the root. No specialized morphological structure (e.g., nodule) is formed. Viable cortical cells are not colonized. The bacteria are therefore not present in large number **within** the root and those present are not efficiently linked to the energy-supplying transport system of the plant. It appears that the bacteria colonize and achieve large populations primarily at the root surface, where their growth and N-fixing activities are dependent on the supply of soluble carbohydrates which "leak" in various amounts from the roots. In this unprotected situation, these organisms must compete with the other indigenous microbial flora for the available carbohydrates. In addition, N fixed at the root surface is outside the plant and must be mineralized prior to plant uptake. The plant is therefore subject to competition from the indigenous root surface microflora for this N.

Bearing these considerations in mind, let us re-examine the nature of plant response in terms of what is measured and how it is measured. Inoculation of various grasses with *Azospirillum* under field conditions has resulted in beneficial crop response in several instances (10). It has generally been inferred that this was due to N fixation. However, the response is usually reported in terms of DM gain and not N gain. N increases, when consistently observed, are often not statistically significant. Significant N fixation, such as occurs in the legumes, should be measurable by the same widely-used macro-Kjeldahl method. The disturbingly frequent observation that this is not possible creates some doubt concerning the magnitude of N fixation in the grasses. Reports of high rates of N fixation frequently result from measurement by the acetylene reduction assay, which is highly sensitive and highly specific for this process. It is usually used in conjunction with the "excised root technique" (7).

This method involves assay of initially washed segments of roots following a 24 h preincubation in a medium enriched with energy-supplying carbohydrates. Several studies now indicate that the high rates obtained are an artifact of rapid microbial growth in the system prior to measurement (6). These values are erroneously extrapolated to field conditions to give "probable" fixation values which are not real. The efficiency of N fixation in the open or unprotected grass-bacteria field system is highly susceptible to the negative effects of many environmental factors which are minimized under laboratory conditions. N fixation rates as measured by acetylene reduction, in either field or laboratory, may never be achieved in a **sustained** manner which would ultimately result in significant N gain.

It was mentioned earlier that there have been several reports of statistically significant crop response to inoculation as measured by DM yield. Evidence that N fixation is more than a contributing cause is equivocal. Since this response is real or consistent, we must consider possible explanations other than N fixation. Many common soil bacteria, including several plant-associated genera, are known to produce compounds which are similar or identical to plant growth hormones in structure and activity (1). Historically, numerous early works reported beneficial crop response to inoculation with *Azotobacter* or various phosphate-dissolving bacteria, due respectively to N fixation or increased P solubilization and plant uptake. It is now widely accepted that the response is primarily the effect of plant growth hormones produced in the

rhizosphere of inoculated plants (2). It is quite possible that this phenomenon could explain the yield responses reported for the grass/bacteria systems. Laboratory studies at the University of Florida (García, Gaskins, Tien, Hubbell; unpublished) have shown that grasses inoculated with *Azospirillum* show increased shoot and root growth which closely mimics known hormone effects. It has also been shown that pure cultures of *Azospirillum* produce auxin, cytokinins and gibberellin-like substances. These studies are consistent with the earlier work of Brown on the *Azotobacter-Paspalum* association (3).

I must emphasize that my comments so far are based on very preliminary and incomplete studies. It is still difficult to evaluate or compare the studies which now exist. Methodology is inadequate and certainly not standardized. Many critical questions remain uninvestigated and/or inconclusively answered. The comments that I offer in relation to the potential of grass/bacteria BNFS for exploitation is not based on conclusive results but on what I see as emerging trends in the gradually accumulating information.

I do not believe that the grass/bacteria BNFS, **as currently understood,** have major potential for exploitation in crop or forage production systems. My reasons may be summarized as follows: Exploitation implies manipulation of this system. Inherent in this is the practice of inoculation. The success of inoculation depends on the natural limitations of the bacteria in terms of distribution, N fixing ability, and efficiency of the plant-bacteria association. Information now at hand indicates that many kinds of free-living N-fixing bacteria may be associated with grass roots. These bacteria are widely distributed geographically and they do not appear to vary appreciably in efficiency of N fixation. The nature of their association with grass roots appears to be unspecialized and therefore non-specific. In essence, there does not appear to be much chance for selecting special strains which will form superior BNF associations in combination with specific plant hosts. In essence, it now appears that the microbial component is a constant in the system and therefore perhaps not amenable to the manipulation which is routine for *Rhizobium*. The biological nature of these loose or "associative" grass-bacteria systems would seem to preclude the establishment of efficient BNFS which could rival legume-*Rhizobium* systems in N fixation. Efficient means of transfer of energy-supplying carbohydrate from plant to bacteria and means of transfer of fixed N from the bacteria to the plant are severely limiting.

I have presented a deliberately pessimistic assessment of the potential of grass-bacteria BNFS in forage production. However, I believe there is still some reason for guarded optimism. There is some evidence for beneficial plant response to inoculation. The great variability in experimental results is perhaps due to our basic ignorance of the nature of this very complex system. The number of apparently critical variables appears endless at present and experiments which are repeated may well yield different results because they are not in fact duplicates of the original experiment but instead differ in one or more critical details. It is by no means resolved that observed plant response is due primarily to N fixation or to activity of plant growth hormones. There is some evidence to support both explanations. It is therefore reasonable to assume, at least temporarily, that both BNFS and hormones contribute to plant response. It then becomes a matter of determining which factor dominates under which conditions. Once this is understood we can address the problem of improving the system in specific ways, thus clearing the way for manipulation or exploitation of the system. We must understand the system before we can control it.

Some people may be discouraged by the disappointing evidence for "significant" N fixation. This need not be the case. It depends on what one is willing to accept as a minimum value for significance. The legume

system is clearly a more efficient BNFS than is the grass system. It is unreasonable to expect comparable rates of N fixation. A forage grass, growing under N-deficient conditions, and with no prospect of receiving N fertilizer, may justifiably consider any amount of biologically fixed N as significant. The challenge is to gain an understanding of the system, improve it and learn to manipulate it under diverse field conditions. Perhaps the greatest potential for improvement and manipulation resides in the area of plant genetics. There is some evidence that plant response may be more prevalent in primitive genotypes than in hybrid genotypes. If this is valid then plant response is a heritable trait and may be amenable to improvement through plant breeding. It may be worthwhile to select for plant genotypes which inherently possess the many and complex characteristics which favor associative N-fixation, and which may have been "bred out" of our currently used hybrids. Positive results may be slow in coming but, once arrived, would certainly justify the time, effort and expense expended.

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PART III

PASTURE ESTABLISHMENT AND MANAGEMENT SYSTEMS

PASTURES ESTABLISHMENT AND MANAGEMENT IN THE CERRADO OF BRAZIL

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ABSTRACT

The Brazilian Cerrado covers approximately 150 million ha of land and contains nearly half of Brazil's cattle population. As a result of the soil's low native fertility ant the uneven rainfall distribution, there is a serious forage deficiency problem and the productivity indices of beef cattle ranches are very low. The majority of the cattle industry is extensive, extractive and largely limited to cow-calf operations. Nevertheless, if the forage deficiency problem is corrected, the Cerrado offers an enormous potential for cattle raising. In order to accomplish this is imperative to upgrade the carrying capacity of pastures. This can be accomplished by improving the native pastures with the introduction of higher yielding and drought resistant species, but there is no technology available. Another valid alternative is to plant part of the farm to improved pasture species. This is a costly method and requires the use of fertilizers, especially phosphate. It is recommended that pasture establishment be done in association with other crops to facilitate the task.

The Brazilian Cerrado occupies more than 150 million ha, corresponding to about 20% of the land area of that country. Almost 50% of the country's cattle population is concentrated in this area. With regard to natural and socio-economic resources, the Cerrado region shows a cattle industry with rather low productivity indices. However, the potential for improving these indices through the utilization of technology is enormous. The objectives of this paper are to characterize the potential of the region, indicating the principal limitations for cattle production, and to review present knowledge of pasture establishment and management technology.

THE CERRADO REGION

The Brazilian Cerrado extends through the central-western part of the country, reaching into the northern, northeastern and southeastern sections (Fig. 1). About 73% of the region is located in the states of Goiás, Mato Grosso and Minas Gerais. In both ecological and socio-economic terms, however, this region is heterogeneous in distribution and dimension, and one must be careful in extrapolating data.

The Cerrado region brings together a series of favorable characteristics that make

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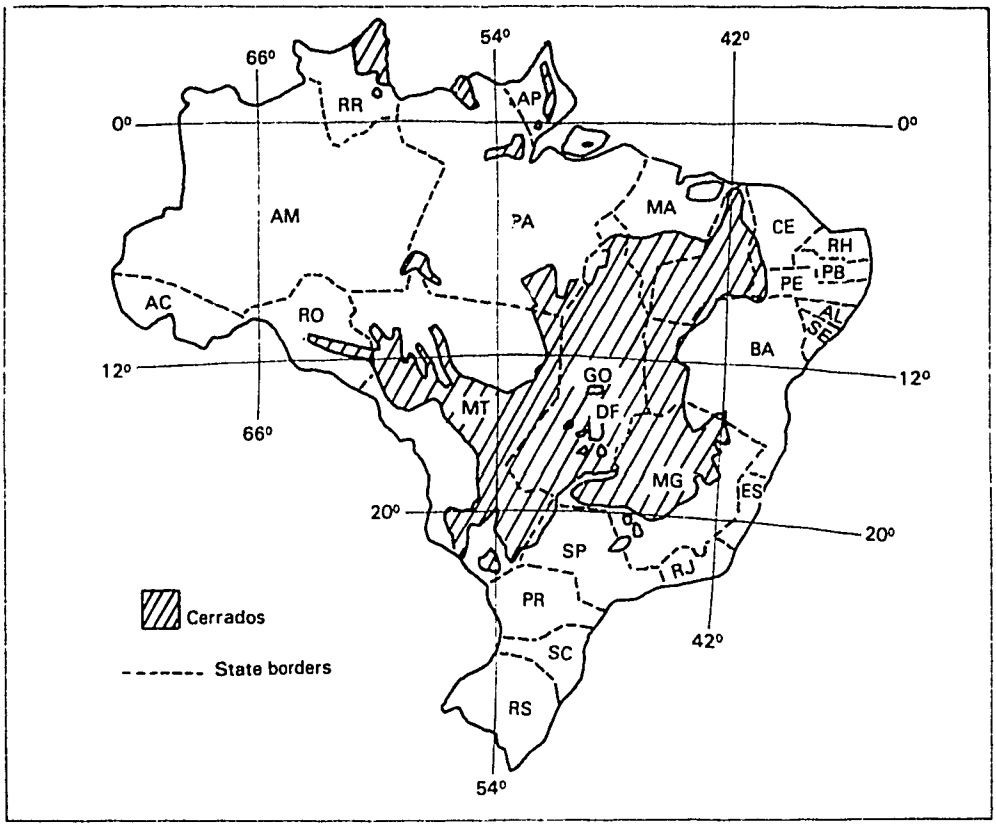

Figure 1. Distribution of the Cerrados region of Brazil including transition areas with other formations (5).

it especially suitable for the agriculture. Topography and physical properties of the soil highly favor year around mechanization. Solar radiation is very high and temperature is optimum for the large majority of crops. Although its distribution is poor, total rainfall is high (Fig. 2). Socio-economically, the Cerrado have improved considerably because of migration generated by the creation of Brasilia, and other cities. Today, a local market exists for a large part of the production and the communication system with other regions has progressed satisfactorily.

Despite its enormous agricultural potential, utilization of the Cerrado has been very limited, because of several technological and socio-economic factors. In the case of beef production, the limitations are intimately related to soils, water, native forage species and infrastructure. These resources are characterized and discussed in more detail.

Soils

Table 1 shows an approximate distribution of the major soil units in the Cerrado. The Latosols (Oxisols), with the Yellow-Red and Dark Red ones predominating, are the most important and comprise about 52% of the Cerrado. They are characterized by being deep, highly-weathered soils of low natural fertility and with a high level of Al saturation, extremely low levels of P and a high capacity to fix this element into non-available forms.

The Quartz Sands (Entisols), that occupy some 20% of the area, are derived from

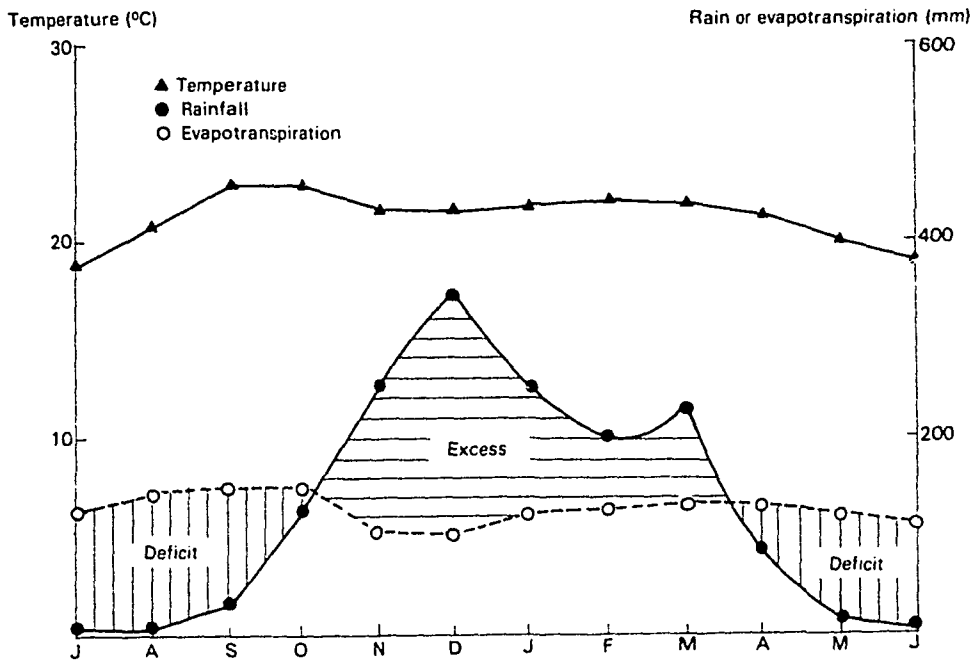

Figure 2. **Water balance and average monthly temperature over 35 years of study in Formosa, Goiás, calculated according to Hargreaves (5).**

Table 1. **Approximate distribution of the most extensive soil units of the continuous area of the Cerrados in relation to the soil taxonomy and the Brazilian system (16)**

Brazilian system	Order	Soil Taxonomy Great Group	Total area	Cerrado
			millions of ha	%
Latossolos	Oxisols			
Latossolo Vermelho Amarelo		Acrustox	69.7	41
Latossolo Vermelho Escuro		Haplustox	17.9	11
Latossolo Roxo		Haplustox	6.9	4
			94.5	56
Areas Quartzosas	Entisols	Quartzipsamments	34.3	20
Laterita Hidromórfica	Ultisols	Plinthaquults	17.0	10
Podzólico Vermelho-Amarelo Distrófico		Ustults	2.1	1
			19.1	11
Podzólico Vermelho-Amarelo equiv. Eutrófico	Alfisols	Ustalfs	7.0	4
Litossolos	-	Lithic groups	15.1	9
Total			170.0	100

sandy sediments and are of very low natural fertility.

The Ground Water Laterites (Ultisols) have very poor drainage during the rainy season; they also have a low natural fertility, but not as low as the Oxisols and the Quartz Sands.

The Red Yellow Eutrophic Podzolic soils (Alfisols) have a high base saturation, are fertile but comprise only about 6% of the total area of the Cerrado. The Lithosols are shallow soils associated with rocks, generally of low fertility and with serious physical and chemical limitations.

Table 2 shows data from chemical analyses of 528 topsoil samples from the central area of the Cerrado taken from Lopes and Cox (9). The majority of the soils analyzed have a pH (H_2O) under 5. More than 90% of the samples had contents of Ca, Mg, P, K and Zn less than the suggested critical level. About 92% of the samples had Al saturation levels over 20%, at which the majority of crops diminish their yields.

Water

Total rainfall is relatively high, varying between, 1,200 and 1,700 mm/yr (2). However, distribution is rather irregular, causing severe moisture deficiency problems. This fact, along with the low water retention capacity of the Oxisols and Entisols difficulties root development, causing drought problems even during the rainy season. Root development difficulties are related to Al toxicity and deficiencies of P, and Ca.

Agro-meteorological data are scarce for this region. Figure 2 shows data obtained in the municipality of Formosa, Goiás, which are considered typical of the Federal District. Rainfall data for other areas of the Cerrado have been presented by Azevedo (2).

Table 2. **Relationship between the native vegetation in the center of the Brazilian Cerrados and topsoil characteristics found in 538 soil samples (9).**

Soil characteristics	Physiognomic type of vegetation				
	Campo limpo (64)*	Campo sujo (148)	Cerrado (225)	Cerradão (45)	Semideciduous forest (16)
pH (H_2O)	4.87	4.94	5.00	5.14	5.28
OM (%)	2.21	2.33	2.35	2.32	3.14
Exchangeable Ca (meq/100g)	0.20	0.33	0.45	0.69	1.50
Exchangeable Mg (meq/100g)	0.06	0.13	0.21	0.38	0.55
Exchangeable K (meq/100g)	0.08	0.10	0.11	0.13	0.17
Exchangeable Al (meq/100g)	0.74	0.63	0.66	0.61	0.78
Effective CEC (meq/100g)	1.08	1.19	1.43	1.81	3.00
Al Saturation (%)	69	58	54	44	40
Available P (ppm)**	0.50	0.5	0.9	2.1	1.4
Available Zn (ppm)**	0.5	0.6	0.6	0.6	1.1
Available Cu (ppm)**	0.6	0.7	0.9	1.3	0.9
Available Mn (ppm)**	5.4	10.3	15.9	22.9	24.1
Available Fe (ppm)**	35.7	33.9	33.0	27.1	37.2
Clay (%)	33	36	34	32	37
Silt (%)	20	16	15	16	16
Sands (%)	46	48	51	53	47

* Number of samples taken

** Extracted by HCl 0.05 *N* + H_2SO_4 0.025 *N*

There is one rainy season which generally begins at the end of September and lasts until April. The dry season coincides with the coldest months of the year (Fig. 2), although the annual temperature variation is slight. The dry season, varying from three to seven months in the region, is the principal factor limiting the development of beef cattle production. As will be discussed later, forage availability during the year is irregular.

After the dry season, it is normal to have short dry periods of one to three weeks during the rainy season, commoly known as "veranicos". However, these become important only when they coincide with pasture establishment.

Forage resources

The native forage resources of the Cerrado still are not well-known due to the size of the region and the large quantity of species present. Besides the grasses, many treelike species also serve as browse, especially during the dry season.

Forage production follows the rainfall distribution curve. Considering the normal carrying capacity of the area (0.2 AU/ha), there is excess forage production in the rainy season and a deficit in the dry season. According to data shown by Vilela (19), the available native forage varies from 1.6 to 2.2 t/ha of dry matter (DM) over the year.

The principal native genera of the Cerrado as are as follows (see 4, 7, 18, 19 for detailed information): Grasses: *Andropogon, Aristida, Axonopus, Ctenium, Eragrostis, Mesosetum, Panicum, Paspalum, Pennisetum, Setaria, Trachypogon* and *Tristachya*. Legumes: *Stylosanthes, Desmodium, Zornia, Cassia, Aeschynomene, Indigofera, Galactia, Crotalaria, Arachis, Bauhinia* and *Centrosema*. Others: *Acanthosperum, Vernonia, Euphorbia, Camarea* and *Borreria*.

Infrastructure

The infrastructure of the Cerrado is still rather deficient, even though appreciable improvements were made in the last decade. The availability of inputs is still irregular and the system of storage, transport and marketing is deficient. Limited infrastructure, plus soil and water limitations, govern the type of cattle industry in the region. Now, in large part, it is still of the extensive type.

BEEF CATTLE IN THE CERRADO REGION

According to Saturnino *et al.* (17), the utilization of the Cerrado for grazing takes four basic forms, each depicting alternating peculiarities inherent to each area of the Cerrado (Fig. 3).

Its use as pasture varies from the simplest of grazing native vegetation to completely clearing the land, followed by liming and fertilization, soil conservation and the introduction of improved grasses and legumes, sometimes preceeded by annual crops. An intermediate alternative is cutting Cerrado vegetation for charcoal and utilization of the natural grasses until a new bush canopy grows. Another alternative is manual clearing, followed by seeding the predominant grasses of the region, without soil preparation.

The methods of utilizing the Cerrado for grazing does not differ much in these regions. Generally, the land is used all year, and especially during the dry season. Large areas of the Cerrado are burned, to stimulate regrowth. The arboreal vegetation is equally important at this time because of the presence of bushes and weeds. Total clearing of the Cerrado and the subsequent formation of improved pastures, however, has steadily been acquiring more importance.

The carrying capacity of the native Cerrado is very low (0.2 to 0.6 AU/ha/yr), and the scarcity of forage during the dry season accentuates this problem.

Because of the low carrying capacity and lack of infrastructure, the dominant type of exploitation is cow-calf operation. On the

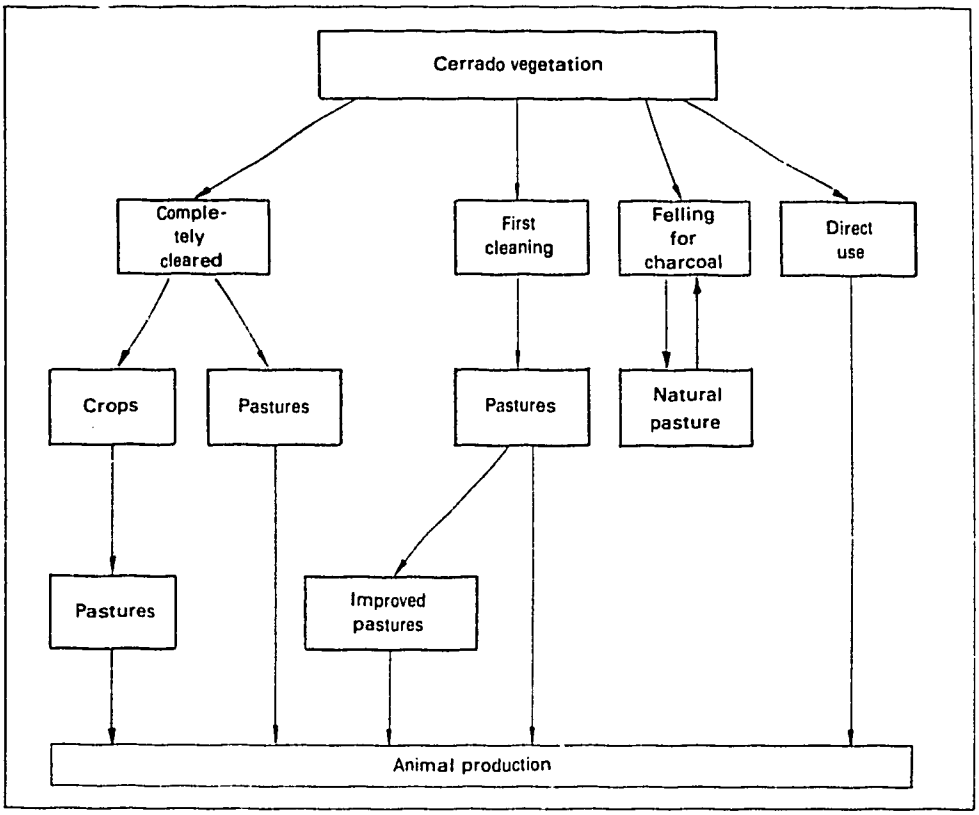

Figure 3. **Alternatives studied for grazing of the Cerrados region.**

average, 60% of the farms specialize in cow-calf, and 35% practice both cow-calf and growing (CPAC, 1977: unpublished data).

The predominant breeds are Zebu types, without defined characteristics, but Nellore bulls have been introduced in Goiás and Mato Grosso and Gir bulls, in Minas Gerais.

The average performance of the beef industry in the Cerrado is rather poor as can be observed in Table 3 (taken from Saturnino

Table 3. **Beef cattle index in the three main states of the Cerrados region.(Summarized from 17).**

Index	Minas Gerais	Goiás	Mato Grosso
Bull: cow ratio	1:50 - 1:30	1:50 - 1:30	1:30 - 1:30
Estrous period	Sept - Mar	Oct - Mar	Oct - Feb
Reproductive rate (%)	35 - 60	40 - 70	40 - 50
Female age at first calving (months)	36 - 60	36 - 48	42 - 54
Calving interval (months)	16 - 28	16 - 24	24 - 30
Weaning (%)	32 - 57	35 - 60	35 - 45
Male age at slaughter (months)	38 - 60	40 - 50	48 - 54

et al., 17). While the calving rate is low, calf mortality is also low, approximately 10%. Thus, a cow produces a calf every 2 to 2.5 years. In addition, principally because of nutrition problems, the first pregnancy occurs at a rather late age. On the average, a cow produces only four or five calves during her life time.

In the last five years a rapid improvement infrastructure has occurred due to several factors: population, improvement in communications, credit availability, increased incentives from the government, etc. As a consequence, agriculture, which was essentially extensive, is being transformed. The diversification of annual crops, such as soybeans and maize, has provided improvements in soil fertility and has facilitated the introduction of more productive forage species.

PASTURE ESTABLISHMENT

Of the four previously described basic forms of using the Cerrado for grazing, the utilization of native pastures in a purely extensive manner, with some changes in the larger vegetation, can be verified as the predominating form.

Nevertheless, the Cerrado region has undergone a significant transformation, principally in some areas where agriculture and cultivated pastures are changing the features of the region. According to data of the Empresa Brasileira de Asistencia Técnica e Extensao Rural (EMBRATER) (personal communication), of the 800,000 ha financed by the POLOCENTRO Project up to 1977, 400,000 were converted into cultivated pastures. Of the other 400,000 ha devoted to crops, 320,000 ha (80%) are being cultivated with rice and after one to three years in crops, they will be converted in pastures. About 1.3 million ha of the Cerrado will be incorporated into a more intensive farming system by the end of 1978.

The potential for cattle production in the Cerrado is very great and Saturnino *et al.* (17), in an effort to delimit it, obtained the following data: raising the carrying capacity from 0.2 to 1.6 AU/ha, would increase by approximately nine times the number of animals available for sale and by 11 times the total weight sold for slaughter, although the area would remain constant.

It is evident that despite the interest for improving the natural forage resources by introducing and establishing genetically improved species, without destroying the native vegetation, only a part of the Cerrado region is likely to be covered with cultivated pastures.

Pasture establishment methods

Establishment methods range from the rudimentary, with or without using small amount of inputs, up to complete clearing of the land, application of lime and fertilizers and certified seed.

Establishing forage species in native pastures

Introducing forage species into native pastures can be done in different ways such as, burning, clearing, making furrows and grading.

Burning is a widely-used practice in the Cerrado. The objective is to eliminate unpalatable vegetation and promote high quality regrowth near the end of the dry season. It adversely affects some species, especially some legumes and the grass *Melinis minutiflora* Beauv., as can be seen from Table 4. Burning, along with phosphate fertilization and liming, however, provides better establishment of introduced species. However, development is precarious and does not affect DM production, which reveals the predominance of native vegetation (Table 4).

Partial clearing the Cerrado is another method used in more fertile soil areas, generally bordering watercourses or the small areas of "Cerradão", where *M. minutiflora* and *Hyparrhenia rufa* (Nees)

Table 4. **Total *M. minutiflora* and legume plant population and DM production in Unaí, Minas Gerais (5).**

Treatment		Land Preparation	Pasture status	*M. minutiflora*	Legumes	DM
P_2O_5	Lime					
kg/ha	t/ha				plants/15 m²	kg/ha
0	0	Burning	Native savanna	0	0	940
			M. minutiflora	0	0	820
			M. minutiflora + legumes	0	4	970
		Burning	Native savanna	0	0	0
		+	*M. minutiflora*	11	0	0
		Raking	*M. minutiflora* + legumes	4	22	0
		Raking	Native savanna	0	0	0
			M. minutiflora	19	0	900
			M. minutiflora + legumes	46	34	0
220	0	Burning	Native savanna	0	0	1190
			M. minutiflora	14	1	960
			M. minutiflora + legumes	1	17	1100
		Burning	Native savanna	0	0	0
		+	*M. minutiflora*	76	0	1070
		Raking	*M. minutiflora* + legumes	33	50	1560
		Raking	Native savanna	0	0	0
			M. minutiflora	177	0	780
			M. minutiflora + legumes	28	55	1180
220	1	Burning	Native savanna	0	0	1060
			M. minutiflora	8	0	840
			M. minutiflora + legumes	72	28	820
		Burning	Native savanna	0	0	0
		+	*M. minutiflora*	24	0	1280
		Raking	*M. minutiflora* + legumes	75	46	1240
		Raking	Native savanna	0	0	0
			M. minutiflora	149	0	840
			M. minutiflora + legumes	78	39	1080

Stapf. establish spontaneously. Partial clearing and seeding these species, without any other treatment to the soil, is a common procedure that allows better pasture establishment by increasing the available sunlight. Ferreira *et al.* (6) obtained similar production of DM and protein from *M. minutiflora* with total or partial clearing, both followed by fertilization.

Extensive areas of Cerrado covered with grasses are called "campo limpo"; there exotic species can be established more easily, principally by using furrows. This method is not widely used because of lack of adequate machinery, and the fact that "campo limpo" soils are of extremely low fertility, requiring large amounts of fertilizers. Vilela (20) introduced *M. minutiflora* and *Stylosanthes guianensis* (Aubl.) Sw. in fertilized furrows one meter apart opened with Caterpillar tractors and plows. The pasture retained its composition of native grasses, *M. minutiflora* and *S. guianensis.*

Forage species can be established in "campo limpo" as well as "campo sujo" (grasses with scattered brush) using only a harrow, thus decreasing establishment costs. Work done by the Centro de Pesquisa

Agropecuaria dos Cerrados (CPAC), in the municipality of Unai, Minas Gerais, shows the advantage of using a harrow in establishing *M. minutiflora* and legumes, especially when it is accompanied by phosphate fertilization (Table 4). The native grasses with their tussock growth habit were easily destroyed by harrowing and their slow regrowth allows the establishment of the introduced forage species. Legumes seeded at this time germinated but did not establish themselves due to lack of adequate contact with the soil, a fact also observed by Ferreira *et al.* (6). Reis and Barreto (13) obtained good establishment and persistence of tropical legumes introduced only by harrowing the soil surface of native savanna. Vilela (20) obtained good establishment of the legumes *S. guianensis* and *Macroptilium atropurpureum* (DC.) Urb., by harrowing the Cerrado after clearing and fertilizing. In addition to the legumes, other vegetation was composed of *M. minutiflora, H. rufa,* native grasses and weeds and brush.

Establishment of forage species after total erradication of native vegetation

Owing to high operating costs, in areas where the native vegetation has been eradicated, pastures should be well-established and able to persist for long periods. Poor soil preparation and inadequate fertilization are the principal factors responsible for the regrowth of native vegetation and the disappearance of improved forage species in a short time.

Pasture establishment methods vary according to the area to be seeded, machinery available and farmer's level of technology.

Pastures can be planted alone or with an annual crop. In either case, the seeding method is either broadcast (manual or mechanical) or planting in furrows.

Traditionally, in the Cerrado region, pastures are established alone immediately after clearing the land or after upland rice has been grown for one to three years (17). Seeding in association with rice and maize is one practice that has expanded in recent years contributing to lowering pasture establishment costs.

Broadcast seeding, either manually or mechanically, has not provided good results (1, 6). Seeds that remain on the soil germinate, but only a small percentage establish. The short but intense rains are the principal reason of poor establishment. This situation can be improved with seeding at very much higher densities (11), but as this increases the costs. It is recommended to cover the seeds for establishment.

Seeding forage species in furrows, either alone or simultaneously with an annual crop, is relatively common. Fertilizer-seeder implements are utilized for annual crops like rice, soybeans and wheat. The efficiency of seeding in furrows can be observed in Table 5, where the number of plants per m^2 was very superior to that of broascast seeding, confirming the data obtained by several authors (11, 14).

CPAC initiated two experiments to study methods of seeding and establishing forage species after the total eradication of vegetation and soil preparation. Although these trials have yet to be completed, some observations and comments can be made.

Table 5 shows results obtained with different forms of establishing forage species in rice crops. Without corrective phosphate fertilization, planting forage species did not affect rice production, regardless of the seeding methods used. Generally, establishment of forage species that were broadcast or planted between the rice rows was weak, because of P deficiency. With P fertilization, rice production suffered a marked reduction when *M. minutiflora* was planted. Seeding *Brachiaria decumbens* Stapf. between the rice rows produced a greater decrease in rice production, because of the better development and competition of the forage with the rice. When *B. decumbens* was broadcast, the

Table 5. **Upland rice production and forage plant population when grown together with rice, with or without the application of phosphate fertilizers (5).**

Forage species	Seeding system	Forage plant population		Rice yield	
		0	230 P_2O_5	0	230 P_2O_5
		Plants/m²		t/ha	
B. decumbens	Broadcast	2.1	2.7	0.95	1.66
	With rice	4.7	3.5	0.95	1.63
	Between rice rows	6.4	8.7	1.08	1.24
M. minutiflora	Broadcast	23.9	57.6	1.09	1.27
	With rice	36.4	70.7	0.98	0.97
	Between rice rows	40.7	86.5	1.04	1.19
C. pubescens	Broadcast	3.1	2.1	0.76	1.84
	With rice	11.5	11.4	1.01	1.74
	Between rice rows	12.1	15.4	0.92	1.83
S. guianensis	Broadcast	6.3	7.9	1.02	1.93
	With rice	6.2	6.5	1.17	1.95
	Between rice rows	7.5	7.2	0.70	1.97
Rice only				0.97	1.86

decrease in rice yield was not marked, because it was less competitive.

It is possible that the use of annual crops over two to three years allows the recovery of the initial investment in liming and phosphate fertilization. Also, one can assume that the residue formed by the rice straw with the forage species could be utilized as a supplement for the animals during the dry season, with its quality improved by forage legumes. The crude protein in the residue varied from 5.8 to 7.8% and the *in vitro* digestibility, from 43.6 to 51.9%. The quantity of straw in the rice harvest was more than 1.4 t/ha of DM, in fertilized plots seeded with *M. minutiflora*.

In 1976, CPAC began another experiment on a Dark Red Latosol with the primary objective of comparing four cropping sequences of which three were aimed at pasture establishment (Tables 6 and 7). A cleared area of 80 ha received 4 t/ha of lime (PRNT = 53%), 90 kg K_2O/ha, 8 kg/ha of zinc sulfate and 0.5 kg/ha of sodium molybdate. Two levels of phosphate fertilization were used: 120 and 240 kg P_2O_5/ha. In the plots where the species were seeded with rice, half of those quantities was used.

Seeding was made during November with a Brillion seeder. In the rice/grass plots (S_2) the rice was seeded first, followed by the mixture of forage species.

Table 6. **Sequences for established crops.**

	First year	Second year	Third year	Fourth year
S_1	Pasture	Pasture	Pasture	Pasture
S_2	Rice + pasture	Pasture	Pasture	Pasture
S_3	Rice	Rice	Rice + pasture	Pasture
S_4	Soybean	Soybean	Corn	Soybean

Table 7. **Forage species, germination and amount of seeds/ha in the direct establishment (5).**

Species	Germination	Amount of seeds
	%	kg/ha
B. ruziziensis	50	6
S. guianensis cv. Endeavour	75	3
C. pubescens	70	4
M. atropurpureum cv. Siratro	70	3
G. wightii cv. IRI 1394 and 2705	71	1.5

Table 8 shows the results of fresh matter production (FM) and the percentage stand of each species, for those plots planted directly with forage species. Yields of FM, 130 days after seeding, were very different in the two levels of phosphate. In the first cutting, in March 1977, the predominance of *B. decumbens* was very marked, especially at the level of 240 kg P_2O_5/ha. Because it was not possible to graze the plots, in April 1977, hay was made. Yields were 675 and 1,462 kg/ha of hay for the levels of 140 and 240 kg P_2O_5/ha, respectively. After this cutting, abundant rains fell and stimulated regrowth. In May 1977, it was possible to harvest seed of *B. decumbens* obtaining 35 and 110 kg/ha for the levels of 120 and 240 kg P_2O_5/ha, respectively. Seed harvesting was done with a Penha combine.

In the sampling at the beginning of the rainy season (Sept. 9), a decrease in the percentage of *B. decumbens* and a considerable increase in the percentage of legumes were observed. It is very possible that the rapid growth of *B. decumbens* had hindered the legumes during their initial establishment, but they recuperated afterwards because they endured the drought better. Furtado *et al.* (1977), cited by Vilela (19), also observed similar results of the increase in percentage of legumes.

In those plots where the grass was seeded with rice (S_2) the quantity of grass decreased in the dry season, owing to the grazing of the animals. The available forage was 1.52 and 2.75 t/ha of FM for 120 and 240 kg P_2O_5/ha, respectively, in August 1977.

Sampling done in December 1977, at the beginning of the second rainy season, indicated good establishment of the pasture seeded with rice (Table 9). The percentage of *B. decumbens* was much higher at 240 kg P_2O_5/ha for the two types of pasture establishment. In plots seeded directly with forage species, a larger proportion of other grasses, especially *M. minutiflora* and a

Table 8. **Fresh matter (FM) production and percentage botanical composition of *B. decumbens* and legumes at the two phosphate fertilization levels. (CPAC, 1977; unpublished).**

Sampling date	P_2O_5 applied	Total FM	Grasses		Legumes		Weeds	
			FM	%	FM	%	FM	%
	kg/ha				kg/ha		kg/ha	
March 26-30	120	933	816	87.4	117	12.6	-	-
	240	3146	3053	97.1	92	2.9	-	-
August 15-16	120	1526	N.S.*	N.S.	N.S.	N.S.	N.S.	N.S.
	240	2752	N.S.	N.S.	N.S.	N.S.	N.S.	N.S
September 30	120	1860	752	40.5	618	33.2	490	26.3
	240	2868	2000	69.7	246	8.5	623	21.7

* No separation made

Table 9. **Fresh matter (FM) production and botanical composition of directly formed pastures and pastures associated with rice (CPAC, 1977; unpublished).**

	B. decumbens		Other grasses		*S. guianensis*		Other Legumes		Weeds		Total forage crops
P_2O_5	FM	%	FM	%	FM	%	FM	%	FM	%	
kg/ha	t/ha		t/ha		t/ha		t/ha		t/ha		t/ha
Directly-formed pastures (2nd year)*											
120	1.00	19.4	0.67	12.7	3.13	60.2	0.13	2.5	0.27	5.3	4.94
240	2.01	39.7	0.78	13.5	2.26	41.0	0.09	1.9	0.21	4.0	5.15
Pastures associated with rice (1st year)**											
120	2.58	31.0	0.12	1.7	4.01	47.4	0.77	8.8	0.95	11.1	7.49
240	3.08	48.2	0.10	1.4	2.00	29.8	0.62	10.3	0.61	10.3	5.80

* Samples taken on 13/12/77
** Samples taken on 27/12/77

native *Panicum,* were observed (Table 9). The percentage of legumes increased considerably, with *S. guianensis* predominating. Unlike *B. decumbens;* the growth of *S. guianensis* was very good at the lower level of phosphate fertilization. The percentage of *S. guianensis* in association with rice was also less, leading to the supposition that the shade hindered its development. This was confirmed in a experiment done by CPAC at Unai, Minas Gerais (Table 5). On the other hand, the percentages of the other legumes increased as a consequence of their growth habits that permit their entwinement on the rice plants in search of light. In the pasture associated with rice, the production of FM of invading weed species was very superior to that in which the pastures was directly established (Table 9).

Even though the theory of the economic viability of making high investments to establish cultivated pastures is debatable, considering that cow-calf operation is the primary activity of the Cerrado, it appears that, with crop agriculture, pasture establishment can be accomplished at lower costs. Probably, if this does occur, the estimated percentages for the structure of the cattle population will be altered, where breeding would actually represent 40% of the entire herd, the growing phase, 48%, and finishing or fattening, 11% (3). It is necessary to incorporate a larger number of calves into the system, by improving the reproductive capacity of the cows and decreasing the duration of the growing phase. The use of natural resources associated with cultivated pasture areas assumes an important role in attaining the true objective for the native Cerrado—an excellent region for raising cattle. In this manner one can also receive the benefits of the most profitable step of the process: cattle fattening.

Forage species and crops for the Cerrado

Several forage species sprout spontaneously in the Cerrado region, in soils of better fertility. Once the nutrient deficiencies and toxic levels of soil acidity are corrected, a large number of species show good potential. Over four years Ferreira *et al.* (6) evaluated 16 grasses. Most productive were the following: *Brachiaria ruziziensis* Germain & Evrard., *Panicum maximum* Jacq. cv. Guiné, *B. decumbens* and *Brachiaria humidicola* (Rendle.) Schweickt. with levels between 22 and 23 t/ha of DM. Many others produced above 20 t/ha. With the exception of the first species above, the others were conspicuous by their better resistance to drought.

Data collected at the CPAC site over a period of 27 months with five cuttings, show the most conspicuous species being *Brachiaria* sp. (IRI 409), with 21 t/ha of DM, and *B. decumbens* and some species of *Digitaria,* which produced from 14 to 15 t/ha. Among the legumes, *S. guianensis* cv. IRI 1022 and 2870 were outstanding with 24.9 and 20.9 t/ha, in four cuttings. These were the only legumes that produced at the lowest level of P. After two years, the only legumes persisting were *Stylosanthes* spp., *G. wightii* and *C. pubescens.*

In unpublished data from CPAC (1977), several germplasm accessions distinguished themselves as promising for the Cerrado region including legumes of the genera *Stylosanthes, Centrosema* and *Galactia* and the grasses of genera *Brachiaria, Panicum, Digitaria* and *Andropogon.*

Associated pastures

As well as fixing atmospheric N, the legumes have better nutritional value which makes them important components of an association. Nevertheless, the failures appear to be more numerous than their successes. Multiple reasons can be pointed out as being responsible for failure of persistence of legumes under grazing. It is necessary to know more about the nutrients that limit legume development, the management that associated pastures should receive, and more about fixation efficiency in order to eliminate the factors affecting their

establishment and persistence. It is possible to gain better results if native species whose potential for the region is great can be conveniently developed.

Many experiments show the importance of the legumes in associations, resulting in better liveweight gains per ha (12, 15). Furtado *et al.* (1977), cited by Vilela (19) mentioned the associative compatibility of some grasses and legumes. Only *C. pubescens* and *M. atropurpureum* established themselves well enough to be associated with *B. decumbens* and *H. rufa.*

PASTURE MANAGEMENT

Basically, there are three forms of utilizing pastures in the Cerrado: continuous grazing, rotational grazing, and cutting, principally for hay.

Continuous grazing

The average carrying capacity under continuous grazing management is basically determined by three factors: the longevity of the pasture, the persistence of legumes in asociated pastures and in native pastures improved with these species, and the maximum utilization of what is available. When the carrying capacity increases, the weight increase per animal decreases.

Vilela and Oliveira (20), utilizing three stocking rates, with Gir steers on native pasture improved with *S. guianensis* and *M. minutiflora,* obtained average daily gains during 364 days of 0.358 and 0.076 kg for 0.3 and 0.7 AU/ha, respectively. An intermediate stocking rate (0.5 AU/ha) furnished the highest liveweight/ha, but the daily gain was lower, 0.258 kg/an/day. From the standpoint of persistence of the forage species utilized, the percentages of native grasses, of *M. minutiflora* and of *S. guianensis* decreased 11, 29 and 38%, respectively in one year.

Vilela *et al.* (20), studied the production from a *B. decumbens* pasture, fertilized with N, and that of an associated pasture with *Leucaena leucocephala* (Lam.) De Wit and *C. pubescens.* Annual liveweight increases/ha were 771 and 591 kg/ha for the two pastures, with a stocking rate of 2 AU/ha. According to the authors, the lower yield of the associated pasture is explained by the effect of N on the quantity and quality of the forage in this particular pasture and the fact that the legume population was very low.

Rotational grazing

A very scattered practice on farms of the Cerrado region is grazing in a manner similar to the principles of rotational grazing. The animals are moved from one location to another within the property according to the availability of forage.

In this region, experimental data on the use of rotational grazing are very scarce. More knowledge is needed in this respect since some form of rotational grazing is already an on-going practice and is probably increasing in importance as operation for breeding, raising and fattening cattle.

Utilizing *M. minutiflora, H. rufa* and *D. decumbens* and these grasses associated with a mixture of *M. atropurpureum, G. wightii, S. guianensis* and *Stylosanthes humilis* H.B.K., Zuñiga *et al.* (22) compared continuous and rotational grazing systems. The average weight increases obtained over one year were 492, 446, 368 and 315 g/an/day, for rotational grazing in a grass-legume pasture, continuous grazing in the associated pasture, rotational grazing in a grass pasture and continuous grazing in the grass pasture, respectively. These data explain the preference for associations and rotational grazing (Fig. 4).

Hay production

The need to satisfy the nutritional requirements of cattle during the dry season, on one hand, and the favorable conditions for high production of forage during the rainy season, on the other, leads to the belief that hay is a potential alternative. This has been

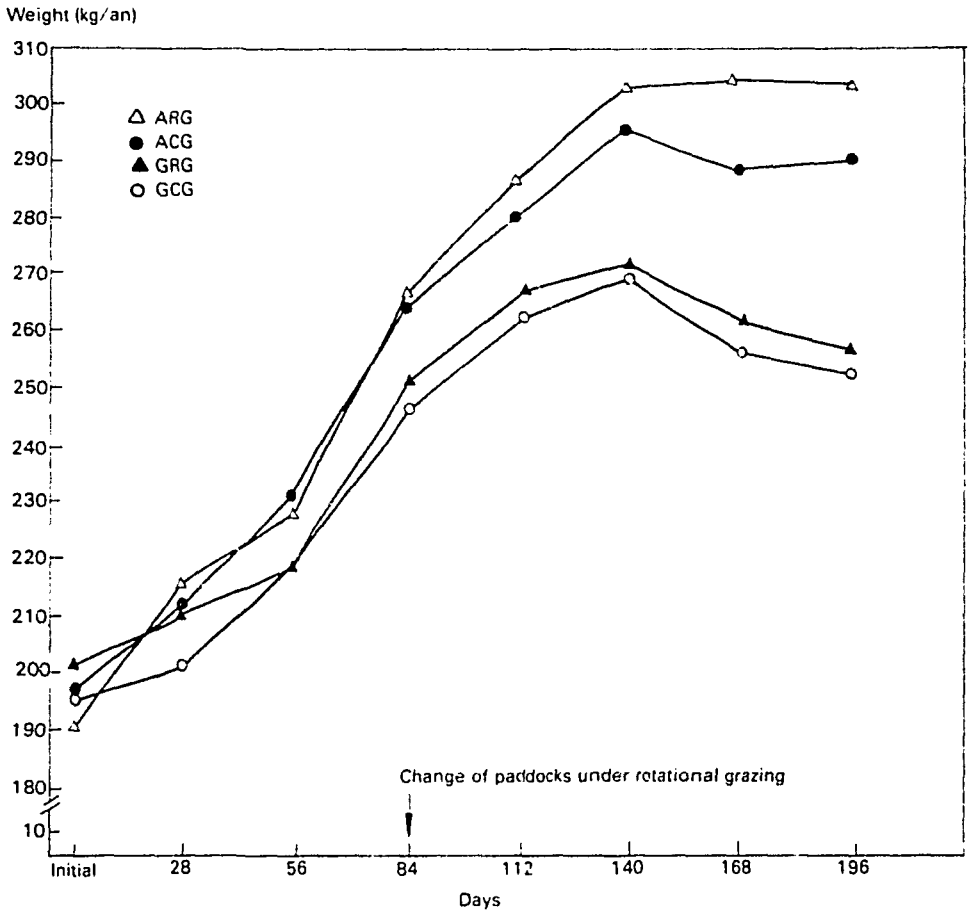

Figure 4. Animal weight increase up to 196 days in grasses under continuous grazing (GCG), grasses under rotational grazing (GRG), and associations under both types of grazing (ACG and ARG). The experiment took place from February 5 to August 24, 1974 (22).

an important aspect in the beef research program of CPAC.

In the last three years, the pastures of the CPAC experimental station have been used both for grazing and for hay production. This system is, up to a certain point, a form of rotational grazing. Hay is produced during the period from January to May (end of the rainy season), when there is an excess of grass and favorable climatic conditions for drying. The majority of the investigations in CPAC were done using cut, dried and stored hay. However, utilizing the hay directly in the field is a possibility, since pastures should not lose all their nutritive value in the dry season (a *B. decumbens* pastures at the end of the dry season showed abot 57% DM and 5% crude protein).

Actually, production and use of hay already is a scattered practice in the region, principally where cattle are grown out. Nevertheless, very little is known about the technology of producing hay and about managing a farm where the use of hay is introduced. To clarify these questions, CPAC is developing a research program to study the parameters related to hay production, especially the forage species, fertilization, time of cutting, and the effects of hay supplementation on animal performance.

Knowing these parameters, the management of a farm can be planned, establishing how much improved pasture is needed based on the number and type of animals in the herd.

CPAC is also conducting other experiments to study the potential of some species for hay production. The species being tested are *S. guianensis, H. rufa, M. minutiflora* and *B. decumbens.*

In general these experiments also include pasture fertilization, so that the quantity and quality of hay can be strictly related to pasture establishment and maintenance fertilization practices.

In 1974, an experiment was initiated to study the production of *B. decumbens* in relation to sources and levels of P and levels of lime (Table 10). An increase was observed in DM production up to the highest level of P, although the application of 345 kg P_2O_5/ha initially, or the application of 86 kg P_2O_5/yr, provided yields of more than 3 t/ha, in each cutting. Liming did not significantly influence production, suggesting that *B. decumbens* is a species tolerant to acidity.

Comparing the relative production obtained with rock phosphate from Araxá and with simple superphosphate (SSP), and calculating the costs of these inputs, the economic advantage from using the natural phosphate is evident. In view of the slight solubility of this rock phosphate, the pasture should be established using a mixture of rock phosphate and a more soluble source.

Another experiment was done with *H. rufa* and *M. minutiflora* established spontaneously in a Low Humid Gley soil (Aquox). After one surface-applied fertilization of 100 kg P_2O_5/ha, 120 kg K_2O/ha and 90 kg N/ha, two cuttings were made during the rainy season. Hay yields (90% DM) were 5.65 and 5.95 t/ha for *H. rufa* and *M. minutiflora,* respectively. Under similar conditions of fertilization, *Cynodon nlemfuensis* Vanderyst produced 5.75 t/ha of hay in two cuttings, on a Dark Red Latosol (Haplustox).

Table 10. **DM production of *B. decumbens* in 10 cuttings showing responses to P sources and lime levels.(Data provided by Edson Lobato).**

P sources	P_2O_5 levels	Lime levels 0.0	3.0	4.5	Relative production
	kg/ha	t/ha			%
Control	0	7.5	6.3	9.7	17
SSP	86	18.0	14.7	17.8	36
	345	34.8	38.8	37.4	80
	1380	43.8	46.0	48.0	100
		96.6	99.5	103.2	-
Araxá phosphate	86	4.3	9.3	1.4	18
	345	26.3	26.1	23.8	55
	1380	38.1	39.8	40.2	85
		68.7	75.2	75.4	-
SSP applied annually	86	29.9	34.4	34.2	71

The nutritive value of hay varies according to several factors including, time of cutting, fertilization and the forage species. It has been demonstrated that an interval of 45 to 60 days between each cutting is adequate. However, this interval depends on the ocurrence of the rains. Nutritive values of some hays utilized in CPAC are shown in Table 11. *B. decumbens* and *S. guianensis* constitute the best forages for hay as they combine the highest protein content and energy.

Studies on the effect of hay supplementation have been done principally with animals in the growing stage. During the dry season of 1976 an experiment was conducted to evaluate the weight increase of animals supplemented with hay of *S. guianensis*. For 126 days Zebu animals 8 to 10 months of age with an average weight of 136 kg, grazed a field invaded by *M. minutiflora* and were supplemented with different quantities of hay. Laboratory analyses of the hay showed average values of 43% *in vitro* digestibility and 12% crude protein. The results (Table 12) revealed that animals not receiving supplementation had minimal weight increases, and that weights increased parallel to increases in supplementation levels. These results indicate that a supplementation level based on 2% of the animal's weight, per day, should be adequate.

In the dry season of 1977 another similar experiment was conducted using *M. minutiflora* hay with an *in vitro* digestibility of 52% and 8% protein. The results were very similar to those obtained with *S. guianensis* hay. Weight increases of 0.17 kg/day were recorded with supplementation of 2.2% hay, according to animal liveweight. Thus, observations from CPAC indicate that with daily consumption of hay based on 2% of animal liveweight, animals can gain a small amount of weight during the dry season.

To sum up, results from CPAC reveal that one ha of *B. decumbens* can supply 10 t/yr of hay in three cuttings (Table 10), and that this quantity is sufficient to maintain or even produce small weight increases in 110 animals of 150 kg, for a period of 30 days. Thus, one ha of *B decumbens* can produce hay to maintain 35 animals during the three-month dry period in the area of the Federal District. In addition, data calculated by CPAC in 1976, indicate that the approximate cost of producing one ton of hay is Cr$ 200 (about US$12.50).

Although these data are preliminary, they provide evidence of the advantage of producing and using hay in the Cerrado region. Moreover, the data allow the formulation of plans for managing a farm where the problems of feed deficiency in the dry season can be solved. Also, the adoption of haying could allow the region to be used for a system of animal production where all the steps of breeding, growing and fattening are included.

Another alternative for solving the problem of feed deficiency during the dry

Table 11 **Apparent digestibility coefficient (ADC) and DM content, gross protein (GP), gross fiber (GF) and gross energy (GE) of hay of some forage species (8).**

	DM		GP		GF		GE	
Hay species	Content	ADC	Content	ADC	Content	ADC	Content	ADC
			%				Calories/kg	%
M. minutiflora	91.3	48.9	5.9	75.7	35.0	73.2	4365	50.7
H. rufa	90.8	44.9	4.1	54.4	32.9	51.9	4160	46.7
B. decumbens	91.7	65.3	9.1	85.2	33 9	82.7	4386	63.5
S. guianensis	89.3	58.0	16.1	87.2	33.0	70.2	4456	56.6

Table 12. **Weight increase of weaned steers fed with *S. guianensis* hay as a dry season supplement in 1976. Average of 12 animals. (CPAC, 1977; unpublished).**

Treatments*	Initial weight	Final weight	Weight increase/ an/day	Total weight increase/an
	kg			
I	137.8	139.1	0.010	1.3
II	135.4	157.9	0.172	21.7
III	136.3	167.3	0.246	31.0

* I = Natural field with *M. minutiflora*
II = Treatment I + hay (1% of the animal's average weight)
III = Treatment I + hay (2% of the animal's average weight)

season is the use of irrigated grasses. Experiences from CPAC indicate that forage production in the dry season, under irrigation, is similar to that of the normal rainy season for those species discussed in this paper.

After having examined several aspects of managing cultivated pastures, one cannot omit one of the problems that significantly affects their production: spittlebug attacks. Among the species identified the most important are *Deois flavopicta, Deois schach* and *Zulia entreriana.* Attacks of these insects have been most intense in *B. decumbens* pastures, perhaps because this is the species most commonly cultivated. Several methods of control have been tried, including insecticides, biological control and careful management of the pasture, but with little success. It is evident that a research program sould be developed. Up to now, the most useful method to avoid the probl em at the farm level is to graze pastures intensively in order to keep the plant height low.

CONCLUSIONS

The Cerrado region in Brazil presents an enormous potential for beef cattle production. Its utilization in based on systems of extensive farming that focus on the breeding stage of production (cow-calf). Favorable conditions exist for exploitation with a more complete system, including breeding, growing and fattening. However, for this to be viable, it is necessary to improve the availability of forage.

One alternative that has been widely used is the introduction of forage species, mostly exotic ones, directly into the native pasture, using few inputs. In most cases introduction is spontaneous (natural invasion), with the grasses *M. minutiflora* and *H. rufa* being the most common. This practice has not had much success up to now because of the poor persistence of the introduced species, especially during the dry season. There is an urgent need for investigations in this area, directed to finding forage species (principally legumes) that are adapted to the poor soils and one drought resistant, as well as mechanical methods of introducing these species on a large scale.

Another alternative that has created great interest in recent years is the conversion of one part of the farm to an improved area through soil buildup and planting forage species of high productivity. Of the grasses, the genera most used have been *Brachiaria, Panicum, Digitaria* and *Andropogon,* and among the legumes, *Stylosanthes, Centrosema* and *Galactia.* Even though there has been little experience in evaluating the effects on a large scale, this alternative appears technically and economically viable, as long as the farming system is not completely restricted to the breeding stage of production.

The management system for these improved pastures varies according to many

factors. However, research data reveal that production and utilization of hay is a valid alternative to overcome feed deficiency during the dry season (June to September). One ha of *B. decumbens* can produce hay to maintain the weights of 35 animals of 150 kg during the three-month dry season.

Experience obtained in the region indicate that pasture establishment can be accomplished, probably with an economic advantage, through an association with annual crops. One example is the simultaneous seeding of upland rice and grasses. Another is the introduction of pastures after two or three years of producing an annual crop (rice, soybeans or maize). In this manner, a partial repayment of the investments is gained in the short term, lowering the cost of pasture establishment.

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PASTURE ESTABLISHMENT AND MANAGEMENT IN THE LLANOS ORIENTALES OF COLOMBIA

James M. Spain*

ABSTRACT

The establishment of pastures in the Llanos Orientales of Colombia is relatively easy during several months of the year, but the cost is high, mainly because of the fertilizers and the tillage required to control the native vegetation and prepare the soil. At the Centro Nacional de Investigaciones Agropecuarias in Carimagua, species and ecotypes are being sought that are tolerant to acidity and efficient in the utilization of the available nutrients in the soil, thus trying to reduce the cost of fertilizers and soil amendments. On the other hand, different tillage and sowing systems are being studied in order to reduce the costs of controlling the vegetation and the risk of erosion during pasture establishment. *Brachiaria decumbens* is probably the most widespread grass in tropical America and the one that is most frequently planted at present. As for grass-legume associations in Carimagua, good results have been obtained with *Pueraria phaseoloides* and *B. decumbens*; great domination of the legume over *Hyparrhenia rufa* and *Melinis minutiflora* has been observed. A challenge for the present and the future, for those who work in pasture establishment and maintenance, is to design systems that allow stable and persistent associations among legumes and grasses such as *B. decumbens*, starting many times not with the native savanna but with established pastures.

Pasture establishment in the Llanos Orientales of Colombia is relatively easy due to the favorable environmental conditions that prevail during several months of the year. The Centro Nacional de Investigaciones Agropecuarias (CNIA) at Carimagua, where almost all the work and observations on which the report is based were carried out, is located at 4°37'N; at an altitude of 175 meters. The mean temperature is 26°C, with an annual mean rainfall of 2200 mm (ranging from 1450 to 2500 mm) over a six-year period, and with a mean evapotranspiration potential of 2200 mm. The rainy season normally begins in April and terminates towards the end of November. As can be observed in Figure 1, the monthly rainfall from May to October averages more than 200 mm. Moreover, the frequency of dry periods of more than a week during said season is low, except for August, when it is slightly longer.

The soils are Oxisols (Tropeptic Haplustox isohyperthermic), fine-clayey mixed, with very flat to softly sloping lands (2 to 3% maximum) and excellent physical conditions. The most important characteristics are given in Table 1. It is evident that the

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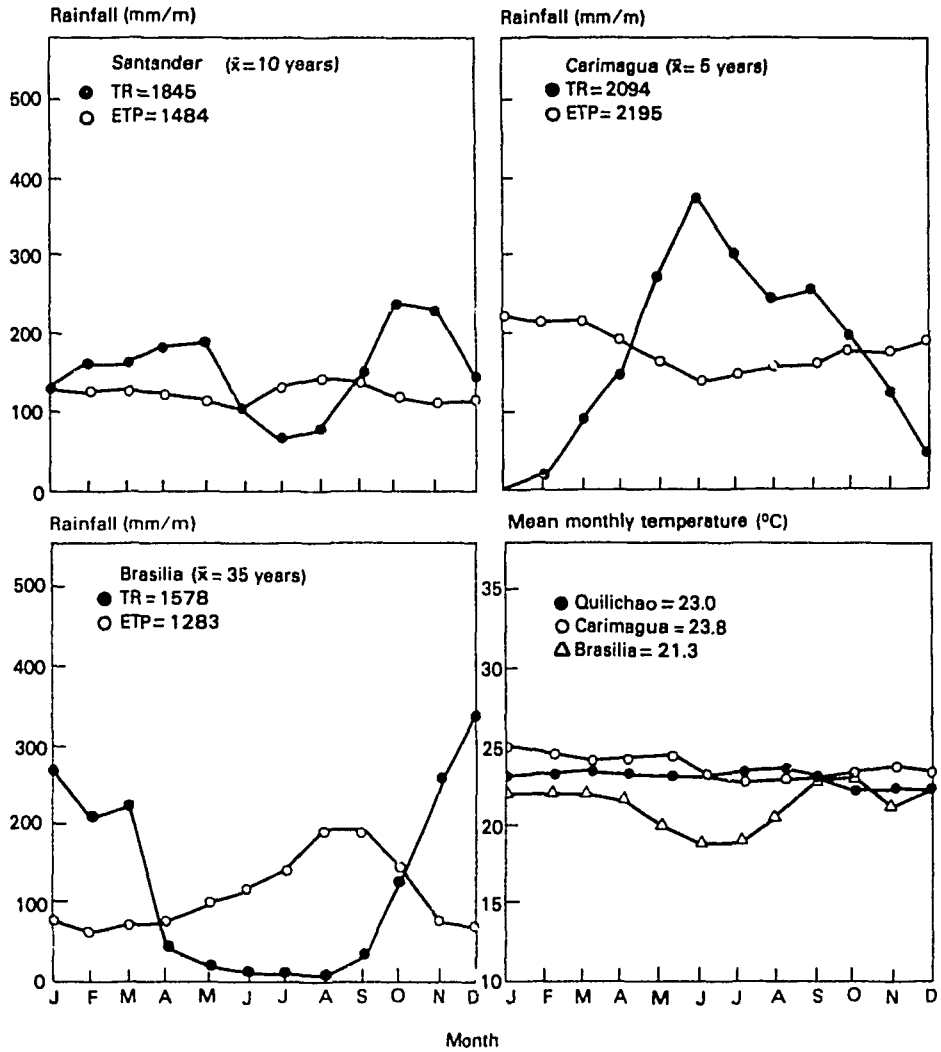

Figure 1. Rainfall and mean temperature at Carimagua, State of Meta, Colombia (Lat. 4°37'N, long. 71°36'W; alt. 200 m); Quilichao, State of Cauca, Colombia (Lat. 3°06'N; long. 76°31'W; alt. 990m); and Brasilia, FD, Brazil (Lat. 15°36'S; long. 47°42'W; alt. 1010 m).

principal problems for pasture establishment in Carimagua lie in the low fertility of the soils and their high level of acidity.

Although pasture establishment is relatively easy, it is too expensive and there is a great danger of erosion when traditional systems are used. Therefore, research at Carimagua has been focused on the reduction of costs and the risk of erosion.

SELECTION FOR EDAPHIC CONDITIONS

The low fertility and high acidity of the soil can be modified by applying fertilizers and lime. An alternative consists in selecting species that are more tolerant to low fertility and acidity of the soil.

Fertilization with phosphorus

Tropical crops, especially forages, vary greatly in their P requirements (5). In 1977 a

Table 1. **Characteristics of an Oxisol (Tropeptic Haplustox, fine-clayey, mixed, isohyperthermic).**

Horizon	Clay	Sand	pH (H_2O)	OM	Exchangeable cations Al	Ca	Mg	K	CEC	Al saturation	Available P Bray II	Available H_2O
cm	—— % ——			%	——— meq/100 g ———					%	ppm	%, vol
0-20	37	6	4.9	3.1	2.8	0.2	0.2	0.1	3.4	82	0.9	9
20-51	39	5	5.0	1.5	2.0	0.1	0.1	0.1	2.3	85	0.4	7
51-82	40	5	4.8	0.8	1.9	0.1	0.1	0.1	2.2	84	0.9	5
82-117	40	5	5.4	0.6	1.1	0.1	0.1	0.1	1.6	69	0.4	5
117-132	48	5	5.8	0.4	-	0.2	0.2	0.3	0.8	-	0.4	6
132-152	52	4	5.9	0.3	-	0.2	0.2	0.3	0.7	-	0.4	7

glasshouse trial was conducted using an Oxisol from Carimagua, to which 0 to 240 kg P/ha were applied (3). Plant-available P was determined by utilizing the Bray II extractant solution and Cate and Nelson's method (1) for determining critical levels; these varied from less than 3 to more than 10 ppm (see Fenster's and León's paper, Fig. 1). Among the six introductions whose P requirement was less than 4 ppm, four belong to the species *Stylosanthes capitata* Vog., one of the most promising for Carimagua conditions. Other promising species for Carimagua are *Andropogon gayanus* Kunth and *Desmodium ovalifolium* Vahl., both with critical levels somewhat higher than the ecotypes of *S. capitata*, *Zornia* sp. and one *Stylosanthes guianensis* (Aubl.) Sw. One ecotype of *Macroptilium* and two of the genera *Desmodium* had much higher requirements, around 10 ppm, but still lower than the critical levels of the majority of annual crops.

Liming trials

During 1977, 38 grass and legume species were tested in the field; 0, 0.5, 2 and 6 t/ha of lime were applied to give an Al saturation level of approximately 90, 85, 60 and 15%, respectively. The effect of lime on DM of 11 grasses is given in Figure 2. Several species including *Brachiaria decumbens* Stapf., *Brachiaria humidicola* (Rendle.) Schweikt., *Brachiaria mutica* (Forsk) Stapf., *A. gayanus*, *Panicum maximum* Jacq. and *Digitaria decumbens* Stent. showed excellent tolerance to Al and all reached near maximum yield with application rates of 0 to 0.5 t. On the other hand, *Hyparrhenia rufa* (Nees) Stapf., a grass that is quite common in the tropics, responded very satisfactorily up to a level of 2 t/ha.

The results in the field were very similar to a glasshouse trial carried out in 1976, in which several tropical grasses were planted in nutrient solutions with Al concentrations ranging from 0 to 4 ppm. The effect of Al on four species is shown in Figure 3. *Cenchrus ciliaris* L. was the most affected, followed by *H. rufa*. *P. maximum* responded to the first increase in Al and was affected adversely only at the highest level. *B. decumbens* was not affected by any of these concentrations. Yields of *P. maximum* decreased at the 0 level of lime (highest level of Al) in the field as well as in the glasshouse.

Table 2 shows the yields of eight legumes in the first cutting. It should be noted that originally the 0 level of lime did not include Mg; the other levels received Mg applications in order to maintain the Ca/Mg relation constant at 10:1. Therefore, part of the response at the level of 0.5 t of lime may be an effect of the Mg and not of the lime itself, especially in the case of *D. ovalifolium* and *Pueraria phaseoloides* (Roxb) Benth. var. *javanica* (Benth.) Bak. and possibly the

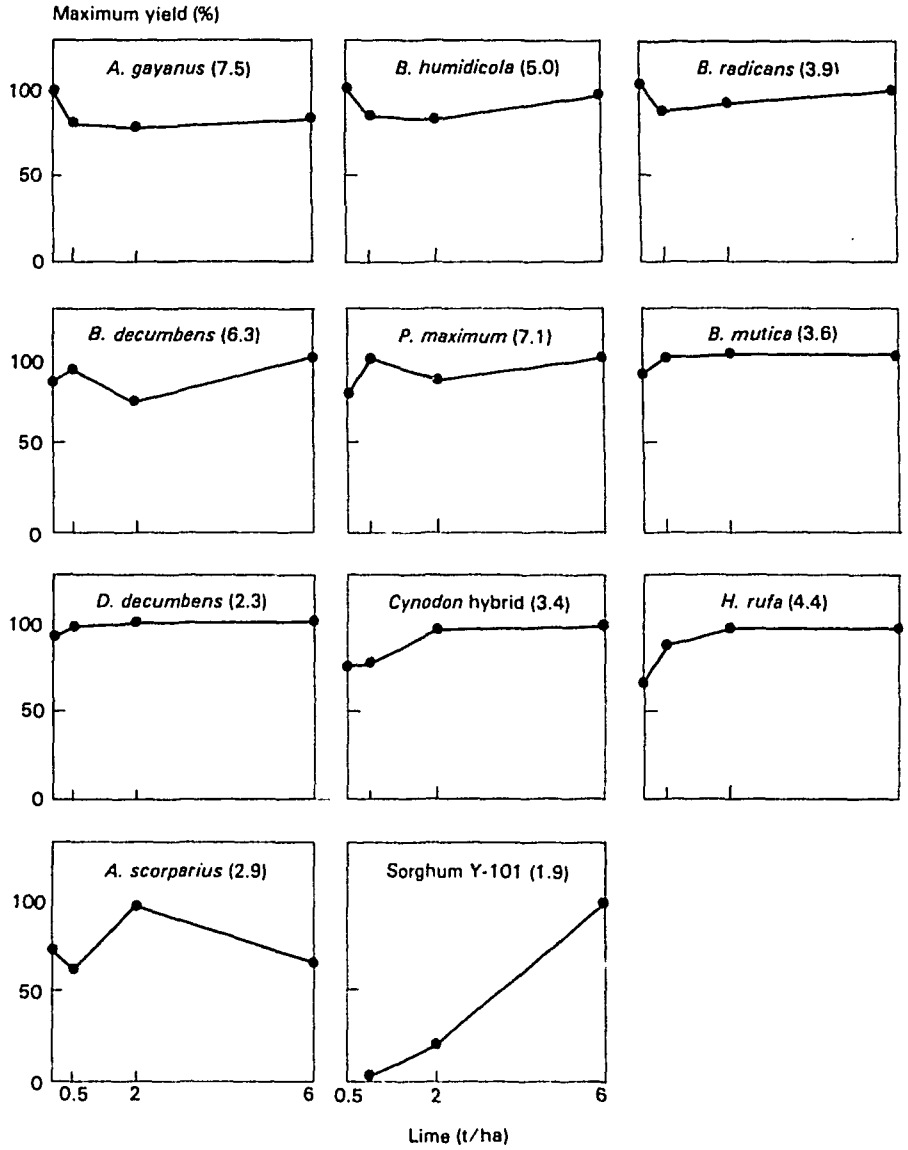

Figure 2. Response of 11 grasses to liming on an Oxisol at Carimagua. DM production is giving in parentheses. The amounts are averages of four to five cuttings during 1977.

hybrid *Centrosema* sp. 1733 and *C. pubescens.*

In another field trial carried out at Carimagua during 1977, a very definite response to Mg was recorded in the case of *D. ovalifolium* and *P. phaseoloides.* The results of the first cutting are given in Table 3. *S. capitata* and *Zornia* sp. CIAT 728, which did not show any response to lime, are exceptionally vigorous. *Centrosema plumieri* (Pers.) Benth. is definitely the most sensitive to acidity in this group of legumes.

It is obvious that among the different species and sometimes among ecotypes of the same species, there are very important substantial differences with regard to acidity

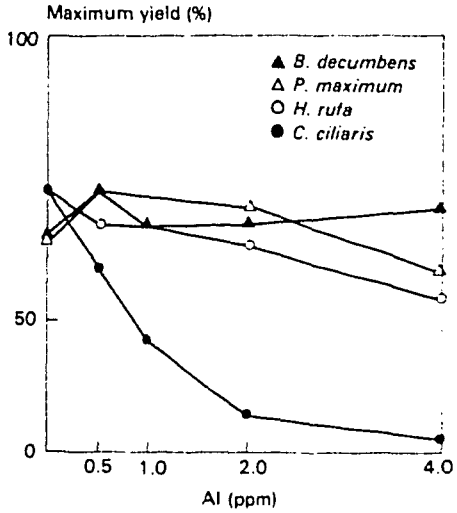

Figure 3. Effect of Al concentration on DM production of grasses in nutrient solutions.

and P requirements. The first step in taking advantage of these differences consists simply in testing and selecting from among the most productive species the ecotypes that require less modification of the soil. Another important step is to include in forage improvement programs the selection of grasses that adapt best to the savanna soils, which as a rule are extremely acid and very low in fertility.

LAND PREPARATION AND CONTROL OF VEGETATION

After modifying the chemical conditions of the soil, the most costly operation in pasture establishment is the preparation of the land and control of native vegetation and weeds that compete with the grass.

The traditional method of preparing the land for pasture establishment in the Llanos Orientales consists in passing heavy offset disks two or three times or once with a plow followed by the offset disks. These systems give adequate, often excessive, preparation of the land for pasture establishment. The problem lies in the high cost of tillage and in the danger of erosion and loss of great quantities of soil when the terrain is sloping.

For the last three years, several minimum and nontillage systems with chemical control of the native savanna have been tried. The system that has given best results to date is the use of stubble mulch sweeps to undercut the savanna vegetation at a very shallow depth to separate the aerial part from the root system, this method leaves all the stubble on the surface of the ground (2). The power required for the job is less than in the case of the disks and plow that are commonly used in this area. The main difficulty with the stubble mulch sweep

Table 2. Effect of lime on DM production of eight legumes at first cutting at Carimagua, 1977.

	Lime (t/ha)			
	0	0.5	2	6
	kg DM/ha			
C. plumieri CIAT 414	0	0	582	1698
Centrosema sp. CIAT 442	445	912	2014	2769
Centrosema sp. CIAT 438	356	1330	1568	1317
C. pubescens CIAT 413	680	1729	1996	2035
D. ovalifolium CIAT 350	1118	2302	2018	2480
P. phaseoloides CIAT 9900	1286	1688	1422	1434
Zornia sp. CIAT 728	3000	3108	2686	2628
s. capitata CIAT 1019	2365	2361	3011	2478

Table 3. **Effect of Mg on DM production of three legumes, at first cutting in Carimagua, 1977.**

	Mg (kg/ha)	
	0	20
	— kg DM/ha —	
Zornia sp. CIAT 728	2436	3151
D. ovalifolium CIAT 350	675	1552
P. phaseoloides CIAT 9900	229	739

method is that a certain level of soil moisture is required for it to work well; but in order to obtain optimal control of the vegetation, some dry days are required after tillage. Therefore, the most appropriate moment for using the sweeps would be at the beginning and towards the end of the rainy season, when the rains are less and still permit adequate control of vegetation. The ideal would be to be able to control the savanna to sow and fertilize the introduced species simultaneously, but conditions favorable for sowing are precisely the least appropriate for controlling the native savanna.

At present several systems are being evaluated, including the sweeps, chemical control of the savanna, burning of the savanna and the traditional systems, with the purpose of studying more thoroughly the possibilities of reducing the costs of preparing the land for pastures.

SOWING SYSTEM

In 1977 a study was started in which several aspects of establishment were combined in a single trial, looking for a way to reduce costs. Inputs such as capital, labor and fertilizers do not generally abound in the savanna zones. In the paricular case of pastures, the seed or vegetative planting material is rarely available in sufficient quantities and is often costly in the initial stages of cattle development programs.

The Oxisols of the Llanos Orientales are kept weed free several months after tillage if fertilizers are not applied. Taking advantage of this fact, ten species were sown at a density of 1000 plants/ha (3.16 m between plants), expecting self-seeding of the intermediate area as the result of either seed production or coverage by stolons. Initially only one plant was fertilized in an area of approximately 0.1 m^2. Sixteen combinations of fertilizers, mainly P and K, were studied. The rates of application in the treated area varied from 50 to 900 kg P_2O_5 and 0 to 150 kg K_2O, since at the beginning only one hundredth of the area was treated. The second stage of fertilization (the area between plants) was delayed until a good population was obtained, by means of seed production or coverage by stolons, in order to prevent weed competition.

In Figure 4 the results obtained with four stoloniferous grasses during the first stage are presented, in terms of length of the four longest stolons of each plant and the number of stolons per plant longer than 1 m (in the case of *Brachiaria radicans* Napper, longer than 2 m). At levels of 0.5 to 1.0 g/plant, P affected the length of the four longest stolons of *B. decumbens*, *B. humidicola* and *B. radicans*. The *Cynodon* hybrid responded up to 3 g/plant. On the other hand, the effect of P on the number of stolons longer than 1 m was especially noticeable for *B. decumbens* and *B. radicans*, especially with rates up to 9 g/plant.

The response to K was especially noticeable in terms of number of stolons longer than 1 or 2 m. In less than three months, *B. radicans* had covered almost all the area between the plants. *B. humidicola* was slower but continued to grow during the dry season, giving almost complete coverage in the best treatments. *B. decumbens*, whose initial development was very fast and almost totally vertical, also extended over more than half the area during the dry season.

A. gayanus and *P. maximum* (planted in August) produced seed as of December; and when the first rains began in April, *A.*

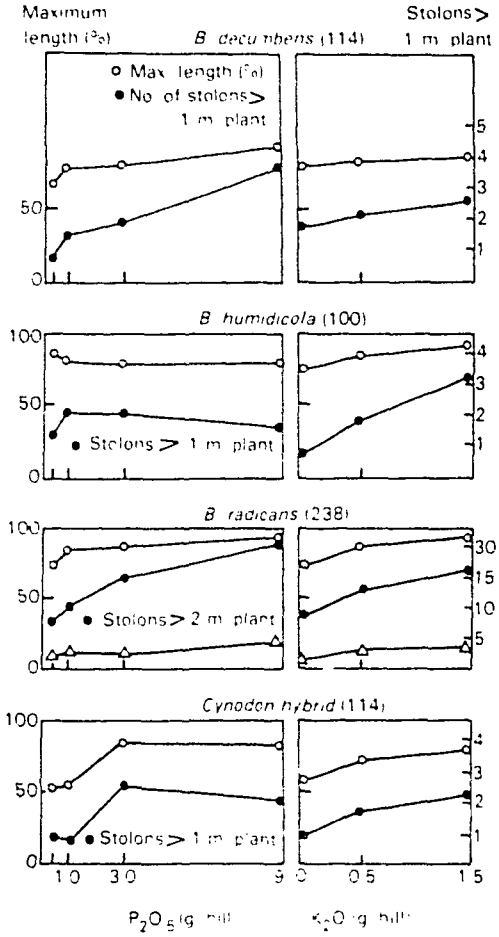

Figure 4 Effect of P and K on the number of stolons and percentage of maximum length of the four longest stolons per plant of four grasses, 12 weeks after planting with vegetative material The average length in cm of the four stolons per plant in the best treatment is given in parentheses

gayanus had covered the whole area with a population that was too dense. *P. maximum* is developing an adequate population in the majority of the treatments.

This system could result highly advantageous for establishing pastures in the less fertile savanna areas. In addition, it is probable that some farmers are willing to wait longer if there is a reduction in the initial investment of capital and other inputs such as labor seed and fertilizers, which are scarce in these areas. This study is being expanded in 1978 in an attempt to find less costly tillage systems within the reach of the medium-size farmer.

SPATIAL DISTRIBUTION OF FORAGE SPECIES

The most appreciated pasture in tropical America at present, is, undoubtedly, *B. decumbens*. It has a very high stocking capacity and is highly resistant to trampling. It does not have high nutrient requirements and is tolerant to soil acidity. Nevertheless, some of its advantages such as aggressiveness and the formation of a very strong grass, become disadvantages when it is planted in association with a legume. There are only a few cases of successful, stable association with *B. decumbens*. At Carimagua a grazing trial was begun in 1976 using *P. phaseoloides* in association with *B. decumbens*, *Melinis minutiflora* Beauv. and *H. rufa*. The legume was planted in 2.5-meter strips, intercalated with equally wide strips of the grasses. The trial includes three resting periods (28, 42 and 56 days) between intensive grazing periods and fertility maintenance treatments by applying 15 to 45 kg/ha/yr of P_2O_5. Thus far the association between *P. phaseoloides* and *B. decumbens* has been good, with a very strong domination of the legume over *H. rufa* and *M. minutiflora*. *B. decumbens* is invading the strips of *P. phaseoloides* but the latter is also invading those of *B. decumbens*. Up to the present, it seems probable to obtain a good association that could last several years utilizing the strip system.

In any pasture formed exclusively by grasses, N becomes a limiting factor sooner or later. One of the greatest challenges for those who work with pastures and forages in the tropics is to develop and perfect systems for introducing legumes into pastures established with *B. decumbens*, which with time become less productive because of the lack of N, especially in areas where it is not economically feasible to use nitrogenous fertilizers.

It is possible that some legumes such as *D. ovalifolium* or *Desmodium heterophyllum* DC.can compete and persist in compatible associations with *B. decumbens* if optimal pasture management systems are found, but the great majority of the legumes do not seem to be able to compete in traditional mixtures.

THE FACTOR OF FERTILITY IN THE MANAGEMENT OF ASSOCIATIONS

In temperate zones it is believed necessary to fertilize the legume of the association and to manage the grass through grazing. Normally, legume requirements are higher than those of the grasses. However, the opposite is true of several tropical species: the grasses are sometimes less demanding than the legumes. This creates the possibility of utilizing the fertility factor as a tool in the management of the associations by using grasses that are more demanding than the legume. It has been noted, in general, that *S. capitata* and *Zornia* sp. are less demanding legumes with regard to P, as compared with grasses such as *P. maximum* and even *A. gayanus*. Trials are being started to prove the hypothesis that fertility (in this case the level of P) can be utilized to stimulate or depress the grass development with relation to the legume in the management of forages under grazing.

When experiments were begun in the Llanos, the most common grasses in the region were *M. minutiflora* and *H. rufa*. It was believed, therefore, that the two of them were rustic with low fertility requirements. Experience has shown that *M. minutiflora* is really an exceptionally rustic species for the savanna soils; but *H. rufa* has very high P and K requirements and is less tolerant to acidity under grazing. After having good populations of *H. rufa* in several pastures, they disappeared completely as a result of the fertility factor and possibly soil acidity, in spite of having been planted in the lowlands where the stress caused by the dry season was much less and where the soils were more fertile and less acid. The dry season tends to intensify both limiting factors. *H. rufa* presently has little priority in the research being done in the savanna at Carimagua.

Based on the experience acquired to date, the grass species can be classified in the following order of requirements: *M. minutiflora*<*B. decumbens*<*A. gayanus*<*P. maximum*≤*H. rufa*. The legumes follow this order: *S. capitata*≤*Zornia* sp.<*D. ovalifolium* <*P. phaseoloides*<*C. pubescens*.

In relation to the maintenance of fertility in pastures under grazing in the Llanos, there is little information available. On the one hand, there is almost no experience in legume/grass associations; on the other hand, it seems that N is the most limiting factor (except for *H. rufa* and *Paspalum plicatulum* Michx.); and therefore there has been no great response to P and K after the establishing stage, when N is not applied. Some experience has been obtained in the utilization of small fenced lots within the pastures in which small parcels are studied for their response to the application of nutrients after a certain number of years of grazing. As soon as some stable legume/grass associations are obtained, it is probable that the rate of fertilizers required for the good maintenance for grass will go up notably as the stocking capacity increases, especially during the dry season.

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ESTABLISHMENT AND MANAGEMENT OF IMPROVED PASTURES IN THE PERUVIAN AMAZON

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Víctor A. Morales*

ABSTRACT

The Ultisols of Amazonia, planted with associated grasses and legumes and fertilized with small amounts of P and S, constitute during the first six to 10 years after land clearing the best solution for the establishment of a successful cattle industry. However, because of the incomplete replacement of nutrients, leaching, the presence of exchangeable Al in the soil, and the compaction of soil over time, it is thought that their productivity will eventually decrease. The main alternative is to develop a more intensive system of management which will enable the fertility of these soils to be recovered so that a cattle industry with a stable production can be established which will ecologically, technically and economically justify clearing the forest. While the approach is described, it is recognized that tremendous gaps exist in our knowledge which must be filled by intensifying the research now being done.

Amazonia is, for South America and especially for Peru, the vastest resource in area and potential for the production of food and industrial goods. As yet, however, the technology which could bring about sustained development in this so far underpopulated and underutilized region is lacking. Despite this, population pressures have forced attempts to colonize the region mainly by individuals and sometimes with the backing of the government. These attempts have always encountered great difficulties when faced with practical adjustments in systems of production, and have so far met with little success.

It is important to emphasize that the development of Amazonia cannot be based exclusively on only one industry, whether it be forestry, crop production or cattle raising. Rather, all three rural industries must act together on a scientific basis to maximize the development of all the natural resources (soil, water, climate, vegetation and fauna). It is here that we agree with what Dourojeanni (3) said when he wrote: "although the development of technology for this region is hardly within the reach of economically depressed countries, an effort must be made or, as has been the case up to now, man will continue to destroy the tropical rain forests which despite their limitations offer him the only alternative for his future in America".

The Amazon basin in Peru does not

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contain a great variety of ecosystems. The Oficina Nacional de Evaluación de Recursos Naturales (ONERN) has classified these as ranging from Tropical Rain Forests to Dry Tropical Forests, and including to the south zones classified as sub-tropical. The climate is tropical with annual mean temperatures ranging from 24° to 26.5°C, and annual rainfall ranges from 1500 to 4000 mm. The soils are much more varied; more than 50% are Ultisols, 20% Inceptisols, 10% Entisols and 10% Vertisols, Alfisols and in much smaller proportion Molisols, Spodosols and Histosols (20).

According to soil classification and their potential productivity there are approximately 14 million ha of land suitable for cattle and/or plantations in different areas of the Peruvian Amazon. This constitutes a great potential to erase the deficit of cattle products in Peru and to satisfy the ever-increasing demands of a rapidly growing population. In light of the ignorance about technology which would permit development of this resource, the Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA) conducts an experimental cattle program for Amazonia. Some of the results of the experiments on pastures which have been carried out since 1969 by the Principal Tropical Station in Pucallpa are presented in this paper.

ENVIRONMENTAL CONDITIONS OF THE STATION

The Principal Tropical Station of IVITA is situated at Neshuya, latitude 8°22'31" S and longitude 74°34'35" W, 50 km from the city of Pucallpa, Peru. It is 250 m above sea level and stands in the heart of the Amazonia plain.

The zone is classified (13) as Tropical Rain Forest. The area has a mean annual temperature of 25.1°C, with very little variation between maximum and minimum temperatures throughout the year (Fig. 1). The relative humidity also does not vary greatly (Fig. 2). The monthly average for

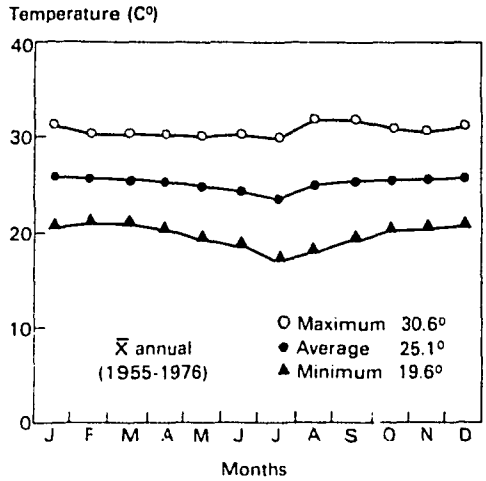

Figure 1. **Temperature regime at Pucallpa. (C.P. Station 407 "San Jorge").**

hours of sunlight varies considerably, with July, August and September being the months with the most sunshine (Fig. 2).

Average annual rainfall is 1700 mm with the period between June and August being less wet when rainfall averages less than 100 mm/mo, while the remaining nine months are very rainy (Fig. 3). These rainfall variations greatly affect the productivity of

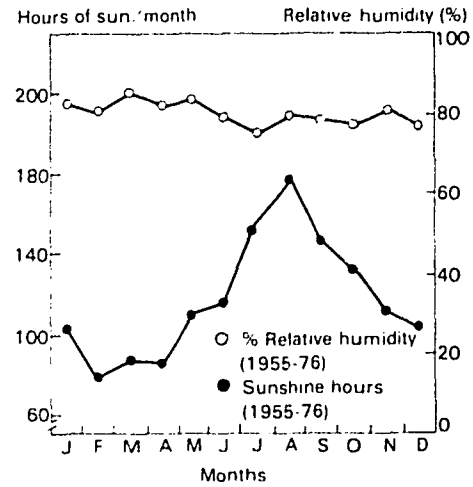

Figure 2 **Relative humidity and number of hours of sun throughout the year. (C.P. Station 407 "San Jorge").**

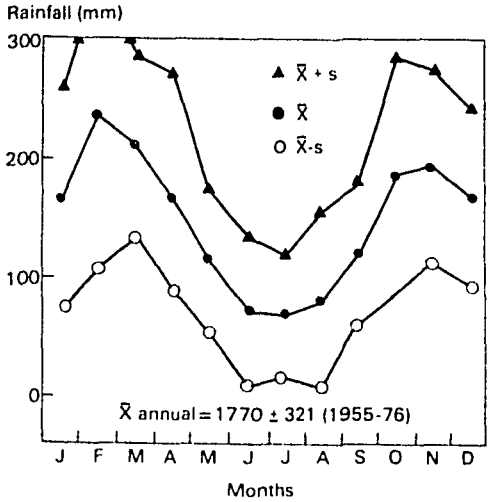

Figure 3. Monthly rainfall distribution mean and standard deviation. (C.P. Station 407 "San Jorge").

the pastures but normally are not so severe as to completely stop plant growth.

The soils of the station are classified (18) as Ultisols (Red Yellow Podzolics) with two distinct sub-groups, one well-drained and classified as Typic Paleudult, and the other poorly-drained and classified as Aquic Paleudult. Their properties are shown in Table 1.

The highest percentages of organic matter (OM) and base saturation have been observed at the surface layer. The Aquic and Typic sub-groups show on the surface low levels of Al which are apparently tolerated by most plants, but these amounts increase considerably at a depth of 3-4 cm, where the percentage of base saturation also decreases.

PRINCIPAL CONSTRAINTS IN PASTURES ESTABLISHMENT

It is a great challenge to establish and maintain productive pastures in Amazonia. In the tropical rain forest basically infertile soils prevail and only forests develop well because of their intensive nutrients recycling. It has been proven (6, 7) that a tropical rain forest in Africa recycles 268 kg of N, 15 kg of P, 303 kg of K, 332 kg of Ca and 75 kg of Mg/ha/yr. This is a high annual fertilization rate which is interrupted when trees are felled in order to practice any kind of exploitation, be it merely cultivation or cattle production.

Another big problem is the proliferation of weeds and jungle regrowth which occurs when large amounts of seeds present in the soil germinate. These find a favorable, fertile and sunny environment after the trees are felled and burned.

Pastures in Amazonia that are established after jungle clearing, benefit from the initial fertility of the soils as a result of the addition of large amounts of nutrients from the forest, in the form of ash. Under these conditions pastures such as *Hyparrhenia rufa* (Nees) Stapf. are capable of carrying 2-3 an/ha. Despite physical control of weeds (by cutting or burning), and because of soil compaction caused by the animals, leaching of nutrients and changing the forest nutrient recycling system to a much inferior one, the productivity of *H. rufa* declines with time. In its place other less productive natural pasture grasses develop *(Paspalum conjugatum* Swartz, *Axonopus compresus* (Swartz) Beauv., *Homolepsis aturensis* (H.B.K.) Chase, etc.), some of which are of low palatability. Under these conditions pastures can carry up to 1 an/ha, but if the settler does not control weeds and jungle regrowth promptly his fields will soon be covered with secondary brush, which will limit even more the productivity of the pasture.

It is important to mention that pastures also recycle nutrients from dead roots, trampled felled vegetation, leaf washing and the addition of manure and urine from the cattle. This is an obviously slower cycle than that of the rain forest, but definitely better than crop cultivation where the level of extraction is maximum and nutrient recycling is minimal.

Table 1. **Properties of two typical soils at the IVITA station in Pucallpa.**

Horizon	Clay	Sand	pH	OM	Available P	Exchangeable cations Al	Ca	Mg	K	CEC	Al saturation
cm	%			%	ppm	meq/100 g					%
Well-drained Ultisol: Typic Paleudult, clayey, kaolinitic, isohyperthermic											
0-4	25	43	4.2	3.7	2	1.9	8.0	1.1	0.36	11.3	17
4-26	29	39	3.1	1.6	1	6.6	3.2	0.6	0.24	10.6	62
26-85	41	33	4.1	0.9	1	9.1	1.2	0.5	0.20	11.0	83
85-150	25	55	4.2	0.4	1	5.9	1.4	0.5	0.20	8.0	73
Imperfectly drained Ultisol: Aquic Paleudult, clayey, mixed, isohyperthermic											
0-3	27	35	5.2	6.3	2	0.2	4.2	2.1	0.52	7.0	3
3-2	45	17	4.3	1.9	1	4.0	2.2	1.2	0.40	7.8	51
21-62	59	15	4.2	1.0	1	8.7	0.8	0.9	0.32	10.7	81
62-+	57	21	4.1	0.5	1	11.6	0.4	0.7	0.24	12.9	90

Apart from these basic problems, the settler must attempt, notwithstanding the difficulties, to stabilize the productivity of the pasture by fertilizing his soil sufficiently at least during the time (6-10 years) when residues from the forest (trunks and stumps) remain in the fields after clearing has taken place. Another serious problem which was mentioned in the introduction is the lack of technology for improving the management of pastures. In addition, it appears that the cattle breeds (Zebu and Criollo) on which the settler will initially depend are not efficient enough to form the basis of a stable cattle industry with sufficient economic productivity to be considered successful.

IVITA'S RESEARCH STRATEGY

The following strategy was developed taking into account the previously mentioned constraints as well as lack of capital, high cost of establishing and maintaining pastures and lack of seed of improved species, apart from *H. rufa*. The basic research objective is to develop a technological package of pastures that is sufficiently stable and productive to justify replacing forest with cattle production. Moreover, the doors should be left open to the possibility of combining cattle raising with development of fisheries, forestry and crop cultivation, as a means of optimizing the productivity of the entire ecosystem.

Figure 4 illustrates this approach which can be summarized as follows. Forest areas suitable for cattle rearing are felled and burned or the timber sold to raise the basic capital needed for initial development. To take advantage of the soil fertility increases due to the ash, the settler should plant one or

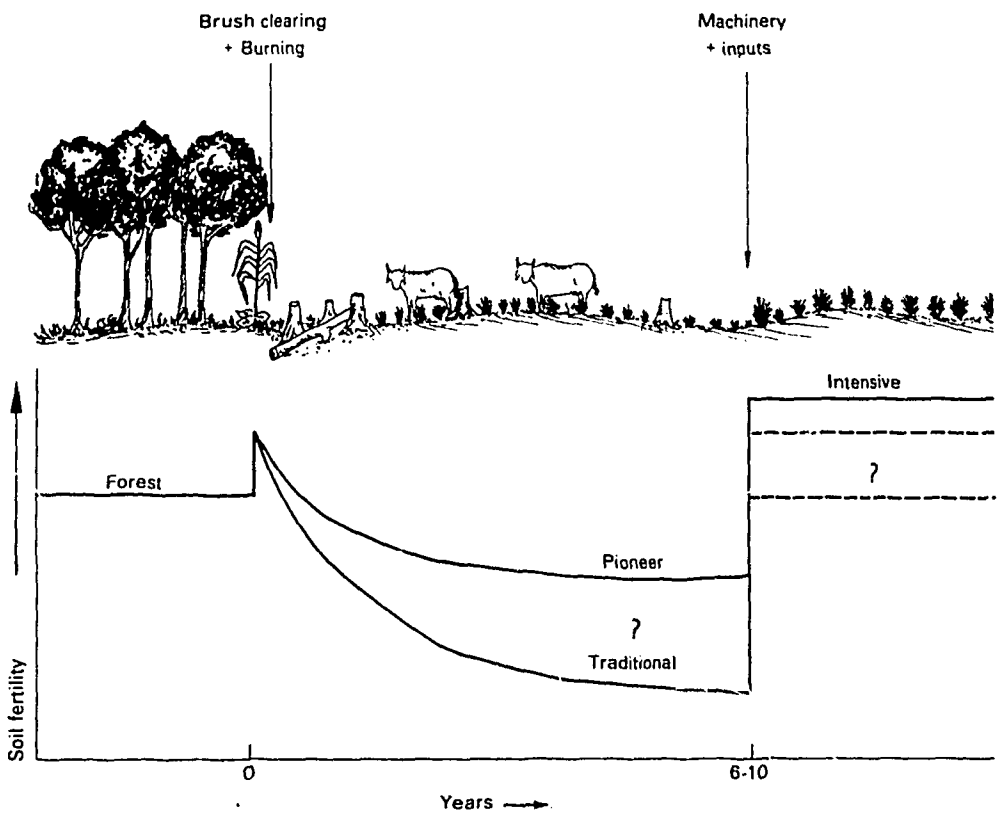

Figure 4. Model suggested for utilization of soil in pastures in the Peruvian Amazon (20).

two cash crops—such as rice or soybeans—which have a short growing cycle and simultaneously, he must interplant the grasses species which will constitute the pasture. In this way he will obtain two crop harvests, get the pasture established, cover the soil quickly and decrease the loss of nutrients and the proliferation of weeds.

The pasture to be established must be better than the "traditional", that is, *H. rufa* alone. The objective is to find a "pioneer" pasture perfectly adapted to the soil conditions during the first years after the clearing. During the first six to 10 years little can be done to introduce better techniques because the farmer is unprepared both technically and economically to adopt them. In addition, the land is full of tree trunks and stumps which do not allow intensive soil or pasture management.

In view of these problems and realizing that the main constraints to improved cattle production on traditional pastures are the low levels of protein and P, the logical course is to try to grow *H. rufa* with a legume. Apart from providing protein, the legume will accumulate much of the available P existing in the soil as well as that which may be applied later. In other words, the objective is to create a pasture which disturbs least the traditional system and which works with a minimum of management.

Stabilizing production at the first year's level is unlikely with this approach, but with a pasture definitely superior to the traditional one, the settler will be able to raise capital and improve his level of technology during the first six to 10 years after clearing. During this time the land will have progressively less forest residues, gradually furnishing the right conditions to use light machinery, improve livestock quality and manage the land more intensively.

The settler should be offered alternative techniques which are economically attractive and which will enable him to produce more from the same area, reinvest his savings, and take full advantage of the best that the Amazon region has to offer. To do this, the physical and chemical changes which increase soil fertility have to be taken into account so as to produce better pasture, and with improved management, to feed better animals or animals which are in their most productive stage (lactating or growing).

Beyond the initial 6-10 year period, an even more intensive use of the land can be considered, for example feeding cut forage to animals in confinement, if this is economical.

This approach divides development into stages which correspond to different intensities of land-use as a function of time. The stages are in terms that may be applied successively or simultaneously to large or small cattle operations. They can be related to the settler's technical knowledge, his level of management and investment required. Therefore, the strategy is to develop a dynamic technological package which will allow realistic development of livestock farming under Amazon conditions.

Using this approach as a guideline, experiments have been conducted since 1969 and the results follow.

RESULTS

Land clearing

Three methods have been used in Peru to clear a tropical forest: (a) with axes and machetes; (b) with bulldozers; and (c) with tree crushers.

Table 2 compares results of the different systems. Land clearing with axes and machetes requires a large labor force which is not always available in a region as sparsely populated as Amazonia; for this reason it is restricted to relatively small areas. This method however, hardly affects the soil and leaves the tree roots intact, causing some of the stumps to re-sprout. Burning can be

Table 2. **Efficiency and comparative cost of land brush-clearing methods in the Peruvian Amazon.**

Method	Operation	Inputs	Cost	
			Labor	Total
		(men/ha) or hour/ha	US$/ha	
Axes and machete*	Cutting	(32.0)	47	59
(Yurimaguas)	Debranching	(17.0)	25	35
	Burning	(1.0)	1	1
	Total	(50.0)	74	96
Bulldozer*	Cutting	3.52	12	76
(Yurimaguas)	Piling	4.59	15	99
	Burning	1.81	6	28
	Total	9.92	33	204
Tree crusher G-40**	Felling	0.80	8	55
(Pucallpa)	Burning	0.04	0	0
	Total	0.84	8	55

* 16

** 23

effective, depending on the work of debranching and when it is done. This method is most widely used because of its relatively low cost.

The bulldozer (270 HP) method reduces the labor requirement to a few skilled operators. Its efficiency is relatively low (9.92 hours/ha) and it is limited to small projects unless a large number of machines are used. This method causes unfavorable changes in the soil as it tends to remove the top layer and compact the ground when piling the bush for burning. It also creates an uneven distribution of ash which results in uneven initial soil fertility. A land clearing study comparing axes and machetes with the bulldozing system, done in Yurimaguas (19) confirms these observations. Clearing with a bulldozer is much more expensive than the other two systems but leaves the land completely ready for mechanizable agricultural operations.

Tree crushers of various sizes have been used successfully in areas between Tournavista and Pucallpa. Table 2 shows data for the tree crusher and its accessories which gave best results (23). This machine is heavy (45 t) and powerful and uses a T-shaped bar which pushes and fells the trees as it passes. It leaves the trees with their roots exposed to the air as it moves over a layer of fallen trees. Tree crushers produce some compaction and movement of the top soil when the tree roots are pulled up, but also leaves a uniform layer of plant material which, when sufficiently dry, burns more easily and efficiently than when cut by axes and machetes. The drawback with this method is that it is not justified for small operations, nevertheless, because of its efficiency and cost it is ideal for medium and large undertakings.

One of the most controversial points when using machinery for brush-clearing is its effect on soil compaction. Table 3 gives data on the pressure exerted on the soil by land clearing machinery, compared with other compacting forces. With bulldozers the area of contact depends on the width of the track. In the case of animals it depends on their movement. The maximum compacting effect of the tree crushers was calculated on the assumption that the three rollers are smooth (without cleats) and that they run on firm flat ground which only allows a penetration of 3 cm.

After calculating the different pressures on the soil it can be seen that machinery produces greater compaction than men on foot, but less than animals like horses or cows. On the other hand, machines such as the tree crusher, which move across layers of fallen trees and branches, greatly increase their area of contact with the soil, thus decreasing their pressure on it. Nevertheless, it is obvious that the manual ax and machete system causes the least soil compaction.

Preliminary species evaluation

The program started with the introduction of grass and legume species. Among the grasses are: *Hyparrhenia rufa* (Nees Stapf., *Setaria anceps* Stapf. ex Massey, *Digitaria decumbens* Stent, *Melinis minutiflora* Beauv., *Brachiaria decumbens* Stapf., *Panicum maximum* Jacq., *Paspalum plicatulum* Michx., *Pennisetum purpureum* Schumach, and among the legumes are *Stylosanthes guianensis* (Aubl.) Sw. cv. Schofield and Cook, *Stylosanthes humilis* H.B.K., *Macroptilium atropurpureum* (DC.) Urb., *Pueraria phaseoloides* (Roxb.) Benth. cv. javanica (Benth.) Bak. *Desmodium intortum* Mill.) Urb., *Glycine wightii* (R. Grah. ex Wight & Arn.) Verdc., *Lotononis bainesii* Baker, and *Centrosema pubescens* Benth.

Among these and other species which did not perform well, those most adapted to the soil and climatic conditions were chosen. Finally, four grasses were selected: *H. rufa* and *P. plicatulum* because of their tussock growth habit adaptable to association with legumes, and *B. decumbens* and *D. decumbens* because their prostrate growth habit makes them especially suitable for intensive management with fertilization. Species suitable for cutting, such as *P. purpureum* and *P. maximum* were left for later evaluation. Three legumes (*S. guianensis, C. pubescens* and *P. phaseoloides*) were chosen to be evaluated in association with the grasses.

Table 3. **Range of pressures exerted on the soil by various compacting agents.**

Compacting agent	Weight	Range of the contact area	Range of pressure on the soil
	t	m²	kg/cm²
Bulldozer (180 HP)*	18.30	2.750-3.560	0.67 - 0.51
Bulldozer (270 HP)*	28.10	2.960-4.120	0.95 - 0.68
Bulldozer (385 HP)*	38.80	4.080-5.090	0.95 - [illegible]76
Tree crusher G-40, (475 HP)**	45.00	4.350- +	1.03 < 1
Tree crusher G-60, (475 HP)**	65.00	4.730- +	1.37 < 1
Horse***	0.40	0.010-0.040	4.00 - 1.00
Cow***	0.35	0.010-0.040	3.50 - 0.88
Man***	0.07	0.015-0.030	0.47 - 0.23

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*** Figures estimated by the authors.

The soil fertility limiting factors were determined by the missing element technique, using *H. rufa* as the control. Table 4 gives the results of the trial in pots. It was observed that N, P and S were the elements which most limit productivity of plants in the first year following land clearing. In subsequent cuttings other elements appear to become deficient. Data taken after the third cutting, which does not appear in the table, shows that there was a response to all the elements studied.

There is no doubt that these pot trials do not represent what happens in undisturbed ground, but they did allow us to determine which are limiting elements at an initial stage and provided an idea of the fragility of the fertility of these soils when managed under a very intense system without nutrient recycling.

On this basis it was considered that a pioneer pasture, consisting of an association of a grass with a legume sown shortly after land clearing, would require applications of P and S while N would come from symbiotic fixation by the legume. Therefore attempts were made to estimate the minimum rates level of P and S necessary to guarantee the normal development of the legume.

The possibility of fertilizing with simple superphosphate (SSP) was studied as a means of applying P and S jointly. Three rates of superphosphate were applied to two legumes in pots (Table 5).

It is apparent that an application of 500 kg SSP/ha (containing 100 kg P_2O_5/ha and 100 kg S/ha) decreased germination. The increase in the number of leaves per plant and the production of DM was greater with increases from O to 100 kg SSP/ha than from 100 to 500 kg/ha. This was confirmed in a field experiment when the same levels of SSP were applied to *H. rufa* and *S. guianensis* (Fig. 5).

Other trials were carried out which showed that most tropical legume species introduced on the station did not need lime applications to attain adequate growth (17, 18), demonstrating their adaptation to high levels of Al and low pH.

Trials were also conducted on applications of N fertilizers to grasses, looking ahead to a more intense alternative and with the idea of obtaining preliminary information for designing its management.

To determine frequencies of N

Table 4. **Average DM production of *H. rufa* when one or several soil nutrients are missing (17).**

Treatment	DM production/cut			Total	% of complete	Order of importance
	First	Second	Third			
	g/pot					
– All missing	1.6***	3.6***	15.0***	20.2	21	
+ All present	19.3	33.6	40.0	93.1	100	
– N	4.0***	5.2***	15.3***	24.5	26	1
– P	6.8***	7.2***	13.8***	27.8	29	2
– K	19.6	26.0*	33.6**	79.2	85	
– Ca	20.2	26.4*	31.8**	78.4	84	
– Mg	17.3	31.8	35.1**	84.2	90	
– S	15.8**	19.5***	19.1***	54.4	58	3

* Significance $P < 0.05$

** Significance $P < 0.01$

*** Significance $P < 0.001$.

Table 5. **Effects of applying three levels of SSP on the germination vigor and production of two legumes planted in pots (14).**

Species	SSP applied	Germination	Vigor	DM production 4th week	9th week	14th week
	kg/ha	Plants/ pot	Leaves/ plant	g/plant		
	0	20.30	0.84	0.33	1.88	6.77
P. phaseoloides	100	19.60	1.13	0.38	2.37	10.78
	500	16.40	1.40	0.56	4.20	12.44
	0	14.00	1.01	0.30	1.52	11.78
S. guianensis	100	16.10	1.14	0.37	2.04	15.67
	500	12.00	1.13	0.55	2.10	17.33

applications to a pasture under conditions at Pucallpa a rate of 150 kg N/ha was split in several times of application (Table 6). This experiment showed that the most efficient timing of N applications is at two-month intervals.

A preliminary evaluation was done with four grass species to determine effects on production of different levels of N and different ages at cutting. Nitrogen was applied at 0, 200 and 400 kg/ha to *B. decumbens, D. decumbens, S. anceps* and *H. rufa*. The data samples were taken from one square meter of the plot every two weeks, from the second to the 16th week after the last cutting. *B. decumbens* and *D. decumbens* produced more and responded better to N applications than the other two grasses (Fig. 6). Samples were analyzed for protein content, cell composition and *in vitro* DM digestibility.

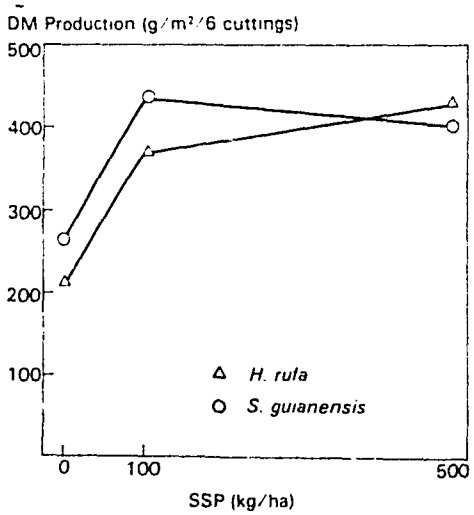

Figure 5. **Effects of applying three levels of SSP on production of DM by *H. rufa* and *S. guianensis* (14).**

Comparative values of *B. decumbens* and *H. rufa* at different ages are presented in this paper, because these two species have different responses to N, different growth habits and different chemical compositions (Figs. 7 and 8). *B. decumbens,* which responds well to N fertilization, grows

Table 6. **DM production of *Panicum maximum* with the application of 150 kg N/ha in different dosages and at different intervals (17).**

Frequency of application	Interval	DM production
Applications/yr	Months	g/m²/yr
Control		1.11
1	12	1.53
2	6	1.69
3	4	1.75
4	3	1.82
6	2	2.17
8	1.5	1.87
12	1	1.68

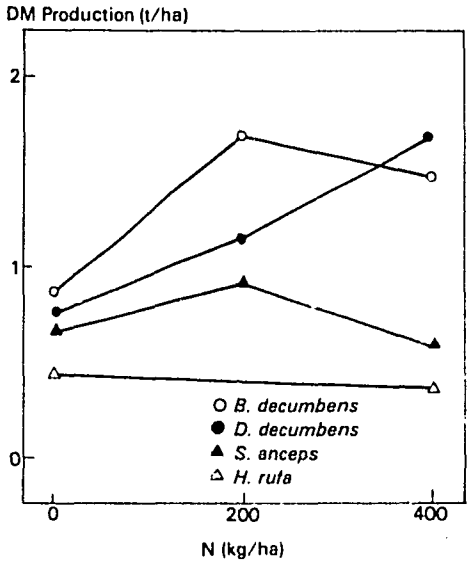

Figure 6. **Production of DM by four tropical grasses with increasing applications of N and cutting at six weeks (21).**

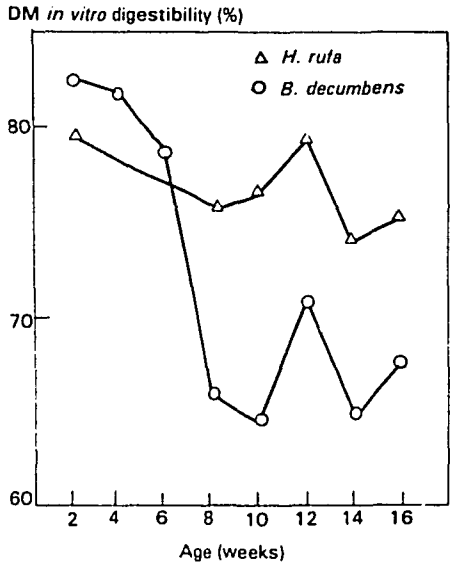

Figure 8. **Digestibility *in vitro* of DM from *B. decumbens* and *H. rufa* at different ages, with the application of 200 kg N/ha (21).**

rapidly but loses quality at an early age (its protein content and DM digestibility decrease very rapidly). It requires intensive management with fertilization with frequent and precise grazings, and does not permit

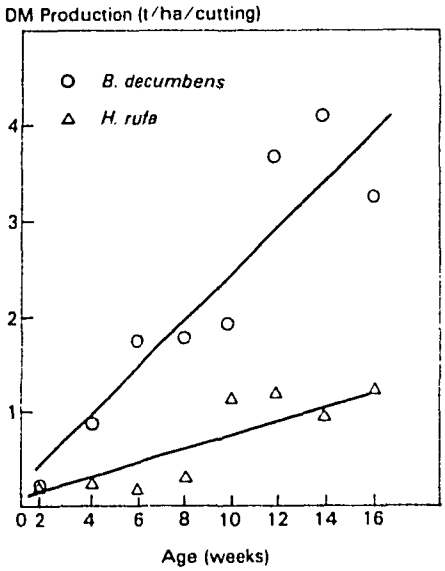

Figure 7. **Production of DM/ha/cutting by *B. decumbens* and *H. rufa* at different ages, with application of 200 kg/ha of N (21).**

association with a legume. On the other hand, *H. rufa* needs a less stringent management when associated with a legume which adds to the productivity of the pasture and provides protein to the animal. *H. rufa* therefore, would adequately form part of the pioneer pasture with minimum management while *B. decumbens* can only be considered for intensive pasture because of its higher management requirements.

The pioneer pasture

The excellent growth of both grasses and legumes immediately following land clearing confirms that is a good time to establish associations. Nevertheless, the fact that grasses generally grow faster and more profusely than legumes in a fertile soil must be taken into account. It is necessary to choose the most compatible species and the correct number of animals, which prefer to consume the grasses, to ensure stabilizing the mixture in adequate proportions.

Moreover, the species chosen must produce seed profusely so that weed control by burning does not affect the pasture stand.

It is also possible to improve traditional pastures by introducing legumes, but it is important to choose compatible species. With these considerations in mind, three legumes were seeded in plots of different grasses. Table 7 gives an evaluation of these legumes at six and 12 months after planting.

These legumes established themselves in paddocks of natural pasture of erect species such as *H. rufa, S. anceps* and *P. maximum,* but plantings of legumes in pastures of *B. decumbens* were not successful.

This was confirmed in a trial (15) in which the relative vigor of three grasses and three legumes was studied. Vigor was of the following order: *B. decumbens* > *P. plicatulum* > *H. rufa* > *P. phaseoloides* > *C. pubescens* > and *S. guianensis.*

H. rufa is a grass well adapted to the region and requires only small quantities of P and S to guarantee its productivity in an associated pasture. Also, *S. guianensis* and *H. rufa* are compatible species. Therefore, an experiment was done to compare the traditional pasture of *H. rufa* alone with the pioneer pasture of *H. rufa* and *S. guianensis,* fertilized with 200 kg/ha/yr of superphosphate at different stocking rates (Table 8). The years of observation varied because of adjustments in stocking rate made in 1977.

With the traditional *H. rufa* pasture, the highest level of production was attained with a stocking rate of 1.8 an/ha, whereas in the pioneer pasture it was attained with 2.6 an/ha. This represents a 44% increase in the carrying capacity as a consequence of introducing the legume and fertilization.

Changing from the traditional to the pioneer system, therefore, tripled annual liveweight gains, 150 to 450 kg/ha.

These figures show the potential for raising cattle on Ultisols in tropical rain forest areas, because even the traditional pasture can produce more than in most other soils or ecological environments in the tropics. The pioneer pasture differs little from the traditional in its investment and

Table 7. **Observations on the compatibility and persistence of promising legumes planted in grass paddocks during the first grazing year.**

Legumes	Grasses	Condition of the legume at: 6 months	12 months
S. guianensis	*H. rufa*	very good	very good
	B. decumbens	none	none
	S. anceps	excellent	excellent
	P. maximum	good	very good
	Native grasses	very good	excellent
P. phaseoloides	H. rufa	excellent	excellent
	B. decumbens	none	bad
	S. anceps	very good	excellent
	P. maximum	excellent	excellent
	Native grasses	very good	excellent
C. pubescens	*H. rufa*	good	excellent
	P. maximum	good	excellent
	Native grasses	good	excellent

Table 8. **Animal performance and beef production per ha in traditional and pioneer pastures (4,5).**

Pasture	Stocking rate	Years of observation	Liveweight gains	
			Per animal	Per hectare
	an/ha	no.	g/day	kg/yr
Traditional	1.2	3	160 ± 16	70
(*H. rufa*)	1.5	4	169 ± 20	92
	1.8	3	227 ± 17	149
	1.9	1	215 ± 50	149
	2.1	3	169 ± 13	129
	2.3	1	203 ± 39	170
	2.6	1	160 ± 61	151
Pioneer	2.1	3	403 ± 39	308
(*H. rufa* +	2.4	3	401 ± 32	351
S. guianensis + P)	2.6	1	495 ± 41	469
	2.7	3	340 ± 41	335
	3.0	3	345 ± 33	377
	3.1	1	439 ± 55	496
	3.6	1	350 ± 62	459
	4.1	1	286 ± 51	428

management requirements and can triple production over the same area.

Research on pioneer pastures continues to fill many gaps in our knowledge and alternative species are being sought which, in association, can give higher yields than the mixture of *H. rufa* and *S. guianensis*.

Intensive pastures

The results of various preliminary experiments (17, 18) for this alternative, in addition to those given in this paper, lead to these conclusions: (a) species exist that, under the conditions at Pucallpa, respond well to high rates of applied N; (b) to maximize the efficiency of these fertilizers, applications of N from chemical sources should be made at eight-week intervals; and (c) the intensive use of these soils will cause deficiencies of nutrients other than N.

On the other hand, this kind of pasture can be established on land which has been in pioneer or traditional pasture for several years, and where the soil fertility has been stabilized at a lower level than immediately follows brush clearing.

To undertake intensive pasture schemes it is necessary to have a thorough knowledge of the soil. For this reason a management system which will give priority to the fertility of the soil is being developed.

For the intensive system several species of grasses have been considered among them: *B. decumbens, D. decumbens, P. maximum* and *P. plicatulum*. Most trials gave priority to *B. decumbens* as this species had shown the best adaptation and persistence in the conditions of the region.

Figure 9 shows the effect of lime applications on the percent Al saturation in the soil and its pH. Al saturation can easily be reduced to levels below 20%, which is

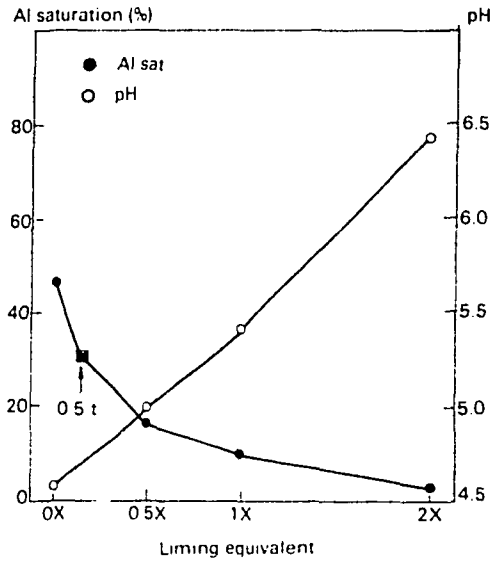

Figure 9 **Effect of liming on percentage Al saturation and pH. Observations recorded four months after applying lime to a depth of 15 cm (20).**

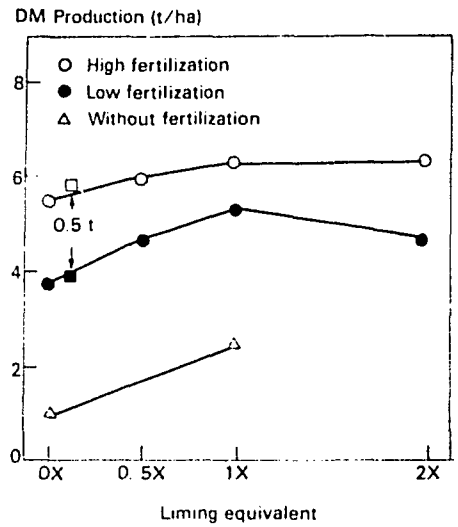

Figure 10. **Effect of liming on bimonthly production of DM in *B. decumbens* (4).**

acceptable to most plants, by applying only 0.5X lime equivalent*, which for this Ultisol is only 1.8 t/ha. In the experiment with *B. decumbens*, lime was applied with the objective of neutralizing the exchangeable Al in the soil and not correcting the pH. Standard levels of Al were thus obtained for equal treatments in different experiments with different soils and pasture species.

Figure 10 shows the effect of lime on the production of *B. decumbens* with different levels of fertilizers. The addition of lime increased production in all cases up to a level of 1.0X, which is probably due to the effect of neutralizing most of the exchangeable Al. On the other hand, the effect of the lime by itself is less than the effect of the fertilizers by themselves.

It is important to emphasize the preliminary nature of these results. It is very likely that for *B. decumbens* in particular and perhaps for many other tropical pasture grasses, the critical level of Al saturation is above 20%. On the other hand, after an application of lime the Al saturation level decreases, but also it is expected to increase again over time. Thus, soil samples are taken periodically in all the trials to determine the critical levels of Al saturation for each species under study and to estimate the frequency for applying lime to keep the plants free from toxic effects of Al. The trial also serves to evaluate the effect of liming and the application of fertilizer on the vegetative establishment of *B. decumbens*. Results evaluated three months after sowing and fertilization and four months after applying lime indicated there were no differences in plant establishment.

Figure 11 shows how much the application of fertilizer helped the vigor and development of *B. decumbens* and controlled more effectively the spread of weeds. This figure also shows that the effect of lime on controlling weeds was strong but that fertilizers tended to eliminate the lime effects.

Preliminary studies showed that the most limiting element is N and in fact, typical response curves have been obtained for N

* Lime equivalent is the amount of lime necessary to neutralize the exchangeable acidity of the soil (1 meq/100 g of soil = 1 t $CaCO_3$/ha).

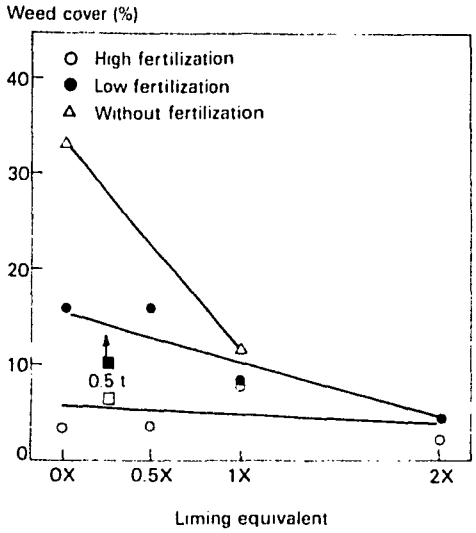

Figure 11 Effect of liming and fertilization on weed cover during establishment of *B. decumbens* (4).

applications. Figure 12 shows two response curves which can be considered extreme; one corresponds to the dry season (June-July) and the other to a period when rainfall conditions are more favorable (October-November).

These curves show that *B. decumbens* responds linearly to N up to a level of 400 kg/ha/yr, when it is applied in small amounts every 60 days. On the other hand, the problem of the change in productivity of the pasture because of rainfall is an important one. During the wet season with fertilizer and optimum management, *B. decumbens* would be capable of carrying up to 5 or 6 an/ha/yr, but during the dry season, this number decreases about one-half. A possible solution to regulating production in this short dry season might be irrigation or some means of animal management which would reduce the stocking rate during the least productive period, possibly eliminating N treatments during this period.

P, which is also known to be deficient in these soils, is being studied in an experiment similar to that of N. Preliminary results are shown in Figure 13, where there are two curves, one for the application of 200 kg N/ha/yr and the other with double that amount. These curves correspond to two cuttings (second and fifth) of the N experiment where response patterns to this element were practically superimposed. It is therefore assumed that they are comparable

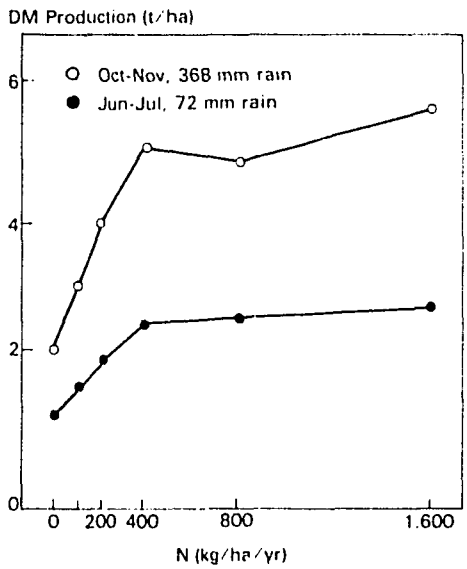

Figure 12. Effect of application of N on bimonthly production of *B. decumbens* in two periods of the year (4).

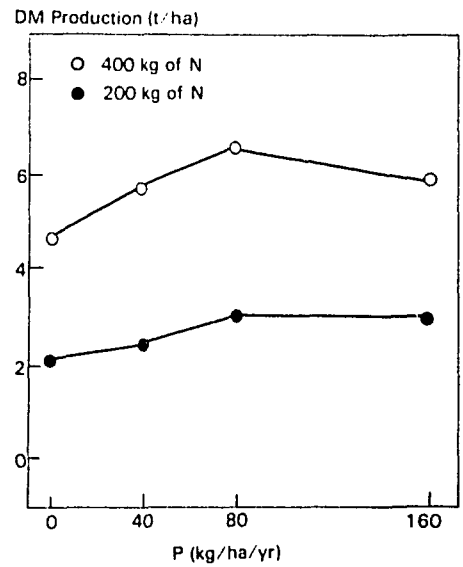

Figure 13. Effect of P on bimonthly production of DM by *B. decumbens* at two levels of N (4).

in relation to the effect of variables not controlled by the treatments of the experiment.

It can be seen, even if not in such a spectacular form as in the case of N, that *B. decumbens* responds to applications of up to 80 kg P/ha/yr (180 kg P_2O_5/ha). Furthermore, it is possible that an interaction exists between P and N, as can seen in the different gradients from 0 to 80 kg P/ha in these two curves. The small response to P indicates applied P is being fixed when given in the form of SSP, but this could also be explained by lower requirements of P in *B. decumbens* or the ability of this species to use natural and less soluble forms of P. The possible interaction between P and N would indicate that P requirements of the plant would increase when production is greater as a result of large applications of N, thus forcing it to make better use of the applied P.

Parallel experiments are being done with K and Mg and also for other species. This work, together with experiments whose results are partially included in this paper, should provide, in a few years, the guidelines to determine the correct management of this type of intensive pasture with fertilizers, once the optimum application levels of principal macronutrients have been worked out for the species having the greatest potential for this system. The need for lime and its optimum time of application must also be worked out and a fertilizing timetable developed which considers the reduction of yield during the dry season.

Although a foolproof intensive management system is still unavailable, some observations are being done on a paddock of 3.5 ha of intensively-managed *B. decumbens*, fertilized with 280 kg P/ha/yr and grazed in daily rotation by milk cows (Holstein x Zebu) using the pasture as the only feed, with mineral salt supplement. Results over the last two years are shown in Table 9.

In this experiment the intervals between grazings and the stocking rates were adjusted according to the forage available and the rotation made in small paddocks, using electric fences to contain the animals for one day. The animals had shade, water and free-choice salt and were milked twice a day. Stocking rates varied between 3.5 and 4 cows/ha in the rainy season and 2.5-3.0 cows/ha in the dry season. These stocking

Table 9. **Management, consumption and production data of a *B. decumbens* paddock grassed by milk cows (2).**

Parameter	1976		1977	
	Rainy season	Dry season	Rainy season	Dry season
Management				
$\bar{x}$ Interval (days)	22.6 ± 1.1	22.8 ± 3.5	22.9 ± 2.0	21.6 ± 3.3
$\bar{x}$ Stocking rate (cows/ha)	4.0 ± 0.4	2.7 ± 0.7	3.6 ± 0.6	2.8 ± 0.7
Consumption				
$\bar{x}$ Consumption (kg/of DM/ 100 kg of liveweight)	3.1 ± 0.3	2.4 ± 0.5	3.3 ± 0.3	2.8 ± 1.0
Milk Production				
$\bar{x}$ per cow (kg/cow/day)	9.6 ± 3.7	8.3 ± 1.8	8.4 ± 3.6	8.1 ± 1.9
$\bar{x}$ per ha (kg/ha/day)	39.1 ± 3.7	22.7 ± 7.8	29.7 ± 5.0	22.8 ± 7.8

rates, together with an average grazing interval of 22 days, show the speed of regrowth and productivity of the pasture. On the other hand, consumption of between 3.5 and 2.5 kg DM/100 kg liveweight, considered about normal, together with production of more than 9 kg/cow/day of milk without feed supplement and under Pucallpa's climatic conditions, shows that the quality and quantity of forage from the pasture is sufficient to maintain the animals and produce between 30 and 40 kg of milk/ha/day during the wet season and between 20 and 30 in the dry season. The results from the intensive pasture portion of the overall strategy are most encouraging.

This intensive portion requires equally intensive animal husbandry and attention to animal quality. This is why research on intensively managed pastures is being done together with studies on animal husbandry and improvement of cattle quality.

Information in this paper is only part of many experiments which have been and are being done at the Principal Tropical Experimental Station of IVITA at Pucallpa. They clearly demonstrate that pasture-based cattle production in Amazonia shows great promise. Further progress will not be made unless the work continues and intensifies so that many existing gaps in knowledge are filled and a technological package is made available which will guarantee stability and technical and economic success of the cattle industry in the region.

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PRODUCTIVITY OF CULTIVATED PASTURES ON LOW FERTILITY SOILS IN THE AMAZON OF BRAZIL

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ABSTRACT

In the humid tropical region of Brazil there are about 2.5 million ha of cultivated pastures in forested areas. About 90% of these pastures are of *Panicum maximum*, 7% of *Hyparrhenia rufa* and 3% of *Brachiaria humidicola*. The usual establishment procedure for cultivated pastures includes felling the forest, burning the vegetative biomass and then the seeding of forage grasses. Generally, in the first years, and as a consequence of the increased soil fertility from incorporation of the ashes, cultivated pastures have a sufficiently high productivity. However, later, especially after five or six years of use, a more or less gradual diminishing of the grasses is seen, especially *P. maximum*. It is estimated that in a period of less than 20 years of developing cultivated pastures in the region, there already are approximately some 500,000 ha degraded or in an advanced stage of decline. This paper presents a model of the dynamics of the soil-pasture-animal system on soils of the Amazonian forest. The model relates the productivity of *P. maximum* pastures cultivated at two levels of technology with the fertility and texture of the soil and the grazing pressure. From the results it is concluded that: (a) P is the soil nutrient most limiting to the productivity of pastures grown in the Brazilian humid tropics. This limitation seems to be most important for the forage grasses than for forage legumes. Generally, the reduction of soil levels of available P is accompanied by a decrease in productivity of the cultivated pastures. (b) The process of decline in cultivated pasture productivity is much more noticeable in very clayey soils, and grazing pressures above the optimum accelerate the decrease in productivity of pastures on these soils. (c) Periodic corrections of P levels of soils under pasture, especially after the fourth or fifth year, the incorporation of adapted forage legumes, and the use of management systems and grazing pressures necessary for maintaining equilibrium in the soil-plant-animal system, are the key to maintaining the productivity of cultivated pastures for long periods of time. (d) The use of Amazonian forest areas as cultivated pastures for several years results in an improvement of the soil chemical properties, permitting the substitution of the pastures by perennial crops with the addition of small quantities of phosphate fertilizers.

THE HUMID TROPICS OF BRAZIL

The humid tropical region of Brazil corresponds to about one-half of the country's

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area, that is, almost 450 million ha. The region is located between latitudes 5°N and 12°S and longitudes 44° and 74°W (Fig. 1).

Climate

Based on the Koppen classification the Brazilian humid tropics fall within the humid climate group A that includes Af, Am and Aw climate types. Figure 2 shows the approximate distribution of these climates in the region. Mean annual temperatures range from 24° to 28°C with maximum temperatures fluctuating between 29° and 34°C and minima, between 16° and 24°C. In the Am and Aw climate areas, the rainy season is distributed in two rather distinct periods. With a few exceptions, the rainy season begins in November or December and ends in May or June; during the rest of the year rains are moderate. Average annual rainfall fluctuates between 1500 and 3500 mm. In general terms, there is a moisture surplus from January to June and a deficit from August to December.

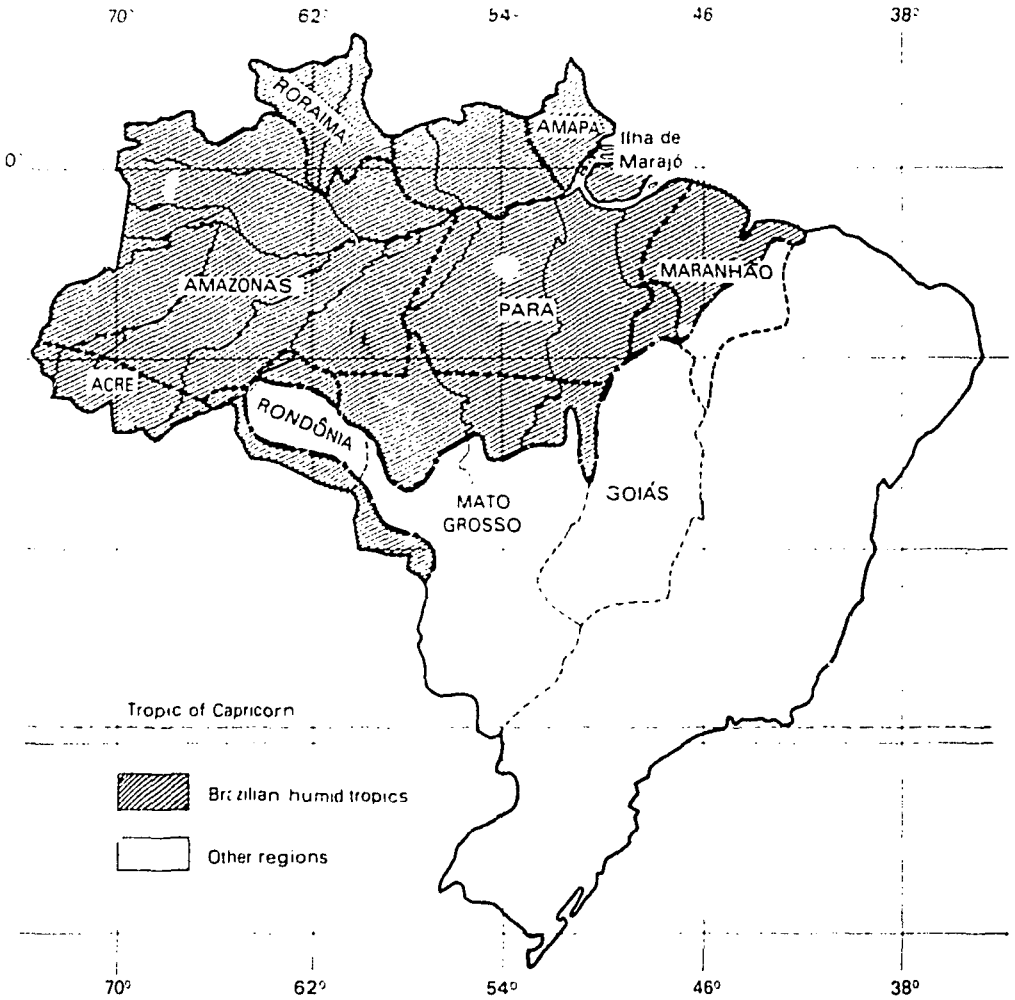

Figure 1. **Brazilian humid tropics.**

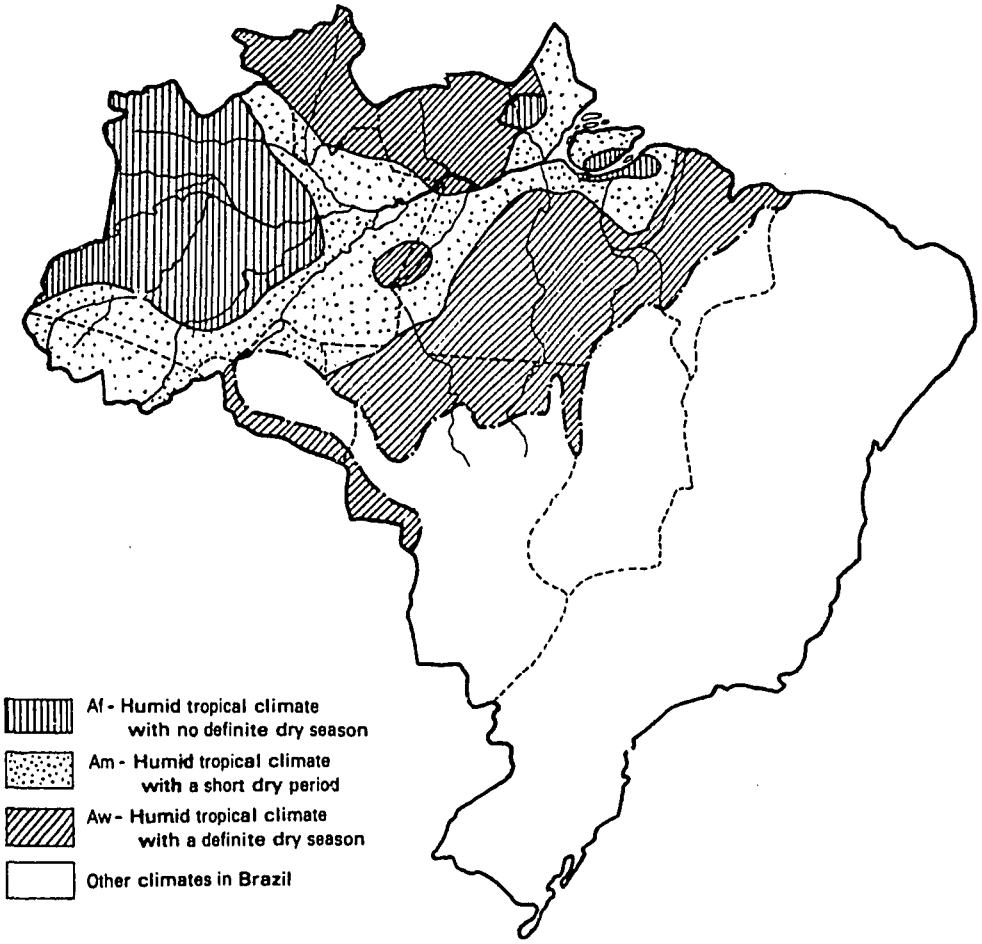

Figure 2. Different types of climate in the Brazilian humid tropics according to Köppen (15; adapted from 3).

Relative humidity values are rarely below 70% and at times reach 90%. Sunshine hours vary from 1500 to 3000 annually, which represents 35 to 65% of the potential radiant energy, indicating a relatively high degree of cloud cover (3). Thermal efficiency indices (3), based on potential evapotranspiration and thermic availability, generally are above 1000 mm, showing that the region is quite hot and humid and is considered an appropriate habitat for the growth of tropical plants.

According to Serrão and Simão Neto (14), the above-mentioned climatic conditions seem to explain the range of adaptation of tropical forage plants—both native and exotic— to similar hydrological and edaphological conditions found in the Brazilian humid tropics. The largest concentration of cultivated pastures in forest areas is located in sites subject to the following types of climate: Aw (principally), and Am, and, to a lesser extent, the Af type.

Forest vegetation

About 85% of the Brazilian humid tropical

region is covered with humid tropical forests which have been classified into three more or less different groups: (1) dense tropical forests found mainly in Af and Am climate areas; (2) open tropical forests found mainly in Aw climate areas; and (3) semi-deciduous tropical forests, typical of some areas also subject to Aw climate. The majority of cultivated pastures on forest soils have been established in areas covered by open tropical forests and, to a lesser extent, in areas of dense tropical forests. Figure 3 shows the approximate distribution of these types of forests in the Brazilian humid tropics.

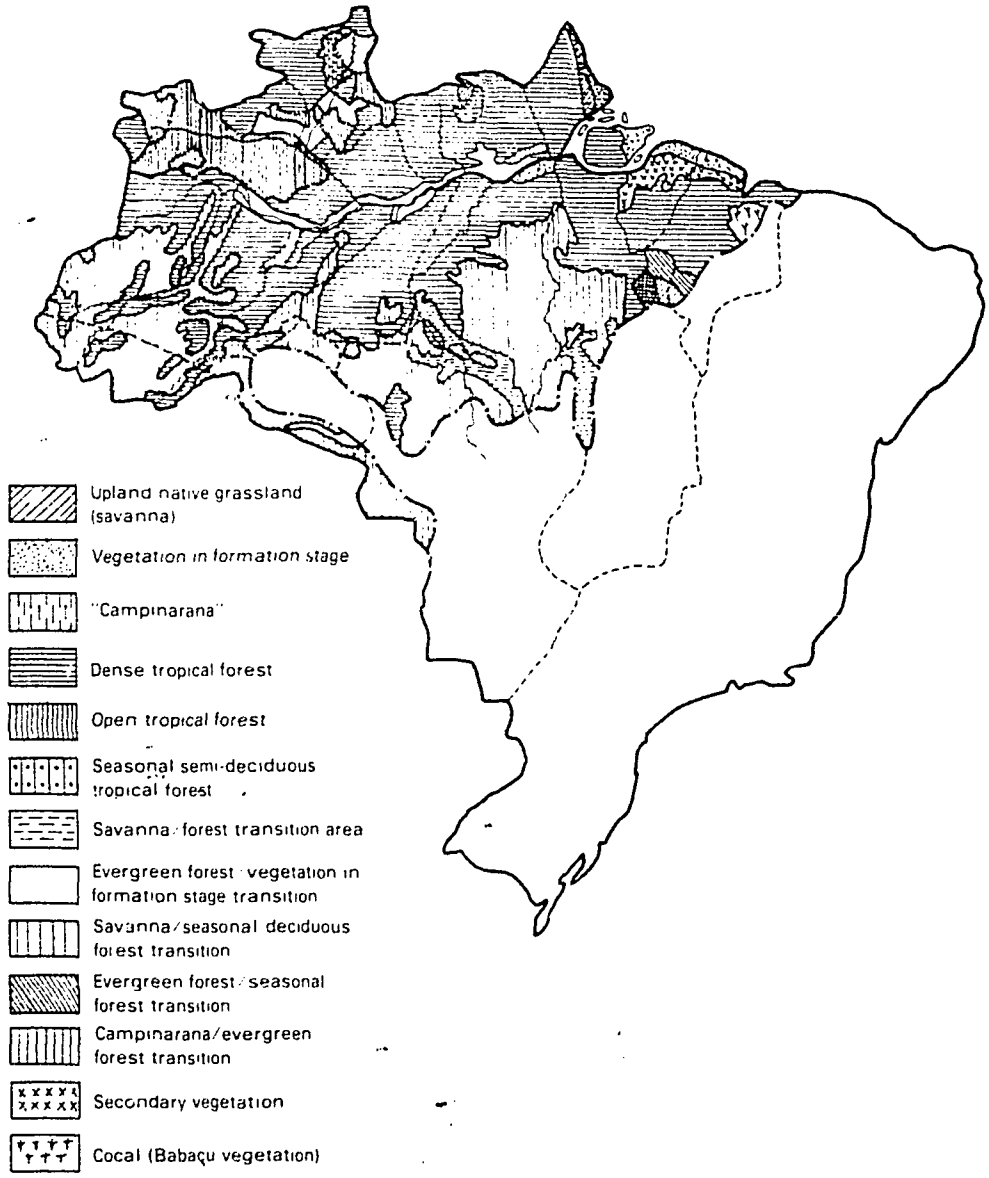

Figure 3. **Main types of vegetation in the Brazilian humid tropics (9, 15).**

Soils

Vieira *et al.* (19) and Falesi (5,6) described the principal soils and soil associations found in the Brazilian humid tropics. Figure 4 shows the general distribution of the region's main soils. According to Vieira *et al.* (19) the soils can be classified in three groups based on their origin and morphology: well-drained soils, hydromorphic soils and developing soils. From the point of view of cultivated pastures, the well-drained soils are those of most interest. The most frequently occurring are the Latosols (Oxisols) which make up about 75% of the region's total area. These soils have a latosolic or oxic B horizon with very good physical properties, are well-drained,

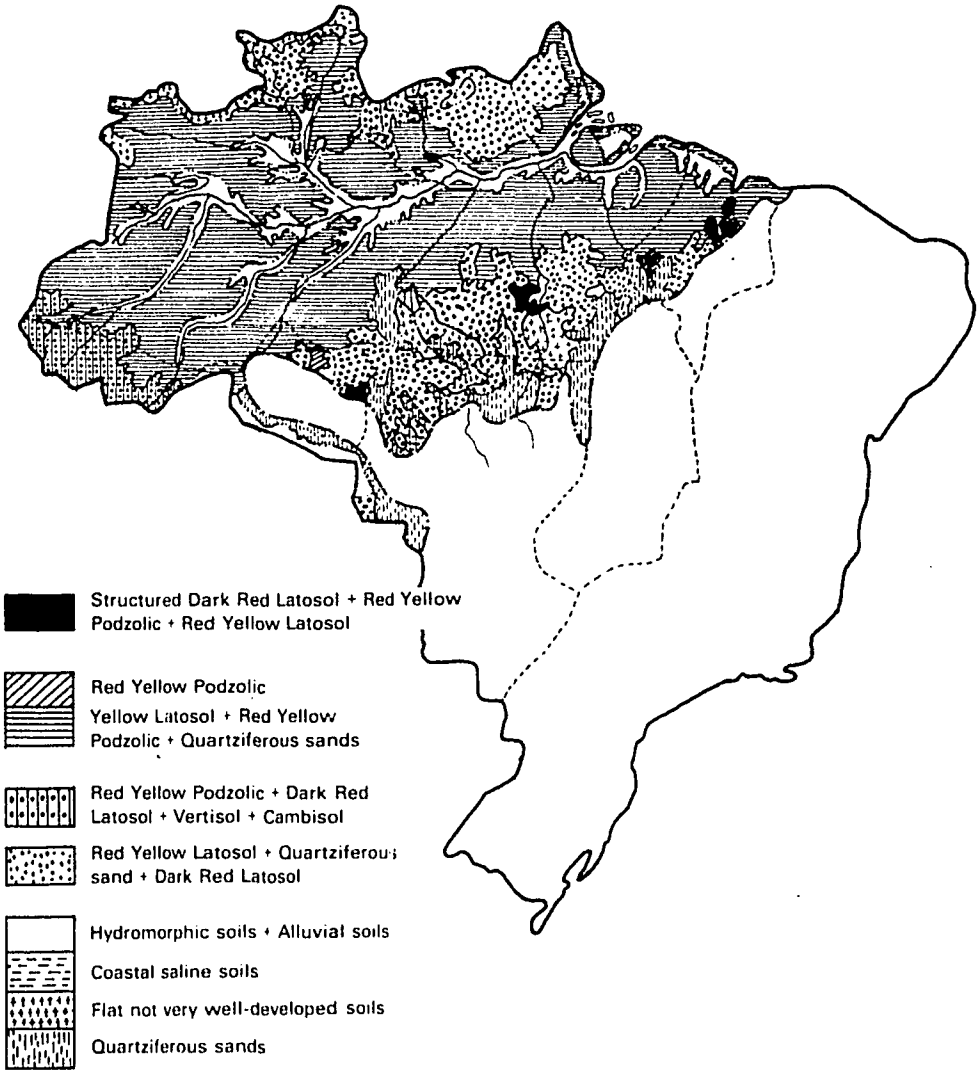

Figure 4 **Main soil types and soil groups in the Brazilian humid tropics (15).**

deep, friable, with a loamy to very clayey texture. Their chemical properties, however, are unfavorable; they have low natural fertility, low pH values, and high contents of exchangeable Al. An exception is the Latosol Roxo (Eutrorthox or Eutrustox) which generally has high fertility but is not common in the region. Oxisols occur on stable land and are found both on level and undulating terrain (5, 6, 19). The majority of the cultivated pastures have been established on Yellow (Red-Yellow), and Dark Red Latosols (all Oxisols).

Podzolic soils (Ultisols and Alfisols) possess a textural or argillic B horizon and also have good physical properties. They are well-developed, relatively deep, with a loamy to clayey texture. Normally, they are acid soils, with a high content of exchangeable Al. In general terms, however, their natural fertility is better than that of the Oxisols. The most common ones are Dystrophic Red Yellow Podzolics (Ultisols) with less than 50% base saturation (5, 6). Large areas of cultivated pastures have been established on such soils, mainly in the southern part of the region. Eutrophic Red-Yellow Podzolics (Alfisols) occur but on a smaller scale. On a rather minor scale, cultivated pastures also exist on concretionary Lateritic soils (petric phases of Oxisols, Ultisols or Alfisols) and on deep acid sands (Entisols).

Table 1 presents the main physical and chemical properties of soils in their natural state (under primary forest), that are of most interest for the discussions in this paper.

CULTIVATED PASTURES

The need to produce food in the region has caused forest to be used for different agricultural alternatives, among them the raising of beef cattle. The option arose due to the ecological constraints for expansion of native pastures located in floodable areas and to the low productivity potential of upland native pastures (14, 15).

Beef cattle production has been the most important activity in the region's development process. Private companies and federal regional development agencies have been investing large sums for this purpose.

During the last 20 years, with the opening of the new Amazonian highways, and mainly the Belém-Brasília road, about 2.5 million ha of cultivated pastures have been established. The main species used are *Panicum maximum* Jacq., occupying about 85% of the total area and, on a smaller scale, *Hyparrhenia rufa* (Nees) Stapf., *Brachiaria decumbens* Stapf., and *Brachiaria humidicola* (Rendle) Schweickt. For the past three years *B. humidicola* has been

Table 1. **Properties of different soils in primary forests, adjacent to *P. maximum* cultivated pastures. Average of several samples taken at 0-20 cm depth (2, 7, 15).**

Soil	Clay	OM	Total N	pH (H_2O)	Exchangeable cations Ca^{++}	Mg^{++}	Al^{+++}	Available K	P	Al saturation
	%				meq/100 g			ppm		%
LAm[a]	20	-	-	4.1	0.3	1.0		16	4	75
LAma[b]	60	2.8	0.16	4.4	1.4	1.8		23	2	53
LVEm[c]	23	2.0	0.10	4.3	0.5	1.1		31	1	62
PVAm[d]	10	1.2	0.07	4.2	0.3	0.9		20	3	70

[a] Loamy textured Yellow Latosol (Oxisol)
[b] Very clayey textured Yellow Latosol (Oxisol)
[c] Loamy textured Dark Red Latosol (Oxisol)
[d] Loamy textured Red Yellow Podzolic (Ultisol).

spreading on a large scale at a very fast rate replacing *B. decumbens* (14, 15, 16, 17).

Figure 5 shows the approximate distribution of native and cultivated pastures in the Brazilian Amazon. Pastures cultivated in forest areas are concentrated along the Belém-Brasilia highway, in southern Pará, in the northern Mato Grosso and Goiás, and on a smaller scale, in the states of Acre and Amazonas and in the Federal Territory of Rondônia.

The general pasture establishment in these areas includes felling the forest, followed by burning of the vegetative biomass and, finally, seeding of forage grasses. Felling is generally done manually, but in some cases, mechanically (chains pulled by tractors) especially in the less-dense forest areas. *P. maximum* is the most utilized grass up to now on large areas of pasture; introduction is principally by seeds, broadcast manually or by air (7).

Usually after the first years of establishment and as a consequence of the greater soil fertility obtained by incorporating ashes

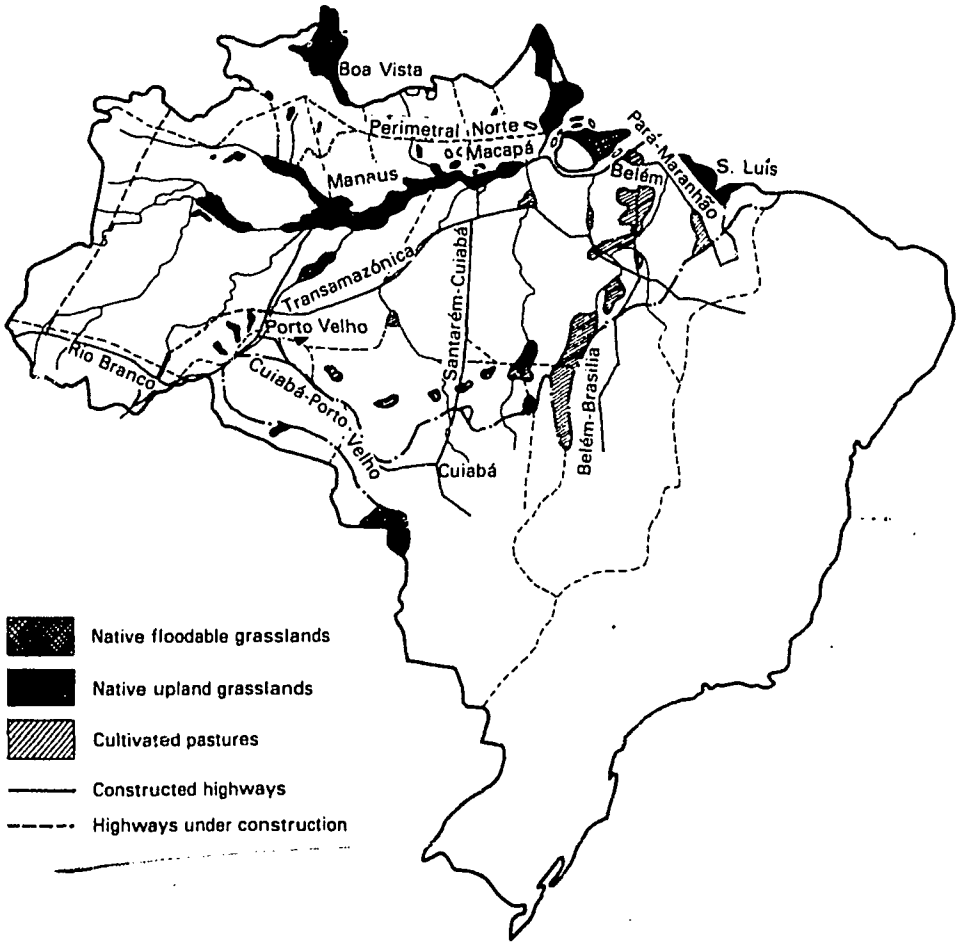

Figure 5. **Different types of pastures and their approximate distribution in the Brazilian humid tropics. (Adapted from 14, 15).**

(1, 7, 12), cultivated pastures with *P. maximum* or *H. rufa* are rather productive. Nevertheless, with time, especially after five to six years of use, a gradual decrease in production is observed, especially on *P. maximum* pastures, and even with annual systematic weedings of "juquira" (the regional name for pasture weeds). This decrease is positively correlated with weed infestations which considerably lessen the pasture carrying capacity, gradually increasing weed control costs and, on many occasions, finally resulting in an irreversible decline in productivity. In such extreme cases the alternatives have been to open new areas and abandon the degraded ones. More recently, the most accepted alternative has been reclamation of these pastures by introducing forage species which apparently are less demanding of physical and chemical soil constraints than *P. maximum*. Reclamation normally includes mechanization to prepare the soil. It is estimated that the Amazon region of Brazil has approximately 500,000 ha of degraded pastures or in advanced stages of degradation.

As a direct consequence of the above-mentioned situation the question "Does the Brazilian humid tropics have the appropriate conditions for cattle production?" has been a theme that has recently aroused much controversy.

Considering that there are beef cattle breeds very well-adapted to the conditions of the Brazilian Amazon, and that the expansion of beef production at the regional level has been possible through the utilization of forest areas for establishing new pastures, one of the main questions about the region could be phrased as follows: "Since pastures represent the cheapest raw material for animal protein production and without which cattle production cannot exist, can the forest areas of the Brazilian humid tropical region maintain highly-productive cultivated pastures over a long period of time?"

What factors have been affecting the productivity of grass pastures in the forest areas of the Brazilian humid tropics? According to Serrão and Simão Neto (14) and Serrão and Falesi (15), in spite of the region's general climatic conditions and the architecture of the majority of forage grasses adapted and used in the region which favor high growth rates, those same climatic conditions negatively affect, either directly or indirectly, pasture productivity.

These same authors mention the following limiting factors that are a consequence of the direct and indirect effects of the region's eco-climate: low forage quality (when compared with forage produced in subtropical and temperate climates); low forage plant seed production (mainly of grasses) and the low quality of seeds produced; diseases affecting the production of seed of *P. maximum* and others, which reduce forage production of some important legumes; pests, among which the spittlebug (*Deois incompleta* and others) is the most serious and a major pest of *B. decumbens;* and finally, the fact that the forest soils have some properties and characteristics that limit productivity of cultivated pastures, and are generally low in natural fertility (Table 1).

Besides these limiting factors, man has also contributed, in many cases, to accelerating the process of decline of productivity in cultivated pastures, especially those of *P. maximum*, and to a lesser extent, *H. rufa* (15). The inadequate planting of pastures (due to inappropriate felling of the forest, poor burning or seeding) makes establishment more difficult and exposes it to a more rapid process of degradation. Furthermore, studies done in the region indicate that cultivated pastures in forest areas have been utilized, with few exceptions, under heavy grazing pressures and continuous grazing, or with minimum rest periods, both breaking the equilibrium of a good balance of the soil-plant-animal-climate complex. As a consequence of this type of utilization, and due to surface erosion, nutrient leaching, and soil compaction (mainly in clayey textured soils), produc-

tivity has decreased at an accelerated rate. The above factors contribute to weed growth and reduced vigor of the grasses and lead to an almost irreversible degradation as has occurred in large areas of cultivated pastures in the state of Pará, as along the Belém-Brasilia highway (especially in the Paragominas region) and in the south of the state, along the Manáus-Itacoatiara highway in the state of Amazonas, and in some areas of Rondônia and Acre.

Attempts to control the decline of production in pastures of *P. maximum* have been limited to controlling weeds by manual, chemical, physical or integrated methods. These procedures are associated with periodic burnings followed by variable rest periods in order to reduce weed competition and favor better grass recovery. But in the majority of cases, even with long rest periods, the results have not met expectations. Weeding operations become more frequent and inefficient, and generally, the grass does not recover its vigor. Since the weed community is composed of native plants adapted to the conditions of the somewhat fragile ecosystem of the cultivated pastures and since animals do not consume the majority of them, the weed group gradually dominates the ecosystem (15).

Given the great importance of management factors (especially grazing pressure), and their interactions with other factors involved in the maintenance of productivity of cultivated pastures, the most important subject to consider is the soil-plant-animal system of these pastures. The main research programs are presently aimed to avoiding decreases in pasture productivity, and developing economic reclamation methods for degraded pastures or on pastures in advanced stages of degradation.

SOIL-PLANT-ANIMAL RELATIONSHIPS

Soils under cultivated pastures

The former Instituto de Pesquisa Agropecuária do Norte initiated a major soils research project on large ranches representative of two of the main grazing regions of the Brazilian Amazon (northern Mato Grosso and the Paragominas region in the state of Pará). The study was recently completed by the Centro de Pesquisa Agropecuario do Trópico Umido (CPATU), of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), and the results were published by Falesi (7) and Serrão and Falesi (15).

Tables 2, 3 and 4 show that in the traditional process of establishing and utilizing cultivated pastures on three typical soils of forested areas, after burning the forest, a large quantity of nutrients was incorporated into the soil through the ashes. This increased fertility considerably raised the pH by at least one unit and practically neutralized the exchangeable Al.

Most important, however, is the fact that with time, nutrients like Ca and Mg remain at rather high levels, pH values generally range from 5.5 to 6.5 and exchangeable Al remains practically neutralized in *P. maximum* pastures (Tables 2, 3, 4). Therefore, the Al saturation of stress is eliminated. Potassium remains more or less at satisfactory and stable levels for maintaining pasture productivity. Organic matter (OM) and N contents also are being maintained at more or less satisfactory levels in spite of periodic burnings.

In Tables 2, 3 and 4, one can see clearly that P availability (as determined by the North Carolina method) increases considerably after burning the forest, remaining above the critical level like the other nutrients. These conditions permit high pasture productivity during the first four or five years. From this point on available P begins to decline with time until it reaches almost undetectable levels as shown in degraded pastures after 10 or more years of use.

Although grazing system and grazing

Table 2. **Average chemical composition (0-20 cm) of a Yellow Latosol of very clayey texture (Oxisol) under forest and *P. maximum* pastures (different ages) in the Paragominas region, Pará (7, 15).**

Soil cover	Total clay	OM	N.	pH (H_2O)	Exchangeable cations $Ca^{++}+Mg^{++}$	Exchangeable cations Al^{+++}	Available K	Available P	Al saturation
		%			—meq/100g—		—ppm—		%
Forest	65	2.79	0.16	4.4	1.47	1.8	23	1	53
1 year grass	50	2.04	0.09	6.5	7.53	0.0	31	10	0
3 year grass	60	3.09	0.18	6.9	7.80	0.0	78	11	0
4 year grass	55	2.20	0.11	5.4	3.02	0.2	62	2	6
5 year grass	50	1.90	0.10	5.7	2.81	0.2	66	3	6
6 year grass	51	1.90	0.09	6.0	3.84	0.0	74	7	0
7 year grass	48	1.77	0.08	5.7	2.61	0.0	47	1	0
8 year grass	52	1.69	0.08	5.4	2.10	0.0	39	1	0
9 year grass	50	2.34	0.11	5.9	4.10	0.1	70	2	2
11 year grass	45	3.37	0.15	6.0	4.10	0.0	86	1	0
13 year grass*	62	2.80	0.20	5.6	4.80	0.0	54	1	0

* Pasture in advanced stage of degradation

pressure undoubtedly contribute to the degradation of cultivated pastures (especially those of *P. maximum*), Tables 2, 3 and 4 show clearly that P is one of the most serious problems for the maintenance of pasture productivity. During the last 10 years, the authors of this paper followed closely the development of cultivated pastures in the

Table 3. **Average chemical composition (0-20 cm) of a Red Yellow Podzolic soil, of loamy texture (Ultisol) under forest and *P. maximum* pastures (different ages) in the Paragominas region Pará (7, 15).**

Soil cover	Total clay	OM	N	pH (H_2O)	Exchangeable cations $Ca^{++}+Mg^{++}$	Exchangeable cations Al^{+++}	Available K	Available P	Al saturation
	—— % ——				—meq/100g—		—ppm—		%
Forest	0	1.17	0.05	4.2	0.30	0.9	20	3	70
Just planted to grass	9	1.04	0.06	7.1	3.05	0.0	27	12	0
1 year grass	7	1.04	0.05	6.7	2.31	0.0	70	9	0
2 year grass	8	1.32	0.06	6.5	2.65	0.0	59	8	0
4 year grass	10	1.20	0.05	6.7	3.56	0.0	51	10	0
5 year grass	7	0.93	0.05	6.2	2.13	0.0	20	2	0
6 year grass	11	1.41	0.06	5.8	1.98	0.0	39	3	0
7 year grass	10	1.34	0.06	6.0	1.75	0.0	98	3	0
8 year grass	8	1.08	0.06	6.0	1.92	0.0	23	3	0
9 year grass	7	1.19	0.06	6.4	3.18	0.0	43	3	0
10 year grass	7	0.93	0.04	6.3	2.33	0.0	20	2	0

Table 4. **Average chemical composition (0-20 cm) of a Dark Red Latosol, of loamy texture (Oxisol) under forest and *P. maximum* cultivated pastures of different ages in northern Mato Grosso (7, 15).**

Soil cover	Total clay	OM	N	pH (H_2O)	Exchangeable cations $Ca^{++}+Mg^{++}$	Exchangeable cations Al^{+++}	Available K	Available P	Al saturation
	%				meq/100g		ppm		%
Forest	23	1.95	0.09	4.3	0.45	1.1	31	2	62
Burnt forest	11	1.31	0.07	5.8	2.33	0.1	74	8	4
1 year grass	11	0.99	0.07	6.8	3.33	0.2	78	5	4
2 year grass	12	1.07	0.06	6.0	1.86	0.2	132	3	9
4 year grass	12	1.39	0.07	6.1	2.58	0.1	70	4	3
5 year grass	12	0.98	0.06	6.4	2.21	0.1	70	6	4
6 year grass	10	0.98	0.06	6.4	2.68	0.1	70	2	3
7 year grass	11	1.07	0.06	6.0	2.15	0.0	70	3	5
8 year grass	10	1.20	0.05	6.7	2.69	0.0	51	2	0
9 year grass	14	1.30	0.06	6.6	2.40	0.0	98	2	0
10 year grass	10	0.98	0.04	6.7	1.84	0.0	70	3	0
11 year grass	10	1.00	0.04	6.4	2.04	0.0	70	2	0

Amazon. They observed that the decline in productivity of these pastures is more rapid and marked on very clayey textured soils, and that a low P content as well as excessively high grazing pressures aggravates the problem.

Recent surveys reveal that pasture fertilization is almost non-existent in the region, and that the use of chemical inputs is limited to herbicides for controlling weeds.

According to this information, research efforts have concentrated on developing, on one hand, practical technologies to avoid yield decline from pastures that are still productive, and on the other, to recover the productivity of degraded pastures. To attain these objectives, EMBRAPA, through CPATU and other research agencies, has developed in the past two years a Pasture Improvement Project for the Legal Amazonia (PROPASTO), with financial support from the Banco da Amazonia S.A. (BASA) and from POLAMAZONIA, a federal government program. All research is being carried out on private ranches (Fig. 6), selected according to their strategic location and because they are representative of the different cattle-raising regions and sub-regions of the Brazilian Amazonia. About 180 ha of degraded pastures are selected on each farm to carry out the tests. In addition to pasture management studies, the investigation includes introduction and evaluation of forage species (grasses and legumes) and studies of pasture fertilization, with emphasis on phosphate fertilization.

Phosphorus: the most limiting edaphic factor

PROPASTO's partial but definitive research results have shown that P is undoubtedly the nutrient which most limits the Amazonian forest soils in their capacity to sustain highly productive pastures of *P. maximum*, and probably other forage species for long periods of time. Furthermore, results indicate that P limitations, either to a greater or lesser degree, seem to be related to other factors, especially soil texture and grazing pressure.

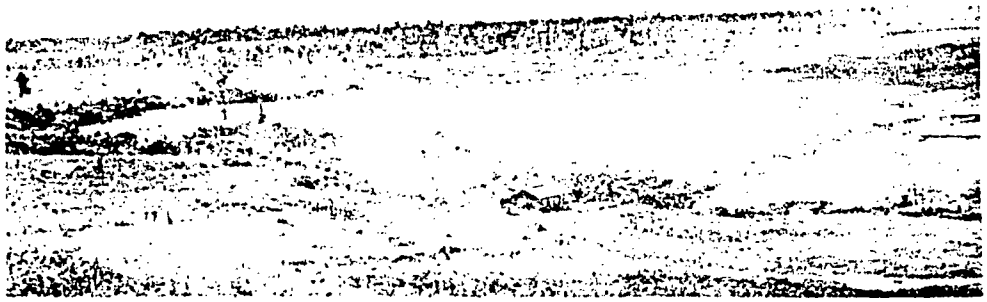

Figure 6 General view of a ranch "experimental field" where recovery and maintenance research is being carried out on cultivated pastures in forest areas of the Brazilian humid tropical region (region of Paragominas, state of Pará)

The results obtained in three different regions will be used to illustrate the evidences and concepts that follow. Table 5 summarizes the main characteristics of these locations, approximate age and conditions of the pastures and soil types and chemical properties.

One of the experiments involved evaluating grass and legume species that could be introduced in degraded *P. maximum* pastures or that could replace it. Each species was evaluated with or without phosphate fertilization. Figures 7, 8 and 9 show the responses of five grasses and five legumes that are used or are potentially usable in the cultivated pastures of the region. Although responses vary from one place to another, it is evident that the most outstanding responses of grasses to P occurred on very clayey soils. This response is especially high with *P. maximum*. In general, these studies revealed that legumes seem to tolerate the lowest P levels better than the grasses. Studies on mixed pastures in the process of degradation with the species *P. maximum* and *Pueraria phaseoloides* (Roxb.) Benth. var. Javanica (Benth.) Bak. (8) where the legume dominated, showed that after fertilizer application, the percentage of *P. maximum* in the association increased considerably compared to *P. phaseoloides*, suggesting that the grass needs more P in the soil for its persistence than does the legume.

Other experiments were conducted to verify the possibility of reclaiming degraded pastures by using only phosphate fertilization at different levels. On each location a degraded *P. maximum* pasture was selected. The different P rates from 0 to 150 kg P_2O_5/ha were broadcast, with three replications. Fritted trace elements (FTE) and S were added to the intermediate treatment (75 kg P_2O_5/ha). Figures 10, 11 and 12 show the partial results obtained in Paragominas, and in Manaus-Itacoatiara.

Table 5. **Location and average chemical composition of topsoils (0-20 cm) in areas where research is being carried out for recovery and maintenance of *P. maximum* pastures in the degradation stage.**

Location	Climate	Soil*	Pasture age	Clay	OM	N	pH (H_2O)	Exchangeable cations $Ca^{++}+Mg^{++}$	Exchangeable cations Al^{+++}	Available K	Available P	Pasture condition
		Years			%			meq/100g		ppm		
Paragominas	Am/Aw	LA_{ma}	13	72	2.8	0.15	6;1	4;8	0.0	54	1	Advanced degradation**
Southern Pará	Aw	QS	12	14	0.67	0.05	6.0	1.8	0.0	39	2	Advanced degradation**
Northern Mato Grosso	Aw	LVE_m	10	10	1.2	0.06	6.1	1.9	0.0	56	2	Production still satisfactory***
Manaus-Itacoatiara, AM	Am	LA_{ma}	6	-	-	-	-	-	-	-	-	Moderate degradation

*LA_{ma} = Yellow Latosol, very clayey texture (Oxisol)
QS = Quartz Sand (Entisol)
LVE_m = Dark Red Latosol, loamy texture (Oxisol)
** "Juquira" represents 75-80% of plant biomass; reduced vigor of *P. maximum*; "juquira" control uneconomic
*** "Juquira" represents 30% of the plant biomass; reduced vigor of *P. maximum*.

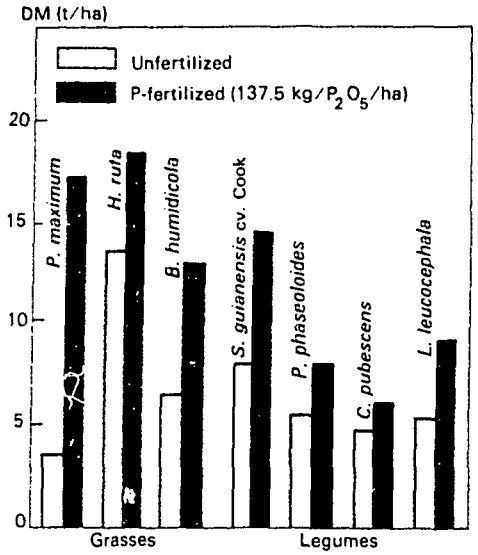

Figure 7. Response of selected forage grasses and legumes to phosphate fertilizers on LA ma soil (Yellow Latosol, very clayey texture, Oxisol) under *P. maximum* 13-year-old pasture in advanced degradation stage (Paragominas).

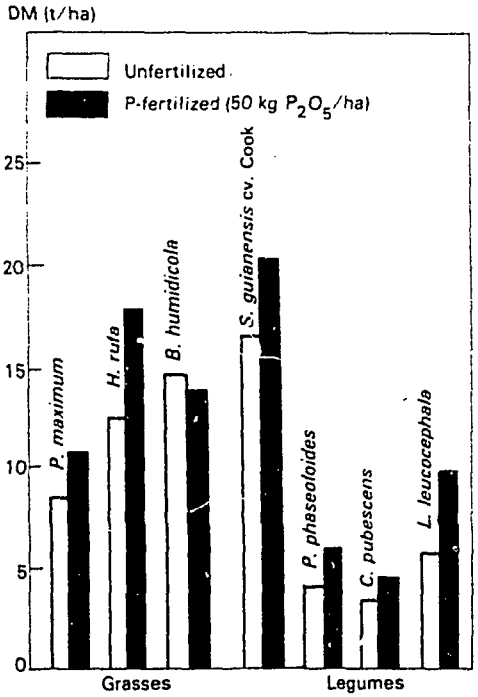

Figure 8. Response of selected forage grasses and legumes to phosphate fertilizers on AQ soils (quartz sand) (Entisol), under *P. maximum* 12-year-old pasture in advanced degradation stage (South of Pará).

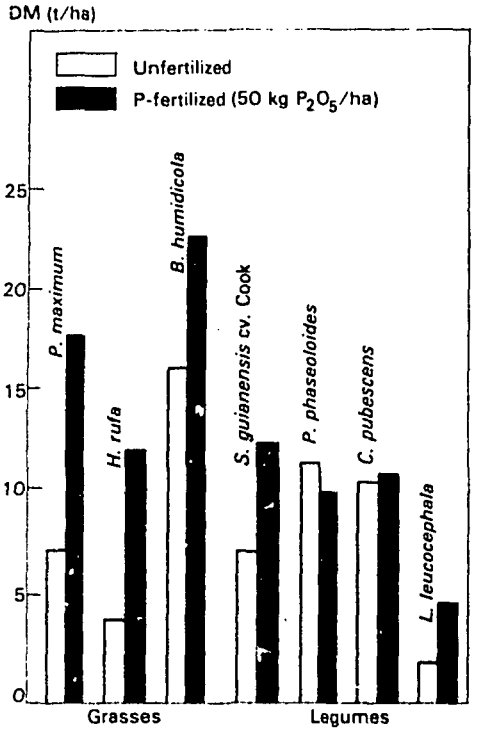

Figure 9. Response of selected forage grasses and legumes to P fertilization on LA ma soil (Yellow Latosol, very clayey texture Oxisol) in *P. maximum* 8-year-old pasture under moderate degradation stage (Manaus-Itacoatiara).

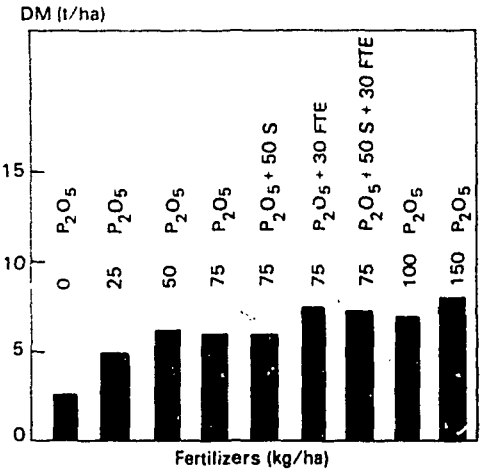

Figure 10. Response of a *P. maximum* 13-year-old pasture in advanced degradation stage to different P levels, to S and micronutrients in LA ma soil (Paragominas); total of three cuts.

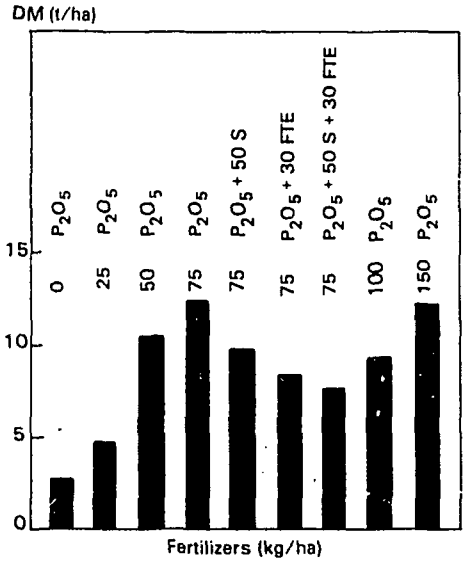

Figure 11. **Response of a *P. maximum* 13-year-old pasture in advanced degradation stage to different P levels, to S and micronutrients in AQ soil (south of Pará); total of four cuts.**

Generally, small quantities of P (e.g. 25 kg P_2O_5/ha) at least doubled the production of degraded pastures. Although gradual production increments were registered with higher P rates, it is evident that on a short-term basis (one to two years), phosphate

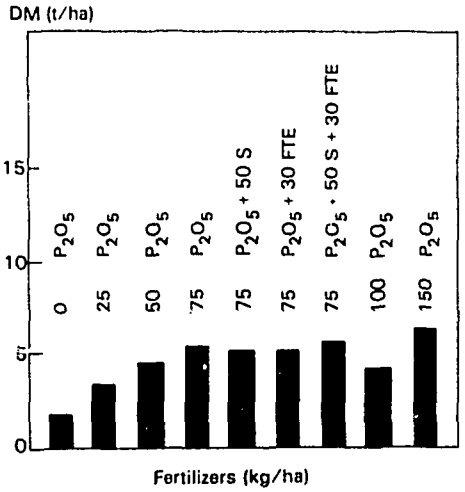

Figure 12. **Response of a *P. maximum* 8-year-old pasture in moderate degradation stage, to different P levels, to S and micronutrients in LA_{ma} soil (Manaus-Itacoatiara); total of two cuts.**

fertilization above 50 kg P_2O_5/ha is not necessary. Koster *et al.* (8) obtained similar results with *P. maximum* degraded pastures on a LA_{ma}* soil (Oxisol) in the Paragominas region. Phosphorus applications at a rate of 75 kg P_2O_5/ha increased forage production of *P. maximum* approximately ten times, compared to unfertilized controls. This increase in production is similar to that obtained with 150 kg P_2O_5/ha.

A greenhouse trial using LA_{ma} Oxisol representative of *P. maximum* pastures in an advanced stage of degradation in the Paragominas region, also shows quite clearly the importance of relatively low P levels for recovering production on these pastures (Fig. 13). In this experiment, with *P. maximum* no N fertilization was applied. The production increase was practically linear for P applications up to 150 kg P_2O_5/ha. Figure 13 also shows that on LA_{ma} soils and at least on a short-term basis, both the simple superphosphate (SSP) as well as triple superphosphate (TSP) and Hiperfosfato (commercial Gafsa rock phosphate) when applied separately or together, provided the same beneficial effect.

While degrading pastures on LA_{ma} soils have responded very favorably to P applications, the responses have not been so marked in pastures approximately 10 years old on LVE_m** soils. The authors of this paper have followed for the last 10 years the development of *P. maximum* cultivated pastures in the Paragominas region where LA_{ma} soils prevail. In this region, traditionally, the pastures have been used under relatively high grazing pressures. The available P in the soil of the oldest pastures hardly ever exceeds 2 ppm P. Very rarely in this region are these pastures more than eight years old still maintaining satisfactory productivity. Similar conditions are found in pastures along the Manaus-Itacoatiara highway. Still productive *P. maximum* pastures on LVE_m soil in the northern region of Mato Grosso (8)

* Yellow Latosol heavy clayey texture (Oxisol).

** Dark Red Latosols of loamy texture (Oxisol).

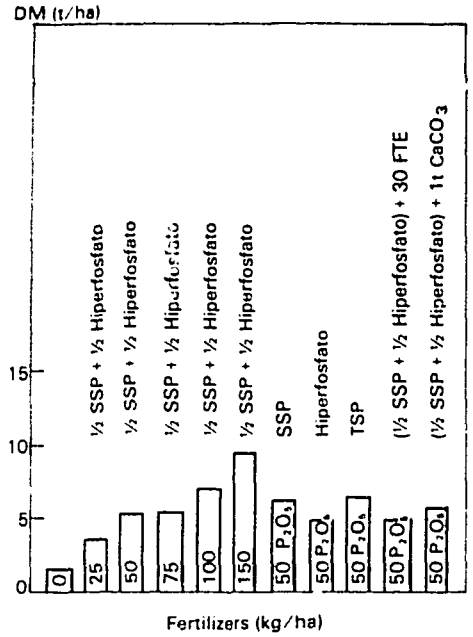

Figure 13. **Response of *P. maximum* to different levels and sources of P, to lime and micronutrients on LAma soil of a 13-year-old *P. maximum* pasture in advanced stage of degradation; first harvest.**

showed increased DM production by only 20% with phosphate fertilization in spite of the fact that the soil contained only 1-2 ppm of available P. Nevertheless, it is important, to mention that in the northern region of Mato Grosso there are rather productive 17-year-old pastures of *P. maximum* in forest areas, that have never received fertilization. Analyses of the soils (with LVE_m predominating), in these pastures indicate that available P is rarely in quantities above 2 ppm in the top 20 cm of soil. Equally important is the fact that most of this region's pastures have not been subjected to heavy grazing pressures.

Soil analyses given in Table 4, together with the results obtained by Koster *et al.* (8), and the authors' observations during the development of cultivated pastures in the northern region of Mato Grosso and the Paragominas region during the last decade, suggest that the low P content of Amazonian forest soils is most limiting for productivity of cultivated pastures on very clayey soils, especially when heavy grazing pressures are employed. In other words, apparently there is an interaction between the soil's P content, its texture and the grazing pressure on the pasture.

And the other nutrients?

Besides P, do other nutrients also limit production of cultivated pastures? Considering fertility standards and conventional critical levels of some nutrients in cultivated pastures (Table 6) and soil analyses shown in Tables 2, 3 and 4, one could suppose, *a priori*, that even in 10-year-old degraded pastures, possible nutrient responses other than P, would not be outstanding in view of the more or less satisfactory levels of OM and K and rather favorable conditions in terms of exchangeable bases, Al saturation, and pH level.

In order to answer the question raised above, missing-element fertilization experiments were done on degrading pastures of *P. maximum*, in Paragominas, and in Manaus-Itacoatiara. Treatments were broadcast on plots selected after completely cleaning them of weeds. The partial results are in Figures 14, 15 and 16.

These figures show that degrading pastures of *P. maximum* which had been growing for more than eight years, responded in a much less marked fashion to the absence of K, N, S and micronutrients as fritted trace elements (FTE) than to the absence of P, although K, N and S can sometimes be limiting. In the experiment whose results appear in Figure 13, although the level of 150 kg P_2O_5/ha produced more forage, it also caused marked symptoms of K deficiency, unlike from the lowest levels. This indicates that K can also limit pasture production whenever high rates of phosphate fertilizers are applied.

Figure 13 also shows that for these conditions, micronutrients (as FTE) and liming exerted no influence at the optimum P level (50 kg P_2O_5/ha).

Table 6. **Critical levels of some nutrients in the soil (depth: 0-20 cm) on cultivated pastures (4).**

Parameter	General fertility level	Soil test levels	Soil critical levels
	Low	<10 ppm of P	
Available P	Average	10-30 ppm of P	10 ppm
(North Carolina)	High	>30 ppm of P	
	Low	<60 ppm of K	
Exchangeable K	Average	60-120 ppm of K	60 ppm
	High	>120 ppm of K	
	Low	<2 meq/100g	
Exchangeable	Average	2-5 meq/100g	2 meq/100g
Ca + Mg	High	>5 meq/100g	
	Low	<0.3 meq/100g	
Exchangeable Al*	Average	0.3-1.0 meq/100g	0.3 meq/100g
	High	>1.0 meq/100g	
	Low	<1.5%	
Organic matter	Average	1.5 - 2.5%	1.5%
	High	>2.5%	
	Highly acid	<5.0	
	Acid	5.0-5.5	
pH (H_2O)	Medium acid	5.6-6.0	5.5
	Low acid	6.0-6.9	
	Alkaline	>7.0	

* Aluminum toxicity index

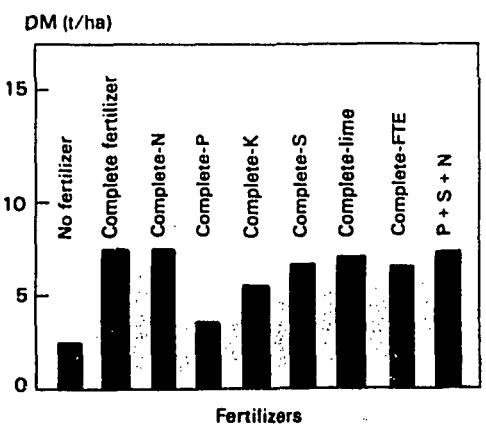

Figure 14. **Response of a *P. maximum* 13-year-old pasture in advanced degradation stage to several nutrients on LA_{ma} soil (Paragominas); total of three cuts.**

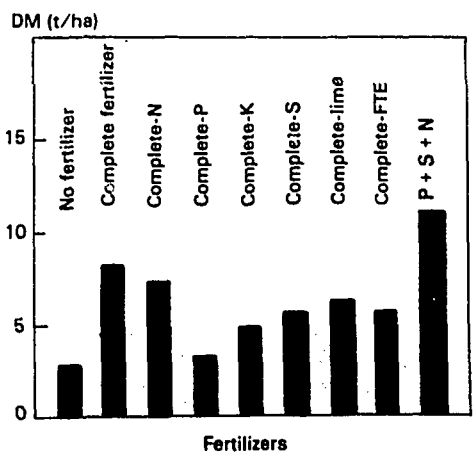

Figure 15. **Response of a 12-year-old *P. maximum* pasture in advanced degradation stage to several nutrients on AQ soil (South of Pará); total of four cuts.**

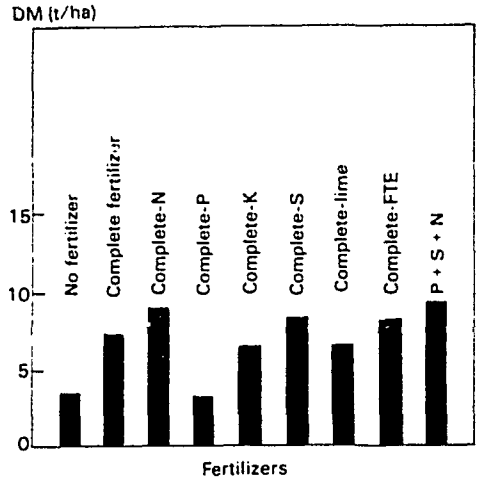

Figure 16. **Response of an 8-year-old *P. maximum* pasture in moderate degradation stage to several nutrients on LA_{ma} soil (Manaus-Itacoatiara): total of two cuts.**

In general, it seems quite evident that liming apparently does not cause any production increases on degrading pastures of *P. maximum*. Similar results were obtained in tests of more or less the same nature, in Paragominas and northern Mato Grosso (8). Results are shown in Table 7. The lack of P caused a very low forage production in relation to the absence of other nutrients in LA_{ma} soil, although the lack of K, S and B also contributed to reducing forage production to a lesser degree in relation to the "complete" treatment. On LVE_m soil, the absence of any nutrient did not cause a significant decline in production of forage in relation to the complete treatment.

Although Serrão *et al.* (13), have observed marked responses of some forage grasses to K in degraded LA_m soil, Mott and Popenoe (10) among others, state that in general a K response is hardly ever observed in well established productive pastures due to the efficient recycling of this element in the soil-plant-animal system.

Table 7. **Response of an eight-year-old pasture of *P. maximum* and *P. phaseoloides* to 13 nutrient elements and lime.**

Treatment	Relative forage production[a]	
	Melhoramentos[b]	Suiá Missú[c]
Control	15	88
Complete (P+K+Ca+Mg+S+Cu+Zn+B+Mo+Co)	100	100
Complete + N	106	84
Complete + dolomitic lime	96	118
Complete + Fe	100	86
Complete + Mn	60	82
Complete + P	19**	79
Complete - K	69	78
Complete - Mg	100	96
Complete - S	55**	85
Complete - Cu	75	87
Complete - Zn	69	99
Complete - B	70	79
Complete - Mo	96	90
Complete - Co	116	118

a Expressed in percentages in relation to the complete treatment
b Paragominas Region, La_{ma} soil; pasture in advanced degradation stage
c Northern Region of Mato Grosso, LVE_m soil; pasture production still satisfactory
**Significantly different in relation to the complete treatment.

RECOVERY OF PASTURES IN DEGRADATION

PROPASTO's research program also includes pasture reclamation and management experiments of degraded pastures on each test location. Each experiment covers nearly 180 ha of pastures in degradation and has three main treatments: (1) control: weed control only; (2) weed control plus phosphate fertilization plus legume introduction; and (3) weed control plus phosphate fertilization, plus legume and *B. humidicola* introduction.

After a convenient rest period, each treatment is submitted to different management alternatives (combination of management systems with grazing pressures).

In the Paragominas region (LA_{ma}soil) this experiment is well-advanced and it is precisely in this region where degradation problems on *P. maximum* pastures have reached alarming proportions. With the use of phosphate fertilizers very satisfactory and important results were obtained on the recovery of degrading pastures. The *P. maximum* pasture area selected had been cultivated for 13 years and showed a vegetative biomass of 75 to 80% of weeds which included shrubs and few woody species. Other pasture recovery attempts had not provided satisfactory results in these conditions, but a single application of 50 kg P_2O_5/ha (one-half as SSP and one-half as Hiperfosfato), after manual cleaning of weeds and pasture burning, followed by a four-month rest period, produced a very significant increase both in pasture productivity (Table 8) and vigor. The stand of *P. maximum* increased to represent 90 to 95% of the plant biomass (Fig. 17). Table 8 reveals that the P content of the grass also increased in view of the enormous need that the plant has for this element.

This experience can be considered a demonstration trial even though it is still research. It points out clearly that only weed control, as the ranchers have been practicing, is not enough to maintain pasture production and avoid degradation. With time, weeding operations will become more costly and inefficient, causing serious economic problems.

It is advisable to mention that in treatments 2 and 3 of the work described above, difficulties were encountered in the establishment of the legumes *Centrosema pubescens* Benth., *P. phaseoloides* and *Stylosanthes guianensis* (Aubl.) Sw. and *B. humidicola* as a consequence of the rapid growth of *P. maximum* grass once phosphate fertilizers had been applied and which caused serious shading of these other species.

In order to verify the changes which occurred in the soil after applying phosphate fertilizers, soil samples were taken (four months after application) of non-fertilized and fertilized treatments. Sampling was extended to a pasture with the normal weeds and to the adjacent forest. Table 9 shows the analytical results. Considering

Table 8. **Effects of phosphate fertilization on recovery of a 13-year-old *P. maximum* pasture in highly degraded stage, on a LA_{ma} soil. The evaluation was made four months after fertilization.**

Treatment	Dry forage	"Juquira"	P in grass
	t/ha	%	
Grass with "Juquira"	-	80-85	-
Weed control + burning	1.5	± 50	0.08
Weed control + burning + 50 kg P_2O_5/ha	5.0	± 5	0.13

Figure 17 Recuperation of a *P. maximum* pasture in advanced stage of degradation. Left of fence: control of "juquira" + burning of the pasture; right of fence: control of "juquira" + burning of the pasture + 50 kg P_2O_5/ha (one-half as SSP and one-half as Hiperfosfato). Photograph taken four months after P fertilization. Note solid weedless pasture on the right and weedy pasture on the left. (PROPASTO "experimental field" Paragominas, state of Pará).

the conventional critical levels of some nutrients, the pasture was strongly deficient in P for its satisfactory development. It is interesting to note that apart from an immediate recovery of the pasture, the available P level in the soil increased from 1.5 to nearly 6 ppm P. This level was reached only during the first two to three years after forest burning and establishment of pastures had taken place (Tables 2, 3 and 4). Table 10 shows the soil's chemical properties with the same treatments a year after P

Table 9 Average chemical composition of a LA_{ma} soil in 13-year-old *P. maximum* pasture with and without phosphate fertilization and compared to adjacent forest (appraisal made four months after P application).

Treatment	OM	N	Ca^{++}	Mg^{++}	Al^{+++}	pH (H_2O)	K	P
	%		meq/100g				ppm	
Adjacent forest	3.2	0.2	1.8	1.2		4.2	35	1.5
Grass with "juquira"*	2.8	0.2	4.8	0.0		5.6	54	1.0
Weed control + burning**	3.6	0.2	5.5	0.0		5.7	84	1.5
Weed control + burning + 50 kg P_2O_5/ha***	2.2	0.2	4.8	0.2		5.8	73	6.0

* Average of 5 simple samples
** Average of 30 simple samples
*** Average of 60 simple samples.

Table 10. **Average chemical composition of a $LA_{mâ}$ soil in 13-year-old *P. maximum* pasture with and without fertilization, approximately 12 months after P application.**

Treatment	OM	N	$Ca^{++}+Mg^{++}$	Al^{+++}	pH (H_2O)	K	P
	—— % ——		— meq/100g —			—— ppm ——	
Weed control + burning*	2.2	0.16	3.9	0.0	5.8	71	0.8
Weed control + burning + 50 kg P_2O_5/ha**	2.5	0.16	4.0	0.1	5.5	60	2.5

* Average of 30 simple samples
** Average of 60 simple samples.

applications. Available P content in fertilized pastures declined to approximately 2.5 ppm P, although the pasture continued to be fairly highly productive.

It still has to be determined to what extent the amount of P applied can maintain satisfactory production levels. Nevertheless, the evidence shows that phosphate fertilization is a very viable method for recovering production of degraded pastures.

PROPOSALS

Toledo and Ara (18) proposed a model for the utilization of cultivated pastures on the Amazonian forest soils of Peru (see chapter by Toledo and Morales in this book). Considering Tables 2, 3 and 4, the general soil fertility curve under "traditional" pasture (without P addition) present in this model does not seem to reveal what actually happens with the chemical elements which determine the soil fertility. Moreover, a decline in the soil fertility in "improved" pastures (grass and legumes with annual applications of P) as shown in the model, is not compatible with the results of Tables 2, 3 and 4 and other information included in this paper*. With legumes and annual, biannual or triannual P applications, and adequate pasture management, it is expected that the soil's general fertility will remain satisfactory for relatively long periods of time, considering that P is the main limiting element of the ecosystem.

Reviewing data in Tables 2, 3 and 4 and several other soil analyses made on cultivated pastures in forest areas and trying to leave aside errors in soil analysis and sampling or fluctuations due to eventual pasture burnings, Figures 18 to 25 show the probable trends of nutrients and the values or indices of soil fertility in soils under pasture, over time. When nutrient content or fertility indices are compared with conventional critical levels (where applicable), it is quite evident that the majority of these values, even in the oldest pastures, remain satisfactory and acceptable in the most common soils except for available P. After four to five years, exchangeable K remains at more or less stable levels near the conventional critical level. Due to this fact sporadic responses to this element are observed. These considerations can also be applied to N even though this problem could be solved by introducing legumes in the pasture.

Correlating the soil's chemical properties with pasture productivity throughout the years, and with the responses of still-productive pastures as well as those in moderate or advanced stages of degradation to the different soil nutrients, the conventional critical levels (Table 7 and Figs. 18-25) appear to be satisfactory indicators for the majority of critical levels of the soil.

* The climate in Pucallpa in the Peruvian Amazonia, where Toledo and Morales work, is more humid (Am) than in Pará and Mato Grosso (Aw) where Serrão and his collaborators carried out this research. The soils are also different. (Editor's note).

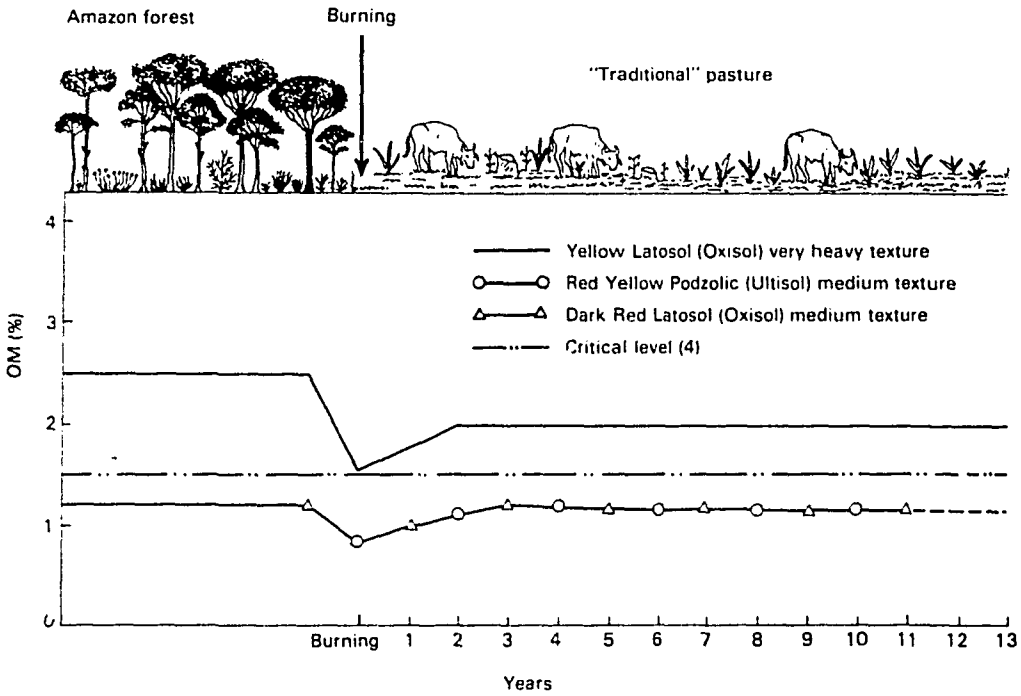

Figure 18. **Changes in soil OM values in forest and *P. maximum* pastures of different ages (7, 15).**

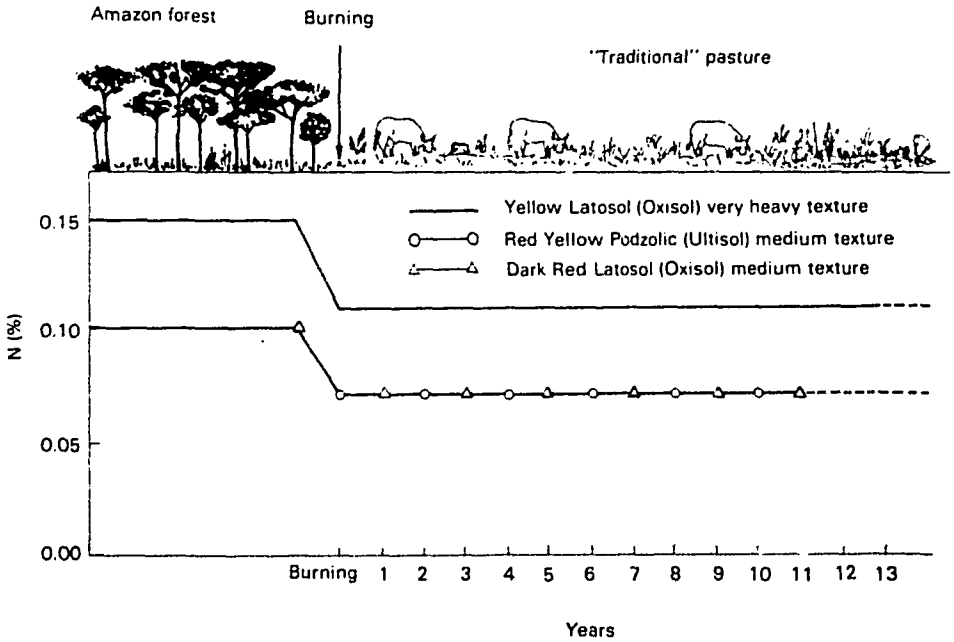

Figure 19. **Changes in soil N content in forest and *P. maximum* pastures of different ages (7, 15).**

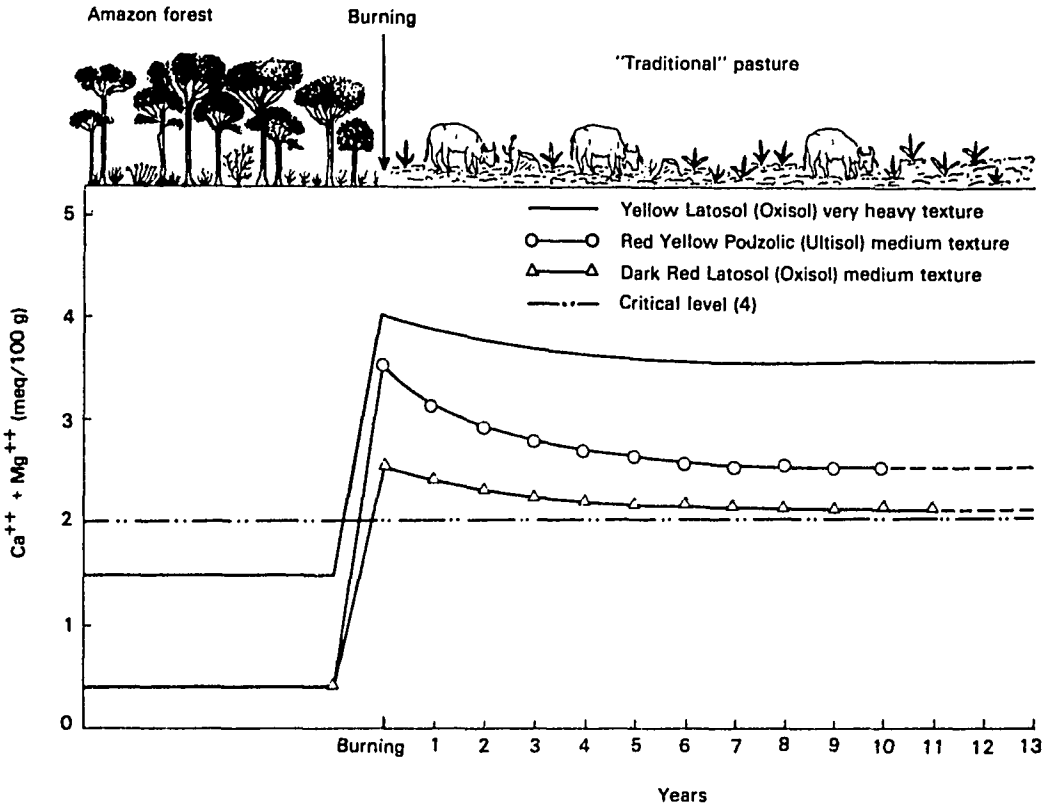

Figure 20. **Changes in soil $Ca^{++} + Mg^{++}$ content in forest and *P. maximum* pastures of different ages (7, 15).**

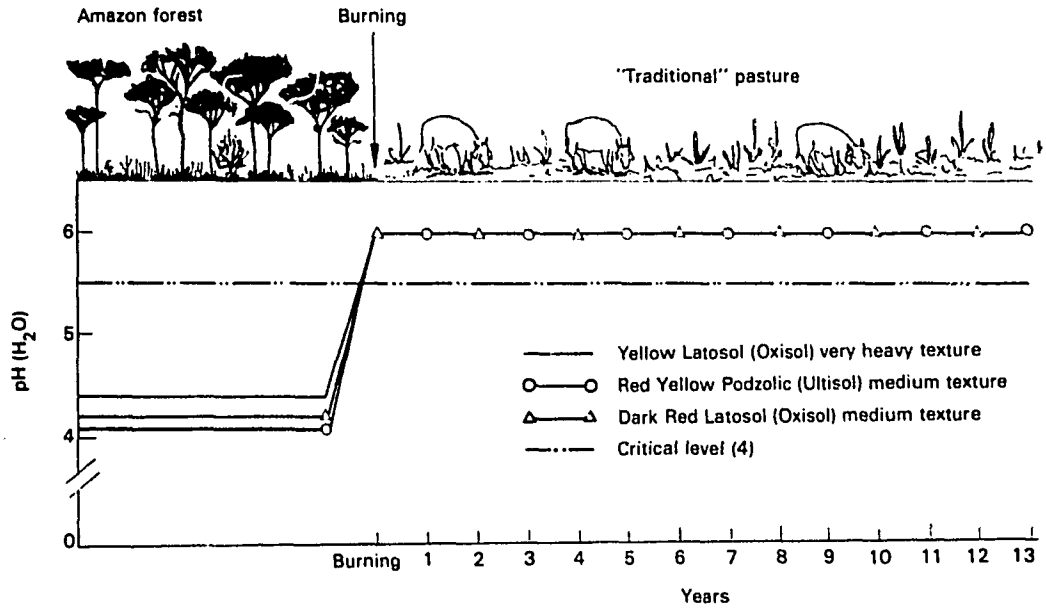

Figure 21. **Changes in soil pH in forest and *P. maximum* pastures of different ages (7, 15).**

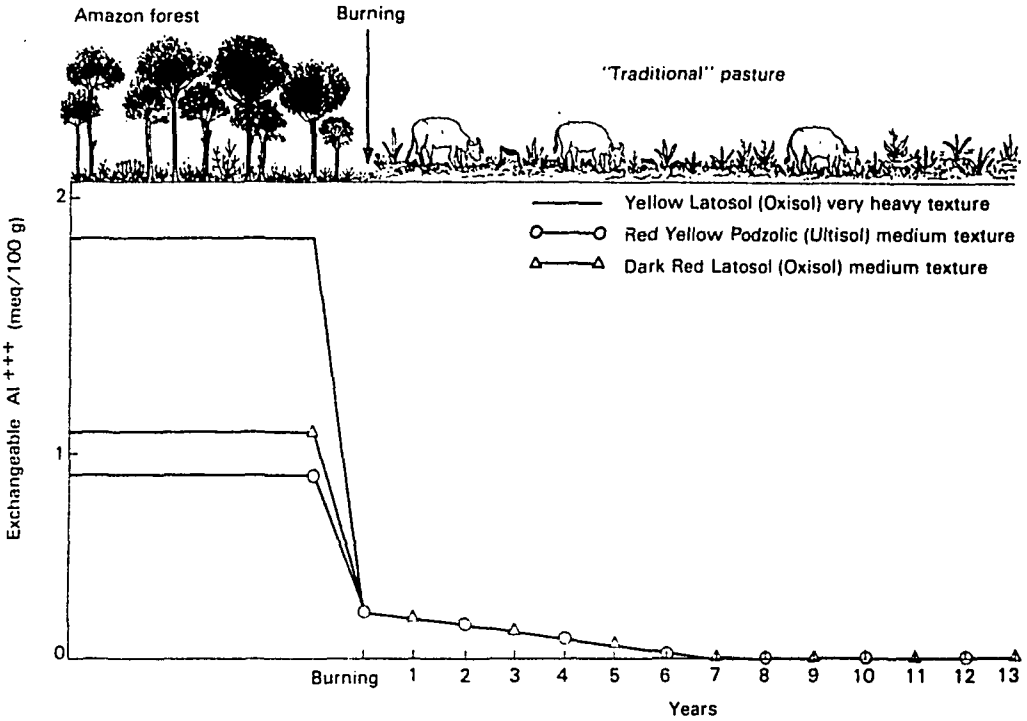

Figure 22. **Changes in soil exchangeable Al^{+++}content in forest and *P. maximum* pastures of different ages (7, 15).**

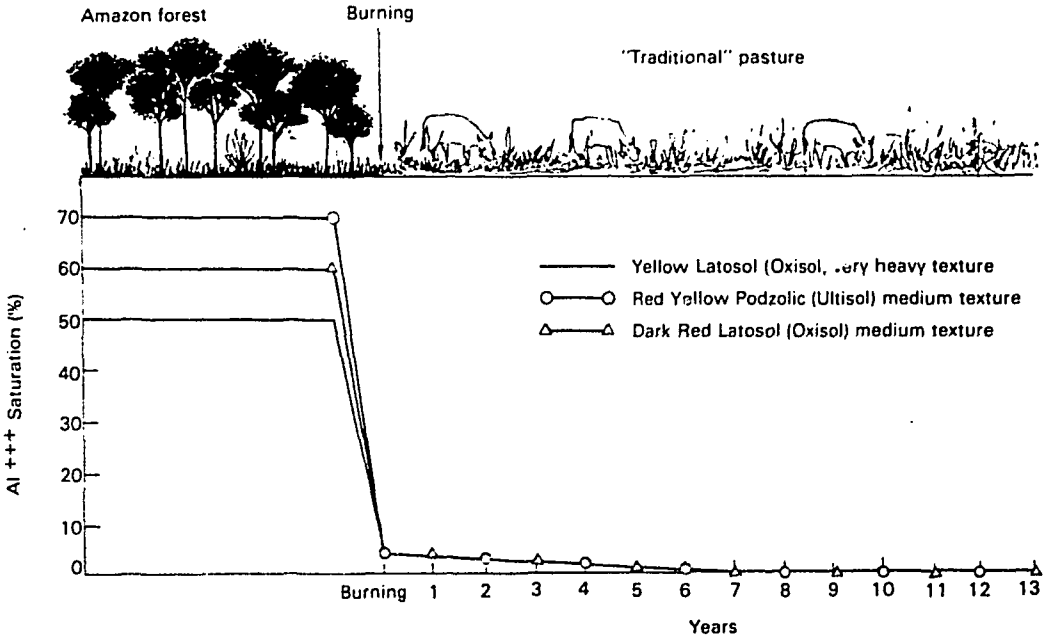

Figure 23. **Changes in soil Al^{+++} saturation levels in forest and *P. maximum* pastures of different ages (7, 15).**

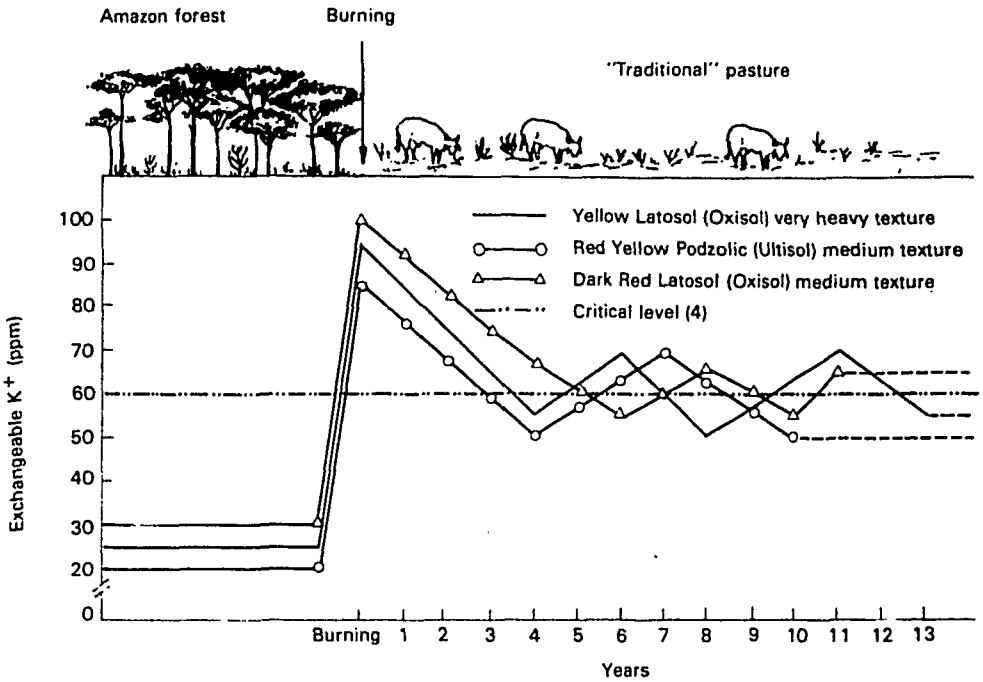

Figure 24. **Changes in soil exchangeable K content in forest and *P. maximum* pastures of different ages (7, 15).**

Nevertheless, for available P the critical level of 10 ppm does not appear totally applicable to some situations. On one hand, even during the highest production period of the pastures (first four or five years), only on very few occasions does this nutrient exceed levels above 10 ppm, except immediately after forest burning. On the other hand, how can one explain marked differences in responses to phosphate fertilizers of pastures on soils that although different in texture all have very low available P levels (1 to 2 ppm), while the levels of other chemical components remain quite satisfactory?* Although determination of critical levels is difficult, experience shows that at least in *P. maximum* pastures established and cultivated with traditional methods of the humid tropical forest, a critical level of available P of 5 ppm can be considered appropriate for pastures established in very clayey soils. This level can be even lower on medium textured soils. However, from the discussions in this paper, it seems necessary, whenever possible, to correlate the soil's P content with the pasture productivity, without leaving aside soil texture and pasture management.

Based on the information discussed in this paper, Figures 26 and 28 show a utilization model for Amazonian forest soils with cultivated pastures taking into account the soil-plant-animal complex. Like the proposal of Toledo and Ara (18), this model basically includes: (1) the Amazonian forest, (2) cultivated pastures with two technologies and, (3) other alternatives. The low technology level corresponds to the "traditional" pasture of *P. maximum* with no fertilizers or legumes, and which represents practically all the region's cultivated pastures. The high technology level corresponds to the "improved" pasture of *P. maximum* in association with adapted legumes (e.g. *Pueraria phaseoloides)* and

* A clayey Oxisol is likely to fix more P than a loamy Oxisol, because of a much larger surface area. Higher P fixation probably explains these differences (Editor's note).

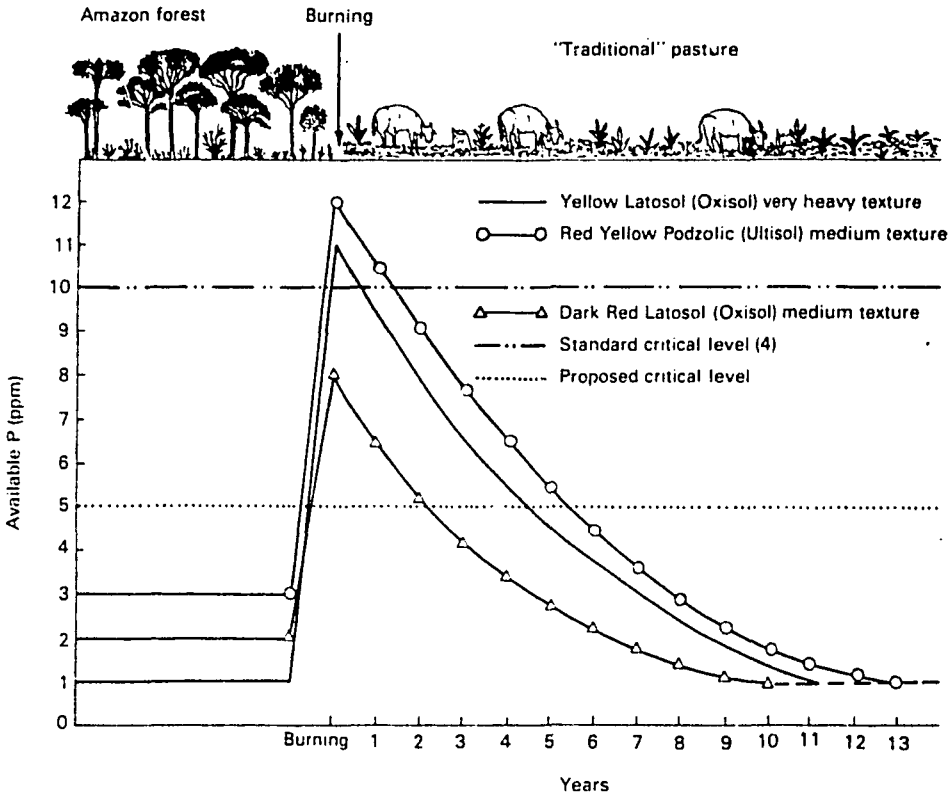

Figure 25. **Changes in soil available P content in forest and *P. maximum* pastures of different ages (7, 15).**

with phosphate fertilizers applied at a rate of 25 to 50 kg P_2O_5/ha (preferably as SSP or as a mixture of equal parts of SSP and Hiperfosfato). The frequency of application is still to be determined but would probably be every two or three years.

The model in Figure 26 refers to pastures on clayey Oxisols (Yellow Latosol, very clayey texture). During the first four or five years following forest burnings, the pasture's vigor and productivity are quite high. During these first years, perhaps it is not necessary to apply phosphate fertilizers, even on "improved" pastures. If pastures are grazed at optimum pressures, with a proper balance between the pasture potential and the animal potential, a natural and gradual decline of the "traditional" pasture will occur, as the consequence of a decrease in the soil's available P level. The effect of heavy grazing pressures should accelerate this natural decline and shorten the pasture's productive life to not more than a decade, as is happening in the areas mentioned in this paper. Soil compaction and soil exposure to surface and gully erosion will strongly influence the process.

In the "improved" pastures of grass and legumes, phosphate fertilizers would be applied only after the fourth or fifth years of use, when the pasture's natural productivity decline begins to accompany the decline of available P in the soil. In this system, especially if the pasture is submitted to optimum grazing pressure, it is probably possible to maintain satisfactory production levels for a few decades. Of course, even with periodic phosphate fertilization, there

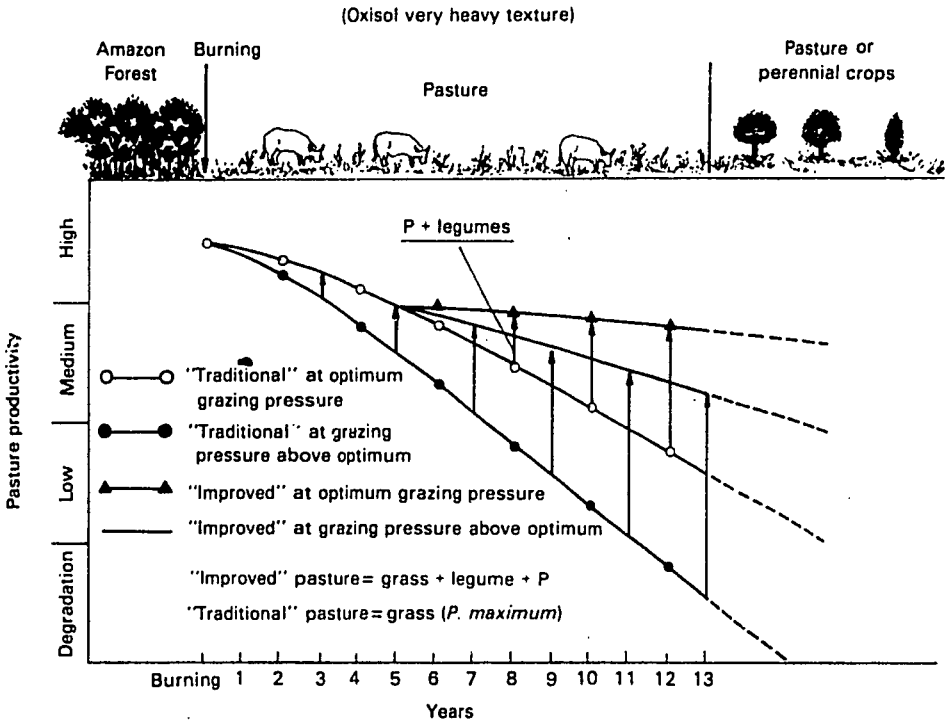

Figure 26. Model of the dynamics of the animal-pasture-soil systems in very clayey-textured Oxisols of the Amazon forest.

Figure 27. Pasture of *B. humidicola* presently the most appropriate grass for recuperation of degraded pastures in the Brazilian humid tropics, since it tolerates the soil's low P content and the spittle bug *(Deois incompleta)*.

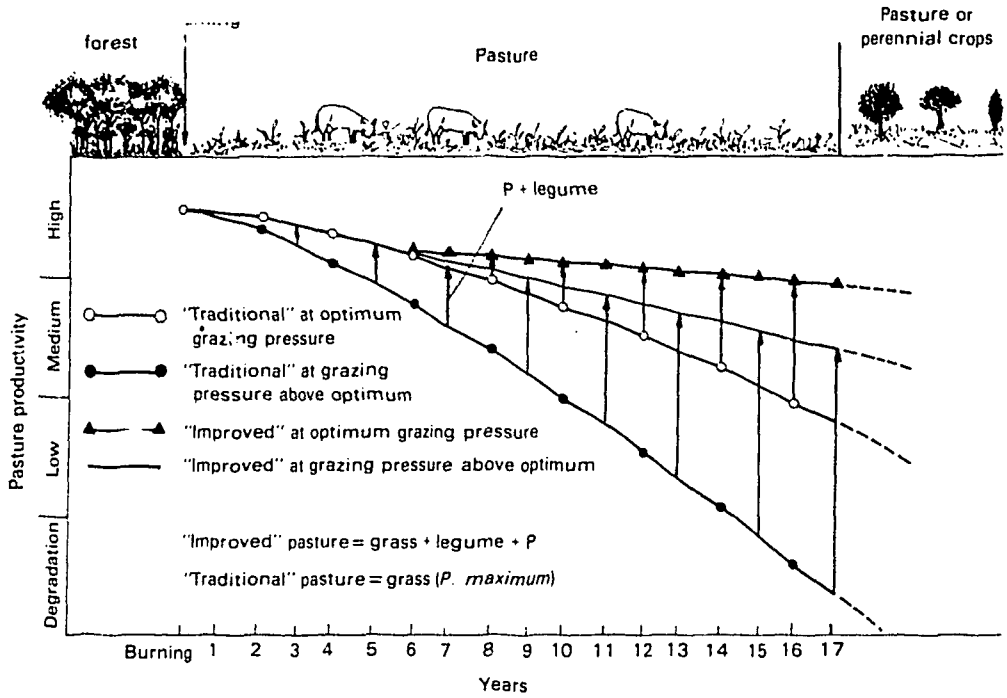

Figure 28. **Model of the dynamics of the animal-pasture-soil system in loamy textured Ultisols and Oxisols in the Amazon forest.**

will be a gradual production decline resulting from possible low K (Fig. 24) and micronutrient contents in the soil, even though there is the possibility that the periodic phosphate fertilization, the introduction of legumes, and an appropriate management of the pasture will render the recycling mechanism of K in the soil-plant-animal system more efficient (10).

Grazing pressure above optimum levels will speed up the expected natural decline because the soil will gradually lose its fertility. The model also indicates that if the pasture has not yet reached an irreversible degradation stage, it is possible to recover satisfactorily acceptable production levels, by combining weed control, phosphate fertilization and an adequate rest period (Fig. 17).

If the pasture maintains a good production level throughout the years, its replacement is not justified. But in cases where pastures have reached an advanced or irreversible degradation stage, renewal can be done by using less demanding forage species in relation to the soil's physical and chemical properties. One example is *B. humidicola* which has replaced *P. maximum* on nearly 45,000 ha in the past four years (Fig. 27). Another alternative could be substituting the pasture where mechanized operations are feasible with perennial crops such as black pepper *(Piper nigrum)*, rubber *(Hevea* spp.) and cocoa *(Thebroma cacao)* which will probably need only small amounts of phosphate fertilizers for development and production due to the favorable conditions of the majority of the soil's chemical components after long periods under pasture. This alternative is already in use in areas with degraded *P. maximum* pastures in the Paragominas region, where, in the past two or three years, hundreds of ha have been seeded to black pepper.

Figure 28 presents the same model for medium-textured forest soils. The main difference in relation to the model for very clayey soils is that pastures with satisfactory productivity have a longer useful life even under low P conditions especially when managed under optimum grazing pressures.

ADDITIONAL RESEARCH

To have a better understanding of the ecosystem of cultivated pastures in forest areas, and in order to explain with greater clarity some of the points discussed in this paper, it is necessary to conduct in-depth research work in the following fields: (a) selection of highly productive grasses and legumes adapted to edaphic conditions with low P levels; (b) more accurate appraisal of soil test critical levels for soils under cultivated pastures; (c) determination of management and edaphic factors affecting productivity and vigor of forage legumes; (d) evaluation of the more exact role of P and the micronutrients in the production of associated pastures of grasses and legumes; (e) determination of minimum necessary quantities, adequate application frequencies and appropriate P sources to maintain productivity in cultivated pastures; and, (f) development of management and utilization systems for cultivated pastures which are compatible with the equilibrium of the climate-soil-pasture-animal complex.

CONCLUSIONS

1) Burnings in forests felled for establishing pastures can be considered as a necessity due to the advantages the system offers, especially for incorporation of large amounts of nutrients into the soil, improving considerably the soil's chemical properties at least during the first four to five years, which in turn increases pasture production.

2) Over the years, the majority of the nutrients incorporated into the soil through the ashes generally remain above their critical levels, with the exception of soil P levels. After the fourth or fifth year of cultivation, P declines until it reaches levels which are very difficult to detect with laboratory instruments.

3) Undoubtedly, P is the most limiting nutrient for cultivated pasture productivity in the Brazilian Amazon. This limitation seems to be more important for grasses than for forage legumes.

4) In general terms, the productivity decline in cultivated pastures (especially of *P. maximum)* is accompanied by a decrease in levels of available soil P.

5) Occasional responses have been observed to other nutrients on degraded pastures, but the effect has not been as pronounced or generalized as with P.

6) The production decline process on cultivated pastures is faster in very clayey Oxisols.

7) Grazing pressures above optimum levels speed up the productivity decline, especially in very clayey soils. The conventional critical soil test level of 10 ppm of available P is high for pastures in forest soils in the humid tropics.

9) Pastures in an advanced stage of degradation can recover their production through fertilization, by applying small quantities of P followed by an appropriate rest period.

10) Periodic corrections of soil levels of P in pastures— especially after the fourth or fifth year—, the incorporation into the pasture of adapted forage legumes, and the use of management and stocking rates compatible with conserving the balance in the soil-plant-animal system, can be considered as the key to maintaining cultivated pasture productivity for long periods.

11) The substitution of the Amazonian forest for cultivated pastures over several years improves the soil's chemical properties and permits the eventual replacement of the pasture by perennial crops of economic interest probably with the addition of small amounts of phosphate fertilizers.

12) To have a better understanding of the ecosystem's problems inherent to pastures cultivated on forest soils, additional research will have to be done to attain more efficient land utilization levels.

13) Finally, the authors believe that although cultivated pastures in forest areas of the Brazilian Amazon region represent a relatively fragile ecosystem, this region can be considered to have a great animal protein production potential, using the cultivation pastures as raw material, if the pasture is established and managed as a true crop.

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FORAGE PRODUCTION ON ACID INFERTILE SOILS OF SUBTROPICAL FLORIDA*

Albert E. Kretschmer, Jr.
George H. Snyder**

ABSTRACT

A wide variety of tropical grasses and legumes are adapted to the subtropical climate of south Florida, although growth is severely limited during the cool-dry winter period. The soils of this area are acid, infertile, and are generally poorly drained. They are predominantly in the Spodosol and Entisol orders. Some success has been achieved in selecting tropical grasses for growth in the winter period, but stored hay or silage will probably always be needed to overcome the problem of cyclic pasture growth. The main characteristics sought in tropical legume selections are tolerance to flooding and waterlogging, heavy seed production, and perennial growth. Ability to withstand severe defoliation is also required for persistence. Tropical legumes can supply more N to grass/legume mixtures than ranchers are willing to buy as fertilizer. To obtain optimum legume production, liming and P fertilization are essential. In the absence of a legume, late summer-early fall N fertilization can be used to obtain reserve pasture for winter feeding, but crude protein will be progressively diminished with the passage of time since fertilization. N applied in the winter will only have a small effect on forage production, but will significantly increase crude protein in standing grass. Inclusion of a tropical legume with the grass can reduce or eliminate the need for these N fertilizations.

The emphasis in this presentation will be on the forages and soils in south Florida. This subtropical region is located south of an imaginary semicircular line between latitude 28 and 29°N (Fig. 1). It includes about 24 of the 67 counties in the State. Omitted in the discussion will be the organic (1) and marl (100) soils since they are not acid infertile soils.

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Climate

Rainfall averages about 1300 to 1600 mm annually (23), with about 75% falling during the six months, May through October (19).

Minimum mean monthly temperatures vary from about 10 to 12°C in winter and 21 to 23°C in the summer at the Agricultural Research Center, Ft. Pierce (ARC-FP), while maximum mean temperatures range from 23 to 25°C in winter and 32 to 33°C in summer. Areas to the north of Ft. Pierce and in the central part of the area are colder in the winter and somewhat warmer in the

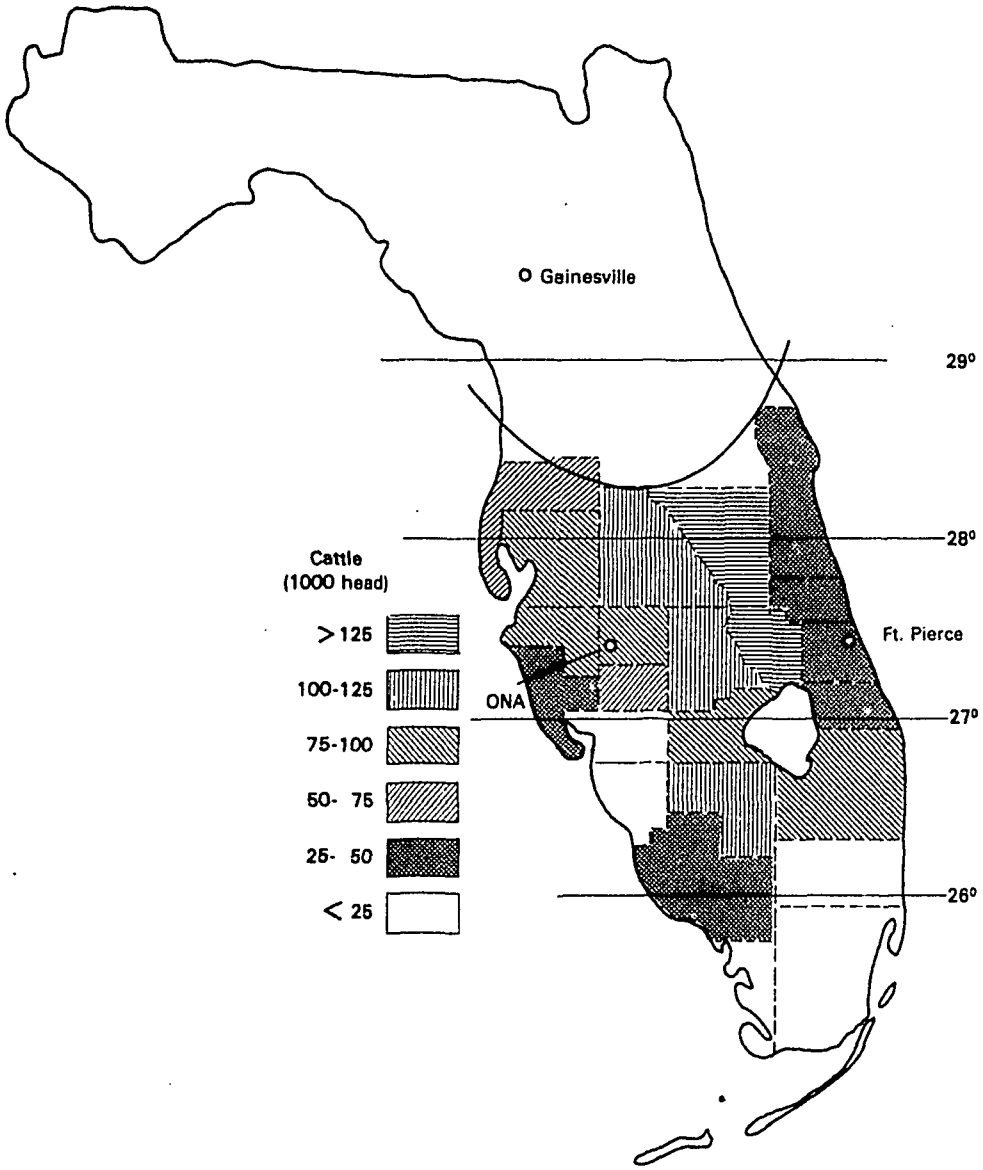

Figure 1. Distribution of cattle population in south Florida.

summer. Most of the region is subjected to several frosts during the December-March cool season.

At least one species adapted in south Florida is listed in each of the climatically delineated regions presented by Reid (120). Almost all legumes and grasses listed by Russell and Webb (131) as being commercially used in the tropics and subtropics have been grown successfully at the ARC-FP. Thus research results obtained from south Florida locations may be adaptable to other subtropical and tropical areas of the world.

Historical overview

The livestock industry in Florida had its

beginning in 1520, when Ponce de Leon brought the first cattle from Cuba (28, 65). But high water tables, low soil fertility, poor transportation facilities, and inaccessibility of markets prevented rapid development of the industry in south Florida until the present century. In 1929 there were about 355,000 head of cattle in Florida. In 1974 there were approximately 2.4 million cattle in the State, with 1.5 million reported in south Florida (43).

It was not until the 1930's that the "salt sick" (nutritional anemia) cattle problem was solved through proper mineral nutrition. The deficient elements included Ca, P, Cu, and Co. On the majority of soils now used for cattle production in south Florida it was not unusual to have calf crops of 30-35% (4). Mott and Moore (112) thoroughly reviewed the history and present day techniques of finishing cattle on forage or on limited feed in Florida.

Until the 1940's, a large majority of the pastures consisted of native grass species which included *Panicum hemitomon, Andropogon stolonifer,* and *Andropogon capillipes.* These desirable species were slowly replaced by *Aristida stricta, Sporobolus poiretii* (R.E. Scholt) Hitch. and others. Encroachment of undesirable shrubs such as *Serenoa repens, Myrica cerifera* and *Ilex glabra* also decreased carrying capacities (130). The stocking rate on native south Florida pastures is about 1 AU/7-15 ha.

Pasture species introductions

Research on introduced improved pasture species began in 1892 (56) and fertilization recommendations made in 1893 to use 400 to 800 kg/ha of a 6-6-8 (N-P_2O_5-K_2O) fertilizer did not change markedly until the mid 1950's (45). The first successfully used introduction was *Rhynchelytrum roseum* (Nees) Stapf. and Hubb. and the first reported legume to be used as forage was *Mucuna pruriens* (L.) DC. var. utilis (Wall) Burck. (104).

Introductions of other grasses, ie. *Brachiaria mutica* (Forsk.) Stapf. (1910), *Paspalum notatum* Flügge (1913), *Eremochloa ophiuroides* (Munro) Hack. (1919), and legumes *Crotalaria mucronata* Desv. (1909), *Alysicarpus vaginalis* (L.) DC. (1924), and *Indigofera hirsuta* L. (1931) helped in the development of better forages. These efforts generally were related to the cattle industry outside of south Florida. Recognition of the benefits of liming (64) and fertilization (36), helped in the establishment and use of newer introductions of grasses, particularly *Digitaria decumbens* Stent. (47) and legumes, particularly *Trifolium repens* L. (6, 68) in south Florida. The only two tropical or summer-growing introduced legumes having some success for grazing were *I. hirsuta* (146) and *A. vaginalis* (109). Creeping *Desmodium canum* (J.F. Gmel.) Schinz & Thell., a native legume, is an invader in many pastures (128, 150).

Although *P. notatum* and *D. decumbens* presently comprise the largest areas of permanent pasture, during the last 15 years many introduced pasture species have been described or released through the Florida Agricultural Experiment Stations, Institute of Food and Agricultural Sciences. Grasses include Slenderstem (103), Transvala (13) and Taiwan (92) digitgrasses (*D. decumbens* Stent.), *Cynodon aethiopicus* Clayton and Harlan cv. McCaleb (49), *Chloris gayana* Kunth. (78), *Hemarthria altissima* (Poir.) Stapf. and Hubbard (93, 118). Legumes include *Trifolium alexandrinum* L. (69), *Stylosanthes hurnilis* H.B.K. (73), *Macroptilium atropurpureum* (DC.) Urb. (77), *Desmodium heterocarpon* (Linn.) DC. (91), *Arachia* spp. (116), *Macroptilium lathyroides* L. (17), and *Aeschynomene americana* L. (48).

Soils

The mineral soils of subtropical Florida are dominated by Spodosols and Entisols (Fig. 2). With the exception of marl soils found in the extreme southern part of the State, and

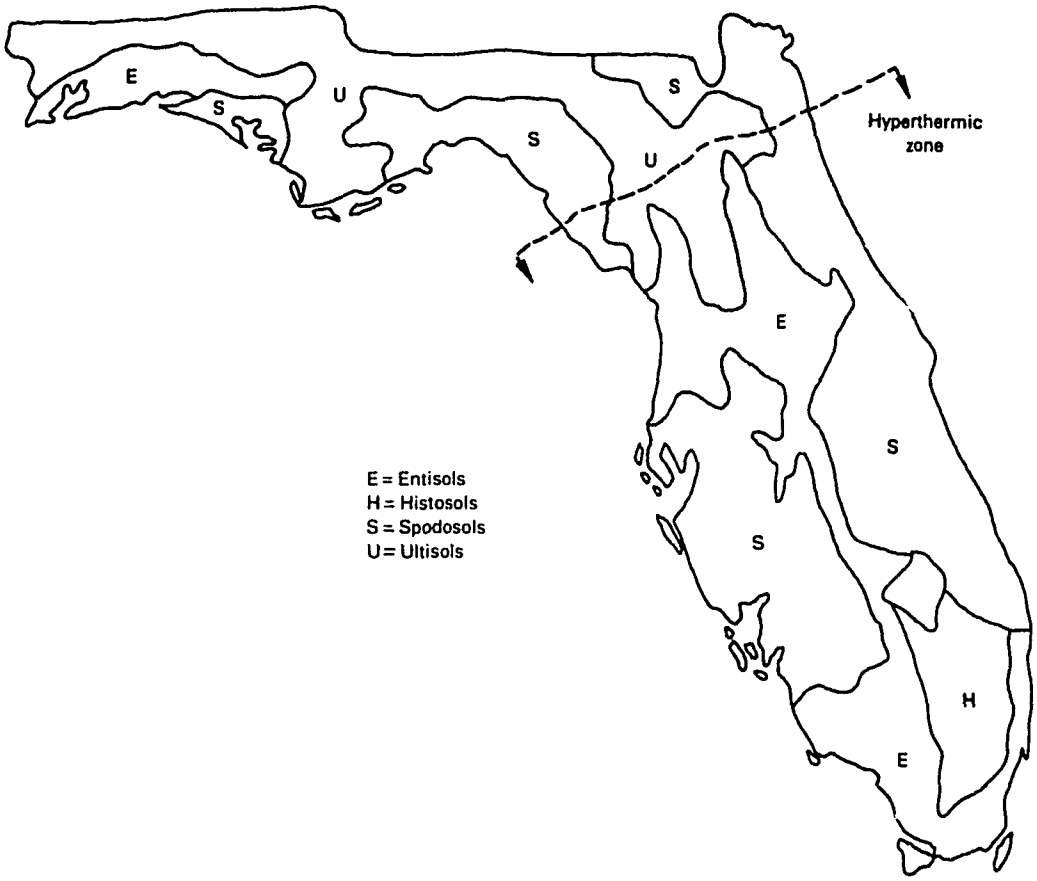

Figure 2. **Generalized map of Soil Orders found in Florida.**

organic soils south of Lake Okeechobee, the soils are acid, infertile, and sandy in texture. They fall within the hyperthermic zone. The soil parent material consists of various marine sediments. Although quartz sand is the predominant, and often the only mineral present in the surface horizons, clays, shell and marl may be found at depth in some soil types. However, when present at all, these materials are generally well below the root zone of forage grasses and legumes. As compared to many other soils in the hyperthermic zone, Florida soils are very low in Fe and Al sesquioxides. Neutral 1N KCl exchangeable Al is often less than 1 meq/100 (33).

Cation exchange capacity (CEC) is low and predominantely pH-dependent, since it results almost entirely from organic matter (OM). Surface horizon OM may be very low in the Entisols, and is quite variable in the Spodosols. The Spodosols are often intermingled with Entisols and even with small pockets of Histosols, giving the landscape a pockmarked appearance from the air. This association is known locally as the "flatwoods" soils. The influence of these soil associations on plant growth is often very apparent long after the land has been cleared and placed under cultivation. Over short distances there can be drastic changes in certain soil properties, such as OM content and CEC. Therefore it is essentially impossible to manage large areas in a manner that is optimum for all soil conditions present. For example, following lime application to plots within a 12 x 70 m area of

Myakka fine sand (Spodosol) at 4073 kg/ha. pH's among the plots ranged from 5.1 to 6.5. Soil pH was negatively correlated with OM content (pH = 6.54 - 0.56 (% OM), $R^2 = 0.73$) which ranged from 0.2 to 2.3% within the 0.084 ha area (unpublished data from study by Gascho *et al.*, 1973)

The Entisols found on the ridge area of the central part of the State are often well or excessively well drained. But the soils of the flatwoods regions are predominantly poorly drained. Poor drainage results primarily from the low, level topography. In addition, the Spodosols are characterized by a water restricting B2h horizon less than one half to more than one meter in depth (Table 1). In their native state the flatwoods soils are periodically flooded during the wet season. Some drainage is provided for pasture lands, but water tables are nevertheless often quite high.

SELECTION OF FORAGE SPECIES

Seasonal variations in production

In south Florida, because of the length and intensity of cold temperatures in the winter and normal lack of effective soil moisture from February to May or June, it is difficult to estimate the annual optimum stocking rate. Stocking rates of the predominantly cow-calf beef system used in south Florida are a compromise between overabundance of pasture during summer and paucity during winter and spring. It appears that although minor changes may be made by growing specialized forages to overcome the lack of winter feed, only the use of high-quality stored hay or silage may solve the cyclic problem in an economic manner to permit similar year-round stocking rates.

Clipping tests have shown that winter growing clovers and ryegrass can contribute up to five to six metric tons of dry matter (DM) in the winter and spring period (72, 81). But both require adequate irrigation in the spring. Because of this and the difficulty of maintaining an adequate water table for seep irrigation, emphasis on developing and using temperate species for winter growth has decreased, and will not be considered in this presentation.

Tropical grasses

The main attribute being sought in perennial tropical grasses is cool season growth. Recently, modest success has been achieved with several cultivars of *H. altissima* and digitgrasses which yield more than *D. decumbens* in the fall and spring (Fig. 3). More than 600 ecotypes from 20 genera have been evaluated at the ARC-FP. In the secondary evaluation phases, small-plot clipping tests have been used to determine

Table 1. **Typical profile of a Florida Spodosol as synthesized from statistical data on 34 pedons (24).**

Horizon	Depth	Sand	Silt	Clay	Water retention (bars) 0.1	0.33	15	pH	Base saturation	CEC	OM
	cm	%			%, vol				%	meq/100 g	%
A1	0-15	94.0	4.5	1.5	13	11	3.5	4.7	30	7	3.5
A2	15-65	97.0	2.0	1.0	3	2	1.5	5.1	50	<1	0.3
B21h	65-83	92.0	4.0	4.0	15	14	4.0	5.0	15	10	3.5
B22h	83-103	94.0	3.0	3.0	6	6	2.0	5.3	20	5	2.0
B3	103-133	94.5	2.5	3.0	6	3	1.5	5.6	40	2	0.4

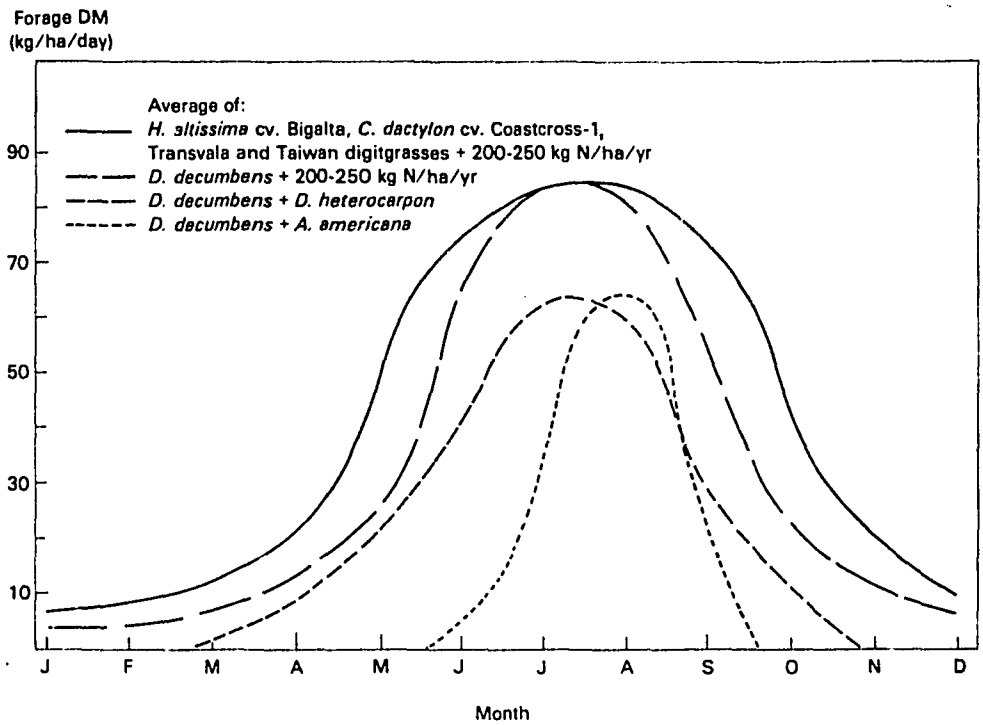

Figure 3. Effect of season on daily DM forage production of grasses growing alone and in mixture with legumes at the ARC-Ft. Pierce.

productivity in comparison with the standard grass, *D. decumbens* (75, 76). More recently only cool season growth has been studied since summer growth of *D. decumbens* and most vigorous tropical grasses tested is known to be limited by the quantity of fertilizer N applied. Crude protein content (CPC) of grasses during the summer is regulated by age of regrowth and fertilizer N rate, and tends to increase in the cool season because of slower growth. Since the trend has been established there is no reason for additional protein analyses in the standard evaluation tests except unusual circumstances. *In vitro* OM digestibility (IVOMD) values for numerous tropical grasses in the cool season have ranged from about 55 to 65%. During the summer, levels depend on the stage of growth but usually after about eight weeks are in the range of 40 to 50%. Additional IVOMD analysis will only be made under special circumstances. The primary aim is not quality but more vigorous growth in the cool season.

Tropical legumes

Published information that classifies ecotypes into like groups may helpful in predetermining the desirable characteristics sought. Classifications that have been made on relative resistance of legumes (81) to grazing pressure, waterlogging, drought, and other environmental factors help to point out several genera or species that should be evaluated initially for a given set of local conditions. Additionally, the morphologic diversity within a genus and species helps in determining how much emphasis should be placed on evaluation of either. In Table 2 selected genera and species and their general morphological diversity are listed. If, for example, *Glycine wightii* (R. Grah. ex. Wight. & Arn.) Verdc.

Table 2. **General extent of gross morphological diversity (MD) within selected genera and species of tropical legumes.**

	Genus	MD*	Species	MD*
1.	*Aeschynomene*	VL	*americana*	S
2.	*Calopogonium*	S	*mucunoides*	S
3.	*Centrosema*	L	*pubescens*	M
			virginianum	M
4.	*Desmodium*	VL	*intortum*	S
			uncinatum	S
			heterocarpon	M
5.	*Glycine*	M	*wightii*	S
6.	*Leucaena*	L	*leucocephala*	S
7.	*Lotononis*	L	*bainesii*	S
8.	*Macroptilium*	L	*atropurpureum*	S
			bracteatum	S
9.	*Pueraria*	S	*phaseoloides*	S
10.	*Stylosanthes*	VL	*guianensis*	L
			hamata	M
			humilis	M
11.	*Teramnus*	M	*labialis*	S
			uncinatus	S
			volubilis	S

* S = small; M = moderate; L = large; and VL = very large relative diversity

does not grow well or persist, rather than introduce many additional accessions of this legume, more productive results may come from evaluating other genera. The extent of diversity does not reflect the value of a given genus or species, however, since some of those with the least diversity, eg. *Calopogonium mucunoides* Desv. and *Pueraria phaseoloides* (Roxb.) Benth., var. Javanica (Benth.) Bak. have been very successful. On the other hand, with the wide diversity in *Stylosanthes* (and the proven value of several cultivars), there is little wonder that evaluation of this genus is receiving priority by many researchers.

Australian researchers near Townsville have been developing a morphological-agronomical (M-A) system using numerical analysis for grouping of accessions of *Stylosanthes* spp. having similar characteristics (21). The M-A information has been utilized to relate the agronomic performance and climate of species origin (22, 121). This method appears to be applicable to seasonally dry tropical areas, since of the 14 genera of *Stylosanthes* evaluated in the Townsville, Australia area, the potentially adaptive ecotypes (where site or origin was known) all originated in dry subtropical, tropical semi-arid, or hot subtropical desert conditions.

There is little evidence to support or contradict the M-A method of classification for areas receiving more and better distributed rainfall, although McIvor (105) found little relationship between M-A groupings and waterlogging tolerance. Annual rainfall in Townsville is amost as high as that of south Florida, but distribution in Florida is much better. Furthermore, rainfall in a larger area west of Townsville ranges from about 550 to 900 mm with poor distribution. Selection of pasture species for arid or presumably flooded environments

may be best from those legumes collected from arid or flooded origins, but it is unknown whether plants from arid origins are more adapted to 1250-2500 mm rainfall zones compared with those collected from 1250-2500 mm areas. The authors believe, however, that increasing soil moisture in arid zones or during droughty periods in other tropical climatic zones (through irrigation) would increase productivity of most, if not all *Stylosanthes* spp. Plants would respond to soil moisture above that found under arid conditions. Other factors such as increasing soil clay contents, which would transcend rainfall zones, have been found to be negatively correlated with *Stylosanthes* spp. survival (26).

The characterization of *Stylosanthes* seeds using protein band patterns, although separating ecotypes into 13 groups by numerical analysis, did not compare favorably with the M-A grouping (125). Furthermore, the M-A groupings may not be satisfactory for growth and nutrition characterization as indicated by Jones (59).

In south Florida no selections of forage plants have been made for growth on unlimed, unfertilized soils. Lime is inexpensive and cattlemen follow the recommended practice of applying lime to acid soils that are cleared for planting. This may be fortunate since work by Rees and Minson (119) showed rather marked increases in voluntary intake (sheep) with increasing Ca levels in *D. decumbens* while mineral Ca supplements were ineffective.

The approaches to the development of new tropical legumes to compliment legumes now used in south Florida are similar to those in other countries (8). Low temperatures and particularly periodic flooding are two factors limiting productivity and seed production of some legume species in south Florida. They must be considered in the evaluation program. Most legumes evaluated at the ARC-FP persist under conditions of moderate drainage but fail to survive under commercial conditions with poorer drainage. For this reason *M. atropurpureum* cv. Siratro has not been more widely used. Although *Aeschynomene* is a genus known as water tolerant, it is difficult to predetermine which ecotypes from other genera are water tolerant unless they are collected in areas subject to flooding. For example, *Macroptilium* (except for *M. lathyroides*) and *Desmodium* (except for *D. canum*) are genera with commercial cultivars not generally praised for their waterlogging tolerance, yet they have large diverse germplasms. Flood tolerant ecotypes of these genera probably exist. None of the released cultivars, except *A. americana*, are ideally adapted to the pasture area in south Florida that are periodically flooded. Although introductions can be tested for flooding in controlled greenhouse tests (105), it is not known whether these results are applicable to field conditions. Thus field flooding tests at the ARC-FP are being used for secondary screening of germplasm having good agronomic attributes.

Perennial tropical legumes are preferred over annual, self-regenerating types because of higher total and particularly higher spring productivity (88, 90); yet historically the heavy seed producing annual types have been successful. This is especially true for *A. americana* in south Florida, although its maximum growth period is only from June until October (Fig. 3). Because drought and cool spring temperatures prohibit early seed germination and growth and seed production is limited by frosts in December, there appears to be little chance of extending the growth period of new annuals compared to *A. americana* except for possibly a month in the fall.

Seed production and self-regeneration is also essential for long-term persistence of perennial tropical legumes. Therefore, even though *Desmodium intortum* (Mill.) Urb. cv. Greenleaf has been the highest yielding legume tested at the ARC-FP (88), it cannot be generally recommended because of late and inconsistent seed production.

In conjunction with temperature and flooding factors, emphasis is placed on herbaceous legumes having low crown areas that will persist under frequent defoliation.

No effort is made to test plants from suspect toxic species. *Crotalaria, Leucaena,* and other genera are avoided when collecting or introducing new germplasm, unless herbarium specimens are desired. It is particularly important to be sure that toxic or unpalatable accessions are not permitted to spread so as to become weeds.

Results have indicated that greatest success for tropical legume development will be with *Stylosanthes* (14, 15, 16), *Aeschynomene, Centrosema* (80), *Calopogonium, Teramnus labialis* (Linn. F.) Spreng., *Desmodium* and *Macroptilium.*

ESTABLISHMENT

Planting material

Florida is one of the few areas using tropical grasses where vegetative rather than seeded species are of widespread use. Presently, only the *P. notatum* cv. Paraguay, Pensacola or Argentine are seeded in south Florida; and their quality and winter growth is poor. *Digitaria* spp., *Cynodon* spp., *Hemarthria* spp. and other grasses are vegetatively propagated.

On virgin, weed-free soils 500 to 11000 kg/ha of vegetative material, or as much as 2000 kg/ha on renovated, weedy fields, should be used for grass establishment. Legumes are established from seed treated with "cowpea" inoculant. Care should be taken in selecting the seed source. Among other diseases, *Collectotrichum* spp. can be transmitted on *Stylosanthes* seed (96), and virus diseases on *M. atropurpureum* (111) and *M. lathyroides* seeds (117). Poor seedling growth or plant death might result from these diseases.

Weeds

Pasture establishment on virgin soils generally is faster than on old vegetable fields or in renovated pastures because of the weed problem. Where weeds are expected 2 kg/ha (active ingredient) of 2, 4-D amine or simazine herbicides control many weeds during the establishment of most vegetatively planted grasses (114). The herbicide should be applied as a spray one to three days after planting the grass. When replanting a weed-infested grass pasture to the same or other grass species, an intermediate crop such as *Lolium multiflorum* Lam. can be seeded in the fall when the grass is planted. This aids in the elimination of weed species.

Where weeds are known to be a problem, higher seeding rates should be used for legumes since plant populations can be severely reduced in weed-infested areas compared to weed-free areas (43). The use of preemergent herbicides has not been commercially successful, and probably is not economical. To control broadleaf species 2, 4-D or silvex can be applied to areas recently planted to grass about three to four weeks after weed germination. Legumes can be seeded three to four weeks later. Bolton (12) found that rates of 0.5 to 1.5 kg/ha of dinoseb, applied one to five months after seeding, would control weeds without damaging *M. atropurpureum, C. gayana, Paspalum plicatulum* Michx. or *Setaria anceps* Stapf. ex. Massey.

Soil factors

In south Florida initital establishment of tropical legumes in newly planted grass pastures is relatively simple and generally successful. The few failures might be explained in part by high soil temperatures.

Soil surface temperatures of 45°C and above can be reached in the summer (39). Germination of certain species may be slowed or stopped by these high

temperatures. Since there are few sources of vegetative grass planting material available until June when rains have begun, tropical legumes planted with grasses would normally be seeded from June to August when high temperatures occur. After planting the grass and rolling the area, legume seeds are broadcast and the area is rolled again. Depth of planting is another factor that may be involved in initital poor establishment. Burying seed too deeply is known to result in a large reduction in seedling population. This was shown with *A. americana* seeded in a sandy loam soil where germination was reduced by 50% at a seeding depth of about 4 cm (44). However, in the Florida sandy soils where moisture is periodically limiting, deep planting may be best. For example much better germination of *P. notatum* occurred when seeded at about 2.5 to 5.0 cm compared with 0 to 1.3 cm (20). This difference was intensified during droughty periods.

Establishing legumes in sods

Several procedures have been suggested for legume establishment in sods. Preliminary information (38) indicates that initital establishment depends on tillage treatment and legume species. Lightly disking the sod once, broadcast seeding, and rolling was better than broadcast seeding, disking, and rolling, and was equal to sod-seeding for *M. atropurpureum, Centrosema pubescens* Benth., *Stylosanthes hamata* (L.) Taub. cv. Verano and *D. heterocarpon*. There were no differences in *A. americana* plant population, however, resulting from no tillage to complete tillage and including the above treatments. With *M. atropurpureum, D. heterocarpon* and other high seed producing perennial legumes that self-regenerate well, plant populations can be excepted to increase during the years with good management practices.

Burning

For *A. americana* hardseededness was responsible for establishment failures (129). Burning of established *A. americana* grass pasture in the winter or spring increased forage yields by two to four times that of mowed plots (138). Heat from burning reduced hardseededness. Burning permanent sods prior to seeding has been a successful means of establishing other tropical legumes (27, 32, 41, 42, 122).

LEGUME PERSISTENCE

The most important consideration in the use of tropical legumes, whether annual or perennial, is persistence. Without this trait, mixed pastures and the benefits from legumes will be short-lived. Most of the commercial tropical legumes appear to persist longer under a managed cutting regime than under grazing conditions, although we found that *Stylosanthes guianensis* var. guianensis (Aubl.) Sw. cv. Cook and Endeavour failed to persist under clipping, even if cut at a height of 15-20 cm. These cultivars also failed to persist, however, more than two years under grazing in parts of Africa (115, 139). Some of the important factors affecting persistence are discussed below. Additional reports by Kretschmer (79, 81) and Brolmann (16) deal in more depth with persistence.

Seed production

Without high seed production and seed supplies in the soil, annual legumes cannot persist for long, and perennial legume populations will decrease slowly. The result of this attribute has been demonstrated by the success with *A. americana, S. humilis* and *M. atropurpureum*. Seeds can survive from year to year and in the case of *M. atropurpureum* accumulate up to 500 to 1000 kg/ha (50, 51). Other legumes such as *S. guianensis* produce large quantities of seed (98, 99) but have not persisted well under limited tests in south Florida and parts of Africa (115, 122, 139) because of other factors. The effects of insect or rodent attacks on maturing or mature seeds on seed germination is not well known although "pea weevils" (Bruchidae) were found to

destroy from 10 to 99% of seeds of *Leucaena leucocephala* (Lam.) De Wit., 42% of *Rhynchosia pyramidalis* (Lam.) Urb., and 52% of *Phaseolus lunatus* L. (53). Stink bugs (Chlorochroasayi), and lygus bugs (*Lygus* spp.) also may reduce seed production or seed germination (97).

Seedling vigor

Information on the fate of seedlings in the establishment year is limited, but conditions for legume seedling survival should be better when seeded in conjunction with the grass on weed-free areas compared with seedings in established sods or in weed infested areas. It was shown that the bean fly (*Melanagromyza phaseoli* Coq.) reduced *M. atropurpureum* seedling populations by 80% and also killed seedlings of *Lablab purpureus* (L.) Sweet and *M. lathyroides* (58). We have observed lesser cornstalk borers *Elasmopalpus lignosellus* (Zeller) at the ARC-FP feeding on *C. gayana* and *P. notatum* seedlings and causing death of seedlings. They also feed on most of the prominent tropical legumes, being particularly active when the soil surface is dry during the warmer months. Mole crickets (*Scaptoriscus* spp.) can cause severe damage to *P. notatum* plants and to legume seedlings. Seed-borne fungi, *Colletotrichum dematium*, have damaged *D. intortum* seedlings (148). In greenhouse pathogenicity tests *C. dematium* and *C. gloeosporioides* killed seedlings of various accessions of *Stylosanthes* spp. (94, 95). Sonoda (137) has reported several other diseases on legumes in Florida. Other air, seed or soil-borne fungi may damage or kill seedlings and prevent seedling emergence. Since *D. intortum* seedlings were killed by application of 100-200 kg/ha of KCl (61), saline soils probably would prevent emergence of susceptible ecotypes (52).

There does not appear to be a close relationship between seed size and seedling vigor or persistence. The large seeded *L. leucocephala* is difficult to establish because of slow seedling growth, while the much smaller seeded *M. atropurpureum* is very vigorous. The larger seeded *G. wightii* cv. Tinaroo lacked the seedling vigor of *S. guianensis* cv Cook and Endeavour at the ARC-FP. Other factors such as shade from competing species, which affect seedling vigor of the shade intolerant *S. humilis*, drought and waterlogging tolerances, and slow nodulation of *G. wightii* (140) may influence seedling vigor and persistence.

Patterns of germination and seedling growth of the annual, *S. humilis*, in Australia were described in detail by Torssell *et al.* (142) and Torssell (141). Parts of the dynamics of this system also may be applicable to seed germination and seedling growth of self-regenerating perennial legumes.

Soil factors

Soil characteristics that favor competitive species would have an adverse effect on tropical legume persistence. These aspects are discussed by Kretschmer (81) and Humphreys and Jones (52). In south Florida, surface soil physical differences are slight compared with water table fluctuations and concomitant potential for waterlogging and excessive drainage of soils. The soil nutrient status is determined more by soil fertilization and liming than by inherent characteristics. No noticeable reduction to *S. humilis* (in *D. decumbens* sod) and *M. atropurpureum* (in *Cynodon dactylon* (L.) Pers. cv. Coastcross-1 sod) plant populations has been observed with annual applications of N (81) although N probably should be used only when additional forage is needed in fall or spring when the legume is dormant. With increasing soil N levels, the effect on persistence of established legumes in grass pastures probably depends on the associated grass species. Persistence of *S. humilis* would be reduced at lower N levels than would be *M. atropurpureum* when grown with vigorous tall-growing grasses and both legume populations would be reduced or eliminated with high soil N levels. This would result from competitive effects of

the grass component and would be modified by grazing management and other factors. From this standpoint the south Florida soils are ideally suited for tropical legume use. The effect of N fertilization on grass stimulation is short-lived. The discussion of lime and fertilizer elements in another section of this presentation show data on the optimum levels of Ca and P for growth of some tropical legumes. With maintenance of these levels or even rather marked reductions, *A. americana, M. atropurpureum, S. guianensis* cv. Cook, *D. heterocarpon* cv. Florida and *C. pubescens* plants persisted and produced adequate seed through the second year.

It is difficult to attribute non-persistence of tropical legumes in improved south Florida pastures to the lack of one or more essential elements. It is easier to attribute lack of persistence to periodic (and many times sustained for several weeks) flooding or waterlogging. A field flooding experiment at the ARC-FP yielded some preliminary evidence on survival of tropical legumes. Water was maintained at a 3-cm level above the soil surface for most of a 45-day period, with waterlogging conditions during the entire period. Of 10 plants from each of 11 introductions of *Aeschynomene* (six species) seven or more plants survived in all but *A. facalta.* Survival was better for a *C. virginianum* collected in a flooded area in the "Pantanal" of Mato Grosso, Brazil, than for the commercial Australian cultivar *(C. pubescens),* and two other *C. virginianum* introductions from well-drained sites in the Caribbean Islands. Surprisingly all 10 *S. hamata* cv. Verano plants survived while only four and three plants, respectively, of *S. guianensis* cv. Cook and Endeavour survived. As expected, *M. lathyroides* survival was good while *M. atropurpureum* survival was poor.

Although no experimental evidence is available on death of mature plants from drought in the spring, observations on flatwood soils indicate that this factor would have little effect on overall survival.

Temperature factors

No experimental evidence is available on the effects of frost or freezes on perennial legume plant survival, but there have been enough evaluations of introductions at the ARC-FP and effects of frosts in Australia on survival (56) to believe that only a small minority of introductions would not survive south Florida winter temperatures.

Grazing management

With south Florida's cow-calf program of beef production, grazing management can be varied during the June to October growing season; and with the reserve standing forage normally available, to December or longer. Grazing during the cool season results in consumption of almost all forage available, and consists essentially of continuous grazing as the season progresses. If *Trifolium* species or annual cool season grasses are included in the program they are grazed rotationally, although they are heavily defoliated as the season progresses. Because of this management system tropical legumes must be resistant to constant defoliation during the five to six months of the cool season. Legumes that have crown areas at or near the soil surface will survive this cool season severe defoliation better than those with higher crown areas. Legumes such as *S. humilis* which can survive under low soil P contents and severe defoliation, as contrasted to *Desmodium uncinatum,* would persist under different sets of environmental conditions (2, 123).

Preference by cattle of the legume over that of the associated grass is not desirable unless the legume is resistant to frequent defoliation or the morphology of the grass protects the legume from becoming overgrazed. Should tropical legumes be selected for less acceptability by cattle if the legume's morphology is not adapted for heavy grazing? Presumably physical and chemical factors are involved in animal acceptance, and relative acceptability of the

associated grass would affect the level of legume acceptability. Observations by the senior author in Colombia indicated that grazing management for maintaining persistence of *S. guianensis* and *C. pubescens* planted between rows of *Brachiaria decumbens* Stapf. or *Panicum maximum* Jacq. should not be difficult if rotation grazing were based on visual defoliation patterns. With these mixtures, the cattle preferred the grasses almost to the exclusion of grazing the legumes. Cattle could be removed when the grasses were completely defoliated or when the legumes had been grazed to the desired level. A similar situation occurred in Ecuador where *P. maximum* had been almost completely eliminated by grazing, and cattle were exclusively grazing *P. phaseoloides* (through competition, grazing pressure or differential acceptability *M. atropurpureum, C. pubescens* and *G. wightii* cv. Tinaroo had almost been eliminated). In Australia, *S. humilis* in native grass pastures is not heavily grazed until the end of the growing season but in Florida it is grazed in mixtures with *D. decumbens* and *C. dactylon* cv. Coastcross-1 during the entire growing season. *A. americana* is moderately to heavily grazed (depending on stocking rate and grazing time) when mixed with *H. altissima* cv. Bigalta or *D. decumbens. I. hirsuta* is only lightly grazed even in mixtures with *P. notatum,* while *A. vaginalis* is readily consumed. With perennial twining legumes continuous stocking rates of greater than about 2 AU/ha reduced persistence. However, the length of resting mixed pastures when stocked at higher rates is not known (52). Animal preference of grass over legume would favor legume persistence under low to moderate continuous grazing pressures, but unless the legumes were very unacceptable or were morphologically adapted, legume persistence would be reduced at heavy stocking rates. Kretschmer (81) discussed grazing effects in more detail and also discussed clipping effect on persistence.

Based on our observations on commercially grazed plantings of various tropical legumes (under good climatic and edaphic environments), and experimental tests, the following suggestions are offered for maximizing productivity and persistence in south Florida. *M. atropurpureum* should be grazed as needed from January to June, rested until September, and grazed continuously or rotationally until the following June. When used for hay or deferred winter grazing, the pasture can be rested in June, lightly grazed rotationally until August, rested, and grazed from November-December until June. *D. heterocarpon* cv. Florida is less susceptible to damage by severe clipping or grazing than *M. atropurpureum.* Excellent seed production will occur if cattle are removed at the first sign of flowering (about September 1) even after intense grazing during the summer. After about November 1 sufficient mature seeds have been produced, and since little vegetative growth occurs until April, the pasture can be grazed from November until September of the next year. For maximum seed production, however, cattle should be removed about August 1 if heavily grazed prior to this time. With the annuals, grazing can continue from after sufficient seeds are produced in the fall until June or when seeds have germinated. Probably *I. hirsuta* and *A. americana* pasture should be rested at this time for about a month, but with *S. humilis* and *A. vaginalis,* grass height should be reduced by light grazing until new plants are well established in July. Both will produce large quantities of seeds even under heavy grazing pressure so they may be grazed moderately to heavily from July until the following year.

Since the N returned by the legume to the pasture system depends in large measure on the quantity of foliage produced (32), it is logical to permit foliage to accumulate sometime during the two to three months of active summer growth.

LIME AND FERTILIZATION FOR FORAGE PRODUCTION

Although far from being exhaustive and

complete, probably more work has been carried out on the lime and fertilization needs of tropical forages in Florida than in any other geographic region in the Western Hemisphere. Many of these studies have been greenhouse trials of short duration conducted in Gainesville in conjunction with graduate studies, but some information from long term field studies is also available. The field studies have, at times, revealed important information that could not have been obtained otherwise.

Lime

Although they generally can survive without liming, tropical legumes in Florida have repeatedly responded favorably to additions of lime to virgin soils. In a pot study using Leon fine sand (Spodosol) top growth of *C. pubescens* increased five-fold with 2760 kg lime/ha as compared to the unlimed check (143). In pot studies with Oldsmar fine sand (Spodosol), Kretschmer (74) found a 2511 kg/ha application of lime increased *S. humilis* top weight three-fold over the unlimed check, and *M. atropurpureum* top growth increased 10-fold. In a series of pot studies and a short term field study involving *C. pubescens, M. atropurpureum, C. guianensis* cv. Endeavour and *D. heterocarpon,* we generally found significant responses to lime applied to virgin Oldsmar fine sand (133). In a more recent field study utilizing this same soil type, we observed maximum total DM production of *C. pubescens, D. heterocarpon, S. guianensis* cv. Cook and *M. atropurpureum* at lime applications of about 2200 kg/ha (136). *D. canum* grown in Myakka fine sand (Spodosol) in greenhouse studies gave better top growth at about 2500 kg lime/ha than the check, although no intermediate rates were tried (150). In the first harvest of a field study that is still underway in Oldsmar fine sand, the authors obtained *A. americana* top growth of 174, 315 and 755 kg/ha for lime rates of 200, 1000 and 2000 kg/ha, respectively, when 40 kg/ha of P was applied.

In some cases quadratic responses to lime have been obtained. Snyder *et al.* (136) observed reduced yields of *D. heterocarpon* at high lime rates. There was a positive lime x P interaction in this study, i.e., high lime rates reduced yield unless sufficient P was applied. The optimum rate of lime and P was 2620 and 45 kg/ha, respectively. Snyder *et al.*, (136) obtained a quadratic lime response and a lime x P interaction for *C. pubescens* in this field study, as did Urrutia (143) in a pot study using Leon fine sand. These data indicate that although tropical legumes have usually responded favorably to lime in Florida Spodosols, lime should not be used carelessly, for yield reductions of some species may result from excessively high applications. Soil pH's associated with optimum lime rates in the above cited studies have been in the range of 5.5.-6.0. For *C. pubescens* and *M. atropurpureum,* however, the cautiously projected optimum lime rates might be in the 3500-4500 kg/ha range (136). On Andros and Abaco islands of the Bahamas mixtures of *M. atropurpureum* and *D. intortum* with *H. altissima* cv. Bigalta under grazing, were observed growing well and persisting over two years on calcareous rock soils with pH's of 8.0 to 8.3. *S. hamata* and other tropical legumes are native to these islands.

There is less information relating increased pasture grass production to liming in Florida. In a field study, *D. decumbens* growth was improved by liming Immokalee fine sand (Spodosol) at 2240 kg/ha, as compared to the check, but no intermediate rates were used (29). Liming at rates up to 8960 kg/ha produced no change in yield. In a pot study using Leon fine sand, *D. decumbens* yield was increased at approximately 400 kg lime/ha but no further response was obtained at higher rates (126). *P. notatum* did not respond to lime when sufficient Cu was present. However *Pennisetum americanum* (L.) K. Schum. responded to lime up to the highest rate of 3200 kg/ha. Snyder *et al.* (135) have obtained excellent growth of *C. dactylon* cv. Tifgreen (*Cynodon* x *Magenissii* Hurcombe) maintained as a closely mowed turf when

the pH of Pompano fine sand (Entisol) was below 5.0 and Ca was continually supplied with the irrigation water.

Thus it appears that lime rates that are suitable for tropical legumes in Florida soils will be acceptable for many pasture grasses. However, this conclusion is based on very limited data and needs further verification.

Nitrogen

Of all plant nutrients, N is probably the most deficient and transient for forage production in the flatwoods soils of Florida. N may be applied to forage grasses to optimize total annual production. But N may also be used to achieve other management goals, such as having a sufficient quantity of forage of acceptable quality at a particular time of the year. Having adequate forage during normally forage deficient periods may be of much greater importance than total annual production. Some of the uses of N in pasture management are discussed in a later section of this paper.

Under Florida conditions, most warm season grasses will respond to N rates well in excess of those commonly used and those recommended by the University of Florida. In a recent field study in Gainesville (in northern Florida) using Arredondo fine sand (Ultisol) annual yields of *D. decumbens*, Transvala digitgrass and *C. dactylon* cv. Coastcross-1 were optimized at N rates of approximately 650, 700 and 800 kg/ha/yr, respectively (63). Linear increases in *P. notatum* production were obtained for N rates up to 224 kg/ha/yr in all but the first year of a 10-year study using Leon fine sand in Gainesville (10). Optimum yields (three year average) of *D. decumbens* and *P. notatum* were obtained at 450 and 370 kg N/ha/yr, respectively, in another study conducted in Gainesville on Leon fine sand (147). *P. notatum* cv. Pensacola and Argentine and *C. dactylon* cv. Coastcross produced highest yields at 896 kg N/ha in a study in the panhandle region of Florida (54). Responses to even higher rates might be possible in south Florida where the growing season is longer. For example, in south Florida Kretschmer and Martin (89) have reported a linear growth response to *D. decumbens* up to 1344 kg N/ha/season. But the University recommends less than 70 kg N/ha annually for established pasture under grazing (Agronomy Facts No. 70, Dec. 13, 1977, Florida Coop. Ext. Ser., IFAS, Gainesville, Fla.), and most range and pasture land in Florida receives only a fraction of the N that is required for optimum production (55). N deficiencies are widespread. Part of the reason for lower recommendations and usage of N than research has shown to be optimum lies in the fact that with grazing there is some recycling of N that does not occur in clipping trials. The predominant reason however is probably economic. Ranchers either cannot afford to buy more N or are not confident that it will be of economic benefit. In addition, using high rates of N to improve summer yields may not be justified if stocking rates must be drastically reduced during the winter period.

The problems associated with N fertilization of grasses in Florida emphasize the importance of utilizing legumes in Florida's pastures. In south Florida, Kretschmer *et al.*, (88) have shown that *S. humilis, M. atropurpureum, D. heterocarpon, D. intortum* with *D. decumbens* produce the equivalent of about 98, 110, 135 and 185 kg N/ha/yr, respectively, in relation to *D. decumbens* alone. For *P. notatum* mixtures, respective values were about 200, 220, 250 and 370 kg N/ha.

Concern has often been expressed about the efficiency of N uptake and the effect of rates and dates of pasture fertilization on N leaching losses. In a series of papers Blue and his coworkers have shown that for Florida's most widely used forage grass, *P. notatum*, N losses may not be as great as once thought. Short term clipping studies have shown rather low uptake efficiencies for *P. notatum*, with only 40-50% of the applied N being recovered in clippings (7,

145). However, large amounts of N are utilized in the production of the massive stolon-root system (102). After the pasture has been established for several years, N recovery in clippings has been shown to increase to about 70-80% (10, 11). In a three-year experiment on Myakka fine sand there was little difference in N recovery or annual DM production of an established *P. notatum* sod fertilized at various annual rates when from 1 to 16 applications were made from March to September (11). The only exception was one case when very intense rainfall (202 mm) fell within 12 days after a fertilization. Using established plots of *D. decumbens,* which does not have as massive a root-stolon system as *P. notatum,* the authors have observed N recovery in clippings as great as 85% when N was applied at 56 kg/ha/cut (168 kg/ha/season, 44 day cutting interval) but as low as 23% when N was applied at 224 kg/ha/cut (1344 kg/ha/season, 22 day cutting interval) (three year averages, unpublished data).

Phosphorus

Tropical legume production in Florida is dependent on adequate P fertilization. In field studies the authors have observed striking yield increases for *C. pubescens, D. heterocarpon, S. guianensis* cv. Cook, *M. atropurpureum* and *A. americana* (133, 136, and unpublished data) as a result of P fertilization of virgin Oldsmar fine sand soil. Optimum production has occurred at P rates of 40-80 kg/ha, depending on species and season. Virtually no growth occurs in the unfertilized soil.

Forage grasses in Florida appear to require lower rates of P than other parts of the world. The University now only recommends about 20 kg P/ha at time of establishment (Agronomy Facts, cited above) and this is a 38% reduction from the amount that was recommended a few years ago (57). In a pot study using virgin Leon fine sand, *P. notatum* response to P was observed up to about 16 kg P/ha, although the yield of the check was nearly 75% of the maximum yield (127). In another pot study, using Immokalee fine sand, *D. decumbens* yield (total of nine harvests) increased up to the maximum P rate used (48 ppm) (40). This apparent high P requirement may have resulted from the multiple harvesting and removal of top growth. When clippings from the first five harvests were returned following the ninth harvest, there was no effect of fertilizer P application on the 10th harvest.

In a 10-year grazing study on Immokalee fine sand in which P (from SSP) was applied at 24.4 kg/ha/yr for three years and N at 26 kg/ha/yr, grazed *D. decumbens* yielded 39% greater than in the no P check (46). During the next four years when the N rate was doubled, the field receiving P averaged 31% greater yield than the check. In the final four years when the N rate was again doubled but the P rate was halved, the P treatment still resulted in about 31% more forage production than the no P check. It was concluded that annual applications of P from superphosphate at 12 to 24 kg/ha would support vigorous *D. decumbens* growth without accumulation of soil P. Interestingly, although P fertilization made it possible to use higher stocking rates, beef cows on the no P treatment remained vigorous and productive even though the forage consistently was low in P (0.10 to 0.12%).

In lieu of liming, P is subject to considerable leaching from acid surface horizons of south Florida mineral soils because of their sandy textures (113). P is retained by the spodic horizon which restricts water movement and contains appreciable Al and Fe (124). But soils that are adequately limed appear to retain P well. In a laboratory study, P retention by Leon fine sand increased linearly with $CaCO_3$ applications up to 10,000 kg/ha (8).

Most P retention appears to occur as the Al phosphates in Florida soils, although this observation seems at odds with the general increase in P retention that occurs with liming which suggests Ca-P forms. P reten-

tion correlated well with Al, and sometimes with Fe, extractable by several reagents (151). The correlations were generally better for Entisols and Ultisols than for Inceptisols and Spodosols. Fractionation of P forms in a limed Leon fine sand showed that Al-P forms dominated at all lime rates (8). However, some question was raised about the fractionation procedure when it was observed that the 1*N* NH_4Cl and 0.5*N* NH_4F (pH 8.2) reagents, which are used to extract unbound and loosely bound P and Al-P, respectively, also extracted considerable Ca-P from $Ca_3(PO_4)_2$.

P. notatum has been shown to utilize residual soil P in Leon fine sand, and response to P fertilization is unlikely on soils with over 300 ppm total P (127). However, for *D. decumbens* in a pot study using selected horizons of virgin Immokalee and Myakka fine sands, herbage yields increased throughout the residual total soil P (native P) range of 52 to 1650 ppm (40). In terms of plant growth, residual P levels of 500 and 1650 ppm were approximately equivalent to 24 and 48 ppm of applied soluble P, respectively.

The 1*N* NH_4OAc (pH 4.8) extractant that was used for many years by the University Soil Testing Laboratory has been shown to extract little Al-P (3). Thus much of the residual soil P (either native or from old fertilizations) has not been measured. Recently the Laboratory changed to the double acid extractant (0.05*N* HCl in 0.025*N* H_2SO_4) which is known to extract Al-P. Since grasses appear to utilize residual P (probably Al-P), the double acid extractant should give a better measure of available P. Thus far, however, this has not been proven for Florida soils. In a pot study using a number of Florida soils, DM production of *P. americanum* was poorly correlated with P extractable by either ammonium acetate or the double acid, although there was a significant correlation with ammonium acetate (132). Also, poor correlations were found between total P uptake or P concentration in the tissue vs. extractable P for both extractants. Nor did the authors find much difference between these extractants when attempting to correlate soil P with the growth of four tropical legumes in a field study (134). Using these and other data the authors are continuing to determine the effectiveness of various P extraction methods for predicting tropical legume growth.

Thus, although P is one important nutrient that is retained well by Florida soils and for which it should be possible to establish soil test availability ranges, this work has not been done for tropical forage grasses and legumes.

Potassium

Generally K does not accumulate in the surface horizons of south Florida mineral soils, since these soils contain little organic matter (OM) clay or K bearing minerals. K is either leached by rainfall or it is taken up by the crop. As a result of either process, it is removed from the soil. Thus soil samples usually test low (less than 100 kg K/ha). But a low K soil test does not guarantee that there will be a positive response to K fertilization, especially in a pasture situation. Since K is easily recycled, and plants take up K in excess of need, sufficient K may be returned to the growing crop to satisfy needs. For determining fertilizations in these soils, it may be better to use tissue testing rather than soil testing, since most of the K in a field of grass-legume probably resides in the plant, rather than in the soil.

As a result of K recycling through the animal, fertilizer K which is evenly applied over the pasture becomes concentrated in excreta spots scattered across the field. With time, regions of K deficiency are intermixed with regions of luxury consumption. The question, which we are unable to answer at this time, is: when does it become economically feasible to refertilize the entire field with K? For Histosols in Florida, which have high CEC and are better able to retain K, ranchers are advised to take three

separate soil samples per pasture and the fertilizer recommendation is based on the lowest of the three. While this method probably results in at least adequate fertilization of all portions of the pasture, some areas are excessively fertilized. The economics of this method are undetermined.

Liming at low rates improves K retention by increasing the soil's CEC, and because K can better compete with Ca for exchange sites than with Al, H or Fe (62). But high rates of lime may so saturate the exchange complex with Ca that K retention is low. If the soil pH is raised by using K_2CO_3 instead of $CaCO_3$, K retention is improved, since no competing cation is added. But the most practical way of managing K in Florida's coarse textured soils is to apply it in relatively large quantities only when there is little chance of leaching rainfall and/or when there is an actively absorbing root system present. For an established *P. notatum* pasture on Leon fine sand from 73 to 103% of the K applied was recovered in clippings (9). Time of application or number of applications (single vs. split) did not have a great effect on K recovery by the grass when K was applied at 93 kg/ha. Apparently yields were not affected by K leaching losses from the root zone. In another study using Myakka fine sand, recovery of applied K (93 kg/ha) by *D. decumbens* averaged from 55 to 69% and was not affected by dates of fertilization or by single vs. split applications (31).

In a two-year study in which K was applied at 11.6 kg/ha after each harvest, the authors observed recovery (average over six harvests) somewhat in excess of K applied for *H. altissima* cv. Bigalta, *C. gayana*, Transvala digitgrass and *C. dactylon* cv. Coastcross-1 (unpublished data). At 46.5 kg/ha/harvest, recovery was 77, 51, 77 and 65%, respectively, for these grasses. There was some improvement in recovery in the latter harvests. Even though soil tests in check plots indicated only 2-3 kg available K/ha and K bearing minerals would not be expected in the Oldsmar fine sand used in this study, an average of 6-7 kg K/ha/harvest was obtained in the clippings of the four grasses grown without K fertilization.

There is little research on which to establish K fertilization rates for tropical legumes in Florida. Brolmann and Sonoda (18) reported K deficiency on introductions of *S. guianensis* grown at ARC-FP. Leaf tissue K values of 0.70 and 0.35% were associated with healthy and deficient plants, respectively. In a pot study using K rates of 19, 38, and 95 kg/ha, these workers reported increased top growth at the highest rate for all harvests after the first.

For grasses, K fertilization should be related to N fertilization in order to maintain an optimum K level in the forage for proper growth. When fertilized with N at 56 kg/ha/harvest, and all clippings were removed, the authors have observed highly significant linear correlations between K fertilizations up to 46.5 kg/ha/harvest and yield of *H. altissima* cv. Bigalta, *C. gayana*, Transvala digitgrass and *C. dactylon* cv. Coastcross-1 (unpublished data). In cases where the data could be better represented by a quadratic function, optimum yield was generally predicted at 30-40 kg K/harvest. Following one application of K at the highest rate (46.5 kg/ha), plots of *H. altissima* cv. Bigalta, *C. gayana* and Transvala digitgrass which had previously received no K and were therefore very K deficient, produced yields equivalent to those which had been fertilized at the highest K rate throughout the two-year study. Tissue K percentages of 0.6 and greater were generally associated with the highest yields. The following critical levels have been presented by other Florida researchers (35): *Eragrostis curvula* (Schrad.) Nees-0.3%, *P. notatum*-0.5%, *P. notatum* cv. Pensacola-0.6%, *P. notatum* cv. Argentine-0.9%, *Axonopus compressus* (Swartz.) Beauv.-0.75%, *C. dactylon* 99-0.8%, *C. dactylon* cv. Coastcross-1-1.0%, and *D. decumbens*-2.0%. It has been reported that a large portion of the high K requirement of *D. decumbens* can be satisfied by Na (34). However, in another study, *D. decumbens* yields were reduced by

NaCl applications in irrigation water at any level over the check (30). The authors of this paper have been unable to detect a beneficial Na substitution for K requirement of *H. altissima* cv. Bigalta in a field study (unpublished data), but in another study greater Na concentrations were observed in the tissue of *C. gayana* and Transvala digitgrass than in *H. altissima* cv. Bigalta or *C. dactylon* cv. Coastcross-1 when all were grown under similar conditions without Na fertilization (unpublished data). Perhaps this indicates that there is more Na utilization by the former two grasses than by the latter two.

Other nutrients

Most ranchers supply mineral supplements containing Fe and Cu and other micronutrients as conditions warrant. The University of Florida recommends applying the following to virgin soils to prevent deficiencies in the forage: B-6, Cu-3, Fe-4, Mn-3, Zn-4 kg/ha, respectively. After 5 to 10 years under grazing, about half of the above quantities are suggested to be applied. Fritted trace elements (FTE 503) at a rate of about 22 kg/ha may be used as an alternate source of micronutrients. These rates are sufficient on the Spodosols, but lower rates also may be adequate, as evidenced by numerous commercial applications to virgin soils of half or less of the above amounts.

Although surveys of micronutrient contents of tropical grasses growing on Florida organic soils have been made (66) there has been very little evidence of micronutrient deficiencies in forages grown on Spodosols in south Florida. Kretschmer (67) did not obtain a response to additions of micronutrients, including Mo, in an experiment with tropical legumes. Yields of establishing *T. repens* seedlings were not increased in cutting experiments by adding Mo (67). Because ranchers are aware of the relatively high Mo levels found in forages growing on the organic soils (84, 85), and the associated debilitating effects on cattle, there has been little interest in applying this element even to pastures growing on mineral soils. For maximum yields of *T. repens—D. decumbens* mixtures it was concluded that soil Ca and Mg contents (0.5 *N* acetic acid extractant) of 380 and 78 kg/ha, respectively, were adequate (86). South Florida soils are deficient in Co, but including this element in the mineral mixture appears to have prevented Co deficiency from occurring in cattle (83). Sulfate in the upper (artesian) water aquifer in all but a small northern area of south Florida exceeds 250 ppm (149) and may reach levels of 500-1000 ppm (5). When these waters are used for irrigation, as is often the case, there is no reason to believe that forages would be S deficient. Critical S contents of the common tropical legumes are between 0.13 and 0.18% (81).

MANAGEMENT PRACTICES FOR INCREASED PRODUCTIVITY AND QUALITY OF PERMANENT PASTURE GRASSES

Fall N fertilization

Since grass growth slows considerably in the fall and winter as a result of shorter days, cooler mean temperatures, and particularly cooler night temperatures, herbage yield per kg of N applied is progressively diminished. For this reason, if N is to be used for producing sufficient herbage for winter grazing, it must be applied in the early fall when climatic conditions will permit rapid forage growth, and grazing must be deferred. Normally a rancher would like to delay the fall fertilization so that the pasture could be grazed as long as possible into the fall. But it is difficult to consistently predict the last acceptable date for fall N fertilizations, because of differences in temperature and rainfall from year to year. Kretschmer *et al.* (87) have suggested that for maximum *D. decumbens* growth in the Fort Pierce area N should be applied early in September, and no later than the first of October. Areas to the north and west might have to be fertilized up to two weeks earlier. *H. altissima* cv. Bigalta produces more

herbage in the winter than *D. decumbens,* and Kretschmer and Snyder (93) found that the fall N fertilization date might be delayed somewhat. For example, during 91 day growth intervals commencing with N fertilizations (112 kg/ha) on September 17, October 1, October 15 or October 29, DM yields of 3840, 5400, 4360 and 2250 kg/ha respectively were obtained. However CPC increased as fertilization was delayed with respective values of 2.9, 5.0, 9.1 and 14.6%. With respect to time following a fall N application, there is an inverse relationship between yield and protein content of the herbage produced. A longer growth interval in the fall results in greater forage production, but the CPC has been shown to decrease. For example, following mowing and N fertilization (70 kg/ha) on August 2, August 31, October 3 or October 31, *D. decumbens* yields on January 16 of the following year were 7670, 4540, 2690 and 810 kg/ha, respectively (Fig. 4). But CPC of the respective herbages were 3.4, 3.4, 5.1 and 6.1%, respectively (71). Thus a rancher must consider whether forage production alone, or producing forage of acceptable quality will be his management goal when planning a fall N fertilization program. Kretschmer *et al.* (87) have suggested that if a rancher will accept lesser tonnage in order to obtain better quality *D. decumbens,* the fall fertilization should be made in the middle of October and no later than the first of November, in the Fort Pierce area.

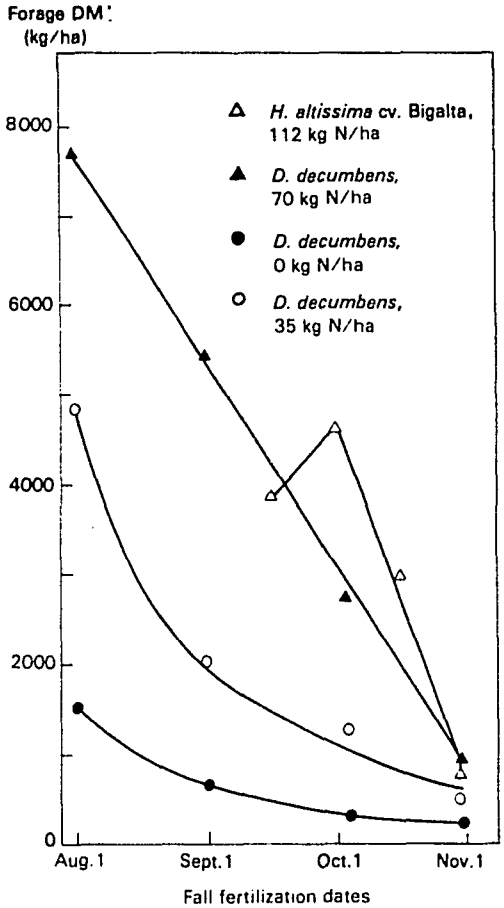

Figure 4. **Effect of different fall fertilization dates on DM grass yields at the ARC-Ft. Pierce. The crops were harvested on Dec. 17.**

Daily intake of digestible nutrients from tropical pastures and hay is more closely correlated with voluntary intake (r = 0.92) than with digestibility (r = 0.55) (107). Voluntary intake generally decreases with age of grass more than with tropical legumes. Voluntary intake of *D. decumbens* was not affected by CPC above about 7% but decreased rapidly and linearly below that value (107, 109). *M. atropurpureum* intake ramained at a high level up to 260 days of growth. With tropical grasses zero crude protein digestibility was obtained when CPC were about 4% (106). Zero N balance in sheep occurred at a crude protein digestibility of about 49% or about 7% crude protein in the DM of the tropical forage. The relationships between digestible crude protein (Y) and crude protein in the DM (X) was found to have r values greater than 0.97, and could be expressed by the equation: Y = 0.85X-2.72 (108).

These relationships have a direct bearing on animal production particularly during the cool season stress period in south Florida. Although crude protein normally is not limiting (75), DM production is limited. Thus voluntary intake is limited by lack of available DM. Large quantities of reserve pasture for winter grazing or for hay (as reported earlier in this section) obtained by

fall fertilization normally have CPC of less than 7%, and again voluntary intake would be limited; in this instance because of low crude protein.

Late N fertilization

The solution to the problem of obtaining high DM production with a CPC at an acceptable level (about 7%) was found by Kretschmer (70, 71). By applying ammonium nitrate to reserved *D. decumbens* two to three weeks prior to grazing or haying, crude protein increases were achieved. The advantage of this "late" N fertilization technique is that one already knows how much DM is available and the CPC can be adjusted to the cattle needs by N fertilization. For example, N applications of 0, 50 and 100 kg/ha on December 22 had only a slight effect on *D. decumbens* yields on January 16 of the following year. But the protein content of the forage, which had been last harvested and fertilized (70 kg N/ha) on August 2, was 3.4, 4.1 and 5.2% for the three December 22 N rates, respectively. Grass that had only received half as much N on August 2 only produced about half as much forage on January 16; and again, the tonnages were not greatly increased by the December 22 fertilization. But with only half as much forage standing at the time of the three N fertilizations on December 22, the protein contents were 2.6, 5.4 and 6.1%, respectively, for the three N rates. Thus the protein increase that will be realized from a given N application in the winter will vary with the amount of forage present at the time of fertilization. Conversely, to achieve a given protein level, a rancher will have to use more N if more grass is present at fertilization. Using data from an experiment with *D. decumbens*, this relationship can be expressed by the equation $Y = 16.233 - 2.10(\log H) + 0.0632N$, ($R^2 = 0.82$), where Y is the units increase in protein percent, H is the quantity of herbage DM present in the field (kg/ha) at the time of fertilization, and N is the amount of N applied (kg/ha) (Snyder and Kretschmer, unpublished data). From this equation it can be seen that the amount of protein increase is reduced exponentially with increasing herbage, but increases with N fertilization.

Chapman and Kretschmer (25) fed normal and "late" N fertilized (NH_4NO_3) *D. decumbens* hay to steers in two experiments. The general results (Fig. 5) confirmed voluntary intake studies previously mentioned in this section. Maximum intake occurred with CPC of hay between 7 and 9%. Minson (100) in a detailed feeding test with sheep using "late" urea fertilized *D. decumbens* hay confirmed the results that voluntary intake was increased over non-fertilized grass.

Preliminary steer feeding tests with *S. humilis-D. decumbens* and *M. atropurpureum-D. decumbens* hays with CPC of about 4.5 and 4.9%, respectively, almost maintained body weights

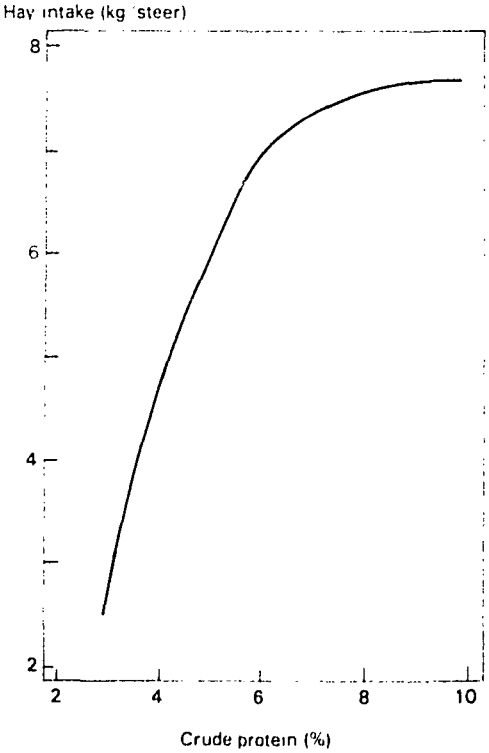

Figure 5 **Effect of crude protein content of *D. decumbens* hay on intake by steers.**

(Kretschmer and Hays, unpublished). Thus, in some instances mature stands of tropical legume-grass mixtures may need to be "late" N fertilized to increase crude protein.

Legumes

If a tropical legume is included with the grass, however, it should be possible to omit any fall fertilizations and possibly late N fertilization. Our cutting studies using seven legumes each mixed with six grasses, showed that crude protein levels of 8.6 to 18.0% resulted from regrowth from September 17 to December 10. However crude protein ranged from only 5.1 to 14.8% for regrowth from July 9 to December 17. *In vitro* digestibilities ranged from about 40 to 60 and 35 to 50%, respectively. At some period in the fall cattle could be removed from a pasture so that considerable forage could accumulate for winter feeding. Approximately two to three weeks before the pasture is to be grazed in the winter, N could be applied to increase the protein content of the standing forage should it be low. Utilizing the tropical legumes and winter N fertilization to raise protein levels, a rancher could obtain high quality winter forage with a relatively small expenditure for N. Another method of judicious use of N fertilizer would be its application in early spring, if soil moisture is available and if the newer more productive grasses are used. This will help in providing additional feed during a stress period (93).

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FORAGE WEED PROBLEMS IN ACID INFERTILE TROPICAL SOILS

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ABSTRACT

The importance of weeds in forages of temperate zones and fertile regions of the tropics has been long recognized, and adequate control measures have been developed. In tropical areas of acid infertile soils relatively little research on weeds and their control has been done. Proper pasture management is the basis for any weed control system as a vigorous forage competes favorably with most weeds. The judicious use of herbicides may be necessary to keep certain weeds in check. Special application techniques and equipment may be required to prevent injury to desirable forages, especially the leguminous species. Future research on weeds in tropical forages on acid infertile soils should focus on pasture management and soil fertility interactions with weeds; weed biology; effects of weeds on forage yields and quality; herbicide effectiveness, application, persistence, leaching, and economics; weed-free seed production; and weed-insect-forage interactions. Forage agronomists, animal scientists, range managers, and weed scientists should be trained in the principles and practices of weed management and control in regions of acid infertile soils.

If we observe the history of agriculture, it is probably safe to say that as man began to select and improve those species he chose as crops, problems with undesirable species became more important. Today we associate modern agriculture with mechanized operations which prepare the land, fertilize and apply pesticides, cultivate, and harvest an improved variety of a crop grown as a monoculture. As we have improved the growing conditions and reduced ecological diversity, weeds have become serious competitors with man's crops. In other words, they too have responded to an improved environment and effective weed control methods are needed to obtain high yields.

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The acid infertile soils of the tropics represent one of the last frontiers in agriculture. Considerable knowledge has been obtained on the problems and potentials of these regions for agricultural production (7). Many people, institutes, and governments hope to develop productive cattle management systems and limited agronomic cropping as well in these regions.

An awareness of the principles related to the invasion of exotic species will allow us to plan accordingly as the savannas and rain forests are modified into more productive systems. Certainly the permanent nature of pastures allows us to more fully develop management practices based on ecological as well as agronomic principles.

This paper will attempt to review the present situation in tropical pasture weed

control, speculate on future weed problems, and suggest areas of weed science research and training important for the production and use of forages on acid infertile soils of the tropics.

PRESENT SITUATION

In temperate zones and more fertile areas of the tropics, much is known about the establishment and management of pastures to keep them relatively weed free (8, 13, 17), but in the acid infertile soils of the tropics, such information is very limited. This is due to man's previously limited interest in these regions and to the fact that there have not been major modifications in the environment of acid infertile soils to promote an abundance of weeds. In fact, given the severely limiting growth conditions, almost any plant that survives in the soils has been considered a desirable species and not a weed.

Traditional Pasture Herbicides

Pasture weeds are principally brush and perennial herbaceous broadleaf species which are susceptible to the hormone-like herbicides 2,4-D; 2,4,5-T; silvex; picloram; and dicamba. Combinations of 2,4-D and 2,4,5-T are perhaps the most commonly used products and may be applied to the foliage, to the lower part of the stems or trunks, or as a cut stump treatment. Picloram is particularly effective on many brush species and is also used in combination with 2,4-D or 2,4,5-T.

In temperate climates picloram's long residual effect in the soil and high solubility has limited its agricultural use to areas where pastures are not rotated to broadleaf crops. This is also the reason it was recently classified as a restricted use pesticide by the Environmental Protection Agency in the United States (12). Personal observations and a research study on the persistence of picloram in the tropics (15) indicate that these problems are less serious in tropical regions.

These herbicides are very selective to grasses. However, if the goal is a grass-legume association, the hormone herbicides may be too toxic for use in broadcast applications. Picloram is especially effective in killing leguminous species. Spot treatment or basal or cut-stump applications will help overcome this problem (2). Various studies have evaluated the relative tolerance of forage legumes to various herbicides and the results of these trials should be followed so that the safest product or formulation is used for a given legume stand (4, 21, 23).

Grass weed species may also invade tropical pasture. *Paspalum virgatum* L. and *Andropogon bicornis* L. are both able to invade acid infertile soils. *A. bicornis* is certainly considered a weed since it is unpalatable and of very low forage quality. Uprooting bunch grasses will effectively control them and may be more economical than chemical control measures in some cases (25). Mechanical or hand control of rhizomatous or creeping weedy grasses is generally ineffective and requires the use of systemic herbicides or pasture renovation.

Dalapon, TCA, and amitrole are effective grass killing herbicides and could be used to spot treat small infestations of grass weeds (22, 25, 26). Glyphosate is a new herbicide which gives excellent control of many perennial and annual grasses (9). It has no soil residue and treated areas can be reseeded within days. Selective grass weed control in grass pastures is not possible with broadcast applications; in areas of heavy grass weed infestation, reseeding the pasture is suggested.

In the establishment of grass pastures, herbicides such as atrazine, simazine, and diuron may be used if vegetative cuttings are used to seed the pasture (26). If true seeds are used, preemergence herbicide selectivity is limited, and further research is needed to find safe treatments. Broadleaf weeds in newly seeded pastures may be killed with the judicious use of 2,4-D in postemergence.

Burning

The practice of periodically burning pasture lands is widespread and has been investigated by many workers (6, 10, 14, 18, 32). With the present environment of native species and acid infertile soils, burning is generally considered an integral part of a pasture management program. It destroys dead, rank vegetation and stimulates the growth of succulent shoots and leaves. Total forage yield and forage quality usually increase (24, 27). Timing and frequency of burning are important considerations and few studies have been done to monitor these effects on weed problems in ranges. An excellent paper by Eiten (14) reports that established brush species and trees in the Cerrado of Brazil are fire tolerant. However, if burning is practiced on a two to three year frequency, the seedlings will be destroyed before the plants become fire tolerant.

Burning to clear an area for pasture establishment in forested areas is also a common practice. It rids the field of much biomass and releases stored nutrients. Often crops such as rice, maize, or cassava are planted prior to pasture establishment. These crops utilize most of the available nutrients, providing a source of food for consumption or sale and then the pasture species are introduced and hopefully become the dominant vegetation. Weed control measures are needed in these areas to assure that the brush does not overtake the area again.

Forage establishment

The successful establishment of introduced species demands effective weed control measures. Trials conducted in several countries (19, 26, 28) indicate that mechanical land preparation is superior to burning or the use of herbicides alone. By broadcasting seed on the soil surface, Ramos (25) achieved a 50% *Hyparrhenia rufa* (Nees) Stapf. stand by cutting, plowing, disking three times, and fertilizing and a 90% stand of *Melinis minutiflora* Beauv. with the same procedure. Using dalapon or paraquat to replace the burning or plowing of the existing vegetation was much less effective.

This does not mean that such systems would always fail. Vicente-Chandler *et al.* (31) report equally successful establishment of *Pennisetum purpureum* Schumach. and *Digitaria decumbens* Stent. with either a prepared seedbed or a sod killed with herbicides. Similarly, CIAT (11) established the legumes *Centrosema pubescens* Benth. and *Desmodium intortum* (Mill.) Urb. in a *D. decumbens* pasture by applying glyphosate or paraquat in bands or spots and then seven days later seeding the legumes into the dying pasture grass. If grazing is delayed until the legumes are well established, grass-legume mixtures can be established in this manner. Equipment could be designed to simultaneously spray and plant legumes in regions where large areas are to be planted or hand labor is scarce.

In forested areas, the possibilities of mechanization are reduced and hand weeding and burning are more important in keeping weeds in check. Herbicides may also be helpful in pasture establishment and maintenance in forested areas, particularly to control broadleaf weeds and brush.

POTENTIAL FUTURE PROBLEMS

The savannas of the Llanos and Cerrado regions and the forested areas of concern are presently dominated by a stable ecosystem of primarily native plants. Several alternatives exist to change the productivity of the present plant communities: (a) The introduction of legumes into existing grass stands; (b) The introduction and establishment of more productive grasses and legumes with no or minimal disturbance of the environment; and (c) The complete destruction of existing vegetation and the establishment of introduced species.

The stability of the present ecosystems has not been greatly disturbed by man. Even

though the current practice in many areas is to graze and periodically burn the grasslands, no deliterious changes in the environment have been observed. However, as we modify these practices, species shifts are likely to take place and some may involve the buildup of invading species we will consider as weeds. Certainly pursuing the third alternative of complete vegetation destruction on a large scale will set the stage for dramatic changes. Soil disturbance, liming, and fertilization will create a greatly modified environment and weeds will very likely become serious competitors with the newly seeded forages.

Minimal environmental disturbance will reduce the risk of this happening. For example, banding fertilizer and lime will not set the stage for widespread species shifts but will hopefully allow the successful establishment of introduced species. Similarly, no-till planting systems will have a much lower disruptive effect than clean cultivation methods of pasture establishment or renovation. Discontinuing periodic burning may allow species (particularly brush and trees) to establish and develop. Periodic mowing or herbicide use may be required to keep such weeds in check.

Unfortunately man continues to be his own worst enemy in regard to introducing weeds into new regions. The promotion of wide scale plantings of grasses and legumes in regions of acid infertile soil will carry with it the risk that weeds will also be introduced into the region either vegetatively or as seeds. An awareness and prior knowledge of the weeds common in the area of seed or vegetative material propagation will forewarn us of such potential weed introductions.

Nevertheless, ranchers may be unaware of the risks involved in bringing contaminated propagating material into their farms and unknowingly introduce weeds into the region. Weed seeds may also arrive in the digestive system or on the skin of cattle shipped into the area as well as in the bedding material used in the trucks to haul cattle. Aggressive educational programs stressing preventive measures will reduce the danger of accidental weed introductions.

An even worse situation would be the remote possibility that the "desired" species introduced would become a weed. The introduction of *Sorghum halepense* (L.) Pers. into the United States as a forage and *Rottboellia exaltata* L.f. into Colombia serve as vivid reminders that the "impossible" may happen. Admittedly this will be less likely in the acid infertile soil regions of the tropics since few large scale agronomic cropping systems are likely to evolve in these areas and it is in such systems where pasture species can become serious weeds. Thorough evaluation in small areas under the control of responsible persons should be the first step in introducing new species into a region.

In both the range and forest regions of acid infertile soils, relatively large areas will be involved in the cattle production system, and the wide scale use of herbicides is not considered the best alternative for weed management and control. The integration of cultural, mechanical, and manual control measures into the overall management program should provide sufficient weed control in most situations. The judicious use of the right herbicide for a specific problem applied at the correct rate at the proper time of weed development will be required on occasion and should be recommended when necessary.

FUTURE NEEDS IN WEED CONTROL

Since so little has been done to study the importance of weeds in regions of acid infertile soils, the opportunities for research and training are limitless. The following areas of weed science should be developed by national and international organizations concerned with these regions to the extent that their financial and personnel resources allow.

Research

Pasture management

Obviously such research has been, is, and will continue to be carried out in this area. It is important that observations be made on how various management practices influence the diversity, abundance, and species shifts of undesirable species. The effects of the frequency and duration of grazing and burning are of special interest. It is generally true that a vigorous, well-established pasture competes favorably with weeds (30), and to this end weed scientists can make valuable observations on the management practices under evaluation.

Weed control practices should not be considered separately from the management system being developed. As Vicente-Chandler *et al.* (31) state: "It is important to carry out all required practices properly and at the right time." As suitable pasture management systems are developed, appropriate weed management and control measures must be integrated into them.

Soil fertility

Several aspects of soil fertility and weed interactions need attention.

- How do changes in soil pH affect weed species diversity and growth?
- How do changes in nutrient levels affect weed species diversity and growth?
- Is there a minimum fertility level at which forages respond favorably but certain weed species do not?
- Does banding of fertilizer reduce overall weed infestation?
- At what time of the year is pasture fertilization most beneficial to the forage species and least likely to stimulate weed growth?

These trials should be carried out at several sites as variations in soils, climate, and weeds will cause different responses between locations.

Weed competition

While data on weed losses in agronomic tropical crops exist, such data in tropical pastures on fertile soils are very rare and nonexistent in the regions of acid infertile soils. Studies should employ grazing animals to measure losses in production caused by various levels of weed infestation. Competition is complex and variables of soil fertility and moisture levels, climate, weed and forage species present, grazing frequency, and weed densities should be taken into account when interpreting the results.

The competitive ability of forages should be determined as well. Michael (20) noted that *Trifolium subterraneum* L. effectively controlled the perennial broadleaf *Hypericum perforatum*, and a vigorous stand of *Pueraria phaseoloides* Roxb. (Benth.) var. Javanica (Benth.) Bak. is recommended to dominate weeds during pasture establishment in Puerto Rico (31).

Weeds and forage quality

In addition to reducing forage production, weeds affect forage quality. Feeding trials and laboratory analysis should be carried out to determine which weeds, at what levels of infestation, and at what stage of development cause significant losses in forage quality.

An area related to forage quality is that of toxic weed species. Apparently there are few toxic species in the acid infertile regions at present (5, 14). Modifications of the ecosystem may change the situation as has happened in Australia (20). Weed species should be evaluated for the presence of toxins at various times during their life cycles.

Weed biology

It is certain that very little biological information on growth patterns, reproductive methods, seed dormancy, soil fertility and moisture requirements, competitive ability, tolerance to fire and soil acidity, etc., will be found for the invading species on acid infertile soils.

The utility of such information is exemplified by Teitzel and Abbott (29). They observed that while the brush weed *Acacia flavescens* could be controlled chemically, minor changes of soil mineral deficiencies and the establishment of improved pastures made herbicide application unnecessary.

Weed control during pasture establishment

Means of establishing desired forage species free of weeds need to be thoroughly investigated. The effects of burning, tillage practices, and no-till planting systems on weed infestations should be determined. It is doubtful that soil applied herbicides would be economical in these regions; however, the identification of selective and effective herbicides for both grass and legume species should be made in the event that particular areas may require such treatments.

Research should be done in the areas of herbicide leaching persistence. Perhaps compounds that rapidly break down or leach after killing germinating weed seeds would allow a delayed direct seeding to be safely made several weeks after application. The relatively low OM content and the predominance of highly weathered clay minerals of many tropical soils reduce their herbicide adsorptive capacity. As a consequence the degree of selectivity of soil applied herbicides will be less than in richer soils and requires testing at several locations before recommendations can be formulated.

Susceptibility of established weeds to herbicides

Effective treatments should be found for the serious weed problems. Information needed includes: time and frequency of application in relation to season of the year and stage of the weed's life cycle, method of application, herbicide rate and formulation, effects of prior cutting or burning, etc. Such data should be collected species by species so that a systematic method to arrive at a recommendation may be used for pastures that have a diversity of weed problems as was done by Doll and Argel (13).

Methods of herbicide application

Effective techniques for herbicide application to weeds in established pastures have been developed. The research needed in grasslands on acid infertile soils should focus on (a) band or spot treatment systems for the introduction of new species into established pastures, (b) variations in nozzle type and positioning to maximize the interception of foliar herbicides by the weeds, and (c) the evaluation of no-till seeders equipped to spray herbicides.

Specialized equipment such as the recycling sprayer and herbicide roller should also be tested in situations where the weeds (especially grassy weeds) are taller than the forage. In this way normally nonselective herbicides are made selective by manipulating the application techniques.

Economics of herbicide use

A key factor for the rancher in deciding which alternative to choose in establishing and maintaining weed-free stands is the cost. Since areas of acid infertile soils have always been ones of low return per ha, ranchers have made few investments to improve production. As technology is developed to increase productivity, the economic analysis of the alternatives available becomes necessary.

Specifically analysis should compare the costs of herbicides to (a) the partial or complete replacement of mechanical means of preparing the land for planting, (b) the manual and mechanical means of maintaining adequate weed control, and (c) the mechanical means of pasture renovation. Spray equipment and herbicide costs and availability in remote areas should also be taken into consideration.

Weed-free seed production

While complete weed control may not be necessary in grazing lands, fields used for

the production of seed and vegetative material for introduction in new areas must be as weed-free as possible. Unlike the situation for agronomic crop seed, there are no criteria to establish minimum tolerances for certain common weed seeds (i.e. 0.1% *Amaranthus* spp. seed in *Medicago sativa* L.) nor to classify other species as noxious weeds with a zero tolerance (i.e. *Agropyron repens* seed in *M. sativa* is prohibited by law in many areas of the United States).

Until such knowledge and enforcement programs are available in the tropics, every effort must be made to produce and introduce weed-free seed. Limited research to find selective herbicides for forage legumes has been conducted (3). Humphreys' (16) manual provides practical guidelines for seed production of tropical forages and states, "There is considerable need for cooperative work between the weed scientist and the pasture seed production agronomist..."

Weed-insect-forage interactions

Weeds are often accused of hosting destructive insects and many such examples are found in any introductory weed science text. The possible beneficial effects of the insects found on weeds is a more recent development (1) and needs further investigation. For example, a weed species at non-competitive levels of infestation may repel certain destructive insects from the forages and the complete eradication of this weed would result in greater insect problems in the forage.

Also, insects already present in an area may help control certain weeds. J.M. Spain (personal communication) has observed the white grub "chiza" feeding selectively and vigorously on *A. bicornis* in the Colombian Llanos. This may explain why *A. bicornis* is not a serious weed in that area and perhaps the grub could be introduced into other areas where this weed is a problem. All these aspects of weed-insect-forage (and perhaps disease) interactions should be explored.

Biological weed control

Most of the successful attempts at biological weed control have occurred in pasture and range environments. They provide the stable, long-term relationships necessary for biocontrol programs to succeed. The cooperation of existing biological weed control laboratories should be sought to evaluate the potential of this approach for the principal weed species in tropical pastures.

Training and education

If the information on weeds already available and that generated by future research is not passed on to those working in the area of concern, development will be slowed accordingly. The lack of more interdisciplinary specialists is due in large part to the lack of opportunity for such training. Now interdisciplinary training is available and the holistic approach to forage management should be taken and weed control should be an integral part of the training experience.

Many trained professionals will be required to form the research and educational network necessary for regional development. The importance and principles of weed management and control should be incorporated into the training of forage agronomists and animal scientists alike. Additionally, weed scientists should be prepared to work in these regions as part of the research teams developing appropriate forage production and utilization systems.

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PART IV

BEEF PRODUCTION FROM TROPICAL PASTURES

INTERPRETATION OF RESEARCH RESULTS IN THE MANAGEMENT OF TROPICAL PASTURES

Tony R. Evans*

ABSTRACT

The paper presents some results of Australian research in pasture and animal production from different management systems These range from improvement of native pasture by introduction of a legume into the pasture system to intensive production from fully sown grass-legume and N fertilized pure grass pastures. The level of animal production from legume based pastures is closely related to the quantity of legume in the pasture and hence the main objective in pasture management is to maintain the legume component. Legume persistence and production is influenced mainly by fertilizer input and grazing pressure Use of N fertilizer is considered in systems of intensive production for pure grass pasture, for strategic use on grass-legume pasture or in improvement of degraded sown pastures. A major constraint in use of N fertilizer is the inefficient utilization and recovery of the N applied All pasture systems involve the soil-plant-animal complex; an understanding of the interrelationships that occur is essential for improvement or maintenance of pasture and animal production and for formulation of appropriate management systems

The tropical and sub-tropical grazing lands of Australia lie between latitudes 11°S and 30°S, extending in an arc from the Kimberley region of northwest Western Australia across the Northern Territory into Queensland and then south into northern coastal New South Wales. Annual rainfall isohyets show a general concentric pattern over the continent and regions of high rainfall (>1500 mm) are confined to the northern tropics and small areas along the eastern coastline (Figure 1) Rainfall distribution is markedly seasonal but with an increasing winter component south of lat. 18°S. Maximum and minimum temperatures decrease from north to south but maximum summer temperatures increase and minimum winter temperatures decrease from the coast inland. Minimum temperatures in winter and the occurrence of frosts can limit pasture growth during this period south of the tropic of Capricorn. However, in most of tropical Australia the distribution of pasture yield and quality is influenced by the pronounced summer incidence of rainfall, which imposes well defined limits to pasture growth.

This paper reviews research undertaken in pasture improvement on infertile acid soils and discusses management systems for beef cattle production arising from research results.

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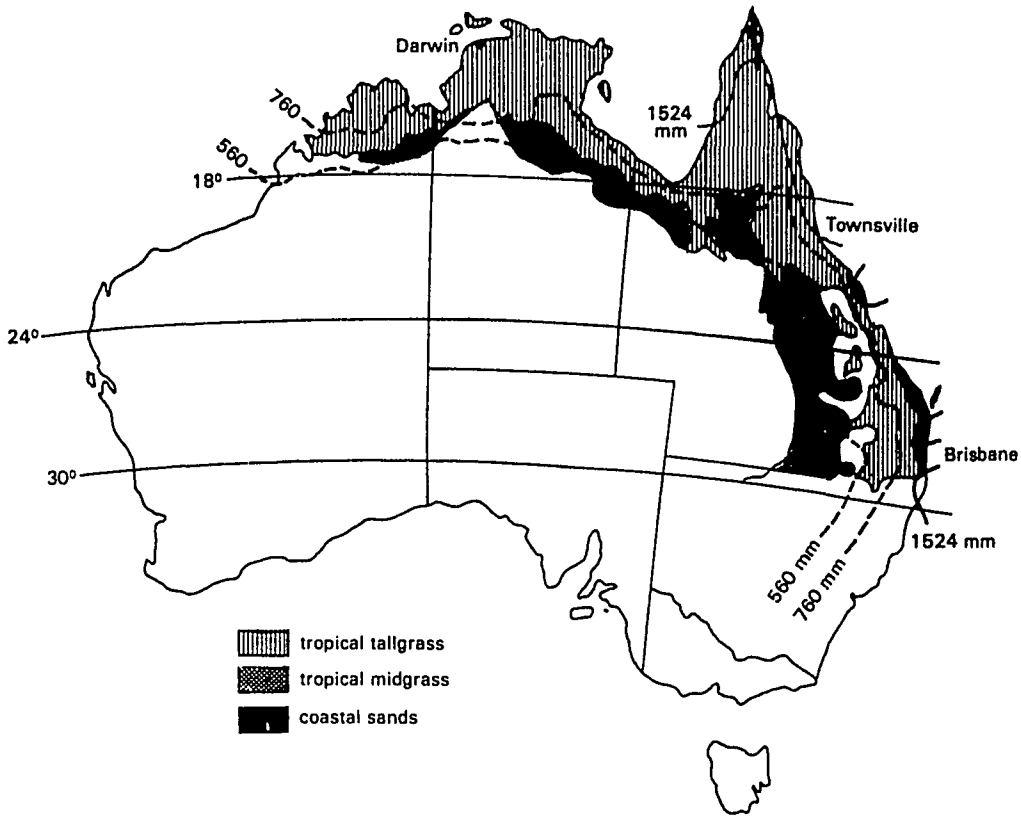

Figure 1. **The distribution of grazing lands and annual rainfall isohyets in northern Australia. (Compiled from 36).**

NATIVE PASTURES —RESOURCES AND IMPROVEMENT

The grazing lands of northern Australia comprise Eucalypt woodlands with an herbaceous understorey of tropical tall grasses (Fig. 1). In the Northern Territory and Western Australia these comprise perennial bunch grasses 1.2-2.8 m tall and annual *Sorghum* spp. which may exceed 3.0 m in height. The prevalent perennial grasses are *Themeda australis* (R. Br.) Stapf., *Sorghum plumosum* (R. Br. Beauv.), *Chrysopogon fallax* S.T. Blake and *Sehima nervosum* (Rott. ex Willd.). In Queensland the herbaceous community comprises perennial tussock grasses to 1.0 m tall in which *Heteropogon contortus* (L.) Beauv. ex Roem & Schult. is the dominant species. There is only a relatively small area of almost treeless *Dichanthium* grassland which occurs on relatively fertile cracking clay soils. These are not considered in this paper.

A general absence of productive indigenous legumes and poor productivity and nutritive value of native grasses place severe constraints on animal production. This is clearly demonstrated from research at Katherine in the Northern Territory (lat. 14°S) where the wet season extends for only ca. 22 weeks and total DM production is approximately 1200 kg/ha a year from tropical tall grass pasture comprising the perennials *T. australis, S. plumosum, C. fallax* and *S. nervosum.* Pastures grow rapidly after the onset of rain until flowering and seed set, when growth rate declines until the end of the wet season, and N and P content satisfy animal requirements only

during the young stage of pasture growth (Fig. 2). Inadequacy in quantity and quality of herbage results in liveweight losses in the dry season of up to 20% of peak body weight and a four to five year period to reach slaughter weight (Fig. 3). Prior the introduction of *Stylosanthes humilis* H.B.K. into this pasture system, the main management practice was burning of native pasture in early wet season to produce a "green shoot" of higher nutritive value. Burning *per se* may not affect botanical composition of these pastures but when accompanied by grazing can induce a succession with an increase in unpalatable species (31).

Attempts to increase productivity by addition of P or N fertilizer can increase DM production, but the efficiency of nutrient recovery is only 10% (38), a very small increase compared with that obtained by the introduction of *S. humilis* into the pasture system.

Removal of tree competition (by poisoning or ringbarking) may double DM production of native pasture (37) but this has little effect on improving protein supply or in extending feed quality into the dry season.

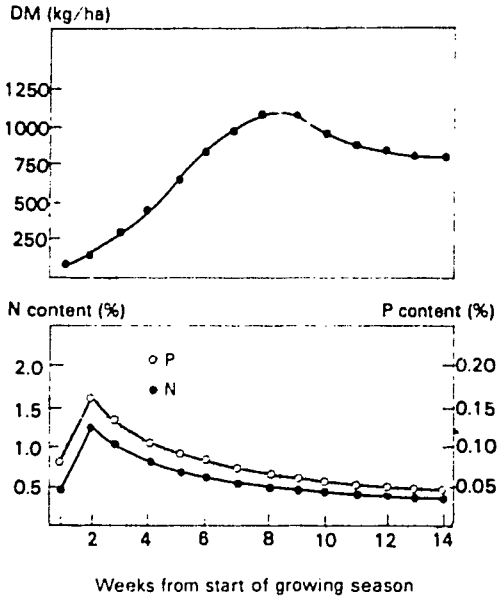

Figure 2. **Distribution of yield, N and P content of native pasture at Katherine (lat 14°S) Northern Territory. Soils are Lateritic Red Earths (Oxisols) (39).**

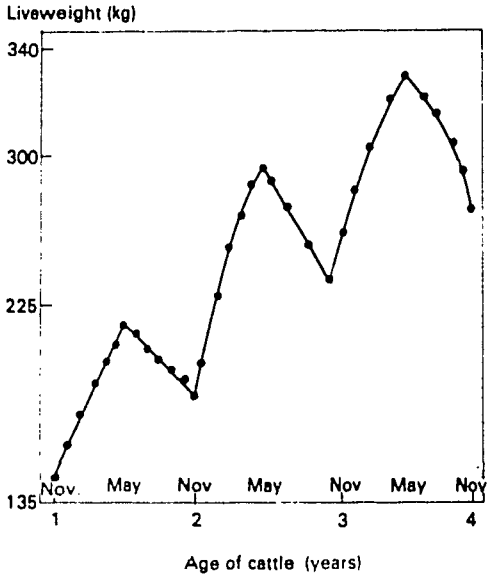

Figure 3 **Liveweight change on native pasture at Katherine (40).**

H. contortus pastures in Queensland show similar low annual production and nutritive value (45) and in the absence of grazing, annual burning increases *H. contortus* content probably because of a reduction in basal cover of this species, an increase in germination of *H. contortus* seed induced by fire and the resistance of established plants to burning (44). A combination of burning and grazing will induce a succession in which unpalatable species increase (54). These studies on native pastures indicate a low potential for improving production through management, without additional input by introduction of better species to increase overall yield and nutritive value. The first stage in attaining increased production is through the use of adapted legume species.

PRODUCTION AND MANAGEMENT OF LEGUME-BASED PASTURES

The role of the legume is to improve the

protein supply to the animal, to provide a N source for associated grasses and to increase soil fertility. One of the main aims of management is to maintain an adequate legume component in the pasture since total pasture yield and animal performance are positively related to legume yield (2, 15, 28, 42).

The value of *S. humilis* in improving animal production by progressive substitution for native pasture in the diet of steers has been clearly demonstrated (42, 57). In the Katherine environment a progressive linear improvement in liveweight gain was obtained with increasing period spent grazing *S. humilis* with a liveweight gain of 280 kg/animal being achieved over 630 days. On a commercial basis the improvement in carrying capacity of native pastures oversown with *S. humilis* is dependent on the proportion of improved pasture on the property (52). Thus with 10% improved area the carrying capacity is about one animal to 12 ha, with 20-30% improvement 1:4.5 ha and with 40-60% 1:2.5 ha. The main determinant of yield of *S. humilis* in this environment appears to be level of P applied, and the relative insensitivity of this legume to within-wet season drought stress (20); a desirable attribute in areas of variable within season rainfall.

There have, however, been problems in maintaining this annual legume in native pasture or with sown perennial grasses such as *Cenchrus ciliaris* L. in this monsoon environment (41, 43). The factors influencing re-establishment of the legume at the commencement of the wet season appear to be competition to seedlings from the rapidly growing perennial grasses, and rainfall events which allow germination of legume seedlings which do not survive unless followup rain occurs. Grazing management, in which pasture growth may be controlled by early grazing of the grass components, can result in replacement of the perennial grasses with less productive and unpalatable annual grass species, and a subsequent decline in pasture stability and production. Current studies on management systems with *S. humilis* indicate better persistence of the legume when grown with *Urochloa mosambicensis* (Hack.) Dandy. under a continuous grazing system (17). Alternatively, use of perennial *Stylosanthes* species such as *S. hamata* (L.) Taub, *S. scabra* Vog. or *S. viscosa* Sw. may successfully overcome the problem of grass competition in the early wet season and prolong animal production into the dry season, through specific characteristics of green leaf retention in some of these species.

In Central and Coastal Queensland, introduction of *S. humilis* into perennial *H. contortus* pastures has not produced management problems in maintaining legume stability (46).

Their study on stages of improvement of native pastures showed that liveweight gain could be doubled and gains per ha increased sixfold with the use of *S. humilis* and the addition of fertilizer (Table 1).

In the above studies, and in most pasture evaluation work undertaken in northern Australia, animal production has been measured using steers rather than with breeding herds. However it is important to determine whether species shown to be of value for fattening cattle, are adequate in meeting the nutritional demands of breeding and lactating cows. Edye *et al.* (11, 12) showed that *H. contortus/S. humilis* pastures fertilized with 126 kg or 377 kg SSP/ha increased cow liveweight, conception and calving rate over non-fertilized *H. contortus/S. humilis* pastures. Calving rates increased from 66% to 85% over the range of P inputs, and weaning percentage increased from 64% to 82%. The preweaning calf liveweight gains were related to the *S. humilis* content of the pastures.

The next stage in further improving production is replacement of native pasture with completely sown pastures. An example of sequential stages in pasture improvement

Table 1. **The influence of fertilizers* and the inclusion of a legume on animal production from *H. contortus* grassland in South East Queensland (46).****

Pasture treatment	Stocking rate	Annual liveweight gain	
	an/ha	kg/head	kg/ha
Native	0.28	83	25
Native	0.61	47	29
Native + fertilizer	0.61	100	62
Native + *S. humilis*	0.74	121	93
Native + *S. humilis* + fertilizer	0.95	149	148

* SSP (125 kg/ha) Mo (37.5 g/ha) and potassium chloride (63 kg/ha) applied annually over this period

** Soils are Solodized Solonetz (predominantly Natrustalfs).(See Appendix 2 in P.A. Sánchez and R.F. Isbell's paper in this book)

and effects on animal production is a study on land use systems in southern Queensland by Tothill (55). The control system (c) is unimproved woodland with a density of 150-200 trees/ha and a predominantly *H. contortus* native pasture and stocked at 0.17 steers/ha. The other systems studied are: (1) Killing trees with an arboricide (K); (2) Killing trees and sod-seeding native pasture with *Macroptilium atropurpureum* (DC.) Urb. cv. Siratro (KS); and (3) Complete clearing and establishment of *C. ciliaris/M. atropurpureum* pasture (PS). Both (2) and (3) received 125 kg/ha molybdenized superphosphate annually.

Animal production in the first and second years for each system is shown in Figure 4 and the gains/ha for the second year in Figure 5. The effect of tree killing was to increase the total DM production of native pasture and in the first year animal production was similar for the K and KS systems because of slow establishment of sod-seeded *M. atropurpureum*. In the second year differences appear between these treatments as *M. atropurpureum* production and the N status of the system improved. Subsequently, at stocking rates of 0.93 steers/ha animal production from the KS and PS systems approach the same level; 136 kg/ha on sod-seeded pasture and 146 kg/ha on fully sown pasture (56).

In the same environment Mannetje and Coates (32) compared grazing systems on reproductive performance of cows and preweaning growth rate of calves. The systems comprised native pasture *H. contortus* grazed at 0.17 cows/ha, sown pasture of

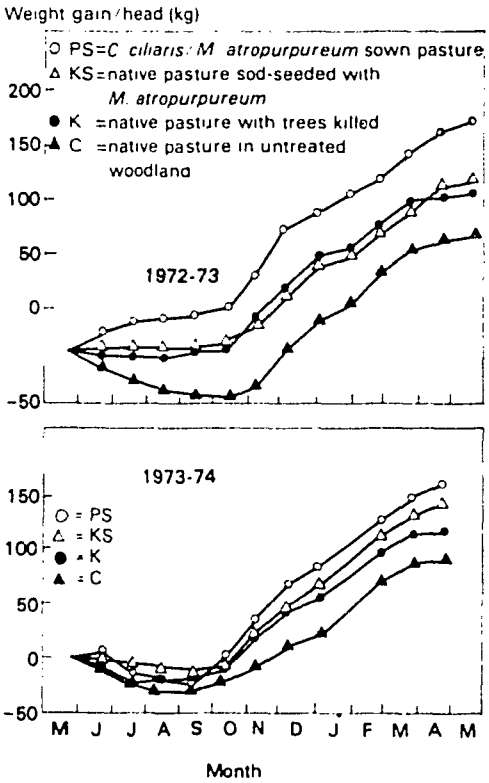

Figure 4. **Animal production from four land use systems at Narayen (lat 25°41'S), southern Queensland. Soils are Yellow Podzolics (Haplustalfs) (54).**

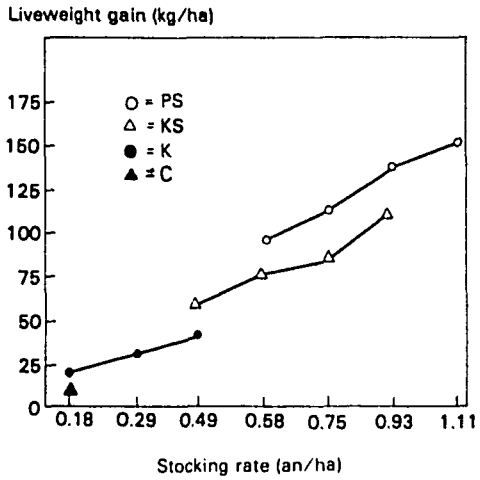

Figure 5. **Animal production in response to different stocking rates for four land use systems at Narayen, southern Queensland (54).**

Panicum maximum Jacq. var. trichoglume with *M. atropurpureum* (0.51 cows/ha) and native pasture grazed in summer at 0.34 cows/ha with access to sown pasture in winter and spring, and stocked at 1.0 cows/ha, i.e. twice the stocking rates of the other treatments but only for half of the year. The results (Table 2) clearly show the advantages of pasture improvement. The integrated use of native pasture with sown pasture shows benefits over native pasture alone, but the higher stocking rate on native pasture in summer may have limited the opportunity for selective intake, thus reducing average daily gains.

In higher rainfall areas (800-2000 mm) with a better distribution of rainfall and longer growing season quite high levels of animal production have been recorded from fertilized fully sown pastures (Table 3).

Maintenance of stable production from these pastures is dependent on management systems that will maintain legume content. As legume content decreases animal production falls (15, 27). Not only does the amount of legume affect total production but it also influences seasonal changes in liveweight as shown in Figure 6 (2).

The major factor influencing legume

Table 2. **Reproduction and pre-weaning growth of Hereford cows and calves at Narayen, lat. 25°41'S (32)[a]**

Treatment[b]	Stocking rate	Conception	Calving	A.D.G.[c] Female	A.D.G.[c] Male	Weaning weight Female	Weaning weight Male	Reproduction index[d]
	Cow/ha	%		kg/ha				
NP	0.17	87	78	0.70	0.72	186	198	166
SPL	0.51	91	82	0.87	0.92	233	244	210
SPH	0.68	97	94	0.81	0.91	223	248	221
NPSP[e]	0.34							
	1.00	96	82	0.71	0.76	197	212	193

[a] Soils are Red and Yellow Podzolics (Paleustalfs, Haplustalfs)

[b] NP = native pasture
SPL = sown pasture, low stocking rate
SPH = sown pasture, high stocking rate
NPSP = native pasture/sown pasture system

[c] ADG = average daily gain of calves, birth to weaning

[d] Reproduction Index = kg of calf weaned/cow mated, adjusted for sex

[e] 0.34 cow/ha on native pasture November to April
1.00 cow/ha on sown pasture with access to native pasture, May to October.

Table 3. **Comparison of beef production (liveweight gains) from grass/legume and N fertilized grass pastures.**

Location	Grass legume	Stocking rate	Grass/ nitrogen	Stocking rate	N applied	Reference
	kg/ha/yr	an/ha	kg/ha/yr	an/ha	kg/ha	
South Johnstone						
lat 17°36'S	469	4.1	660	4.1	168	22
lat 17°36'S	510	3.2	650	3.2	147	33
Samford						
lat 27.5°S	256	2.2	490	5.6	336	27
Beerwah						
lat 27°S	507	3.6	699	4.3	168	4

persistence is stocking rate (provided that fertilizer addition is adequate for normal pasture growth), and especially for pastures based on legumes that have a climbing or trailing growth habit e.g. *Pueraria, Centrosema, Macroptilium.* The relationship between stocking rate and gain/animal is shown in Figure 7 for *Setaria anceps* Stapf. ex Massey/legume pasture and *S. anceps* fertilized with 336 kg N/ha/yr. With increase in stocking rate the reduction in gain/animal is similar for both legume based pastures and substantially greater than with the N fertilized pasture. The greater sensitivity to changes in stocking rate by the grass/legume pastures is attributable to the effect of grazing on the legume component. The greater accessibility of *Desmodium intortum* (Mill.) Urb. and *M. atropurpureum* for defoliation and the removal of buds for potential regrowth reduces the legume content of the pasture and subsequently lowers animal production.

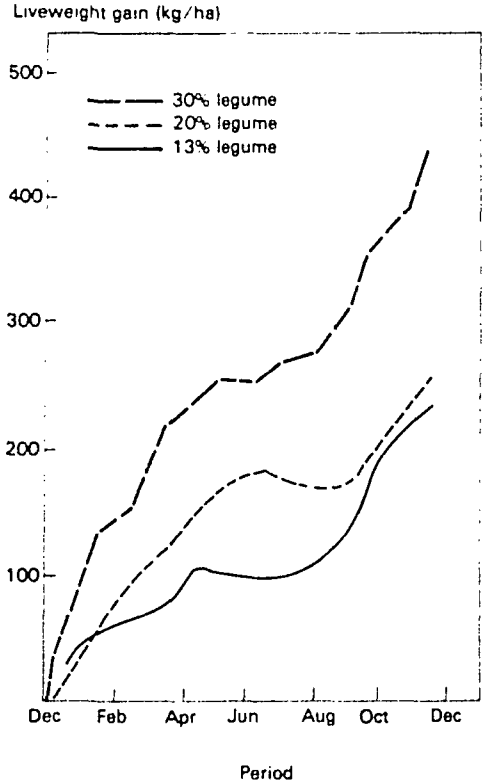

Figure 6. **The effect of legume content on liveweight gain in fully sown sub-tropical pastures continuously grazed at 2.5 steers/ha. Soils are Lateritic Podzolics (Paleustults) (21).**

An understanding of the factors influencing legume persistence is essential to enable formulation of suitable management practices. Detailed studies on the ecology of *M. atropurpureum* (29) have shown that under high grazing pressures individual *M. atropurpureum* plants are grazed more frequently, produce fewer stolons and less DM. Since the quantity of N fixed is dependent on total legume yield (28), a reduction in quantity of fixed N will subse-

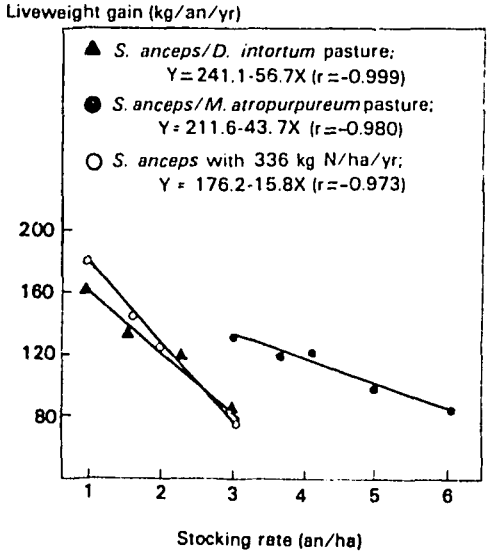

Figure 7. **The relationship between gain/head and stocking rate for grass/legume and N fertilized grass pastures at Samford (lat 27.5°S) south-east Queensland. Soils are Yellow Podzolics (Haplustalfs) (27).**

quently reduce pasture yield and under high grazing pressures this sequence is repeated leading to lower animal production. However, high grazing pressure enables more seedling regeneration from soil seed reserves by reducing competition. At low stocking rate individual plants are larger and longer lived and show secondary rooting from stolons and rhizomes, but new seedlings succumb to competition. The implications for management are to avoid overgrazing in the first year to allow accumulation of soil seed reserves, and on "run down" pastures to reduce the grazing pressure or rest the pastures in late summer and autumn when growth rate of *M. atropurpureum* is highest and seed is being set.

Although there is no evidence for any substantial benefit from using a rotational grazing system in increasing animal production over that obtained from continuous grazing, except with shrub legumes such as *Leucaena leucocephala* (Lam.) De Wit., it may be necessary under some circumstances to include a rest period during flowering and seed set to allow an increase in seed input to the pasture system.

The above studies emphasize the importance of detailed ecological investigation on the behavior of pasture legumes under intensive grazing and which are necessary to obtain an understanding of legume persistence.

Other factors influencing survival of a legume are possible seasonal fluctuations in grazing preference. With *M. atropurpureum,* Stobbs (50) found that in the early grazing period only 2-10% of the diet selected comprised *M. atropurpureum,* but in late summer-autumn this rose to 62-73%. There may be palatability changes with age of plant, but in this instance this cannot be separated from quantitative change in the amount of *M. atropurpureum* on offer which is greater later in the growing season.

The maintenance of adequate levels of pasture production on infertile soils is dependent on adequate maintenance fertilizer application. The level of fertilizer input can affect botanical composition and persistence of the legumes and animal production (15).

The difference in animal production (Fig. 8) between an annual maintenance application of 125 kg/ha of SSP and 250 kg/ha was attributed to (a) higher legume content and (b) higher N and P levels in the legume and P levels in the grasses at the higher superphosphate input. There is very little published data on the length of periods over which a maintenance input is required or for modifying these inputs on a biennial or other basis. Subsequent studies on pastures described by Evans and Bryan (15) have shown that after 10 years of applying 250 kg/ha of SSP omission of this annual application for three years has had little effect on animal production as seen in Figure 9 (Jones, R.M. and Johansen, C., pers. comm.).

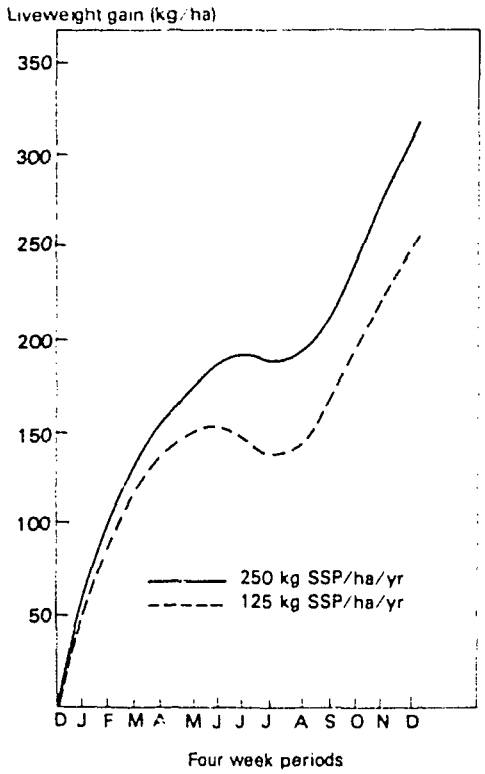

Figure 8. **The effect of different levels of annual maintenance superphosphate on liveweight gain from subtropical pastures at Beerwah (lat 27°S) grazed at 1.6 steers/ha. Soils are Lateritic Podzolic and Gleyed Podzolics (Ultisols). (15).**

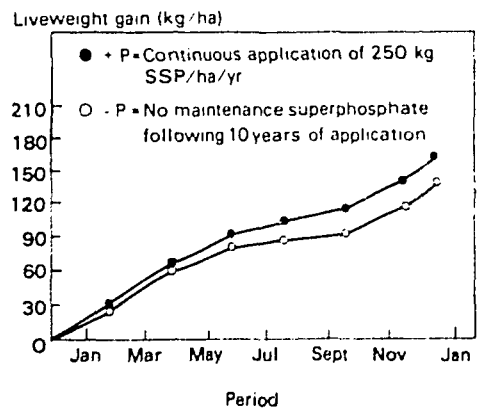

Figure 9. ***Animal performance on established pastures grazed at 1.6 steers/ha after continuation or cessation of maintenance superphosphate application. Soils are Lateritic Podzolic and Gleyed Podzolics (Ultisols). (Jones, Johansen and Evans, unpublished data).***

PRODUCTION AND MANAGEMENT OF NITROGEN FERTILIZED PASTURES

The high photosynthetic efficiency of tropical grasses and their potential for DM production can only be maximized where moisture and nutrient supply is non-limiting. Use of N fertilizer allows expression of this potential, but increase in N content of grasses requires higher N input than that required for maximum growth (23). Beef production from N fertilized pastures is greater per unit area than for legume based pastures (Table 3), primarily because of a higher carrying capacity. There is also less sensitivity to change a stocking rate than with legume based pastures (Fig. 7).

Use of N fertilizer on pastures may be considered within the context of three different management systems, (1) to maximize production per ha on pure grass pastures, (2) as a strategic application to legume based pastures or (3) on pure grass pasture grazed in conjunction with grass-legume pastures in an integrated production system. Both (2) and (3) could be used to increase herbage supply during periods of shortage, such a in winter or for drought periods of short duration. Management decisions involve quantity of N required, frequency of application, the requirements for other nutrients, and decision on optimum stocking rate for any N level.

The quantity of N applied on soils very deficient in N can have a marked effect on animal production. Bryan and Evans (4) found that *D. decumbens* grass fertilized at either 112 kg N/ha or 448 kg N/ha produced similar quantities of DM but animal performance at the lower level was affected by a low N content in plant material. Increasing the level of application to 168 kg N/ha improved pasture quality and animal performance. At high levels of N fertilization, Evans (13) found little difference in animal production between 448 and 896 kg N/ha except during the winter period, when crude protein content (CPC) of pasture at the higher level of N was maintained above 10%

compared to less than 8% at the lower level. Studies on the frequency of application of N (14) clearly showed advantages in more frequent applications (six times a year) in improving distribution of feed supply and increased animal production from pastures receiving a total of 448 kg N/ha a year grazed at 7.4 steers/ha. Under these subtropical conditions where growth rates range from 10 kg/ha/day in winter to 200 kg/ha/day in summer (6), increasing N application in autumn increased animal production, which suggests an important role for strategic application to increase quality of feed in the off season. The range in animal production from applications of three to six times a year was 840 to 1440 kg liveweight gain/ha/yr. Rainfall variation between years influenced total gain but the difference of about 600 kg/ha between these frequencies was maintained.

Pasture species show different responses to level of N input and in total pasture and animal production. Table 4 shows liveweight gains from *D. decumbens* and *S. anceps* cv. Nandi pastures grazed at different stocking rates and with different levels of N fertilizer. *D. decumbens* is less responsive to increase in N above 280 kg N/ha/yr whereas *S. anceps* cv. Nandi shows a marked response up to 476 kg N/ha/yr.

In a comparison of different grass species fertilized at the same N level (378 kg N/ha/yr) there were marked differences in animal liveweight gain (Fig. 10). Sensitivity to increase in stocking rate is less for the Narok cultivar of *S. anceps* and is attributed to a less variable seasonal growth pattern because of its ability for winter growth. The better animal production is probably due to a higher leaf percentage and the effect this has on intake and nutritive value.

When N is applied to grass–legume pastures there is usually a decline in legume content (Table 5). These data suggest that an application of up to 112 kg N/ha could be used to increase grass production, in a system in which different pastures are fertilized each successive year at a time when the legume is producing little growth. In the first year 112 kg N/ha had no effect on *M. atropurpureum* yield whereas there is a marked reduction at 336 kg N/ha.

Applications of N to degraded pastures have resulted in improving botanical composition of better grass species. Henzell (23) increased the content of *Chloris gayana* Kunth. in a degraded pasture to 13% with 112 kg N/ha and 92% with 448 kg N/ha. Gartner (21) obtained similar results with a

Table 4. **Animal production from *S. anceps* cv. Nandi and *D. decumbens* pastures at different N treatments and stocking rates (16).***

Stocking rate (steers/ha)		Liveweight gain			
Species	Fertilization	2.5	4.3	6.2	8.0
	kg N/ha	kg/ha/yr			
S. anceps	280	547	559	558	-
	378		802	725	384
	476		817	889	544
D. decumbens	280	480	795	787	-
	378		830	818	732
	476		774	803	756

* Soils are Lateritic Podzolics (Paleustults).

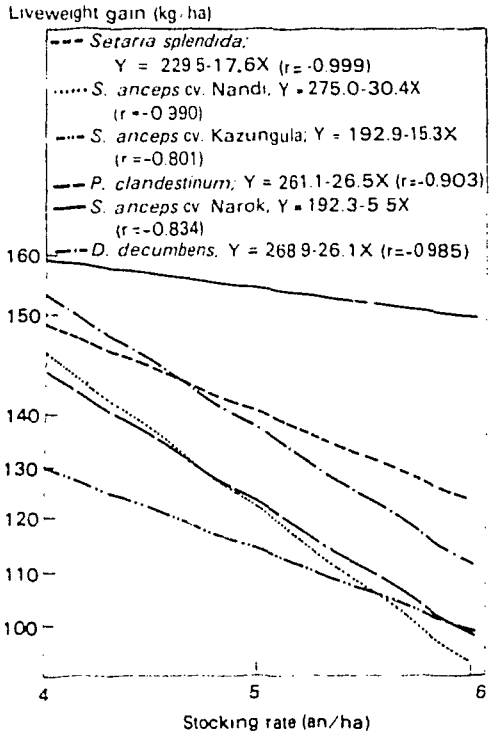

Figure 10. **Relationship between stocking rate and liveweight gain for six pasture grasses receiving 378 kg N/ha/yr at Beerwah (lat 27°S), south-east Queensland. Soils are Lateritic Podzolics (Paleudults). (Evans and Hacker, unpublished data).**

degraded *Pennisetum clandestinum* Hochst. ex Chiov. pasture.

Intensive production from N fertilized pure grass pastures is based on relatively high inputs of fertilizer. In most experiments these include higher maintenance rates of P and K than those used in grass/legume systems. The main objective in higher application of these elements is to avoid either becoming limiting and hence prevent a full expression of the N responses. In the experiments of Bryan and Evans (3) and Evans (13) a ratio of 10:1:1.5 of N:P:K was used. However the ratios required have not been critically examined, and a change in these could have a marked effect on the profitability of the system (18). A further major factor influencing the economy of N use is the poor recovery of applied N in plant tops. Henzell (24, 25) recorded losses of up to 60% of urea N from grazed pastures and of 20-40% from mown pastures. Losses were greater following periods of intense rainfall. N losses may occur through surface runoff, leaching or gaseous evolution. Catchpoole (7) recorded gaseous losses of 27% under waterlogged conditions and a recovery of only 20% in plant tops. Recovery rates may be improved by use of slow release forms of N but this still has to be demonstrated for grazed pastures.

Table 5. **Effect of rate of N application on *M. atropurpureum* yield in mixed swards (26).**

N applied	*M. atropurpureum* yield			
	Year 1	2	3	4
kg/ha/yr	Kg DM/ha			
NIL	620	2190	590	1670
112	340	980	320	620
336	180	120	10	0

PASTURE MANAGEMENT AND THE NUTRITIONAL REQUIREMENTS OF CATTLE

The nutritive value of a pasture is constantly changing with stage of growth, changes in leaf and stem fractions and floral initiation. Grass-legume pastures are particularly heterogeneous because of changes in botanical composition and differences in nutritive value of the component species. Differences between species in digestibility and intake are well documented, and the implications for pasture management arise in choice of species with desirable morphological as well as nutritive characteristics. For example within *Panicum* species and varieties that may have similar digestibilities, there can be substantial differences in intake mainly due to differences in leafiness (34, 35). Leaf is eaten in preference to stem and as plants mature digestibility declines and voluntary intake also declines (30). With increasing maturity the proportion of leaf decreases and hence the overall effect of decline in leaf, digestibility and intake results in lower

nutritive value of the pasture. Differences in intake between grasses and legumes of similar digestibility is apparently due to a shorter retention time of the legume in the rumen through breakdown to a finer particle size and increased rate of passage (53). In terms of pasture management a decline in legume content in the diet could reduce intake.

A further important aspect affecting intake is the ability of the animal to obtain adequate nutrient in a specified time. Stobbs and Hutton (51) suggest that intake is dependent on time spent grazing and rate of grazing; the latter is a function of bite size and rate of biting. Stobbs (47, 48, 49) has studied the effect of sward canopy structure on bite size and grazing time and shown that accessibility of leaf material has an important influence on intake. The number of grazing bites reflects the ease of prehending herbage.

The total number of bites/24 hours ranged from 35,000 on good quality forage to 75,000 on poor quality forage. Availability and accessibility of leaf and leaf density in the canopy appear to be the most important factors controlling bite size. The stage of regrowth of the sward has an important influence in terms of the proportion of leaf, stem, and inflorescences. In the early stages of regrowth animals can select >80% leaf but as defoliation proceeds the quantity of leaf decreases resulting in smaller bite size, and increased grazing time (8, 9).

These studies serve to identify grazing behavior on tropical swards and explain some of the limitations that affect intake and nutritive value. They can provide objectives in management or selection of species to meet the required criteria. Techniques of management to meet these have not been developed. These may be easier to achieve on N fertilized grass pastures than with the more heterogeneous grass-legume pastures.

ECONOMIC EVALUATION OF PRODUCTION SYSTEMS

Many grazing experiments are of short duration and this presents a severe handicap for economic evaluation of production systems. Pastures that are established on low fertility soils gradually improve in production as the fertility status of the soil increases. An example of this improvement in fertility is presented in Table 6 for a soil initially deficient in N, P, K, Ca, S, Cu, Zn, and Mo for plant growth.

Table 6. **Soil fertility changes under grazing (5).***

Soil attribute (0-10 cm depth)	Virgin soil	After 11 years grazing	After 15 years grazing
pH	5.2	-	5.0
O.C. (%)	0.84	2.60	1.56
N (%)	0.047	0.150	0.103
S (ppm)	70	207	205
Total P (ppm)	18	150	160
Available P (ppm)	4	35	40
Total K (ppm)	31	90	202
Total Ca (ppm)	30	550	320
Total Mg (ppm)	29	29	-
Bulk density	1.55	-	1.00
Moisture content	16.0	-	41.0

* Soils are Gleyed Podzolics (Paleudults).

Thus a stable production system may not be achieved for a number of years and economic analyses in these early stages of pasture production may under- or over-estimate returns in the long term. Under Australian conditions the quantity of maintenance fertilizer required has a marked bearing on profitability. The budgetary appraisal of fertilizer and stocking rates on grass-legume production by Firth *et al.* (19) used six years experimental data for prediction of returns over a 20 year period. Subsequently some of these pastures have increased slightly in production and, as shown in Figure 9, omission of superphosphate for three years had little effect on animal production, but would have had a marked effect on economic return.

Ultimately selection of a grazing system and the management imposed should be based on economic and biological criteria, a concept which attempts to relate resources available to plant and animal requirements. The objectives of management may include maintenance of a stable productive pasture system, minimizing animal stress, or maximizing economic return to investment, labor or fertilizer input. However, the basis for management systems must be an understanding of the interrelationships in the soil-plant-animal complex.

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BEEF PRODUCTION IN THE HUMID TROPICS OF MEXICO

Ricardo Garza Treviño*

ABSTRACT

The major beef production problems encountered in all tropical regions are reviewed and include: extensive systems of cattle production; low productivity due to severe droughts, low soil fertility, pests and disease attacks; minimal utilization of legumes; and, ignorance of new improved forage species. Experiences in Mexico are analyzed focusing on four research aspects: (1) **Forage species of low productivity.** The superiority of adapted pastures over native pastures is stressed, although the latter respond satisfactorily to fertilization. (2) **Pasture management.** This is one of the major problems in the use of tropical grasses, since they grow rapidly, produce a large number of stems and lose nutritional value at the onset of and during the rainy season. (3) **Extensive cattle production and dry season effects.** Pasture fertilization, animal supplementation, rotation among paddocks and irrigation during the dry season will make it possible to change from extensive to intensive production systems, which are necessary to maintain animal production continuity in the growing and fattening stages. (4) **Associations of grasses and legumes.** Legumes could help solve the N deficiency problems in tropical soils. Especially useful species are those belonging to the genera *Leucaena, Stylosanthes* or *Glycine*.

Before describing a study of beef production in the humid tropics of Mexico, I will briefly summarize several key problems encountered in all tropical areas. These problems have affected and still continue to affect cattle-raising activities in Mexico.

1. **Extensive cattle production.** Large areas of land are utilized to maintain low animal populations throughout the year, resulting in low levels of income.

2. **Low pasture productivity due to severe droughts.** Pasture production is not uniform throughout the year; surpluses occur during the rainy season and deficits during the dry season. Tall-growing forage grasses rapidly turn fibrous and woody, and are the only feed source during the dry season when practices such as deferred grazing, or hay or silage are employed. When farmers cannot use these practices, they must either move cattle to low, poorly-drained areas which are not usable during the rainy season, or sell a part of the herds.

3. **Low soil fertility.** Rapid loss of soil nutrients is a common problem in

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tropical areas. Heavy rains leach the uneven terrain and/or grazing extends over long periods; both cause forage production to be low.

4. **Pests and diseases.** Pests periodically cause great damage in certain pastures, in given areas and in certain seasons. One example is the fly *Aeneolamia postica* Wlk. which annually causes large losses in pasture production. Likewise, a worm (*Trichoplusia in* Hbn.) has severely attacked pastures in recent years.

5. **Under-utilization of legumes.** The importance of utilizing legumes in animal diets is well-known. In addition to increasing the protein levels for the animals, they also improve soil fertility.

6. **Ignorance about new, improved forage species.** Most farmers use only native or adapted grasses like *Panicum maximum* Jacq. and *Cenchrus ciliaris* L., and for lower-lying areas, *Echinochloa polystachya* (H.B.K.) Hitchc. and *Brachiaria mutica* (Forsk.) Stapf. Actually, a wide variety of species exist, and there will always be one with characteristics most suitable for a given area.

EXPERIENCES IN MEXICO

Low-productivity species

More than one million ha of tropical lands classified as "Af" and "Am" in the Köppen climate system are covered with secondary vegetation or native pastures formed after clearing the primary vegetation. The predominant and most important species include *Paspalum notatum* Flügge, *Paspalum conjugatum* Swartz, *Axonopus affinis* Chase and *Paspalum compresus* (Swartz) Beauv. This native vegetation is usually associated with prostrate legumes of the genera *Centrosema, Desmodium* and *Glycine.*

An investigation on the response of native pastures to soil fertilization was done at the Centro Experimental of Hueytamalco, Puebla. The soil has a silty-clay texture, with good drainage, a pH of 5.7, with 4.39% OM, and intermediate in P and high in K, Ca and Mg.

Total forage DM production increased when applied N increased from 0 to 300 kg N/ha. Response to N was linear; production increased 40 and 67% at N levels of 150 and 300 kg N/ha, respectively, compared to the control. Protein percentage in the forage increased slightly with N fertilization, but no responses were found in yield or forage quality of P. The regression coefficient obtained (Fig. 1) indicates that each kg of N increased forage DM production 20.5 kg/ha (4).

In terms of DM production, the response to fertilization in the above trial was striking. However, native pastures do not respond strongly to fertilizers under grazing conditions (86 vs. 143 kg/ha of liveweight gain). In reality, production on native pastures is very inferior to levels obtained with introduced grasses such as *Cynodon dactylon* (L) Pers. var. Coastacross 1. After an application of 100 kg N/ha that material produced almost three times as much liveweight gain as a native pasture (294 vs. 143 kg/ha) during 168 days of grazing.

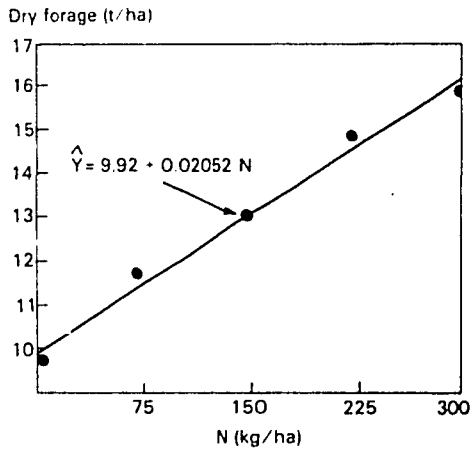

Figure 1. **Yield as a function of N levels.**

After replacing the native grasses by adapted or introduced grasses, the carrying capacity is increased, and consequently, liveweight production per ha is higher. Such is the case with *Cynodon plectostachyus* (K. Schum.) Pilger, *C. dactylon* var. Coastacross 1 and *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf. (Table 1). In the sub-tropical rainy climate of Mexico these species produced an average daily weight gain (ADWG) of 450 g and total liveweight production of about 650 kg/ha (an average of 163 kg/an) when the stocking rate was 4 an/ha, during one year of grazing in pasture on which 150 kg/ha of N were applied (15).

According to Treviño *et al* (16), the optimum stocking rate on native pastures is 1 an/ha, increasing to 2 an/ha if 150 kg/ha of N is applied or if each animal is supplemented with 2 kg/ha of a mixture of 44% molasses, 50% corn husks, 3% urea and 3% salt. As the data in Table 2 shows, beef production/ha increased 82 and 97%, with fertilization and supplementation respectively, compared to the control (177 kg/ha), when the stocking rate was 1 an/ha. Generally, the profitability index from native pastures receiving no inputs is very low (1.21%), while an animal enterprise utilizing these introduced grasses is more profitable.

The region of Hueytamalco, Puebla, with a sub-tropical climate and 2300 mm average annual rainfall, has three well-defined seasons: (a) eight months of rains; (b) two winter months with rains and low temperatures; and, (c) two dry months. Animal production is usually higher during the first of these seasons, and becomes progressively lower during the next two. Efforts have been made to obtain uniform production levels throughout the year (9).

Applications of 75 kg N/ha before the critical winter and dry months considerably increased production during the dry season (60 kg/ha of beef in 28 days of grazing). However, production remained lower for the winter season (35 kg/ha/grazing period) and was attributed to low pasture growth due to low temperatures. Temperatures also affect cattle by impairing normal grazing habits, thus reducing forage intake and weight gains per animal.

Pasture management

Management is one of the major problems affecting tropical grasses because of their rapid growth and abundant production of stems at the beginning of and during the rainy season and the resulting decreases in their nutritional value. In both fertilized and non-fertilized *P. maximum* during one year of grazing the daily gain weight during the first three grazing periods (August, September and October) was low compared to the nine other 28-day periods (Fig. 2). The differences were mainly due to the maturity

Table 1. **Rotational grazing on three tropical grasses during a 364-day period. Comparison of treatment means. Centro Experimental Pecuario de Hueytamalco, 1974 (CEPH).**

	Fertilized*		Unfertilized**	
Grasses	kg/ha	ADWG	kg/ha	ADWG
B. brizantha	637	0.438	345	0.474
C. dactylon	636	0.437	343	0.461
C. plectostachyus	583	0.400	287	0.394
Averages***	618[a]	0.425	325[b]	0.443

* Stocking rate = 4 an/ha
** Stocking rate = 2 an/ha
*** There is no significant difference among averages followed by the same letter ($P < 0.05$) according to Duncan's multiple range test.

Table 2. **Beef production with supplementation for a 364-day grazing period on native pastures under rotation. Centro Experimental Pecuario de Hueytamalco, 1974 (CEPH).**

Treatment	Stocking rate	Liveweight gain/an		Beef production
		Total	Daily	
	an/ha	kg/ha		
Control	1	177[a]*	0.486[a]	177[a]
With fertilization	2	161[ab]	0.442[ab]	322[b]
With supplementation	2	174[a]	0.478[a]	349[b]
Fertilization/supplementation	3	137[b]	0.376[b]	410[c]
Averages		162	0.446	314

* There is no significant difference among figures followed by the same letter (P<0.05) according to Duncan's multiple range test

of the grasses. The grasses had too many stems during the initital grazing periods, while in the last months they were maintained at a height never more than 1m.

By this means the ADWG was 475 g higher than in the stemmier *P. maximum* (220 vs. 695 g), representing a 13 kg difference of liveweight/an in each grazing period. The main source of variation was the pasture's overall nutritional value, and specifically, the protein and crude fiber levels of 3 and 45%, respectively, for stemmy *P. maximum*, and 9 and 35% for the more succulent *P. maximum*.

With fractional applications of 150 kg/ha of N and rotational grazing, *P. maximum*

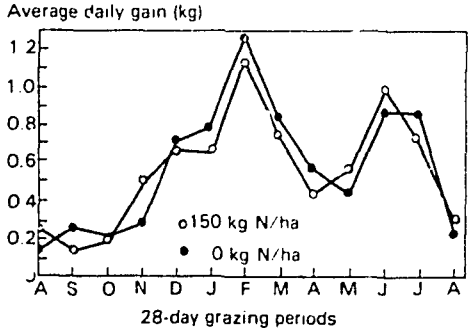

Figure 2. **Average daily weight gains during 13 grazing periods on *P. maximum* with and without fertilization. Centro Experimental Pecuario Playa Vicente, Veracruz, 1972 (CEPPV).**

persisted over one year of grazing at a stocking rate of 4 an/ha (Table 3); the ADWG was 573 g and overall gain was 209 kg/an. These results were not statistically different from non-fertilized *P. maximum* with lower stocking rates; in this case the ADWG was 584 g and overall gain was 213 kg/an. However, production of beef/ha in fertilized *P. maximum* was 834 kg or a 96.3% increase, a highly significant difference (*P<0.05*) compared to *P. maximum* without additional inputs.

In the "Am" humid tropical conditions of Mexico, with nine rainy and three dry months, beef production is higher during January, February and March (Fig. 2) when rainfall is moderate (approximately 5% of the total 2300 mm) and temperatures are not so low (mean of 23°C), and at the beginning of the rainy season when the change from dry to humid weather increases forage availability, palatability and digestibility.

Under this climatic regime the three dry months constitute the critical period for beef cattle production under grazing. (Fig. 3). In addition, there is about one critical month of moisture excess (usually in September) when rainfall averages 358 mm (16% of the annual 2300 mm). This month of highest rainfall comes when the rainy season has already lasted for some time and the soils are totally saturated with water. At this time

Table 3. **Beef production/ha, daily weight gain and carrying capacity of *P. maximum* under rotational grazing for 364 days, with and without fertilization. Centro Experimental Pecuario Playa Vicente, Veracruz, 1972 (CEPPV).**

Treatment	Stocking rate	Liveweight gain/an		Beef production
		Total	Daily	
	an/ha	kg/ha		
0 kg N/ha	2	212.56	0.584	425.00[b]*
150 kg N/ha	4	208.65	0.573	834.15[a]
Averages		210.60	0.579	629.58

* There is no significant difference among figures followed by the same letter ($P < 0.05$) according to Duncan's multiple range test.

the decrease in ADWG is considerable, due to a decrease of rumen capacity, because of excessive moisture in the forage consumed, or animal stress, or some combination of all three factors.

Extensive cattle production and dry season effects

The tropical area in Mexico covers only 13.1% (11 million ha) of the total country, but its potential is great and it supports 25% of the beef cattle population (27 million head in 1974).

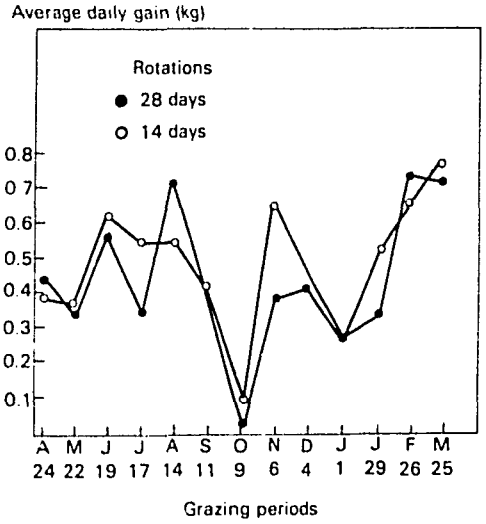

Figure 3. **Average daily weight gains on fertilized *P. maximum* with rotation of pastures every 14 and 28 days during 13 periods. Playa Vicente, Veracruz, 1975.**

In the tropical Aw_0 climate regions there are six to seven months of drought, making it difficult to fatten cattle both because of forage scarcity and since what pasture is available is dry and fibrous from moisture stress. According to several researchers (3, 14), there is a need for pastures that maintain their quality during this period. Moreover, the largest weight gains are obtained with continuous grazing (17), since pastures do not recover well under rotational grazing during this period..

In order to make the land more productive it is necessary to convert the extensive cattle production system now in use to an intensive one by improving fattening systems under grazing. Grazing during the dry season could become feasible and efficient by using deferred grazing of high-quality pastures, supplying cut forage and hay or silage, or through practices such as fertilization, animal supplementation or use of irrigation. In this manner beef production could be similar during the rainy and dry seasons. Employing these factors, higher profits are obtained and the animals go to market at a younger age and higher weight.

Weight increases from deferred grazing in the dry season were studied with *Digitaria decumbens* Stent., *C. dactylon* var. Coasta-

Table 4. **Weight gain during the dry season on *D. decumbens, C. dactylon* var. Coastacross 1 and *C. plectostachyus,* with or without preweaning supplementation. Grazing went on for 140 days and stocking rate was 2 an/ha. Centro Experimental Pecuario de Aldama, Tamaulipas, 1974 (CEPAL).**

Grasses	Liveweight gain/an Total	Daily	Beef production
	kg/ha		
D. decumbens	59.2[a]*	0.423	118[a]
C. dactylon	42.6[b]	0.305	85[b]
C. plectostachyus	40.6[b]	0.290	83[b]
Averages	47.5	0.342	95

* There is no significant difference among figures followed by the same letter (P<0.05) according to Duncan's multiple range test

cross 1 and *C. plectostachyus* grasses (Table 4). *D. decumbens* was superior to the other two grasses since its better quality with respect to crude protein percentage was maintained. When two groups of animals grazing the same three grasses above were raised with and without supplementation prior to weaning, 79 kg/ha of beef were produced by the supplemented group and 111 kg/ha by the non-supplemented group (Table 5). These results are averages over the three grasses studied. Beef production per ha in the group receiving preweaning supplementation was higher in *D. decumbens* (107 kg/ha). The results were better and more uniform in the group with no supplementation. This agrees with the results obtained by Stuedemann *et al.* (13), who studied Holstein calves fed in corrals from birth until eight months of age, at five feeding treatments. Those animals fed at normal and low levels showed a more efficient utilization of their feed from eight months until they reached 430 kg, while those fed at high or very high levels were not so efficient, although the first group took longer to reach slaughter weight. Likewise, Newman and Snapp (11) mention that a group of researchers in California found that, in fact, compensatory growth occurred even after correcting for differences in body structure between the two groups of animals. They concluded that this may be due to a better utilization of the feed and increased consumption by those animals previously fed a lower energy ration.

By using pasture fertilization practices, animal supplementation, paddock rotation and irrigation during the dry season, it is possible to change from the extensive to an intensive cattle-raising system and ensure continuity during growing and finishing stages for cattle produced under grazing. These cattle would go to market at 24-30 months of age weighing 450 kg. For this

Table 5. **Weight gains during the dry season on three tropical pastures, with or without supplementation. Grazing lasted 140 days and the stocking rate was 2 an/ha. Centro Experimental Pecuario de Aldama, Tamaulipas, 1974 (CEPAL).**

Grasses	With preweaning supplementation kg/ha	ADWG	Without preweaning supplementation kg/ha	ADWG
D. decumbens	107[a]*	0.380	131[a]	0.466
C. dactylon	67[b]	0.239	104[a]	0.369
C. plectostachyus	63[b]	0.223	100[a]	0.357
Averages	79[b]	0.280	111[a]	0.397

* There is no significant difference among figures followed by the same letter (P<0.05) according to Duncan's multiple range test

effect, Table 6 shows the different results obtained in ten 28-day grazing periods, five in the rainy season and five in the dry season. Both the supplemented and control treatments produced lower results in the dry season, indicating a decrease in forage production due to moisture deficiency. In both the fertilized and the combined fertilization/supplementation treatments, however, beef production was very similar. Production over the ten grazing periods reached a total of 353 kg/ha of beef in the control, 570 kg/ha with fertilized *D. decumbens* and 531 kg/ha when animals received supplementation. The treatment combining fertilization (100 kg/ha of N) and supplementation gave results (875 kg/ha) statistically superior to all other treatments. In one year of grazing, this treatment makes it feasible to obtain 1200 kg/ha of beef in the Aw Mexican tropics.

Grass-legume associations

For tropical countries, the future of beef and dairy production lies in utilizing grass/legume associations, since they are the cheapest sources of high-quality forage.

The use of fertilizers on pastures, formerly a profitable practice, will tend to diminish in the future because of such factors as worldwide scarcity of fertilizers, their increasing use for cereal production and their high cost.

One of the principal problems found in tropical soils is the deficiency of major elements, especially N, because large amounts are lost through leaching, erosion and evaporation (8). Nitrogen requirements need not be filled solely by applying chemical fertilizers, but also through establishing tropical legumes in association with grasses. Hudgens *et al.* (6) note the considerable influence that these associations had on crude protein yields in forages grown in the Ecuadorian tropics, especially in the case of *Centrosema pubescens* Benth. Its contribution was similar, and at times superior, to the effect of N fertilization. Those authors, as well as Febles (2), point out that the protein intake of cattle can be increased by adding high-quality legumes (such as those in the *Leucaena*, *Stylosanthes* or *Glycine* genera) to animal diets. This is especially advisable during critical periods, since these legumes combine the attributes of high productivity and palatability with a good content of crude protein.

According to some investigators (1, 7, 10, 12), the major advantages of using grass/legume associations over grasses alone are: (a) use is made of the N fixed by the legumes; (b) animal diets are improved through the increased protein levels available; and, (c) forage production per surface unit is increased.

Table 6. **Total and seasonal weight gains (kg/ha) of heifers grazing on fertilized *D. decumbens*, or with supplementation, or with both fertilization and supplementation. Centro Experimental Pecuario Paso del Toro, Veracruz, 1974 (CEPPT).**

	Control	Fertilization*	Supplementation**	Fertilization/ supplementation
Rainy season	223	286	315	419
Dry season	130	284	216	456
Total for 10 periods	353[c] ***	570[b]	531[b]	875[a]
Averages	176.5	285	265.5	437.5

* 100 kg N/ha

** 2 kg/day/animal of urea-molasses (97% - 3%)

*** There is no significant difference among figures followed by the same letter ($P < 0.05$) according to Duncan's multiple range test

Table 7. **Beef production on *P. maximum* alone and in association with a legume. Grazing lasted 364 days and the stocking rate was 3 an/ha. Centro Experimental Pecuario Playa Vicente, Veracruz, 1976-77 (CEPPV).**

Treatments	ADWG	Beef production	
	kg	kg/an	kg/ha
P. maximum/ P. phaseoloides	0.496	181	542
P. maximum	0.422	154	461

At Mexico's Centro Experimental Pecuario (CEP), in Playa Vicente, Veracruz, studies were done during one year of *P. maximum* alone and in association with *Pueraria phaseoloides* (Roxb.) Benth. var. javanica (Benth.) Bak., at a stocking rate of 3 an/ha (Table 7). In the paddock with the association 542 kg/ha of beef was produced while *P. maximum* alone produced only 461 kg/ha. The ADWG was higher in the association, indicating the better nutritional quality of the forage consumed.

Similar results (Table 8) were obtained in Matías Romero, Oaxaca, where the grasses *P. maximum* and *Pennisetum purpureum* Schumach. were compared in associations with *P. phaseoloides*. During 280 days the paddocks supported different stocking rates; the *P. purpureum/P. phaseoloides* association with 4 an/ha performed better than the *P. purpureum* alone, with 3.7 an/ha. The same stocking rate (3 an/ha) was used for the *P. maximum/P. phaseoloides* association and the *P. maximum* control. *P. purpureum* in association produced 556 kg/ha of beef and was superior to the control (459 kg/ha of beef). Generally, *P. maximum* did not yield as well as *P. purpureum;* however, when planted in association with a legume, production increased by 50 kg/ha (420 kg/ha vs. 372 kg/ha, respectively). In both cases the ADWG was higher for the association than for the grass alone. A treatment of the association *P. phaseoloides/Hyparrhenia rufa* in this study was not analyzed as the legume invaded and completely replaced the grass.

The importance of legumes in animal production is considerable as is evident in the following study conducted at Paso del Toro, Veracruz. *D. decumbens* was evaluated alone and in association with three legumes; the stocking rate was 3.3 an/ha. In order to preserve the legume, the association was grazed for 14 days and rested for 28 days. Figure 4 shows, that, in general, the ADWG was more stable during the dry season when irrigation was used than in the rainy season. Also a considerable decrease in ADWG was recorded in December and January, but this situation was more severe for *D. decumbens* than for the associations. This agrees with the findings of Hudgens *et al.*, (6) who observed that by incorporating the legume, the crude protein content of the pasture is stabilized during the dry season. The lower ADWG

Table 8. **Beef production on grass/legume associations over a 280-grazing-day period at Matias Romero, Oaxaca, 1976-1977.**

Treatments	Stocking rate	ADWG	Beef production	
	an/ha	kg	kg/an	kg/ha
P. purpureum-P. phaseoloides	4.0	0.496	139	556
P. purpureum	3.7	0.442	124	459
P. maximum-P. phaseoloides	3.0	0.500	140	420
P. maximum	3.0	0.442	124	372

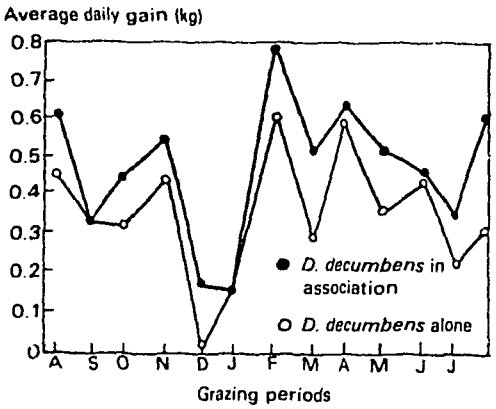

Figure 4. **Average daily weight gains during one-year grazing on *D. decumbens*, with and without legumes.**

values are due to the low temperatures registered at this time of the year, which have a marked effect on cattle grazing habits, since their stressed conditions cause a decrease in forage consumption.

Even though the carrying capacity was uniform in all paddocks (3.3 an/ha), beef production per ha over one year was higher in the associations (Table 9); average production was 629 kg/ha, but the *D. decumbens* control produced only 468 kg/ha. In this case the ADWG was also higher in the association (approximately 150 g), a clear indication of the greater quality of the animal diet.

Of the legumes studied, *Glycine wightii* (R. Grah. ex Wight & Arn.) Verdc. var. Clarence formed a better association than *C. pubescens*, which practically disappeared although it might show more persistence in a more humid tropical area. *Leucaena leucocephala* (Lam.) De Wit., the third legume studied, is bushy and therefore associates perfectly with all creeping or low-growing grasses and is excellent for either dry environments or the Aw tropics. The incorporation of *G. wightii* to an established *D. decumbens* pasture provided 38% increases (647 vs. 468 kg/ha) in beef production over *D. decumbens* alone. This is probably due to the more balanced diet obtained from the association which provides the required energy and protein levels.

Table 9. **Beef production on *D. decumbens* alone and in association with three tropical legumes. Grazing lasted 364 days and the stocking rate was 3.3 an/ha. Centro Experimental Pecuario, Paso del Toro, Veracruz, 1976-77 (CEPPT).**

Treatments	Liveweight gain/an		Beef production
	Total	Daily	
	kg/ha		
D. decumbens	142	390	468
D. decumbens-L. leucocephala	177*	488*	585*
D. decumbens-C. pubescens	193*	529*	636*
D. decumbens-G. wightii	196*	538*	647*

* Statistically significant ($P<0.05$).

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BEEF CATTLE PRODUCTION ON LOW-FERTILITY SOILS OF BRAZIL: STUDY OF TWO PRODUCTION SYSTEMS IN MATO GROSSO DO SUL, USING THE MODEL SIMULATION METHOD

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ABSTRACT

A very important aspect of beef production is the breeding period since it constitutes the foundation of the whole productive system. The objective of this research was to increase the productivity of the breeding herd using low inputs, which would make the opening up of new areas for this activity more attractive. A brief description is given of the area of study and a typical beef production system; emphasis is placed on evaluating the economics of adopting an improved breeding system at the farm level in the Cerrados of Mato Grosso do Sul. The internal rate of return was used as the investment criterion, taking into account the costs and benefits of the additional investment required for the improved system as compared to the traditional one. These two systems differ with regard to animal parameters, the area of cultivated pastures and the use of rural credit. In the improved system, rice is grown for three years prior to planting the grass. The herd was evolved to adapt to the carrying capacity of the pastures and took ten years to become completely stabilized. The grass used in the improved system was *Brachiaria decumbens* Stapf. The improved system was found to be profitable, in real terms, as a result of the response of the animals to the cultivated pasture. The governmental credit policy of granting resources for beef cattle production at subsidized interest rates should be maintained in order to make this activity attractive to the producers and to induce them to invest in an improved breeding system, thereby increasing their productivity and profits. At the same time, research should be intensified to find methods of establishing pastures at lower costs in order to decrease the volume of resources necessary.

In view of the long period of time required to obtain results from research on beef cattle and the high cost of conducting experiments on physical production systems, the use of simulated models has increased in an attempt to create as real a situation as possible. Within this perspective, the identification and elaboration of physical production systems for beef cattle has not been an easy task for investigators since their degree of complexity increases as research results are incorporated into the many physico-

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biological and socioeconomic variables that make up and define the habitat in which the production process is developed.

The breeding period was selected for this work since it constitutes the foundation of all production systems. The objective of this research was to increase the productivity of the breeding herd using low inputs, which would make it more attractive economically to occupy new areas, especially if the agricultural frontier is being expanded.

Although it is known that nutritional deficiencies condition the reproductive efficiency of herds, few papers have been published on this subject for the Cerrado areas. The Centro Nacional de Pesquisa de Gado de Corte and other institutions in the EMBRAPA network consider nutritional deficiencies to be one of the important limiting factors in the beef production process in the Cerrados and are therefore undertaking work in this area in an attempt to find solutions to this problem. Preliminary results indicate the advantage of the strategical use of cultivated pastures for breeding and growing females. Data obtained during the first dry season showed weight gains of more than 0.390 kg/animal/day for Nellore crossbred heifers on a cultivated pasture of *B. decumbens* and gains of 0.150 to 0.200 kg for weaned calves (females) on a pasture of *Hyparrhenia rufa* (Nees.) Stapf. in association with legumes. Nevertheless, to obtain data on reproductive efficiency, more time is required.

In this paper, a brief description is given of the production systems in use in the Brazilian Cerrados, and an attempt is made to evaluate the economics of two breeding systems with the growing of heifers for replacement in the herd.

AREA OF STUDY

Of the 8.5 million square kilometers total surface area of Brazil, nearly 21% or approximately 1.8 million square kilometers are taken up by the Cerrados. These Cerrado areas, which have the greatest portion of low-fertility soils in the nation, are characterized by a distinctive vegetative complex and edapho-climatic conditions. Although found in diverse parts of the country, the major concentration is found in the central plateau, characterizing a region known as the Brasil Central Pecuário (central Brazilian cattle-raising area). In this extensive and important region, located between the 10th and 24th parallels of the southern latitude and the 38th and 58th meridians of the western longitude (5), in the states of Goiás, Minas Gerais and Mato Grosso, more than 70% of the Cerrados are concentrated and almost 42% of the Brazilian cattle herd is found (Table 1, Fig. 1). Detailed characteristics of the climate, soil

Table 1. **Cattle population (1970) and the Cerrado areas in the Central Brazilian Plateau.**

	Beef cattle*		Cerrados**	
	Millions of heads	%	Millions of ha	%
Brazil	78.452	-	182.9	-
Minas Gerais	15.109	19.2	30.8	17.0
Mato Grosso	9.420	12.0	47.9	26.0
Goiás	7.781	9.9	55.5	30.0
Total	-	41.1	-	73.0

* Anuário estatístico do Brasil -FIBGE

** 4.

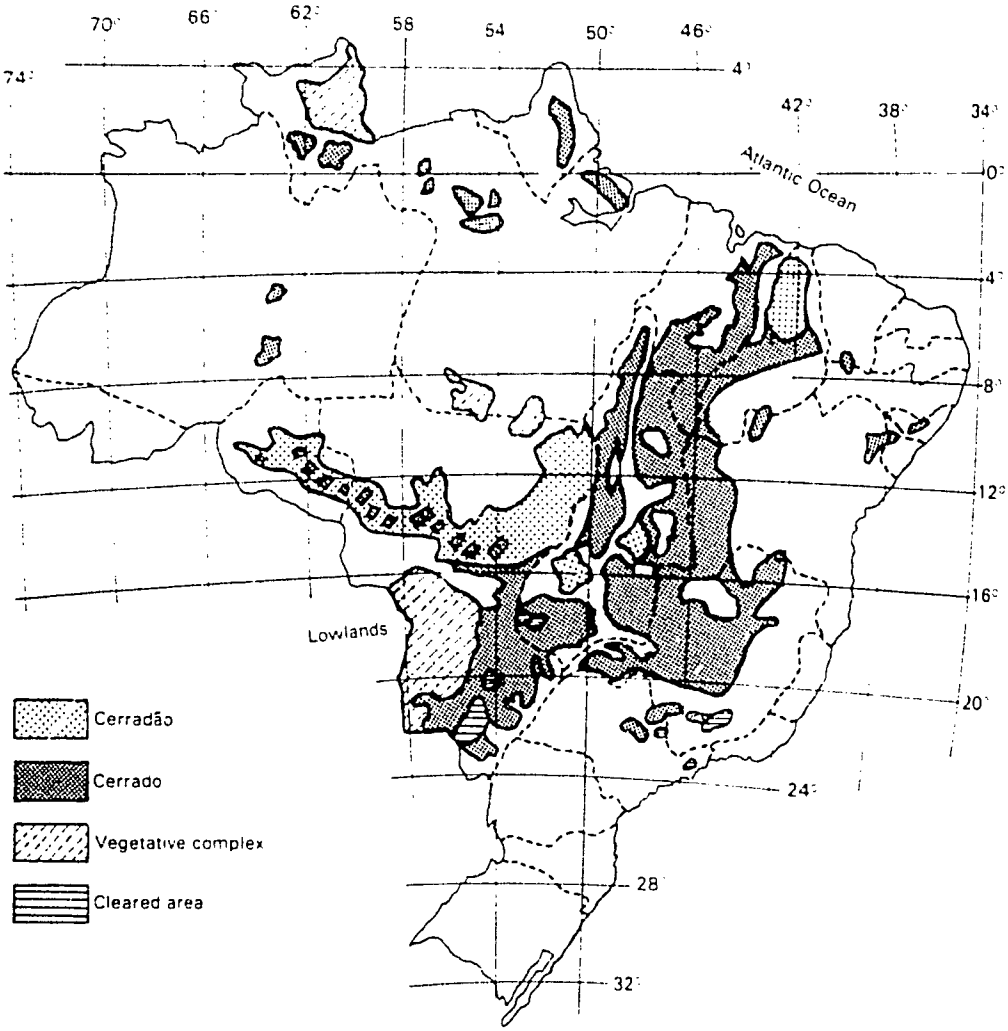

Figure 1 **Distribution of the Cerrado areas in Brazil (2).**

and vegetation of the Cerrado are described in the chapter by Kornelius *et al.*

Beef cattle raising in the Central Brazilian Cerrados, as in the rest of the country, is based on the use of rangeland and naturalized pastures. These pastures, which cover some 70% of the 84 million ha of pasture in the region are for seasonal production only and generally of low productivity, with an estimated carrying capacity of 0.4 to 0.7 head/ha for the dry and rainy seasons, respectively (1). The animals generally require three dry and three rainy seasons from weaning to reach market weight or breeding age. During the dry season when the pastures become quite deficient, it is common for animals to lose a great deal of the weight gained during the rainy season. Moreover, growth of the animals is not linear but follows a gain/loss curve according to fluctuations in the production of forage from those pastures. As a result, the weight gains, as well as the reproductive

development of the animals is quite slow, which is reflected in the late slaughtering ages and age at first calving, as well as the low calving rates, which affect herd profitability (Table 2). Among the factors related to reproduction, age at first parturition and the interval between calving are the most outstanding limiting factors.

In Mato Grosso do Sul where the extensive breeding system is predominant, the most representative activities are breeding and growing (integrated or isolated). Fattening cattle is insignificant and is done only on established pastures in the Mata or Cerradão areas, where the soils have a greater natural fertility potential. Below the 16th parallel, some 65% of the producers are dedicated to breeding, 30% to breeding and growing, and only 5% to growing and fattening (3).

There are practically no planned mating periods; the bulls are kept with the females throughout the year. Only a few farmers have adopted internal divisions (paddocks) of pastures; therefore, animal as well as pasture management can be summed up as simple changes of grass from time to time to solve water problems. Sanitary practices are deficient, vaccinations against foot-and-mouth disease and symptomatic anthrax being the most common. Other preventive health measures are limited to extreme cases. There is almost no feed supplementation during the critical period of forage production (the dry season); and as regards mineral supplementation, only common salt is more or less in common use in spite of the fact that there is a known deficiency of P as well as of some micronutrients.

Table 2. ***Production parameters in the Cerrado area.***

Calving rate (%)	40-45
Calf mortality (%)	7-8
Weaning age (months)	8-10
Age at first parturition (years)	3.5-4.5
Interval between calving (months)	25-30
Slaughtering age (years)	4.5-5.5
Slaughtering rate (%)	12
Carcass weight (kg)	192
Carcass yield (%)	43-52

The installations consist of fences for dividing property, rustic corrals, tying posts and troughs for salt. Administration of the farm and decision-making activities are performed by the owner who generally lives in the city, and his orders are carried out by a foreman who lives on the farm. Field work is done by a minimum number of laborers. The great majority of farmers do not have any cost accounting or herd control records.

It has been observed that the factors limiting to the beef production process in the Cerrados are numerous and quite complex, involving not only insufficient feed during the critical periods of forage production but also herd and farm managerial capacity.

MATERIALS AND METHODS

An analysis was made of investments on the basis of herd development in two production systems in the Cerrado region of Mato Grosso do Sul. The herd was evolved to adapt to the carrying capacity of the pastures and required ten years to become completely stabilized. The two production systems analyzed were the one in use (traditional) and an improved one. The differences between the two systems were animal parameters, the area of cultivated pasture and the external resources used by the owner; i.e., rural credit. The system in use is basically that of breeding, whereas in the improved system the farmer grows and sells the extra heifers.

A hypothetical farm of 6,589 ha was considered, of which 300 ha was *H. rufa* pasture, 4,971 ha of rangeland and 1,318 ha of reserve areas. In the improved system, the cultivated pasture area was increased to

1,038 ha (19% of the total area). In this case the farmer also had 738 ha of *B. decumbens*.

The traditional system permits a maximum of 1,731 animal units (AU) and the improved system, 2,469 AU. A stocking rate of 0.3 AU/ha was used for the rangeland, 0.8 AU/ha for *H. rufa* and 1.3 AU for *B. decumbens*. The animal units were calculated by assigning the following values for the different animal categories: breeding cows and three-year-old heifers, 1 AU; two-year-old heifers, 0.8 AU; one-year-old heifers, 0.6 AU; calves (both sexes), 0.2 AU; and bulls, 1.5 AU.

Production parameters are given in Table 3. The improved system does not reach these parameters immediately but is built up gradually until the fourth year; and by the tenth year, the herd is stabilized. The additional investment can be broken down into two types: for pastures and for machinery and construction. The investment in the former comprised the cost of establishing pastures, while the latter constituted fences, covered troughs, a tractor (Model CBT 1105), plows, harrows, a heavy cultivator, planters, plow implements, machine shed, housing for workers and a rice planter. The process of pasture establishment recommended was conventional (clearing, levelings, plowing, harrowing and planting), and the farmer in the improved system used rice as a precursor to pasture establishment. This crop is grown for three years, basically to help pay for the cost of pasture establishment, as well as to supply residual nutrients for the grass during the first year. It was assumed that there would be no problems in the rice harvest and that yields would be the same as the average obtained in the region. To maintain the production of the introduced grass, it was necessary to make three applications of fertilizer (years 7, 10 and 12), at a rate of 40 kg P_2O_5/ha.

In the traditional system the farmer's income is derived from the sale of calves, culled cows and old bulls. In the improved system, this income is increased by the salo of excess heifers when the herd is stabilized, in addition to the income obtained from the sale of the rice planted during the first three years.

First the costs and additional income and then the internal rate of return were calculated to determine whether the improved system was economically advantageous. Since this is a multiterm investment project, an attempt was made to compare the internal rate of return with the discount rate, considering this to represent the investment cost. The duration of the entire project was 16 years, which is therefore the period of cash flow development. In the sixteenth year, the increased value of the herd (by category of animal) was included in the cash flow. The residual values of equipment and buildings were not

Table 3. **Production parameters for the two systems analyzed.**

Parameters	Systems	
	Traditional	Improved
Mortality rate (%)		
Calves	8	5
Steers/heifers, 1-2 yr	6	4
Adults	5	2
Calving rate (%)	45	70
Bull/cow ratio	1:15	1:25
Cows culled (%)	12	12
Bulls culled (%)	20	20

taken into account. All values were calculated in cruzeiros as of August 1977.

RESULTS AND DISCUSSION

At the end of the first year when the herd management in the two systems became different, the number of cows in both was 1,147. The traditional system had 1,526 AU (1,778 heads) the first year and 1,624 AU (1,909 heads) the tenth year; whereas the improved system which had the same initial values reached 2,239 AU (2,599 heads) in the tenth year. This is equivalent to an increase of 47% over the initial number of animal units and 48% over the number of cows in the first year, representing an addition of 522 cows to the herd. The evolution and composition of the herd are shown in Figure 2 and Table 4, respectively. There is a gap between the two curves of herd evolution, corresponding to the fourth to seventh years, when there is full utilization of the improved pasture (Fig. 2). Beginning with the seventh year, excess heifers were sold since the pasture had reached its full carrying capacity.

Production in terms of kg of liveweight/ha was the most significant variable in terms of differences between the two systems studied. In the tenth year (period in which the herd became stabilized), the traditional system had practically the same kg liveweight value per ha as at the beginning, whereas the improved system showed an increase of 122% over the initial value. This is naturally reflected in the additional income of this production system. The evolution of this physical production is represented in Figure 3. It can be seen that in comparison to the traditional system, the increase in beef production in the improved system was not too accentuated until the seventh year. This can be explained by the fact that the improved system retained the females until this period. Between the seventh and eighth years, the excess heifers were culled and sales reached their highest volume; the herd was stabilized from the ninth year on.

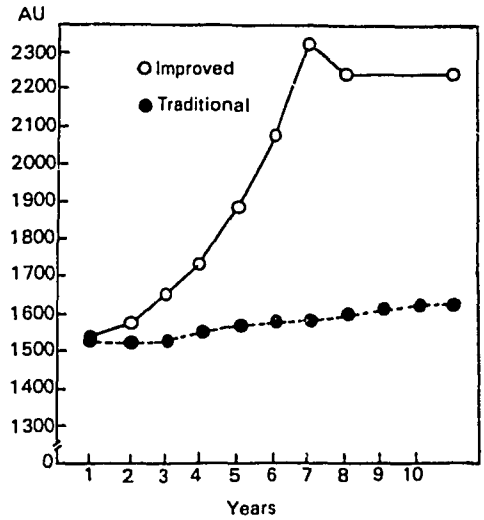

Figure 2. Evolution of the herd in animal units.

Table 4. **Herd composition.**

Categories	Initial no.	Final no. Traditional	Final no. Improved
Breeding cows	1147	1161	1699
Heifers, 3 yr old	151	210	269
Heifers, 2 yr old	157	222	277
Heifers, 1 yr old	248	239	286
Calves (both sexes)	-	-	-
Bulls	76	77	68
Total no. of heads	1178	1909	2599
Total no. of AU	1526	1624	2239

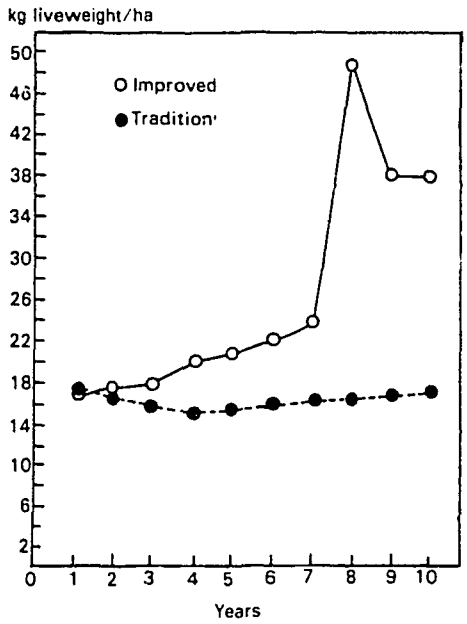

Figure 3. Physical production in kg liveweight/ha.

Table 5 shows the costs and additional income from the improved system. The variable cost is that which has the greatest effect except for investment costs in the first four years. Of the investment costs, 54% in the first year (Cr$604,160), 86% in the second year (Cr$671,430), 79% in the third year (Cr$229,500) and 100% in the fourth year (Cr$133,500) represent expenditures on pasture establishment (clearing, leveling, plowing, harrowing and planting), and construction of fences and salt troughs. The rest was spent on machinery and other construction. The investment made from the fourth year on refers to the acquisition of bulls. Additional costs were higher than income received until the fourth year because of the initial investment. From the fourth year on, additional costs were stabilized.

The internal rate of return on the investment in the improved system was 15%. If the effective discount rate of the economy is considered to be between 7 and 10% yearly, analysis of the investment shows that the return from the additional investment is sufficient to cover additional costs incurred in adopting the recommended technology. In other words, the farmers would obtain profitable gains in their cattle business by adopting the recommended technology (in this case the use of cultivated pastures) within the time period studied. When comparing the internal rate of return with subsidized interest rates of 15% yearly, which is a part of the government support program for beef cattle production, it is evident that those who have access to this type of loan would have the advantage of allocating resources to improve their production process. This is due to the fact that the subsidized interest rates are nominal values; and in an economy with the present inflation rates as those in Brazil, it would at least be a guarantee against the risks of adopting the proposed technology.

CONCLUSIONS

This option offers an opportunity for increasing the Brazilian cattle herd and for utilizing the low-fertility soils in the marginal areas located in the center of the country.

In accordance with the results of this research, it is concluded that farmers could successfully adopt the recommended technology— in this case cultivated pastures —to improve the performance of the breeding herd. By doing so, they would assure the necessary profits to cover the additional costs incurred, principally those associated with the establishment of cultivated pastures.

An immediate implication for research is that investigation should be intensified to develop methods of pasture establishment at lower costs in order to reduce the volume of investment required for this purpose. On the other hand, special attention should be given to research on the management of rangelands since these constitute the majority of pastures presently being utilized for breeding operations.

Table 5. Costs and additional income for the improved system in cruzeiros; the Cerrado region in Mato Grosso do Sul, 1977.

Items	Years											
	1	2	3	4	5	6	7	8	9	10	...	16
1. Variable costs	417,318	874,240	881,100	56,361	65,767	93,392	101,149	122,109	111,670	111,432	...	111,433
Common salt, mineral salt, vaccines & other medication	29,775	35,317	41,352	47,511	57,024	62,697	69,320	67,296	67,468	67,231	...	67,231
Labor	3,972	3,972	3,972	3,972	3,972	24,828	24,828	24,828	24,828	24,828	...	24,828
Rural tax (2.5% on income)	13,455	30,351	31,176	4,878	4,711	5,597	7,001	29,985	19,374	19,374	...	19,374
Cost of growing rice	370,116	804,600	804,600	-	-	-	-	-	-	-	...	-
Fertilizers	-	-	-	-	-	-	91,660	91,660	91,660	91,660	...	91,660
2. Fixed costs												
Salary of administrator	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	...	18,000
3. Investment costs	1,112,960	774,330	289,500	133,500	48,000	92,000	56,000	60,000	60,000	60,000	...	60,000
4. Total costs (1 + 2 + 3)	1,548,278	1,666,570	1,188,600	207,861	131,767	203,392	266,809	291,769	281,330	281,093	...	281,093
5. Income from cattle	0	44,030	77,030	195,120	190,840	223,870	280,060	1,199,400	774,980	774,980	...	1,973,197
6. Income from rice	538,200	1,170,000	1,170,000	-	-	-	-	-	-	-	...	-
7. Total income (5 + 6)	538,200	1,214,030	1,247,030	195,120	190,840	223,870	280,060	1,199,400	774,980	774,980	...	1,973,197
8. Additional liquid income	-1,010,078	-452,540	58,430	-12,741	59,073	20,478	13,251	907,631	493,650	493,887	..	1,692,104

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PASTURE MANAGEMENT AND PRODUCTIVITY IN THE LLANOS ORIENTALES OF COLOMBIA*

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Jorge A. Leal**

ABSTRACT

A review of the information available from Carimagua, Colombia, indicates that the cattle production potential of the Colombian Llanos Orientales is presently limited by the low nutritive value of the native species, particularly during the dry season. Higher per ha production can be obtained with the introduction of improved species of grasses, but per animal production remains low. Also in this case, insufficient nutrition seems to be the limiting factor for higher animal production. A short grazing trial with a legume-grass association demonstrated its much higher production potential both per animal and per unit area. The following values characterize the pastures studied: unburned savanna, 28 kg of liveweight gain/an/yr; savanna burned all at once each year, at the end of the rainy season, 75 kg; savanna burned in a sequential way throughout the year, 95 kg. Productivity per ha varies from 6 kg/ha/yr in the unburned savanna to 19 kg in the savanna sequentially burned. Per ha weight gain increases to 58 kg with *Melinis minutiflora* and reaches 147 kg/ha/yr on *Brachiaria decumbens*. Employing high stocking rates during the wet season and low stocking rates in the dry season (3.06 and 0.7 an/ha, respectively), *B. decumbens* can produce as much as 200 kg/ha/yr. Two other grasses studied, *Hyparrhenia rufa* and *Paspalum plicatulum*, had lower productivity than *M. minutiflora*. During the dry season animals gained as much as 500 kg/day on *Stylosanthes guianensis*-grass associations while all of the grasses when planted alone suffered weight losses ranging from 150 to 350 g/an/day. During the rainy season, while plant diseases and insects were not problems, liveweight gains from the legume ranged between 850 and 950 g/an/day. Urea + cassava or urea + molasses supplementation during the dry season to animals grazing the native savanna or *M. minutiflora* pastures had a positive effect, but because of the strong compensatory weight gain produced during the following rainy season the net increment of weight was insufficient to cover the cost of supplementation. It is concluded that to obtain an important improvement in cattle production in the Llanos Orientales it will be necessary to find a tropical legume which, while adapted to the environment, should be productive and persistent in competition with grasses.

Little is known about the tropical savannas of the Llanos Orientales of Colombia, but its potential value as a cattle producing area is intuitively foreseen as very large. In a previous review of the literature (12), the almost total lack of information on the use and productivity of the native savannas was clearly established. At that time, it was

* The information reviewed in this paper is based on research done at the Centro Nacional de Investigaciones Agropecuarias (CNIA), Carimagua, Meta, Colombia, in a cooperative program between the Instituto Colombiano Agropecuario (ICA) and the Centro Internacional de Agricultura Tropical (CIAT).

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suggested that because of its low production capacity, "in order to obtain significant progress in production it is necessary to change the grass canopy from its native species to others of high productivity and better nutritional value. The species must be capable of survival in the prevailing ecological conditions. For the Latosols of the American tropics it means, first, finding and employing species which are tolerant to high soil acidity and to the low level of available P in the soil, and second, to find and utilize species capable of maintaining its feeding capacity during the dry period".

Furthermore, it was established that it would be rather difficult to extrapolate results obtained in the native pastures of the tropics and subtropics of Africa or Australia to tropical America, because the soil, the climate and the systems of production are different. Among the important differences are the botanical composition of these areas, and the large variations in their consumption by cattle. In many areas of Africa the predominant species belong to the genera *Heteropogon, Hyparrhenia* and *Cynodon* and in Australia to the genera *Heteropogon, Themeda* and *Bothriochloa,* all of which are generally well-consumed by cattle. In the great majority of the American savannas the predominant genera are *Trachypogon, Andropogon, Leptochoryphium, Axonopus* and *Paspalum,* which are only consumed in early stages of growth. *Paspalum* is perhaps the exception. The predominance of species of *Paspalum,* especially *Paspalum plicatulum* Michx., in some of the Venezuelan savannas of intermediate fertility and humidity make these areas more productive and better accepted by cattle (7, 8, 9).

Spain (14) has described the climate and the soils of the intermediate and high plains of the Colombian Llanos. Following that description, CIAT's research program in pasture utilization and management has directed its attention to: (a) characterizing and quantifying the production capacity of the savannas; (b) measuring the effect on animal production of some of the traditional practices such as burning and some of the non-traditional practices such as N-supplementation during the dry period; (c) determining the improvement in animal production which can be obtained by the introduction of easily-adapted but low-producing grass species such as *Melinis minutiflora* Beauv. and better producers such as *Brachiaria decumbens* Stapf.; (d) identifying the most effective management practices which would improve the productivity of these grass species; and (e) estimating the effects on animal production of introducing tropical legumes.

PRODUCTIVITY OF THE SAVANNA

Effect of fire and of the burning systems

It was determined that as the species reached 35 cm or more of height, steer growth was very low as a result of the rapid loss of nutritive value of the native species with age (Table 1). Burning at the beginning of the dry season improved animal production by approximately 350% (Table 2). Animal production on the unburned savannas is so low that it would be impossible to develop a viable livestock industry without the use of fire. This, of course, is very well known by ranchers of this area who regularly burn the savannas.

Cattle can be observed entering the newly burned savannas soon after fire extinguishes and begin avidly consuming the ashes before regrowth starts. Cattle feces consisting totally of ashes can frequently be found as result of the first days of consumption. Feces will rapidly lose ashes so that 10 or 15 days after the burning they have the normal ash content of approximately 15% (Table 3).

With an unrestricted amount of recently burned pasture available with sufficient protein for maximum consumption (Table 1) (11), animals should attain higher gains or at

Table 1. **Protein content of the native savanna of Carimagua, Colombia.(Adapted from 12).**

Days of growth	Height	*Trachypogon vestitus*	Whole savanna
	cm	%	
28	10	10.5	10.0
49	20	8.0	7.5
79	35	6.4	5.8
Dry season	50-80	-	2.7

least they should be able to keep the pasture grazed down and of high nutritive value. Neither of the two things actually occur; the pasture grows to an excessive height while weight gains decrease, making burning necessary the following year to obtain a new regrowth. Low plant density of the savanna may be the cause of insufficient consumption by cattle and dry matter (DM) accumulation (Table 6).

After a recent burn animals pull the young shoots from the base. A hand-plucked sample, simulating grazing, from a savanna 20 days after burning had 10.9% protein, 51% *in vitro* DM digestibility and 0.18% of P, and 126 kg DM/ha. With 5 ha of pasture available it should have been possible for a steer to gain 250 g of weight per day. This however was not the case, the explanation possibly being that to consume enough energy and protein, animals would have to take at least 62,000 bites/day, a number which is above the level of fatigue (14). Insufficient consumption allows an excessive development of the pasture and the consequent decrease in its nutritive value.

The excessive growth of the pasture could possibly also be controlled by burning of the savanna in a sequence to provide periodically a recently burned area to the animals. A sequential burning system, which divided the area into eight parts, was compared with once-a-year burning of the entire area, at the end of the rainy season.

Table 4 shows the five-year average liveweight gains under the two burning systems. The positive effect of sequential burning was influenced by stocking rate and was also different in the two seasons of the year. As expected, weight gains were favored by the burning of the total area at the

Table 2. **Liveweight gain of steers grazing the native savanna of Carimagua, Colombia.(Adapted from 1 and 2).**

Stocking rate	Annual gain: Without burning (1971-72)		Annual gain: With burning (1972-73)	
AU/ha	kg/an	kg/ha	kg/an	kg/ha
0.20	28	6	92	18
0.35	38	13	94	33
0.50	2	1	74	37

Table 3. **Chemical composition of feces voided by cattle grazing a burnt savanna. Carimagua, Colombia.**

Days after burning	Protein	P	Ash
	%		
3-4	0.3	1.8	95.5
10-15	7.0	0.25	13.3
20-30	7.2	0.26	15.5

end of the rainy season because, in this case, the area of young forage available to the animals was twice as much as in the sequential burning. During the rainy season, on the other hand, sequential burning was superior to once-a-year burning. The advantage decreased from 52% at the lower stocking rate to 16% at the highest stocking rate. In summary, sequential burning had a beneficial effect which was measured as 27%, or 20 kg of additional weight gain per animal, when the stocking rate was 0.2 an/ha (5 ha/an).

Liveweight gain/ha was 15, 23 and 15 kg at stocking rates of 0.2, 0.35 and 0.5 an/ha, respectively, in the once-a-year burning and 19, 22 and 18 kg for the same stocking rates in the sequential burning.

Grazing management

The excessive growth of the pasture could also be controlled by establishing a rotational grazing system allowing the animals to consume the forage when young and palatable. In a one-year experiment, continuous grazing was compared with a four-paddock rotational grazing system in which the animals grazed for 28 consecutive days in each of the paddocks. The pasture was burned four months before the start of the experiment. A summary of the results is presented in Table 5. Rotational grazing had no beneficial effect on liveweight gain at any of the three stocking rates employed. The results are not surprising and confirm the inability of the animals to maintain a high enough level of consumption in a situation of very low forage nutritive value.

Table 4. ***Liveweight changes of steers grazing the native savanna of Carimagua under two systems of burning. Average of five years. (Adapted from 2-6).***

Stocking rate	Liveweight changes			Advantage of sequential burning		
	Dry season	Rainy season	Annual	Dry season	Rainy season	Annual
AU/ha	kg/an			%		
Total burning						
0.20	15	60	75	-	-	-
0.35	- 7	73	67	-	-	-
0.50	-24	55	31	-	-	-
Sequential burning						
0.20	4	91	95	-275	52	27
0.35	-25	87	62	-257	19	- 7
0.50	-29	64	35	- 21	16	13

Table 5. **Liveweight changes of steers under continuous and rotational grazing on the native savanna during 131 days of the dry season and 234 days of the rainy season, in Carimagua, Colombia. (Adapted from 1).**

	Liveweight change/period					
	Continuous grazing			Rotational grazing		
Stocking rate	Dry season	Rainy season	Total	Dry season	Rainy season	Total
AU /ha	kg/an					
0.20	-21	49	28	-22	33	11
0.35	-25	63	38	-35	34	- 1
0.50	-33	35	2	-32	16	-16

Forage availability and botanical composition

It is important to point out the low density of plants observed in the savannas. Table 6 shows that the number of plants in the better-known genera decreased significantly over the years. Included under the heading of "other species" are representatives of the genera *Ciperus, Rhyncospora, Aristida, Eragrostis, Digitaria, Desmodium, Phaseolus* and some unidentified herbs. The decrease in plant density is associated with the reduction in DM available per ha. Forage availability decreased 39, 47 and 39% between 1971 and 1976, for the three stocking rates of the annually burned pastures, and may be associated with frequent burning. In farm practice, the savanna is not burned every year, but every two or three years. Stocking rate is also lower in the area. There are only 2 million head of cattle in 20 million ha of savanna, that is 10 ha per head. Table 7 shows the availability of DM/ha was not affected by stocking rate, although weight gain decreased significantly as stocking rate increased (Table 4). The very intensive selection by the grazing animal for the most nutritious portion of the plant is probably responsible for the lack of correlation between total forage availability and animal weight gain.

Table 6. **Number of plants per meter of linear transect in the native savanna of Carimagua, Colombia.**

Stocking rate	Year	*T. vestitus*	*L. lanatus*	*Paspalum Andropogon Axonopus Panicum*	Other	Total
AU/ha						
	1971	3.25	1.85	1.86	0.91	7.87
0.20	1976	1.60	0.40	0.90	0.95	3.90
	Difference	-51%	-78%	-52%	4%	-50%
	1971	2.45	1.45	2.40	1.06	7.36
0.35	1976	1.10	0.35	0.73	1.83	4.01
	Difference	-55%	-76%	-70%	73%	-46%
	1971	2.90	1.75	1.81	0.81	7.27
0.50	1976	0.90	0.35	1.07	2.02	4.34
	Difference	-69%	-80%	-41%	149%	-40%

Table 7. **Available dry matter during the rainy season on the native savanna of Carimagua, Colombia. Average of five years.**

Stocking rate	Burning system	
	Total	Sequential
AU/ha	t/ha	
0.20	2.70 ± 0.65	2.54 ± 0.85
0.35	3.15 ± 0.59	2.34 ± 1.03
0.50	2.58 ± 0.53	2.13 ± 0.88

Nitrogen supplementation

During the dry season, the protein content of the grass falls below 3%; at this protein level the animal cannot obtain a diet of sufficient nutritive value for the maintenance of weight. The volume of DM and energy available is however considerable and could be better utilized supplementing the animal's diet with a small quantity of N to stimulate bacterial activity in the rumen. This practice is extensively used in some areas of the subtropics.

Zemmelink (3) studied the nutritional value of the savanna during the dry period. DM digestibility of the forage increased from 32.2% to 39.7% when supplemented with urea + molasses and DM intake increased by 34%, resulting in an increased intake of digestible DM from 15 g/$W^{.75}$, in the case of unsupplemented grass to 27.4 g when supplemented. With the consumption of 15 g digestible DM only 60% of the maintenance requirement of the animal is met.

Dry season supplementation of animals weighing 150-250 kg was studied offering 80 g of urea and 400 g of cassava meal per head, during 118 days of the dry season. Results summarized in Table 8 indicate that although an improvement in weight gain is obtained when urea + cassava meal are provided during the dry season, compensatory weight gain during the rainy season eliminates a large part of the difference; at the end of the year, the advantage obtained with supplementation is only 14%. This advantage is not high enough to pay for the cost of supplementation. It was estimated that, in the area where the experiment was conducted, 10 kg of weight difference in favor of supplementation with urea + cassava is needed to pay the cost of the supplement and 20 kg if the supplement is urea + molasses. Molasses is produced in distant areas while cassava is produced locally.

When considering the practical implications of supplementation it is important to remenber that animals will make a strong compensatory weight gain during the following rainy season. From experience in Carimagua, compensatory gain makes up for approximately 75% of the weight loss (6), so the cost of supplementation should only be

Table 8. **Liveweight changes of steers supplemented and unsupplemented with urea + cassava meal during the dry season on the native savanna of Carimagua, Colombia. Average of two years.**

Season	Treatment		Advantage of supplementation
	Without urea + cassava	With urea + cassava*	
	kg/an		%
Dry	-11	4	136
Rainy	48	38	-21
Annual	37	42	14

* 80 g urea + 400 g ground dried cassava/an/day were provided for an average of 121 days during the dry season.

matched against 25% of the dry period's advantage.

Mineral supplementation

The level of P in native species is so low that deficiencies are to be expected in cattle. Commercial producers avoid handling their animals for fear of bone fractures. However, "pica" is infrequent in the area and there are no known cases of boutulosis in cattle which can be associated with the consumption of bones.

Figure 1 summarizes the results of a study to determine the mineral status for P and Ca of the pastures in Carimagua. Sampling was done by plucking forage, simulating the grazing animal (10).

P content was about 0.10% throughout the year with small increments associated with pasture regrowth after burning. Ca content, on the other hand, was not affected by burning and decreased only slightly during the dry season. Both P and Ca were insufficient for adequate cattle growth. Other minerals such as Mg, K, Na, Fe, Mn, Zn, Cu, Mo and Co did not appear as deficient for cattle growth (10).

Liveweight and reproduction increased with mineral supplementation in a study comparing herds receiving a complete mineral supplement and unsupplemented herds (Table 9). This result applies to growing animals of 3, 9 and 19 months as well as to cow weight and all measures of conception. Supplementation also notably decreased the high level of abortions (6).

All information collected clearly indicated the need for supplementation of cattle with, at least, P and Ca. The economic analysis of

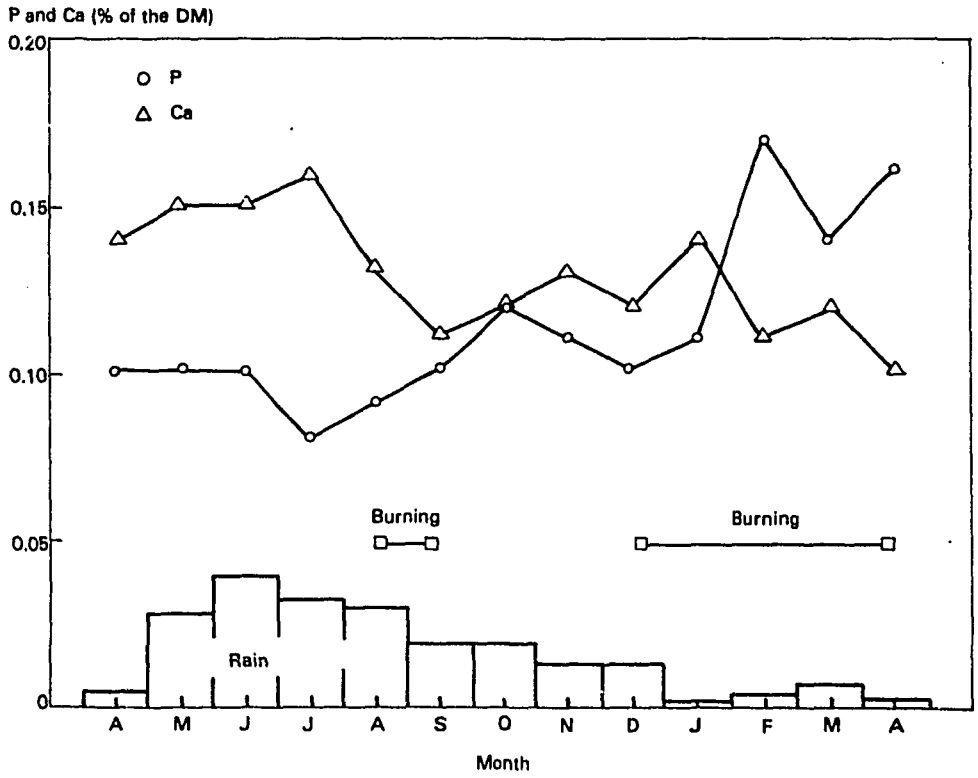

Figure 1. P and Ca content of the native savanna of Carimagua, Colombia.(Adapted from 10).

this information indicates the practice to be highly beneficial economically for the farmer (6).

INTRODUCTION OF NEW FORAGE SPECIES

The impossibility of improving the low productivity of the native savanna through management or supplementation has directed attention to the introduction of new germplasm. The sequence followed was to study first those species known to be adapted to the ecological conditions of the area and those for which seed was available. In the following sections the information available for *M. minutiflora, Hyparrhenia rufa* (Nees) Stapf., *P. plicatulum, B. decumbens* and in a more limited way for *Indigofera hirsuta* L. and *Stylosanthes guianensis* (Aubl.) Sw. will be reviewed.

Melinis minutiflora

This one of the few grasses known in the area, but even then the commercial pastures planted were small and scattered. Producers use it preferentially for fattening, since fattening is not possible on the native savanna alone.

An area of 178 ha was seeded with *M. minutiflora* to study the effect of P and K fertilization on liveweight gain. After two years, the same area was used for a study on the grazing management of the pasture, including N supplementation.

Effect of fertilizer application on animal productivity of *M. minutiflora*

M. minutiflora has invaded large areas of the Campo Cerrado of Brazil and, although this species is not native to the area, its high degree of adaptation has allowed it to become naturalized. This is, however, not the case in the Colombian Llanos Orientales, but the fact that the grass does not respond after establishment to P and K indicates its high degree of adaptation to low-fertility soils (Table 10). The grass has not spread, probably because it was only recently that movement inwards in the plains has occurred and also because there have not been large areas established allowing natural spreading.

A frequent observation in this area is that *M. minutiflora* does not seed during the year of establishment and animals gain weight

Table 9. **Comparison between cattle herds supplemented with salt and salt + minerals at Carimagua, Colombia. (Adapted from 6).**

Parameter	Salt	Salt + minerals	Advantage of minerals
	kg		%
Liveweight of heifers at			
3 months of age	67	78	16
9 months of age	117	147	26
18 months of age	150	175	17
Liveweight of cows at			
service	292	316	8
calving.	335	369	10
weaning	272	305	12
Cow's fertility	%		
Conception (by palpation)	69.5	76.8	11
Abortions	9.3	0.4	96
Calvings	59.4	76.4	29

Table 10. **Liveweight gain of steers on *M. minutiflora*, fertilized and unfertilized at the time of establishment in Carimagua, Colombia. (Adapted from 1 and 2).**

Stocking rate	0	P	P + K
AU/ha		kg/ha/yr	
0.44	49	51	42
0.88*	83	103	89
Mean	66	77	66

* Stocking rate during the dry season was 0.44 AU/ha.

during the first dry season. From the second year onwards the animals lose weight during the dry season. Loss of weight is associated with flowering which occurs at the beginning of the dry season, causing a marked decrease in digestibility and protein content and a marked decrease in animals' consumption of the grass. Zemmelink (2) found the digestibility during the dry season to be 40.7% and an increase of 8% when 20% of the grass was replaced by the tropical legume *S. guianensis*. Even more important was the improvement in consumption from 15.6 to 25.6 g of digestible DM/$W^{.75}$. Consumption of 25 g is approximately the amount required for weight maintenance of these animals. Increased consumption was associated both with the intake of the legume per se and by the increment in protein provided by the legume which stimulated a higher relative consumption of the grass. The weight loss of 300 to 500 g/day/an at Carimagua registered during the dry season with this species can be explained totally by the low level of ingestion of digestible DM.

Effect of rest and of supplementation with urea + molasses during the dry season

Weight losses during the dry season when grazing *M. minutiflora* present a very serious problem in the management of cattle, since animals lose up to 70 kg of weight during the season. There are two alternative solutions: resting the pasture and utilizing it only in the rainy season, or supplementing the grazing animals with a source of N.

Rainy season grazing was not different to year-round grazing in a four-year trial at Carimagua (Table 11). In the year-round grazing treatments, animals lost an average of 18 kg of weight during the dry season, but losses were totally recovered in the next rainy season. A heavier stocking rate, up to 1.3 an/ha, was possible when the pasture was rested during the dry season. This was not possible with the pastures grazed year-round. When grazed all year, pastures produced weight gains of 78 and 98 kg/an/yr at stocking rates of 0.88 and 0.44 an/ha, respectively. These weight gains are similar to the best obtained on the native savanna (Table 4).

Urea + molasses supplemented during the dry season had the effect of preventing

Table 11. **Liveweight changes of steers grazing *M. minutiflora* all year or only during the rainy season at Carimagua, Colombia. Average of four years.**

Grazing system	Stocking rate	Liveweight change/season		
		Dry	Rainy	Year
	AU/ha	kg/ha		
All year	0.44	-18	61	43
	0.88*	-18	87	69
Rainy season only	0.44	-	50	50
	0.88	-	67	67
	1.30	-	69	69

* Stocking rate during the dry season was 0.44 AU/ha.

weight losses. However, also in this case the favorable effect was partially compensated during the rainy season, causing at the end of the year a difference of 15 kg/ha/yr in the low stocking rate and 12 kg in the high stocking rate. These relationships are shown in Figure 2 (16). In economical terms, in Carimagua the additional weight gain is not sufficient to pay for the cost of the supplement.

Hyparrhenia rufa and *Paspalum plicatulum*

H. rufa is possibly the most extensively used grass in Colombia, yet it has not spread to the Llanos Orientales. *P. plicatulum*, on the other hand, is a native of the tropical savannas and well-known in Venezuela. Possibly because it is not as frequent a component of high plains it is not known in Colombia.

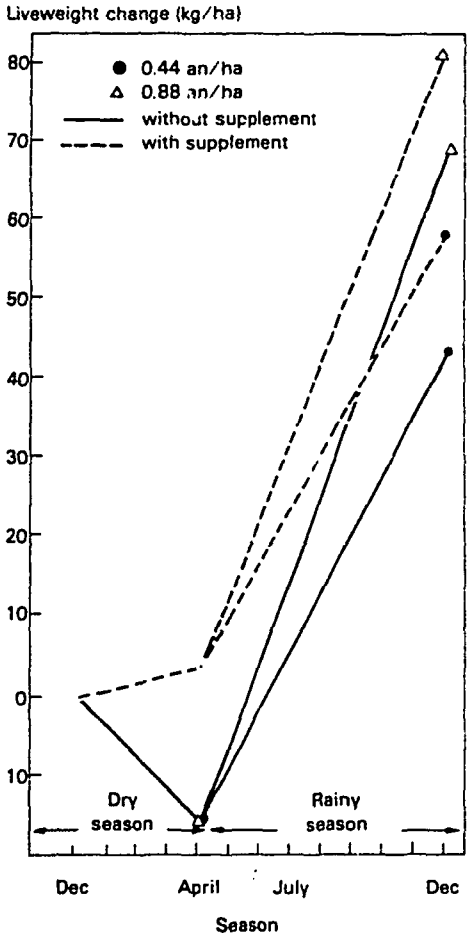

Figure 2. **Liveweight changes of steers on *M. minutiflora* unsupplemented and supplemented with urea + molasses, during the dry season at Carimagua, Colombia. Average of four years (6).**

Table 12 shows that animals lost weight during the dry season both in *H. rufa* and *P. plicatulum*. Losses were high, reaching 43 and 56 kg/an, respectively. During the rainy season all groups gained weight, but gains in *H. rufa* and *P. plicatulum* were inferior to those in *M. minutiflora*.

During the first year, the balance for the two species was rather poor. In the two subsequent years production increased without reaching the level of *M. minutiflora*. Grazing of *H. rufa* was suspended early in the third year because the animals continued to lose weight and the lack of persistence of the species was evident. Spain (6) found *H. rufa* to be very sensitive to the presence of Al in the soil solution; its roots do not develop, and growth is inferior to other tropical species. This can explain the rapid disappearance of the species in the pastures.

Although *P. plicatulum* is the only native species among those studied it is at the same time the one suffering continuously problems of diseases and pests. During the three years of grazing it suffered from infestations of *Helminthosporium*, a stem-borer (Lepidoptera, Colephoridae) and a false army worm (Lepidoptera, Noctuidae-*Mocis* spp.), which forced the removal of the animals for variable periods of time to give the pasture an opportunity to recover.

In some areas of Venezuela, the native legume *I. hirsuta* has prospered and contributed significantly to livestock production when the native, degraded pastures of *P. plicatulum* received an application of P (7, 8). In Carimagua, this species developed rapidly, achieving good establishment with *P. plicatulum*, with the application of 75 kg/ha

Table 12. **Liveweight production of several forage species at Carimagua, Colombia.**

Species	Stocking rate	1974 - 1975 Dry season	1974 - 1975 Rainy season	1974 - 1975 Year	1976 Rainy season	1977 Rainy season
	AU/ha	kg/ha				
M. minutiflora	0.7		50	50	40	66
	1.0		51	51	47	74
	1.4		56	56	36	52
H. rufa	0.5	-22				
	0.7		30	8	24	
	1.0		37	15	29	
	1.4		27	5	34	
P. plicatulum	0.5	-28				
	0.7		46	18	46	34
	1.0		34	6	35	19
	1.4		55	27	73	17
P. plicatulum + *I. hirsuta*	0.9		-37	-37		
	1.3		22	22		
	1.7		-60	-60		

of P_2O_5 at seeding, but the animals refused to consume the legume. Steers were finally removed during the second rainy season after losing much weight; three animals died, apparently of under-nutrition. These results in Carimagua are taken to be conclusive and agree with communications from other areas of Venezuela. The superior performance at medium stocking rates was due apparently to a high population of *P. plicatulum* (Table 12).

Brachiaria decumbens

This tropical grass deserves special mention because of its good adaptation to low pH and to high concentrations of Al in soils. This is the first introduced species which is being planted in large scale in the Colombian Llanos, as has happened in many areas of Brazil.

Tables 13 and 14 show the production with this species in Carimagua. Liveweight gains per animal are not superior to those obtained with *M. minutiflora,* but its high stocking rate allows more than double production per ha. It would appear that 1.7 an/ha throughout the year is not high enough to reach the maximum productivity per ha. Yet, at this stocking rate, per animal production is only 86 kg/yr, too low for effective fattening, since steers would reach 450 kg between four and five years old. This performance is very similar to the properly burned savanna. As shown in Table 14, employing higher stocking rates during the rainy season it is possible to produce 200 kg/ha, but with a large sacrifice in per-animal productivity.

So far, none of the tropical grasses studied in Carimagua have given per-animal weight gains high enough for optimal fattening of steers. For effective fattening, one should think of 150 kg liveweight gain per year, to send steers to market at three years of age weighing 450 kg.

Many reports have indicated toxicity problems with *B. decumbens,* primarily with young stock grazing fresh pastures in an

Table 13. **Liveweight changes of steers grazing for the third year on *B. decumbens* under fixed stocking at Carimagua, Colombia (6).**

Stocking rate	Liveweight change/season					
	Dry	Rainy	Year	Dry	Rainy	Year
AU/ha	kg/an			kg/ha		
0.9	- 6	124	118	- 5	11	106
1.3	-21	118	97	-27	153	126
1.7	-19	105	86	-32	179	147

active stage of growth. In Carimagua, only one event of this nature was observed with steers weighing between 150 and 200 kg. The animals were put in the pasture early in the rainy season in its first year of grazing. Several of the younger animals died even though they were moved away from the pasture as soon as the first symptoms were observed. Symptoms of toxicity were swelling at the base of the horns, in the ears and in the dewlap, followed by photosensitization of the skin. Although no special precautions have been taken since, there has been no symptoms of toxicity. Farmers in the area are aware of the problem which is overcomed by grazing at very high stocking rates early in the grazing season to remove rapidly the first growth.

Legume-grass associations

Primarily because the grasses studied so far do not provide the nutritional level required for effective growth of cattle throughout the year, it has become necessary to find tropical legumes which complement the feeding value of the grass, especially during the dry season. When interpreting the data on animal growth on grasses, one must remember that the total gain during the rainy season includes a compensatory gain effect from the previous dry season. In the case of an animal gaining 118 kg during the rainy season (Table 13), its gain includes at least 10 kg of compensatory weight (50% of the previous loss), thus the real weight gain of the rainy season is less than 500 g/an/day.

Table 15 shows one example of a legume-grass association in which the animals gained between 400 and 500 g/day during the dry season and maintained very high gains during the months in which the mixture persisted. When the legume decreased appreciably, because of diseases and pests, weight gains decreased to the

Table 14. **Liveweight changes of steers grazing for the second year on *B. decumbens* under low stocking during the dry season and variable stocking during the rainy season, at Carimagua, Colombia (6).**

Stocking rate		Liveweight change/season				
Dry season	Rainy season	Dry	Rainy	Dry	Rainy	Year
AU/ha		kg/an		kg/ha		
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

Table 15. **Liveweight gain of steers grazing associations of grasses and *S. guianensis*, at Carimagua, Colombia during 1973-74 (3).**

Stocking rate	Liveweight gain			
	XII/73-IV/74	IV-VI/74	VI-VIII/74	VIII-X/74
AU/ha	g/an/day			
S. guianensis + *M. minutiflora*				
0.50	532	-	-	-
0.90	-	864	976	345
1.30	-	886	885	397
1.70	-	681	940	310
S. guianensis + spontaneous grasses				
0.50	446	-	-	-
0.90	-	1140	976	397
1.30	-	1182	952	379
1.70	-	1209	855	310

level of that of a pure grass pasture. The legume was established in this case with an application of 75 kg/ha of P_2O_5 and did not receive additional fertilization.

The introduction of legumes seems to be the only viable solution to obtain the improvement needed for beef production in a practical and economical sense.

CONCLUSION

In the Colombian Llanos Orientales the native savanna is a natural resource which is only now beginning to be known. This knowledge helps explain the lack of development of the area which should have taken place faster in relation to its broad extension and its large forage availability. Even if a very low stocking rate is used, the low nutritive value of the species limits animal production. A sequence of change in the techniques of pasture management, including the introduction of other species (Table 16), indicates that with the best burning management, liveweight gains per year do not surpass 100 kg per animal and that in the best of cases, the maximum obtainable weight gain is about 130 kg/an/yr on *M. minutiflora*, when grazed under very low stocking rates and with animals receiving N supplementation during the dry season. Production per ha in this case is too low to justify the high investment in the new pasture, and the additional advantage of supplementation does not cover the cost of the supplement. With *B. decumbens*, liveweight gain per ha was tripled, compared to *M. minutiflora*, and multiplied 10 times in relation to the native savanna, but even then, there is no improvement obtained in terms of liveweight gain per animal.

It would seem unlikely, at this point, that a grass species could be found that is adapted to the conditions of the area, particularly the very low soil fertility, which while allowing a high enough per animal weight gain would maintain a stocking rate sufficiently high to reach the necessary per ha weight gain.

As indicated before (12), the challenge continues to be finding a tropical legume capable of producing in this environment, competing with the grasses and providing a higher nutritive value to the pasture.

Table 16. **Liveweight gain of steers under increasing technologies in the Llanos Orientales of Colombia.**

	Maximum/animal*		Maximum/ha**	
	Per animal	*Per* ha	*Per* animal	*Per* ha
	kg/yr			
Unburnt savanna,				
0.35/an/ha	38	13	38	13
Savanna burnt in the dry season,				
0.20 an/ha	75	15	-	-
0.35 an/ha	-	-	67	23
Savanna burnt sequentially during the year,				
0.20 an/ha	95	19	-	-
0.35 an/ha	-	-	62	22
M. minutiflora, grazed all year,				
0.44 an/ha	98	43	-	-
0.44/0.88 an/ha	-	-	58	69
M. minutiflora with urea + molasses during the dry season,				
0.44 an/ha	130	58	-	-
0.44/0.88 an/ha	-	-	102	81
H. rufa, grazed during rainy season,				
0.70 an/ha	34	24	-	-
1.40 an/ha	-	-	24	34
P. plicatulum, grazed during rainy season,				
0.70 an/ha	66	40	-	-
1.40 an/ha	-	-	32	45
B. decumbens, grazed all year,				
0.90 an/ha	118	106	-	-
1.70 an/ha	-	-	86	147

* Weight gain corresponding to the stocking rate in which per animal weight gain was maximum

** Weight gain corresponding to the stocking rate in which per ha weight gain was maximum.

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ECONOMIC EVALUATION OF BEEF PRODUCTION SYSTEMS IN THE LLANOS ORIENTALES OF COLOMBIA

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ABSTRACT

Using preliminary results obtained in a herd systems experiment, farm level adoption of alternative cow-calf production systems was evaluated through simulation using a computerized-activity-budgeting model. The same initial herd was developed over a 25-year period and the farm's net income flow was used to calculate the internal rate of return of each system using the discounted-cash-flow method. The experimental treatments considered as alternative systems were: (a) traditional system of grazing native savanna with salt supplementation, (b) *ad libitum* mineral supplementation, (c) same as above but early weaning all calves at three months of age, (d) breeding herd grazing *Melinis minutiflora* during the wet season and native savanna during the dry season, and (e) same as above plus early weaning. Two additional systems were simulated under a given set of assumptions: (f) the breeding herd grazing *Brachiaria decumbens*, and (g) grazing legume-based pastures. Of all the empirically-based alternatives considered, grazing native savanna with mineral supplementation is the most profitable system. Early weaning is not profitable with present costs and management; though it might become an economic alternative in case of widespread adoption of improved pastures. Grazing the entire breeding herd on *M. minutiflora* is substantially less profitable than the traditional system. Simulation results indicate that *B. decumbens*, in the absence of subsidized credit, would be as profitable as the traditional system, but that legume-based pastures could be significantly more profitable. Based on four years experimental results, fattening systems with *M. minutiflora* and *B. decumbens* pastures were evaluated at the farm level. In addition, fattening on legume-based pastures was simulated under conservative assumptions. Again, *B. decumbens* showed to be more profitable than *M. minutiflora*, and legume-based pastures with minimum inputs appear to be alternatives much more attractive from the economic standpoint. Results of sensitivity analyses indicate that the value of the inputs applied to pastures, as well as the frequency of application, affect the profitability levels significantly. Animal response to pasture fertilization has to be relatively high in order to be profitable. It is concluded that **minimum inputs** (low establishment and maintenance costs), appear to be the correct research strategy for systems in which the bulk of the herd grazes improved pastures. Higher levels of inputs might be afforded only by systems using a small pasture in a **strategic manner** (high animal response), or under highly subsidized conditions.

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Extensive cow-calf operations is predominant in the Llanos Orientes of Colombia*. Grazing native pastures, with stocking rates varying from 0.1 to 0.25 an/ha, and plain salt supplementation (not necessarily *ad libitum*) are the most common practices. Some farms have a small area in improved pastures, usually less than 3% of the total area. The species most commonly used are *Melinis minutiflora* Beauv. and *Brachiaria decumbens* Stapf. Herd productivity is in general quite low. Average calving rate is on the order of 45-55%, abortions are high, and reconception among nursing cows is very low (8, 11, 12). High calf mortality is another reason for the low extraction rate in the region (1, 7).

In this study, farm level adoption of alternative cow-calf production systems was evaluated using preliminary results of a partial life cycle experiment conducted in Carimagua. The experiment was conducted in the Centro Nacional de Investigaciones Agropecuarias—Carimagua of the Instituto Colombiano Agropecuario (ICA), as a cooperative project between ICA and CIAT. The objective of the experiment was to study the effects of several management techniques on reproductive and growth performance of breeding herds, and included the following variables: mineral supplementation, grazing native savanna and/or *M. minutiflora*, urea-molasses supplementation, early weaning, and two breeds of sire. Average results of four reproductive years (reported in 1) were used in this study to evaluate the profitability of selected systems at the farm level. Urea-molasses supplementation was not included as an alternative system since no effect on reproductive parameters was detected in the experiment (1).

SYSTEMS AND ASSUMPTIONS

The experimental treatments considered as alternative systems for evaluation at the farm level 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/yr/AU of salt (as in Herds 2 and 3 of the experiment). In System 1, calf mortality was assumed to be 15% rather than the experimental result of 26%, since this latter value appears to overestimate actual farm losses. In fact, even a 15% calf mortality implies a decreasing herd over time. Thus, System 2 was included as a more representative case of the most common system prevailing in the area.

Systems 3 and 4: All animals grazing native pasture and receiving *ad libitum* supplementation of a full mineral mixture with an average intake of 16 kg/yr/AU (as in Herds 4 and 5).

Systems 5 and 6: Same as above but weaning all calves at 86 days of age. In the experiment, early weaned calves were fed 0.75 kg/day of a carbohydrate-protein supplement (20% protein) and *ad libitum* fresh chopped *Axonopus scoparius* (Flügge) Hitchc. during one month. During an additional period of two months they were fed 0.5 kg/day of the same supplement, while grazing in rotation *Paspalum plicatulum* Michx., *Stylosanthes guianensis* (Aubl.) Sw. (when available), and a mixture of *M. minutiflora* and *Hyparrhenia rufa* (Nees) Stapf. After six months of age, calves grazed native savanna and received 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 irrigation equipment and the corresponding operating expenses and labor costs were 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 were supplemented *ad libitum* with a mineral

* For a detailed description of the environmental conditions as well as of the prevailing production system see 4, 5, 6, 7, 8, 9, 10, 11, 12.

mixture with average intake of 22 kg/yr/AU (as in herds 6 and 7).

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

System 11: Same as System 7, but grazing *B. decumbens* during the wet season with a stocking rate of 1.7 AU/ha, and savanna during the dry season. Reproductive as well as productive performance was assumed to be the same as in System 7. The only additional treatment assumed for this species, as compared to molasses grass, was 200 kg/ha of basic slag every two years.

System 12: Cows, bulls and unweaned calves all grazing a hypothetical legume-based pasture with a stocking rate of 2.0/1.0 an/ha in the wet and dry season, respectively. In this system, reproductive as well as productive parameters are given arbitrary values considered desirable as a target.

For each particular system based on experimental results (Systems 3 through 10), two cases were considered in terms of calving rates and mortality. In systems denoted by odd numbers, the experimental values of these parameters were directly extrapolated to the farm level. In systems denoted by even numbers, both parameters were assigned arbitrary values at the farm level that were lower than those obtained in the experiment. The lower values of calving rates were obtained in each case by subtracting one standard deviation from the corresponding experimental mean values. Calf mortality percentages were also arbitrarily set at lower levels under the assumption of good management of animals close to parturition.

The main biological parameters used to simulate herd development under each system are shown in Table 1. Since the frequency distribution of conception weights of the heifers at the beginning of the experiment had its maximum at 270 kg, that particular weight was used as the mating weight criterion for all systems. Mating age for each system was estimated, simulating heifer growth starting from average heifer weight at 18 months of age as obtained in the experiment for the corresponding treatment, and thereafter according to average annual weight gains as obtained in steer experiments with similar treatments (6), adjusted downward by 10% in order to account for male-female weight differences. In early versus normal weaning systems, it was assumed that absolute weight differences at 18 months of age were maintained over time.

Other parameters used in herd development for all systems were: bull:cow ratio of 0.05:1, culling rate of cows of 15%, culling rate of bulls of 20%, and an equal proportion of males and females at birth.

METHODOLOGY

On the basis of these parameters and assumptions, the same initial herd of 190 cows was developed for all systems over a 25-year period, for a commercial ranch of 2500-3000 ha. The net income flow of the ranch was used to calculate the internal rate of return of each system using the discounted-cash-flow method. All prices used correspond to average farm prices of 1976, which were assumed constant over time in real terms. The model used was a computerized activity budgeting model (HATSIM) developed at CIAT (2).

Pasture establishment costs used in the estimation were those of conventional planting in 1976; i.e.: US$120, 133 and 155 per ha for *M. minutiflora*, *B. decumbens* and the hypothetical legume-based pasture respectively. *M. minutiflora* was assumed to persist for 25 years without refertilization, *B. decumbens* was assumed to persist for 12 years and to require only 30 kg/ha of P_2O_5 at establishment and every two years thereafter. The legume-based pasture was assumed to persist for 12 years and to require 50 kg/ha of P_2O_5, 25 of K_2O, 20 of S and 20 kg/ha of Mg at establishment. The

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

System	Treatments: Pasture	Treatments: Mineral supplementation	Treatments: Weaning	Parameters: Calving rate	Parameters: Mortality rate: Calves[a]	Parameters: Mortality rate: Adults	Parameters: Heifers' mating rate[b]: 2-3 years	Parameters: Heifers' mating rate[b]: 3-4 years	Parameters: Heifers' mating rate[b]: 4-5 years
				%					
1 [c]	Native	Salt	Normal	46	15	5	0	60	100
2 [d]	Native	Salt	Normal	50	8	5	0	60	100
3 [c]	Native	Full mixture	Normal	65	12	5	0	90	100
4 [e]	Native	Full mixture	Normal	61	8	5	0	90	100
5 [c]	Native	Full mixture	Early	87	13	4	0	80	100
6 [e]	Native	Full mixture	Early	77	8	4	0	80	100
7 [c]	*M. minutiflora* + native	Full mixture	Normal	64	10	5	10	90	100
8 [e]	*M. minutiflora* + native	Full mixture	Normal	60	7	5	10	90	100
9 [d]	*M. minutiflora* + native	Full mixture	Early	85	8	4	0	90	100
10 [e]	*M. minutiflora* + native	Full mixture	Early	77	7	4	0	90	100
11 [f]	*B. decumbens* + native	Full mixture	Normal	64	10	5	10	90	100
12 [f]	Legume-based + native	Full mixture	Normal	77	7	3	20	100	-

[a] Up to one year of age
[b] Weight >270 kg
[c] Based on four-year experimental results
[d] Based on survey data
[e] Calving and mortality of calves are reduced by one standard deviation according with the estimate obtained in the experiment
[f] The values of the parameters are assumed.

annual maintenance cost assumed for this pasture was US$22 ha/yr, equivalent to applying 30 kg/ha of P_2O_5, 10 of K_2O, 5 of S and 5 kg/ha of Mg.

Since prices of inputs as well as of cattle vary according to distance from market, the economic evaluation was carried out for two regions: Region A between Puerto López and Puerto Gaitán, and Region B around Carimagua which is further away from the market (Bogotá). Region A averages 280 km from Bogotá while Region B averages 460 km from that city. Market prices of both inputs and cattle were corrected for transportation costs, to obtain prices at the farm level for each of the regions.

RESULTS AND DISCUSSION

Table 2 summarizes the performance of all systems for commercial ranches of 2500-3000 ha. The following analyses of the results use the return on capital and management as a measure of profitability.

Minerals

Systems 3 and 4, grazing native savanna with mineral supplementation are the most profitable of the alternatives considered with the only exception of System 12 which simulates the case of a legume-based pasture. These are followed by Systems 5 and 6 (which include early weaning), and by System 2 (native savanna supplemented only with salt).

Table 2. **Summary of simulated performance of alternative production systems in Colombian Llanos.**

System	Area of improved pastures		Breeding herd size		Investment*		Annual net income*		Rate of return**	
	Initial	Total	Initial	Total	Pasture	Total**	Year 4	Year 13	Region A	Region B
	ha		cows		'000 US$				%	
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	78	172	6.7	9.6	5.0	3.7
8	450	650	190	325	78	172	6.7	9.0	4.6	3.3
9	450	516	190	250	67	160	4.2	18.2	6.3	4.8
10	450	516	190	250	67	160	4.7	16.0	5.2	4.6
11***	100	190	190	325	25	118	6.7	9.6	8.5	n.a.
12***	95	162	190	325	25	121	7.5	27.9	14.0	n.a.

* Values correspond to year 8 and Region A

** Includes value of cattle and improvements, excludes value of land. Region A is between Puerto López and Puerto Gaitán; Region B near Carimagua

*** Based on assumed values for animal performance.

When analyzing the viability of adopting a new technology, the profitability of moving from the traditional system to new ones needs to be considered. The incremental rate of return may be used as an estimate of such profitability. That is, the return on the additional capital, including operating capital, required by the new system. Such incremental rate of return is defined as that rate which equals the discounted value of the increments in gross revenue with the discounted value of the increments in costs. In moving from System 2 to System 3, the incremental rate of return was found to be 25% (Table 3). Hence, mineral supplementation may be considered highly profitable for the Colombian Llanos. One of the reasons why such a profitable practice is not yet widespread in the region, may be the reduction in net income occurring during the first few years after implementation until the additional calf crop obtained is sold (Table 2). Since most farms in the region are large in area, within farm distances are also large. The lack of on-farm transportation causes difficulties in providing a regular supply of minerals to all animals. Irregular mineral supplementation probably reduces the impact of this treatment. Besides the delay in payoff and lack of on-farm transportation, other reasons such as absentee ownership, difficult access to the farm during the rainy season and irregular market supply of high quality mixtures may help explain why regular mineral supplementation is not yet a common practice in the region.

Early weaning

In spite of the high increase in calving rate, this practice was not found to be profitable with present costs and management available in the region. As Table 2 shows, the rate of return of System 5 was lower than that of System 3. A substantial reduction in net income was observed during the first few years after implementation of this practice.

The relatively poor performance of early weaned calves, especially those weaned during the dry season (1), the high cost of carbohydrate-protein supplement and labor, and the cost of establishing and maintaining improved pastures contribute to this result, overshadowing the economic benefits from a larger calf crop. As pointed out in the CIAT Annual Report (1), "due to low soil fertility and rainfall distribution, there is presently

Table 3. **Incremental returns on capital and management, of moving from traditional system (2), to alternative systems.**

System	Treatment: Pasture	Treatment: Mineral supplementation	Investment	Rate of return	Incremental rate of return
			'000 US$	%	%
2	Native	Salt	90	8.1	
3	Native	Minerals	91	10.0	
2 to 3			1	-	25.0
11	*B. decumbens*+ native	Minerals	118	8.5	
2 to 11			28	-	9.4
12	Legume-based + native	Minerals	121	14.0	-
2 to 12			31		22.0

no technology available (for the region) 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". Therefore, at present, early weaning is not profitable for continuous mating systems in the region, since the practice requires year-round availability of high quality feed.

Despite the delay in payoff, this practice was slightly more profitable than normal weaning in the intensive pasture systems (9 and 10 versus 7 and 8), by increasing breeding performance and thus reducing pasture investment per unit of output (sale of steers). Hence, rather than providing an indication of present profitability of early weaning, this result reflects the need for reducing pasture cost if the bulk of the herd is to graze improved pastures.

Since early weaning has been shown to substantially increase calving rates by reducing lactation stress, it merits further research not only in terms of a longer (than 84 days) lactation period to avoid the need for concentrate supplementation, but also in terms of improving post-weaning calf performance through an improved year-round forage base. This again emphasizes the need for pasture research.

Improved Pastures

Systems based on grazing *M. minutiflora* during the wet season (Systems 7-8) were found to be only half as profitable as systems based on native savanna (Systems 3-4, Table 2). Total investment nearly doubled in the former systems because of the low stocking rate of this pasture (0.5 AU/ha).

With a higher stocking rate (1.7 AU/ha) as in System 11 (a simulated case with *B. decumbens* assuming the same reproductive and productive performance as for *M. minutiflora*), the return on capital increases markedly. However, the estimate obtained for the incremental rate of return (9.4%) of moving from the traditional system to this one, suggests that for cow-calf operations, grazing the entire breeding herd on *B. decumbens* is not highly profitable. As will be seen later, subsidized credit would increase its profitability.

System 12, a simulation of a breeding herd grazing a legume-based pasture, appears to be a promising alternative from the economic standpoint. Both total as well as incremental rates of returns are attractive (Tables 2 and 3). Furthermore, if similar reproductive performance could be attained using a smaller area for strategic use (rather than grazing the entire breeding herd on such pasture), return on (the smaller) investment would increase substantially. In such a case, the probability of adoption by a wider base of producers would also be increased. Strategic use refers to grazing the legume-based pasture with animals when they have a high capacity of response. Such would be the case of grazing during the dry season, with cows which are under lactation stress, or to recover sick or weak animals in order to avoid capital losses.

Native pastures have a strong seasonal pattern in terms of both volume of DM production and quality (i.e.: digestibility, protein content, . . .). Since in general, in terms of volume, this is also the case of improved pastures (which make use of capital, or scarce resource), it is not a matter of substituting one for the other, but rather supplementing the native with the improved pastures, thereby capitalizing on their higher quality during the dry season.

Those improved pastures which are highly seasonal producers, both in volume and quality, but whose digestibility is low during the dry season, may still be attractive for fattening purposes in areas of high opportunity cost of land. Substitution of capital for land may be warranted in such a case due to high land values. Also, the possibility of obtaining high compensatory gains may allow for a rapid turnover of the capital invested in the animals.

However, for areas with low opportunity cost of land, such as the Llanos, there is little

advantage in replacing native savanna with improved pastures such as *M. minutiflora*, which are also poor in quality during the dry season. In cow-calf operations, there are no compensatory gains in the reproductive sense. Lack of conception, as well as abortions and higher mortality during the dry season cannot be "compensated" during the rainy season when the pasture is productive. Hence, emphasis in pasture research should be on finding ways of **supplementing** native savanna with improved pastures of high nutritive value during the dry season, rather than replacing one by the other.

Jarvis's (3) conclusion after a detailed analysis of the diffusion of improved pastures in Uruguay, supports this hypothesis: "Most producers find the artificial pastures to be highly profitable when planted on a small proportion of their ranches, this small proportion providing an improved nutrient base during the crucial winter months: . . . (improved pastures) have been used to supplement the traditional pastures, however, not to replace them . . . (they) have not been profitable for most ranches when planted to a large proportion".

Since improved pastures represent a sizeable investment, not exempt from risk, it is quite reasonable for producers to use them in a "strategic manner" as a supplement to forage available from native pastures. Improved pastures are thus first grazed with animals which have a high capacity for response. Further increases in the proportion of area planted with these pastures implies grazing with animals at times that have lowar response capacity and, hence it may be unprofitable and risky. Moreover, unless forage conservation (i.e.: hay, silage, . . .) is economical, forage from the improved pasture will probably be wasted during the wet season. Burning native pastures is a very common practice in the region, but burning to remove inedible forage and to stimulate fresh regrowth of improved pastures is in many cases risky. Undergrazing, as well as overgrazing, is also risky in terms of pasture persistence, particularly in the case of legume-grass mixtures. As Jarvis (3) puts it, "the greater is the proportion of improved pastures on a ranch, the greater is the management sophistication and dedication required".

Thus, it seems logical to conclude that pasture research should emphasize good quality forage for the dry season, and animal management research on strategic use of the improved pastures rather than for the entire breeding herd.

Pasture persistence and establishment failures

Table 4 illustrates the effect of pasture duration on the return 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 and the stocking rate is low (0.44 AU/ha), the returns on capital are quite sensitive to pasture duration (Systems 7 and 9).

Table 5 shows the result of a sensitivity analysis of pasture persistence and establishment losses. Two cases are considered: System 7 and System 7', the latter assuming 50% reduction in establishment costs of this particular pasture *(M. minutiflora)*. It may be observed that reducing establishment costs without affecting

Table 4. **Rates of return: sensitivity analysis with respect to pasture persistence.**

System	Pasture persistence (years) 24	12	9	6
	% return			
5	9.1	9.0	8.9	8.8
7	5.0	2.8	1.3	-*
7'**	7.1	5.9	5.0	3.7
9	6.3	4.2	2.7	0.9

* Negative value

** Assuming 50% reduction in establishment costs.

Table 5. **Rates of return from System 7: sensitivity analysis with respect to pasture persistence and establishment failure.**

Pasture establishment failures	Pasture persistence (years)					
	24		12		9	
	7*	7'**	7	7'	7	7'
% area	% return					
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

* Actual cost

** Assuming 50% reduction in establishment costs

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 (10). They may not be as relevant when dealing with very small areas for strategic use only.

Financing

In Colombia, as in some other Latin American countries, the nominal interest rate on loans is lower than the inflation rate. This implies financing under subsidized conditions. Table 6 is included to illustrate the effect of this type of incentive on the return to the cattleman's own capital. The following conditions are assumed: an annual expected inflation rate of 30%, 18%

Table 6. **Rates for return on producer's own capital and management from alternative systems receiving credit under subsidized conditions.**

System	Percent financing of initial investment				
	0	20	40	60	80
	% return				
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'**	7.1	7.9	8.9	10.2	(12.0)
11	8.5	9.6	11.0	13.1	(16.8)

* Figures in parentheses are improbable cases included only for illustration

** Assuming 50% reduction in establishment costs

nominal interest rate and a four-year grace period on a 12-year loan. These conditions are presently found in the Llanos, though they may not necessarily 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 under 60% financing, System 7 (grazing *M. minutiflora)* is not as profitable as Systems 2 and 3 (native savanna plus salt and minerals, respectively) without financing. However, such is not the case of System 11 which simulates grazing of *B. decumbens.* Beyond 30-40% financing under such subsidized conditions this system becomes more profitable than Systems 2 and 3. This may explain why many producers in the Llanos are adopting this particular improved pasture.

Land values

When analyzing the profitability of alternative production systems which are relatively similar 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, considering that the producer has already invested in land?

However, when comparing the returns on capital of a given technology in two ecologically similar regions which face different input-output prices, because of distance to markets, the value of land has to be incorporated in the analysis in order to explain profitability differences between two 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 away 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 2. For example, comparing normal weaning systems (3 and 7) against early weaning systems (5 and 9 respectively) it may be observed that the regional differences in return are larger in the case of systems incorporating early weaning. This indicates that technology using a larger volume of inputs has a lower probability of adoption in regions further away from the market, due to transportation costs.

Table 8 illustrates the effect of a land-saving technology (improved pastures) on the total return to producer's own capital (including land value). It was assumed that the real price of land increases at an annual rate of 2%. The area below the line

Table 7. **Rates of return* from System 3 (native pasture and mineral supplementation): sensitivity analysis with respect to land values and percent financing of initial investment under subsidy conditions.**

Land value		Percent financing on initial investment**				
		0	20	40	60	80
Col$/ha	US$/ha	% return				
0	0	10.0	10.8	12.8	15.1	18.8
500	14	6.9	7.2	7.9	8.6	9.4
1000	28	5.5	5.7	6.1	6.4	6.8
1500	42	4.7	4.8	5.1	5.3	5.6
2000	56	4.2	4.3	4.5	4.7	4.9

* Rates of return on producer's own capital and management, and on total investment including land value

** Excluding land value.

Table 8. **Rates of return* of System 11 (*B. decumbens* plus native pasture and mineral supplementation): sensitivity analysis with respect to land values and percent financing of initial investment under subsidy conditions.**

Land value		Percent financing of initial investment**				
		0	20	40	60	80
Col$ · ha	US$ha	% return				
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

* Rates of return on producer's own capital and management, and or total investment including land value

** Financing of initial investment excluding land

represents situations in which System 11 (*B. decumbens* plus minerals) is preferable to System 3 (native pasture plus minerals; Table 7), using total returns on capital as the criterion. This explains in part why land-saving technology (improved pastures with high carrying capacity), even under similar ecological conditions, are adopted first in areas closer to the market which have higher land values, as is observed in the case of the Llanos Orientales.

In summary, the fact that in the Llanos many producers are planting *B. decumbens* although it is not more profitable than the traditional system, could be explained by: (a) subsidized financing, (b) higher land values in regions close to the market, (c) lower establishment costs than those assumed in this study, and (d) use of improved pastures for fattening purposes, as discussed next.

Fattening systems

A 1000 ha fattening farm in Region A was simulated, based on four years of experimental results conducted in Carimagua (1, 6). As in previous cases, the economic analysis was carried out for 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.

Four fattening systems were evaluated: (A) grazing *M. minutiflora* for 274 days with a stocking rate of 0.44 AU/ha, (B) same as above but with a stocking rate of 0.88 AU/ha, (C) grazing *B. decumbens* during a similar period, at a stocking rate of 1.3 AU/ha, and (D) same as above but with a stocking rate of 1.7 AU/ha. Results for the four systems are reported in Table 9. Using return on capital (excluding value of land) as the criterion, it may be seen that although System B yields more output per ha, 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.

A similar conclusion could be reached comparing Systems C and D. That is, although the capital invested in pasture is producing more in the systems with higher stocking rates, capital invested in animals is producing substantially less, overshadowing such benefits and yielding an overall lower rate of return. Thus, under these conditions, the optimum stocking rate appears to be closer to maximum production per head than to maximum production per ha.

System C is substantially more profitable than the other systems. This result tends to support those obtained in the simulation of System 11 with the breeding herd grazing *B.*

Table 9. **Animal performance and rates of return on capital[1] and management from finishing cattle on improved pastures in the Colombian Llanos.**

System	Pasture	Stocking rate	Production			Rate of return
			Per-head		Per ha	
		an/ha	g/day	kg/yr	kg/yr	%
A[2]	*M. minutiflora*	0.44	416	114	50	7.2
B[2]	*M. minutiflora*	0.88	277	76	67	4.8
C[3]	*B. decumbens*	1.3	376	103	134	12.1
D[3]	*B. decumbens*	1.7	292	80	136	8.0
E[4]	Legume-based	2.1/0.9	411	150	270	19.3
F[4]	Legume-based	2.1/0.9	500	182	378	15.2

[1] Excluding value of land
[2] Based on four year experimental results
[3] Based on three year experimental results
[4] Parameters on animal performance are assumed values.

decumbens. As already indicated, it was assumed in the calculations that this particular species could persist for 12 years without a loss in productivity and needs no refertilization except for 30 kg of P_2O_5 every second year. It should be pointed out, however, that there is no conclusive evidence regarding maintenance of productivity of this species without periodical N applications beyond the fourth year.

In addition, two systems for fattening (E and F) on a hypothetical legume-based pasture were simulated for the same region. Weight gains assumed as well as the resulting return on capital and management are reported in Table 9. Preliminary research results, because of lack of persistence of the legume—*S. guianensis* in this case, lead us to believe that the assumed liveweight gains per head and per ha are feasible, if not conservative (1, 6). Comparing the returns on investment of the systems using grass species (A through D) with those of the systems using legume-based pastures (E and F), the expected superiority of the latter two is confirmed, thus reinforcing the need to continue seeking persistent legume-based pastures for these savannas.

Table 10 is included to illustrate the type of economic results which could be expected from different pastures needing different levels of inputs with different frequencies in order to achieve similar animal production. Each cell in the table represents a different pasture requiring application of a given amount of fertilizer, with a given frequency, in order to yield the same output per ha with the same stocking rate as in System C (Table

Table 10. **Returns of investment* for simulated fattening systems having identical animal performance with the same stocking rate, but requiring application of inputs with different frequencies.**

Frequency	Value of inputs (US$/ha)			
	0	28	42	56
	% return			
Every year	12.1	4.6	1.0	**
Every 2 years	12.1	8.5	6.7	5.0
Every 3 years	12.1	10.2	8.7	7.6
Every 4 years	12.1	10.4	9.7	8.9

* Excluding land value
** Negative return.

9). In Carimagua (Region B) and at 1976 prices, the amounts indicated in Table 10 would buy the following amounts of N or P_2O_5:

Nutrient	Source	US$28	US$42	US$56
		kg		
N	Urea	50	75	100
P_2O_5	Basic slag	67	101	135
P_2O_5	TSP	39	58	78

As may be seen in Table 10, other things being equal, pastures needing frequent fertilization (at even low levels) are markedly less profitable than the ones 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. For example, if a pasture requires a maintenance rate of 75 kg N/ha every year (costing US$42), it is estimated that animal production has to be at least 50% higher in order to be as profitable as System C *(B. decumbens)*.

Thus, it seems logical to conclude that, in the case of the Carimagua region, pastures needing high and frequent fertilization could become economic alternatives perhaps only for strategic grazing by those animals with rather high response capacity.

Alternatively, for systems in which the bulk of the herd is on improved pasture (fattening farms, or grazing the entire breeding herd), the above results clearly indicate the appropriateness of selecting species and varieties based on minimum input criteria, and therefore again reinforces the need for seeking legume-based pastures.

CONCLUSIONS

In the case of the Llanos Orientales of Colombia, full mineral mixture supplementation is highly profitable. Factors such as delay in payoff, lack of on-farm transportation, absentee ownership, difficult access to the farm during the rainy season and irregular market supply of high quality mixtures may restrain the adoption of this practice in the region.

In spite of a striking increase in calving rate, early weaning was not profitable at present costs and management requirements in the region. However, this practice merits further research in terms of a longer (than 84 days) lactation period to avoid the need for concentrate supplementation, and in terms of improving post-weaning calf performance through an improved year-round forage base.

Field research has clearly identified poor quality of native forage, particularly during the dry season, as the second major constraint to increased beef production in the region. Systems based on grazing the entire breeding herd on *M. minutiflora* during the wet season and native savanna during the dry season were half as profitable as year-round grazing on native savanna. This is due to the poor quality of this particular species during the latter season. Thus, the importance of developing a good quality forage base for the dry season is confirmed. This is not a matter of substituting native with improved pastures, but rather supplementing the former with the latter, thereby capitalizing on their higher quality during the slack season. Furthermore, given the absence of compensatory gains in reproduction, emphasis in animal management research should be given to strategic use of improved pastures rather than to grazing them with the entire breeding herd irrespective of the physiological status and/or condition of each animal.

Comparisons of economic results obtained from simulating performance of legume-based pastures vis-a-vis the two grasses considered *(M. minutiflora* and *B. decumbens)*, reinforce the need to continue seeking legume-based pastures. Finally,

results of sensitivity analyses clearly indicate the appropriateness of selecting species and varieties based on a minimum input strategy. Reducing establishment and maintenance costs without affecting carrying capacity not only increases returns to investment but also implies that these returns are less sensitive to pasture establishment failures and to persistence risk.

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PART V

PASTURE SEED PRODUCTION

SIGNIFICANCE OF CLIMATE IN TROPICAL PASTURE/LEGUME SEED PRODUCTION

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ABSTRACT

An attempt is made, from Australian field experience and the experimental record, to identify the climatic factors important in tropical pasture legume seed production. The main properties of the crops (primarily *Stylosanthes* spp., *Macroptilium atropurpureum, Desmodium* spp. and *Glycine wightii)* taken into account are: their usual adaptation to a cycle of summer vegetative and winter reproductive development; their common short-day flowering response; their need for a reliable dry season to stimulate vigorous reproduction, reduce disease risk, and facilitate harvesting; and their susceptibility to frost. The more important general requirements for suitability of a region for seed production are seen to be that: its annual average rainfall should be 800-2000 mm, with a predominantly summer wet season and no more than 400 mm falling outside the four wettest months; the average daily mean temperature of the coolest month should not fall below 17°C; the ground frost risk should be low; and the latitude should be greater than 10°. These values are used to map Australia, India, South and Central America, and Mexico in terms of their potential for seed production.

Australia has about fifteen years of experience of commercial seed production of tropical pasture legumes. One of the lessons it has learned in that time is that their successful long term seed production is only possible within a very narrow range of climatic conditions. Many decisions influence the success of a seed growing enterprise, but none is more critical than the initial choice of climate in which to grow the crop.

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As tropical pasture development has expanded elsewhere, we have sometimes been called upon to judge the suitability of untried regions for seed production. Also, as new legumes are released at home, we are expected to predict where will be the best seed growing districts for them.

The basis for these judgements is this. We have, in Australia, a wide range of tropical pasture legume cultivars (Table 1). Through trial and error on the part of innumerable farmers, we know where and where not each of the established cultivars can be grown successfully. There is a good enough

Table 1. **Major Australian tropical pasture legume cultivars.**

Species	Cultivar and (common name)	Photoperiodic response*	Temperature sensitivity**
Centrosema pubescens	(Common centro)	WSD	L
	Belalto (centro)	WSD	L
Pueraria phaseoloides	(Puero)	SD	L
Calopogonium mucunoides	(Calopo)	SD	L
Macroptilium atropurpureum	Siratro	WSD	
Macrotyloma axillare	Archer (axillare)	WSD	
Stylosanthes guianensis			
var. *guianensis*	Cook (Stylo)	SD	
	Endeavour (Stylo)	SD	
	Schofield (Stylo)	SD	
var. *intermedia*	Oxley (Stylo)	LD	
Stylosanthes humilis	(Townsville Stylo)	SD	
Stylosanthes hamata	Verano (Stylo)	DN	
Stylosanthes scabra	Seca (Stylo)	DN ?	
Desmodium intortum	Greenleaf (Desmodium)	SD	H
Desmodium uncinatum	Silverleaf (Desmodium)	SD	H
Glycine wightii	Clarence (Glycine)	SD	H
	Cooper (Glycine)	SD	H
	Tinaroo (Glycine)	SD	H
	Malawi (Glycine)	SD	H
Lotononis bainesii	Miles (Lotononis)	DN ?	

* WSD = weak short day, SD = short day, LD = long day; DN = day neutral

** L = apparently sensitive to low temperature, H = sensitive to high temperature, and possibly tolerant of low temperature.

background of climatological data to permit us to characterize the climates of suitable and unsuitable districts; and we can to some extent explain the connection between climate and success in both practical and physiological terms. Given climatic records, therefore, we can crudely map another continent in terms of its climatic potential for seed production; and given some knowledge of the flowering behavior of a new cultivar, we can form opinions on where it is likely to seed satisfactorily.

Such exercises are far from foolproof. New cultivars and new regions are apt to introduce new and unforeseen spectra of weeds, pests and diseases, which affect the relation between climate and crop performance unpredictably. Combinations of climatic elements occur of which we have no experience in Australia, and the consequences of which we can only speculate on. Groups of legumes begin to emerge—for example, browse shrubs— about which we know little. Even so, there is much that can be foreseen, and perhaps if the background of the predictions is documented it will help to reduce the frequency of catastrophe, which has been too common an occurrence in the development of new seed production enterprises in the tropics.

THE CHOICE OF INDICES TO BE USED TO DEFINE SUITABLE CLIMATES FOR SEED PRODUCTION

General

The legumes may be considered singly or collectively, but both approaches are usually

desirable. Each cultivar finds its own niche, and no one locality is ideal for them all. On the other hand, a seed industry cannot for economic reasons spread its assets too widely; nor can it rely on too few species — demands fluctuate and fashions change too rapidly. For these reasons a region which experiences a wide range of broadly suitable climates over a short distance has many advantages; and to locate such a region demands attention to both the individual and collective needs of the crops.

Most of our present pasture legume cultivars were derived from and selected for use in the summer rainfall regions of the seasonally wet tropics and subtropics. When grown for seed, they generally exploit the wet season to produce the vegetative framework of the crop. Vegetative growth commonly ceases and flowering begins during the transition period, and seed ripening takes place in the dry season. The morphological characters and physiological processes that dictate their development have evolved to maintain this general annual rhythm, and it is usually those climates that allow their orderly expression that prove most satisfactory for seed production.

Daylength

As might be expected, many tropical pasture legume species are short-day plants (7). In some the response is weak, and either irrelevant in field conditions or commonly overridden by other influences. The flowering of others is almost wholly dominated by the short-day response, and at higher tropical latitudes occurs at more or less predictable times each year. A few species are apparently day-neutral. Table 1 lists the response type of the more common Australian cultivars.

At and above 12°S in Australia, the short-day cultivars have clearly defined phases of vegetative and reproductive development, and the transition occurs at a reasonably predictable time in each. Reports of the behavior of short-day *Stylosanthes* spp. in Malaysia and New Guinea, at latitudes below 6°, however, indicate no clear distinction between the two phases. In such circumstances heavy seed yields are probably impossible.

It is not possible to specify a critical latitude below which seed production of any cultivar is impracticable, nor is it reasonable to expect a single latitude to be the critical one for all short-day cultivars. But for general seed production it would be unwise, without firm evidence to the contrary, to establish an enterprise within about 10° of the equator.

Stress

An element of stress is often necessary to promote vigorous reproductive activity. Although other growth retarding agents may have the same effect, water stress is the commonest, and the only one of relevance here. The stimulation of reproductive processes through drought is a widely observed but little understood phenomenon (9). In the tropical pasture legumes its effects are most obvious in day neutral (DN) or weak short-day (WSD) plants (Table 1). Salter and Goode (9) though considering totally different crops, suggested that drought stress may only be necessary when other flower induction processes are weak, an observation that accords closely with our own experiences.

Macroptilium atropurpureum (D.C.) Urb., for example, depends entirely on the stress effect to produce worthwhile flushes of flower, and exploitation of this response is central to *M. atropurpureum* management under irrigation (6). *Centrosema pubescens* Benth, though nowhere managed with the care bestowed on *M. atropurpureum,* is observed to behave in the same way. It flowers as the soil dries after the wet season, but readily reverts to vegetative growth at the expense of the seed crop if it receives rain or irrigation during flowering.

Even strongly photoperiodic plants are not wholly immune from this risk, *Glycine wightii* (R. Grah, ex Wight and Arn.) Verdc. cv. Malawi for example, flowers vigorously irrespective of soil moisture at its appropriate time, but suffers massive failure of seed set unless its vegetative growth is curtailed by drought. *Stylosanthes guianensis* (Aubl.) Sw. var. *guianensis* cv. Cook has been observed to revert temporarily to vegetative growth after an ill-advised heavy watering during flowering.

For probably the same reasons, the timing of flowering of some crops is influenced by the time at which the wet season ends. In the day neutral *Stylosanthes hamata* (L.) Urb. cv. Verano it is dominated by it. An early end to the wet season may thus lead to premature flowering of an inadequately developed crop. An indefinite end may produce a poorly synchronized flower flush.

For these reasons all seed crops perform best in a climate in which wet and dry season are reliably and clearly separated.

Duration of vegetative growth

Even the most rapidly developing crops need a wet season of about four months duration for optimum seed production. The annual *Stylosanthes humilis* H.B.K. often suffers from reduced seed set in a shorter wet season, but with the perennials the effects of a short season are more commonly to curtail growth and stimulate flowering before the vegetative framework of the crop is complete. The danger of this is greater, for obvious reasons, in the season of establishment than subsequently.

There is no advantage to most crops in a wet season longer than is necessary to produce a closed vegetative canopy, though a number of less drought tolerant species (e.g. *G. wightii* cultivars and *Desmodium intortum* (Mill.) Urb. cv. Greenleaf) benefit from the greater vigor that accompanies a somewhat longer season. The strong photoperiodic response of these two species reduces the need for stress stimulation, and they are little troubled by the diseases that beset, for example, *M. atropurpureum* and *Stylosanthes* spp.

Disease

An extended wet season, or the occurrence of rain during the dry season, introduce problems with several fungal pathogens. In Australia, *Rhizoctonia* in *M. atropurpureum* and anthracnose *(Colletotrichum gloeosporoides)* on *Stylosanthes* spp. are particularly troublesome. Rain or overcast weather at flowering time encourages *Botrytis* head blight in *Stylosanthes* spp. also, which can cause total failure of the seed crop. For these reasons, any rain beyond that necessary to grow the crop is generally a disadvantage to the seed producer.

Harvest conditions

No seed crop can be harvested in wet conditions, and rain at harvest time therefore causes delays which may lead to losses. Rain at or slightly before harvest ripeness is catastrophic to *S. guianensis* as it knocks all ripe seed to the ground.

High humidity is also a nuisance at harvest time, especially with sticky crops that need heavy threshing, such as *D. intortum* cv. Greenleaf and *S. guianensis* cv. Cook. Under former management systems, high humidity was an advantage with ripening *M. atropurpureum* as it delayed pod shattering, but is a disadvantage with modern management systems in which shattering is of no consequence.

Rainfall

The four preceding sections all emphasize the advantages of having rainfall confined to a reliable, roughly four-month, summer wet season. It is now necessary to quantify the rainfall requirement, in terms of both the range of total annual rainfall and the dry season component. This can only be done

from consideration of the climates of the districts of known production potential (Table 2).

The lower limit of average annual rainfall (AAR) for seed production in the Australian tropics is about 800 mm. It is set not so much by the actual amount as by the reliability that it reflects. Given satisfactory distribution, 800 mm is adequate; but those regions receiving an average less than that do not have reliable enough wet seasons to provide a secure income from seed production. As such, a limit of 800 mm is not necessarily appropriate to other continents in which the risk of failure of the wet season, the acceptability of that risk, and the economics of supplementary irrigation may all differ from what they are in Australia.

Any chosen upper limit to rainfall must also be arbitrary. It is set by the problems of conducting the necessary operations of management during a heavy wet season, and by the ravages of disease in these conditions. The realistic limit in Queensland is an AAR of about 2000 mm. Admittedly, *S. guianensis* seed is grown in districts with an AAR exceeding 4000 mm, but not without extreme difficulty.

If we accept a four-month wet season as necessary for adequate vegetative development, and any rainfall beyond that as undesirable, then a simple record of the amount of rain falling outside the four wettest long-day months will serve as a useful index of distribution. Reliable, successful seed production is not obtained

Table 2. **Climatic records of selected stations representative of districts of known potential for tropical pasture legume seed production in Australia.**

Station No.	Name	Lat.[a]	Long.[a]	Alt.[a]	T_1[b]	T_2[b]	Frost risk[c]	AAR[d]	DSC[e]
		°S	°E	m	—— °C ——			—— mm ——	
1	Katherine	14	132	100	31.0	21.3	L	900	140
2	Cooktown[f]	15	145	<10	27.7	22.3	0	1700	430
3	Georgetown	18	144	300	29.0	19.6	L	800	130
4	Mareeba	17	145	400	25.7	18.1	L	900	160
5	Walkamin	17	145	600	25.0	17.8	L	1100	200
6	Kairi	17	146	700	23.4	15.8	M	1300	350
7	Herberton	17	145	900	23.0	15.2	H	1100	310
8	S. Johnstone	18	146	10	26.3	19.1	0	3200	1020
9	Cardwell	18	146	<10	26.7	18.4	0	2100	590
10	Ayr	20	147	<10	27.3	18.3	L	1000	250
11	Mackay	21	149	10	26.2	16.7	L	1600	490
12	Bundaberg	25	152	10	25.4	15.7	M	1200	440
13	Gympie	26	153	100	25.3	13.9	H	1100	500
14	Biloela	24	150	200	26.6	12.8	H	700	320

[a] Latitude and longitude are given to nearest degree, altitude to nearest ten or hundred meters

[b] T_1 and T_2 are average daily mean temperatures for hottest (January) and coolest (July) months, respectively. Temperature and rainfall data from 2, 3 and Queensland Department of Primary Industries Research Station records

[c] *Frost risk is derived from local experience of crop damage. 0 = negligible; L = low (1 year in ca. 5); M = medium (1 year in ca. 3); H = high (1 year in ca. 2)*

[d] AAR = average annual rainfall to nearest hundred mm

[e] DSC = dry season component (quantity of rain falling outside the four wettest long-day months)

[f] The seed growing districts near this station receive substantially lower AAR than does the Station itself, including a lower DSC

in Australia in districts where this dry season component (DSC) exceeds 400 mm. For the WSD and DN crops, a lower DSC is necessary and 300 mm is a more appropriate figure.

Temperature

Vegetative growth rates of the tropical pasture legumes appear to be greatest at or above mean daily temperatures of about 25°C (4,11). Limitations to vegetative growth due to low temperature are probably seldom a serious restriction during the tropical summer wet season. There is some indication that *D. intortum* cv. Greenleaf and *Desmodium uncinatum* (Jacq.) DC. cv. Silverleaf and the Australian *G. wightii* cultivars are intolerant of much higher temperatures, and their general poor performance at low altitudes in the tropics may be a consequence of this. But otherwise there is little reason to look for a high temperature limit to use as a climatic index for the present purpose.

Low temperature during the reproductive season, on the other hand, must often be a restriction on seed production. There are many well-documented examples of failure due to low temperature at inflorescence initiation and development (7). Species appear to vary in their tolerance of low temperature. One group, typified by *C. pubescens* appears from field behavior to be particularly sensitive (1). Another (the *Desmodium* spp. and *Glycine* cultivars mentioned above) gives some indication of relative tolerance. Table 1 includes an arbitrary separation of species on these bases.

The problem here is to decide what are the critical low temperatures. Unfortunately, outside the broadest limits, the experimental record is little help, and we must again fall back on the connection between field performance and climate. The most useful temperature record for this purpose is the average mean daily temperature of the coolest month. This is also, of course, an indirect indication of the frost risk, and in some situations its use may be superfluous if frost records are available. But mean daily temperatures can be much more realistically mapped than frost records, and have their own value independent of the frost connection. The success of flowering of *M. atropurpureum* in the field, for example, depends greatly on the rate of emergence of new inflorescence buds from the terminal shoot, and this is closely correlated with mean daily temperature (much more closely than with maxima or minima) from the point of frost to at least 23°C (Hopkinson, unpublished data).

In northern Australia the absolute limit for legume seed production coincides with an average daily mean temperature for July of about 13°C (Tables 2 and 3). For the majority of crops a figure of 17°C will serve as the minimum for reliable successful operation, with 18° and 15° serving for specific consideration of groups L and H respectively (Table 1).

Frost

All the legumes under consideration are extremely frost susceptible. A single ground frost is enough to destroy a seed crop of any of them. The more versatile crops, such as *M. atropurpureum* are capable of some recovery under appropriate management, but for the majority the occurrence of frost before completion of seed ripening results in total loss of the seed crop for that year.

The degree of frost damage varies with the severity and duration of the frost, and with its vertical depth. At its worst, complete leaf and shoot tip death occur; at its least, temporary failure of seed set or minor leaf death. *Pueraria phaseoloides* (Roxb.) Benth. var. Javanica (Benth.) Bak. which has perhaps the worst reputation for sensitivity to low temperature, may suffer inflorescence bud and shoot death even without a recorded ground frost. When this happens there is no prospect of recovery in the same season. Inflorescence buds may only develop in the leaf axils of vegetative

Table 3. **Suitability of selected stations for seed production of representative legumes.**

Station No.	*C. pubescens*	*S. guianensis* cv. Cook	*M. atropurpureum**	*S. hamata* cv. Verano	*D. intortum* cv. Greenleaf	*G. wightii* cv. Cooper
1	X	X	A	A	X	X
2	A	A	A	B	X	X
3	-	-	-	A	-	-
4	B	A	A	A	A	B
5	B	A	A	B	A	A
6	X	X	X	X	A	A
7	X	X	X	X	B	B
8	X	X	X	X	X	X
9	X	B	X	X	X	X
10	A	A	-	A	-	-
11	-	X	B	-	-	-
12	X	X	B	-	B	-
13	X	X	B	-	B	-
14	X	X	X	X	X	X

* Availability of irrigation is assumed

A = suitable; B=marginally suitable; X=unsuitable. Inadequately known combinations are left without a letter.

shoots, and the time needed for a new population of vegetative shoots to develop is too long to permit recovery before long days or wet weather intervene.

The chief difficulty with frost lies not in the knowledge of its effects but in the choice of measurements that adequately reflect its occurrence. In marginal districts frost risk varies so much with topography that site selection must rely on local experience. At the level of crude extensive mapping, the limit of occurrence of air (screen) frosts is a useful index. But between it and the limit of occurrence of ground frost lies a marginal zone in which both topographical effects and the degree of risk acceptable to the grower vary so much than any choice of indices is very arbitrary.

CHOOSING LOCATIONS FOR SEED PRODUCTION OF NEW CULTIVARS

Table 4 suggests obvious questions to ask when seed growing districts are being sought for new cultivars. As *Stylosanthes scabra* Vog. cv. Seca is at this stage of development, it will serve to illustrate the procedure. The crop has reached the point where experience of small scale seed multiplication and pastoral evaluation have given us some insight into its behavior, and permitted answers to the questions of Table 5. From these answers we can decide the combination of conditions most likely to favor the *S. scabra* cv. Seca seed crop, and scan the climatic records for stations which provide the appropriate conditions. Of the examples used in this paper, the following stations offer the most promise:

Australia (Table 2), stations 1, 3, 4, 5 and 10;

India (Table 6), stations 6 and (marginally) 4;

South America (Table 7), stations 3, 9, and 13;

Mexico and Central America (Table 8), stations 1, 2, 3, 5 and 7.

Table 4. **Indices used to identify regions climatically unsuitable for tropical pasture legume seed production.**

Climatic Parameter	Basis for exclusion from general seed production* Exclude if:	Qualification**
Latitude	Less than 10°N or S	Except perhaps for WSD and DN plants
Frost	Air frost is recorded (more often than 1 year in 10?)	Acceptable frequency depends on the risk factor acceptable. Group L plants should only be grown in no risk districts.
	Ground frost is observed (more often than 1 year in 2?)	
Average daily mean temperature		
Coolest month	Less than 17°C	15°C applicable to group H, 18°C to group L
Hottest month	No limit	Possibly exclude group L if it exceeds 26°C
Rainfall	AAR is less than 800 mm	Lower AAR tolerable if irrigation is feasible
	AAR exceeds 2000 mm	
	DSC exceeds 400 mm	300 mm more appropriate for WSD and DN plants

* Refer to Table 2 for explanation of AAR and DSC
** Refer to Table 1 for explanation of WSD, DN and groups H and L.

Use of climatic indices to locate and assess potential seed growing regions

From earlier considerations, it follows that the search for seed producing districts will generally be confined to the belts between latitude 10° and the tropic (23°) in either hemisphere. At lower latitudes rainfall distribution is seldom satisfactory, irrespective of any requirement for change in daylength; and even where extreme deflection of the equatorial trough creates favorable rainfall and temperature characteristics outside the tropics, we suspect that deficiencies in winter radiation restrict vigorous reproductive activity. We shall therefore confine our attention mainly to tropical latitudes above 10°, and examine the application of the climatic indices of Table 4 to a number of examples.

Australia

The first test of the validity of indices intended to be used to locate prospective seed growing districts is their application to Australia. Obviously they must fit the continent in which they were derived to have any credibility elsewhere. We must therefore present the evidence that they do so, and the exercise will serve at the same time to put the geography of seed production in Australia in perspective.

Table 5. **Use of known behavior of a new cultivar to predict climatic requirements for seed production. Example: *Stylosanthes scabra*. cv. Seca.**

Question	Answer	Deduction
How is flowering controlled?	Appears to be day-neutral, flower flushes developing in response to drying of soil	Latitude alone probably not important, but low DSC necessary
Into what category of temperature tolerance does it fit?	Certainly tolerant of high summer temperature. No indication of extreme intolerance of low temperature. (i.e. no reason to associate with groups H or L, Table 1)	No need to seek specifically low altitude tropical sites
At what time of year does it flower and its seed ripen?	Variable, depending on season, but tending to late (i.e. August to October harvest at lat. 17°S.)	Unlikely to avoid frost damage in susceptible districts. Therefore avoid all but low to zero frost risk areas
To what diseases is it susceptible?	So far, only *Botrytis*.	Avoid districts with high DSC
Is it drought resistant?	Yes, extremely	Lower end of acceptable AAR range will be suitable
Are multiple crops per season feasible?	No, development is too slow	Irrigation will have little value.

The greater part of the Australian continent is dominated by the influences of the middle latitude high pressure belt and the southern polar front. Only the extreme north falls annually under the seasonal influence of the equatorial trough and experiences a single reliable summer wet season. The east coast between the ocean and the adjacent ranges receives rain also from several other sources, and its winter component rises with latitude.

These factors are largely reflected in the application of the indices of Table 4. There is no limiting low latitude, as the whole continent lies south of the 10th degree. The air frost line and the 800 mm AAR isohyet together exclude all the inland, and the southern portion of the eastern coastline is cut out because its DSC exceeds 400 mm (Fig. 1). The 17°C isotherm (average daily mean July temperature) is omitted as it diverges little from the frost line on a map of that scale. Finally, the 2000 mm AAR and 400 mm DSC isohyets together exclude a strip of the north east coast. The remaining area, shaded on the map, is deemed climatically suitable for seed production.

Consider next where seed is commercially grown (Fig. 2, Tables 2 and 3). The dotted lines enclose the main areas of past and present production.

Station 1 represents a group of districts which produced predominantly *S. humilis*

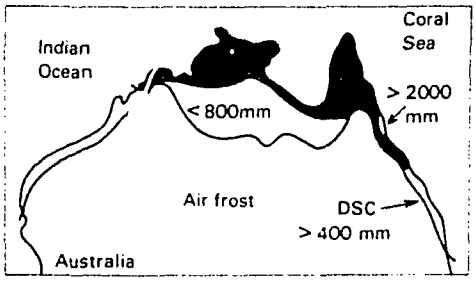

Figure 1. **Elimination of regions of Australia with unsuitable climates for tropical pasture seed production. Elimination is first on the basis of air frost occurence; then on AAR (less than 800 mm and more than 2000 mm); then on DSC (greater than 400 mm). Regions not excluded are shaded. (Map based on 4).**

seed until the collapse of the local market in 1974. Since then, their seed industry has been in a precarious state, illustrating the vulnerability of dependence on too few cultivars, a condition dictated by isolation and lack of markets rather than by faults in the climate.

The region of stations 2 to 9 (including districts climatically like station 3) has produced, and still produces, over 90% of Australia's tropical pasture legume seed. Diversity of climate has allowed a great range of crops to be grown, and seed of all the *S. guianensis* cultivars of Table 1 except Oxley has been produced. An examination of Tables 2 and 3 will show how, within this region, each legume occupies a distinct climatic niche. The range of climates within the region exceeds the range considered suitable for seed production. Station 7, for example, owing to its elevation, has too high a frost risk, while stations 8 and 9 exceed the acceptable AAR and DSC. The districts they represent all produce seed, but only with difficulty and frequent losses.

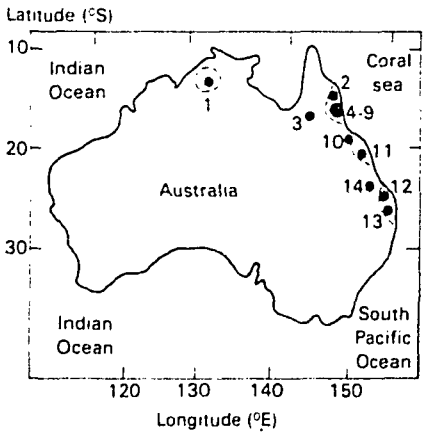

Figure 2. **Map of Australia showing positions of stations listed in Table 2.**

The region enclosing stations 10 and 11 is also one of variable climate. Its drier districts were formerly notable for *S. humilis,* and now produce *Stylosanthes hamata* (L.) Taub. cv. Verano and forage or green manure seed crops. Its wetter areas (e.g. station 11) are only marginally useful.

Stations 12 and 13 represent a region that grows *Lotononis bainesii* Baker cv. Miles and has grown *Desmodium* spp. and *M. atropurpureum,* in valuable quantities. However, its rainfall distribution and winter temperatures are far from ideal; it produced seed only as an opportunist crop because the species were present in pastures at a time when the demand for seed was strong; and its seed production has dwindled to insignificant amounts since prices have fallen.

The adjacent district of station 14 grows no pasture seed at all. The station is included to illustrate a climate just outside the useful range in every important respect.

We can confirm, therefore, that all the good seed growing districts lie within the area deemed suitable on the criteria of Table 4.

India

Confirmation of the validity of the climatic indices when applied to Australia leads us next to test them elsewhere. India provides a convenient example, as one of us recently undertook a study of the prospects for seed production there and was able to confirm by observation some of the predictions made from the study of climatic records.

The Indian subcontinent presents a very

different pattern of climates from that of Australia. Although it covers a similar range of latitudes, the annual migration of the equatorial trough up and down its entire length produces a far more widespread and generous distribution of rainfall (Fig. 3). It is also very much warmer than Australia at most places comparable in latitude (cf. Tables 2 and 6) and the critical winter isotherm (Fig. 4) lies at a much higher latitude.

The approximate ground frost line diverges far to the south of the 17° January isotherm (Fig. 4), reflecting a wide winter diurnal temperature fluctuation, and reducing the seed production prospects of a large and otherwise suitable area of central India. The bimodal rainfall distribution pattern of the southern and eastern peninsula excludes a further large area. It produces too high a DSC for most purposes, especially along the eastern coastline which actually receives its peak rainfall in early winter (e.g. Fig. 5, Table 6, station 8).

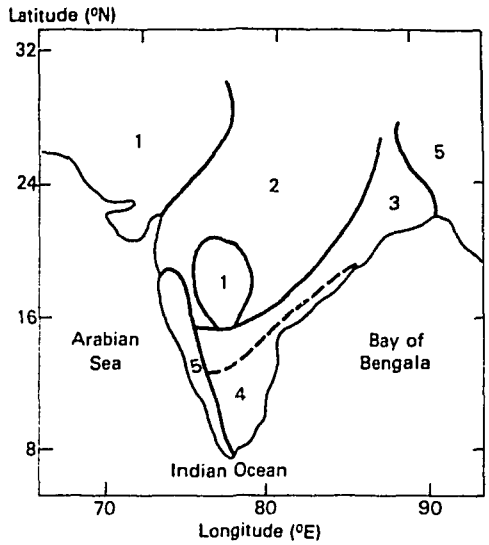

Figure 3. **Elimination of regions with unsuitable rainfall characteristics. 1 = receiving less than 800 mm AAR; 2 = receiving between 800 and 2,000 mm AAR with a DSC of less than 300 mm; 3 = as 2, but with a DSC of between 300 and 400 mm; 4 = as 2, but with a DSC exceeding 400 mm; 5 = receiving more than 2,000 mm AAR. (Based on data from 5).**

The area remaining forms a broad V-shaped belt across the peninsula, with its apex in Karnataka and its arms extending to Maharashtra and West Bengal. Much of the eastern arm experiences too high a DSC to be ideal for general seed production, though it should be useful for a number of SD species. The *S. guianensis* cultivars, for example, appear well adapted to lowland West Bengal (station 3), while niches for the *Desmodium* species and *G. wightii* cultivars occur at several elevated localities (e.g. station 7). The northern edge of the eastern

Table 6. **Climatic records of selected stations in India (Derived from 5).***

Station No.	Name	Lat.	Long.	Alt.	T_1**	T_2**	AAR	DSC
		°N	°E	m	°C		mm	
1	Jodhpur	26	73	200	33.8	16.6	400	40
2	Patna	26	85	50	32.1	16.6	1200	160
3	Calcutta	23	88	<10	30.2	19.3	1600	400
4	Nagpur	21	79	300	35.2	19.6	1200	170
5	Bombay	19	73	10	29.6	23.8	1800	110
6	Hyderabad	17	78	500	33.2	21.6	800	190
7	Bangalore	13	78	900	26.9	20.5	900	400
8	Madras	13	80	20	33.0	24.4	1300	900
9	Cochin	10	76	<10	28.8	26.9	2900	970

* See Table 1 for explanation of terms

** T_1 refers to May or June, T_2 to January.

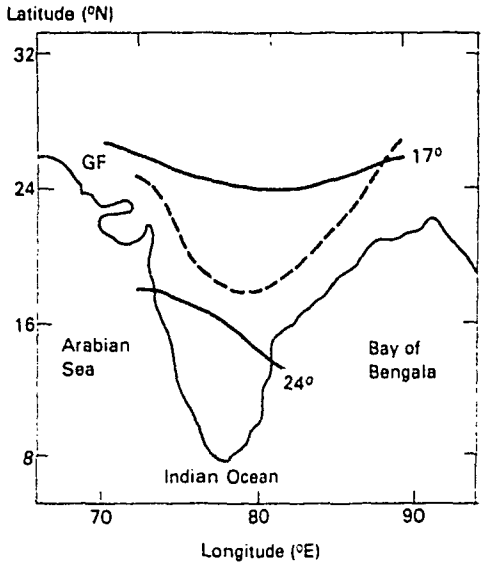

Figure 4. **Isotherms of average daily mean temperature (°C) of coolest month. Approximate limit of ground frost is marked by dotted line. (Based on 12 and 8).**

arm escapes much of the winter rainfall and appears well suited to general seed production, especially where supplementary irrigation is available. In these conditions (e.g. station 6) many legumes, including *M. atropurpureum* and *S. hamata* cv. Verano, show great promise.

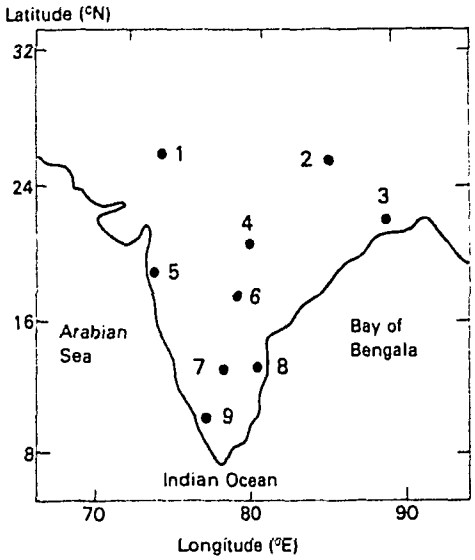

Figure 5. **Map of Indian subcontinent showing positions of stations in Table 6.**

The western arm is more difficult to judge. Sharp climatic and topographical changes occur across it, requiring records more numerous than those we have access to. The situation is much more complicated than Fig. 6 (which may, indeed, be grossly inaccurate) suggests, and it is impossible to say more than that the strip probably contains niches for seed production of every required legume, including districts variable enough to support a compact and versatile seed industry. But without detailed ground surveillance accompanied by consideration of local climatic records, such districts will not be located.

A large area of the northern peninsula, excluded on the grounds of frost risk, must actually be regarded as marginal. Station 4 provides an example. There must be many sites where the frost risk is low enough to ignore, and where seed of several species could be successfully grown in most seasons.

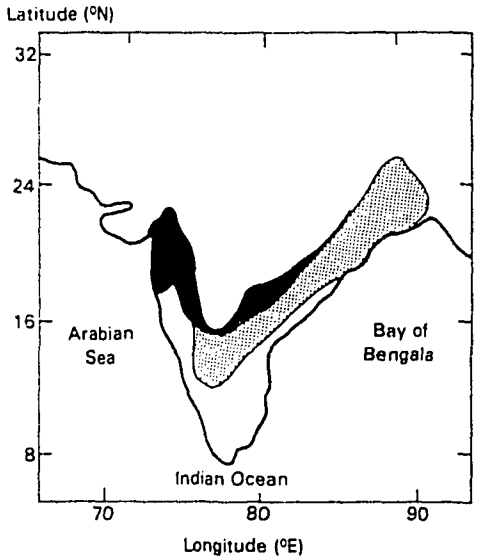

Figure 6. **Regions deemed to have a climate suitable for general (shaded) and restricted (SD plants only) (dotted) tropical pasture legume seed production. (Derived from Figs. 4 and 5).**

South America

Inter-tropical South America is considerably cooler and wetter, allowance being made for elevation, than the corresponding parts of India and Australia. The equatorial trough migrates south in a great arc from about 1°N on the west coast of Colombia, to the tropic in Paraguay, and then northeast to the equator near the mouth of the Amazon. The east of Brazil is thus always on the poleward side of the trough and under the influence of the southeast trade. The west coast of the continent is dominated by deflected Pacific southeast trade, because of which desert conditions prevail.

The land east of the Andes between 10°S and the tropic is occupied by Brazil, Bolivia and Paraguay (and the eastern lowlands of Peru which are omitted from this study). The 17° July isotherm eliminates the southernmost portion of this region from present consideration, and also the elevated approaches to the Andes in the west (Fig. 7, region 3). The approximate ground frost line diverges little from this isotherm, though an occasional massive northward movement of polar air between the Andes and the Brazilian highlands, across Paraguay and western Brazil, may cause frost throughout southern Mato Grosso

Most of the remainder receives between 800 and 2000 mm AAR, the only exceptions being: (a) two wetter regions, one an extension of the Amazon system into Mato Grosso, the other a small isolated area of central Brazil (Fig. 8, regions marked 1); and (b) an extension of the dry northeast zone of eastern Brazil as far south as the middle reaches of the São Francisco valley (Fig. 8, region 2).

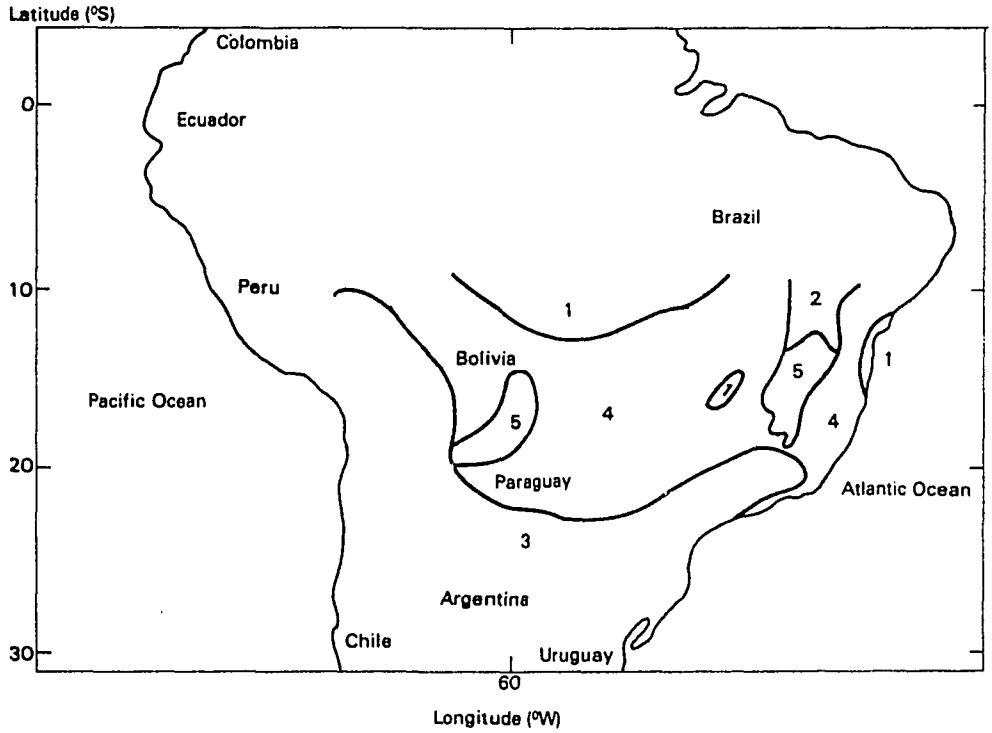

Figure 7. **Elimination of regions with unsuitable rainfall and temperature characteristics. 1 = receiving more than 2000 mm AAR; 2 = receiving less than 800 mm AAR; 3 = below 17°C July average daily isotherm; 4 = receiving between 800 and 2000 mm AAR but with DSC in excess of 400 mm; 5 = as 4 but with DSC less than 400 mm.**

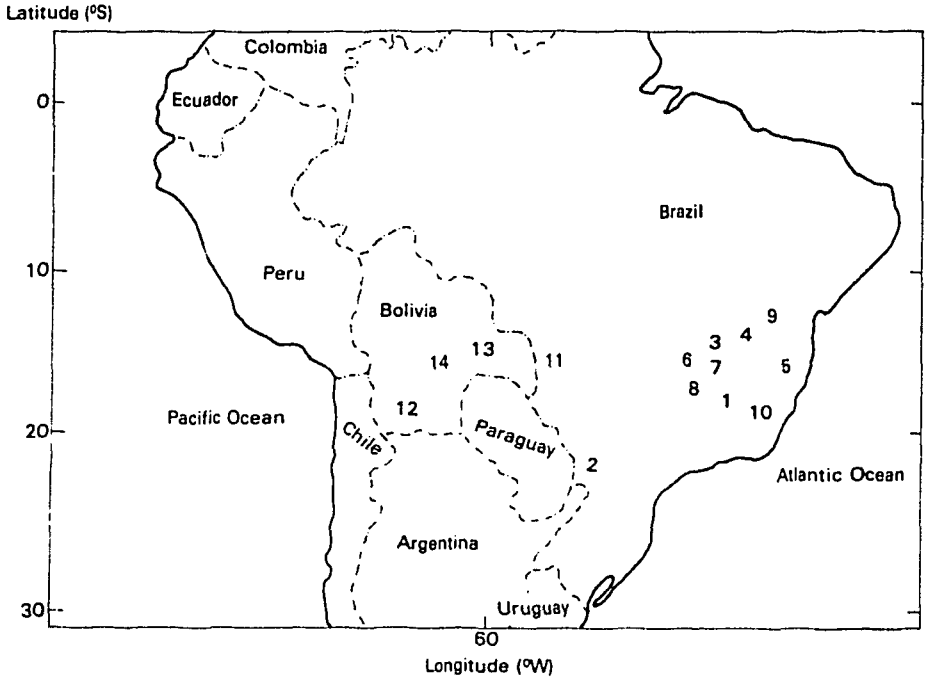

Figure 8. **Map of South America showing positions of stations listed in Table 7.**

This still leaves a very extensive area, but the greater part of it receives too high a DSC to be considered satisfactory for seed production (Fig. 7, region 4), and only two relatively small regions within it (5) fulfil this final requirement.

One is in the southeast corner of Bolivia, probably extending into adjacent northwestern Paraguay. Here a strip of land between Villa Montes in the south and Concepción in the north, bounded by the Andean foothills to the west and stretching east along the Brazilian border, satisfies the required criteria (Table 7, Fig. 8 stations 12 and 13).

The other area of interest is in eastern Brazil between latitudes 14 and 20°S and longitudes 42 and 45°W. It includes much of central northern Minas Gerais and extends over the border into the state of Bahia. The low DSC of this region is partly explained by the rain shadow effect of the Serra do Espinhaço during the winter months, and the only weak southward movement of tropical air masses.

The varied topography of this region suggests that, besides its general suitability for seed production, climatic niches favorable for every required legume will exist. The northern part, for example, appears to be well suited for seed production of *M. atropurpureum* and most of the *Stylosanthes* group (e.g. Table 7, stations 3 and 9), the southern to the *Desmodium* spp. and *G. wightii* cultivars (e.g. station 8).

Mexico and Central America

The region lies for the whole year between the equatorial trough and the sub-tropical high pressure systems of the Atlantic and Pacific. Although it is almost always under the influence of maritime air masses, local variation in both annual and seasonal precipitation is very great. The patterns of

Table 7. **Climatic records of selected stations in South America (Derived from 10)*.**

Station** No.	Name	Lat.	Long.	Alt.	T_1***	T_2***	AAR	DSC
		°S	°W	m	°C		mm	
1	Belo Horizonte	20	44	900	22.5	17.2	1600	470
2	Três Lagoas	20	51	300	25.4	19.2	1300	570
3	Montes Claros	16	43	600	23.8	19.0	1000	270
4	Grão Mogol	16	42	900	23.4	18.3	1200	370
5	Teófilo Otoni	17	41	300	24.7	18.5	1200	470
6	Pirapora	17	44	500	24.7	19.5	1100	330
7	Curvelo	18	44	600	24.0	17.8	1400	420
8	Sête Lagoas	19	44	700	22.9	16.8	1200	360
9	Caetité	14	42	900	22.6	18.9	800	270
10	Caratinga	19	42	600	22.8	16.3	1200	410
11	Corumbá	19	57	100	26.7	21.0	1100	510
12	Villa Montes	21	63	400	29.1	17.1	800	250
13	Concepción	16	62	500	26.2	20.9	1000	280
14	Santa Cruz	17	63	400	31.0	15.0	1000	490

* See Table 2 for explanation of terms

** Stations 1 to 11 are in Brazil; stations 12 to 14 are in Bolivia

*** T_1 refers to December or January, T_2 to July.

both rainfall and temperature are dictated by topography, and are very complex. Therefore one cannot, at the present level of treatment, map the region with accuracy, and many local anomalies in the general pattern will be found.

Nevertheless, certain parts of the region can be eliminated with confidence. The whole northern inland of Mexico, for example is too cold (Fig. 9) and too dry (Fig. 10, region 1). The highlands of Guatemala and the adjoining Mexican state of Chiapas are too cold, and a broad band from the Isthmus of Panama to the Gulf of Mexico is too wet (Fig. 10, region 2).

Within the remainder, much has too high a DSC (Fig. 10, region 3), but it is at this point that local variation defeats the cartographer. Several stations, representative perhaps of small isolated areas, fulfil all the requirements for seed production, though they lie in regions broadly deemed unsatisfactory (Table 8 and Fig. 9, stations 6, 7, 8, 9, 10). A number of suitable districts might also be found along the southern slopes of the Sierra Madre del Sur, particularly if irrigation is available.

Two regions of Mexico show more general promise. One is the central valley of Chiapas (stations 1 and 2), the other is the states of Colima and Jalisco on the west coast (stations 3, 4, 5). Central America, though generally too wet, also contains two limited areas of interest, one on the Honduran plateau (station 10), the other on the lower slopes of the Motagua valley in central Guatemala. Though lacking temperature data for this latter district, we think that it fulfils requirements.

ASSESSMENT OF THE VALUE OF CLIMATIC INDICES

The weakness of an approach that relies on the use of sweeping indices is that it

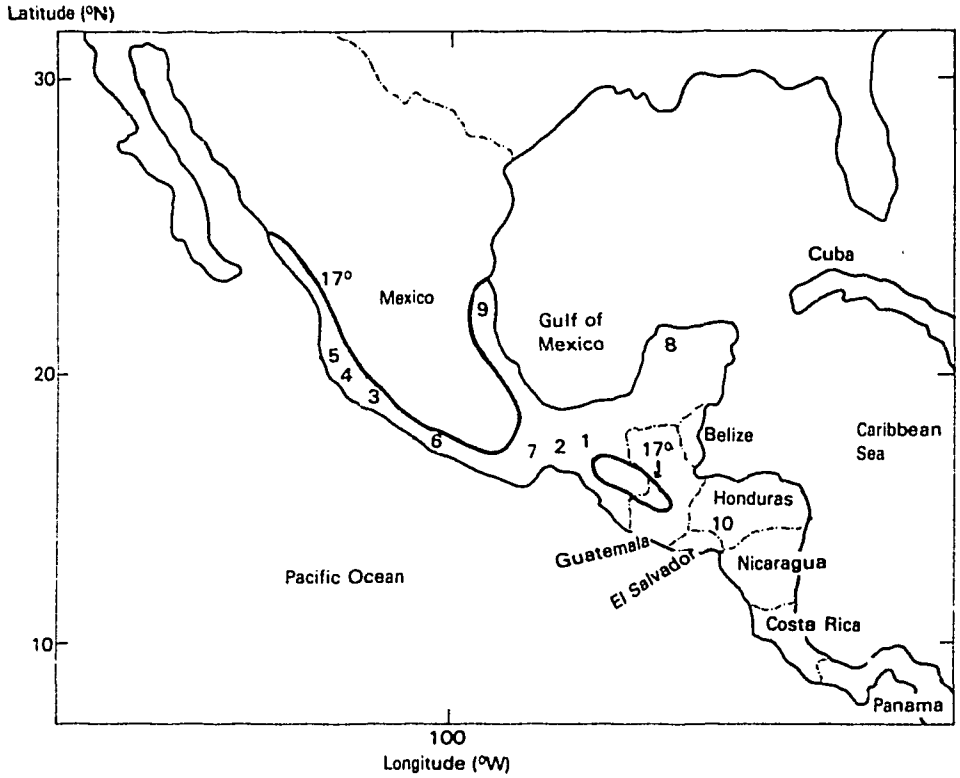

Figure 9. **Map of Mexico and Central America showing positions listed in Table 8, and the 17°C July isotherm.**

tempts their user to judge its results too categorically. There is seldom a sharp boundary between regions of suitable and unsuitable climate; and the picture is further blurred when either inadequacy of a climatic record or imprecision in the definition of a specific index introduce doubts about the prevailing conditions, or their effects.

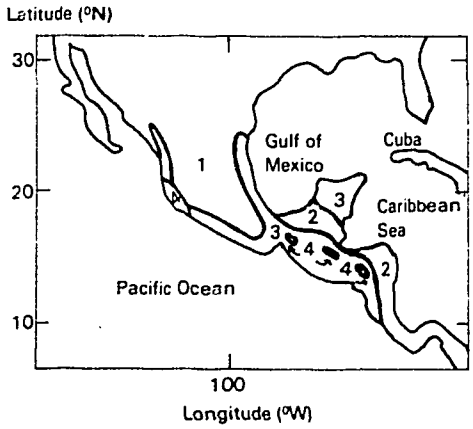

Figure 10. **Elimination of regions with unsuitable rainfall characteristics. 1 = receiving less than 800 mm AAR; 2 = receiving more than 2000 mm AAR; 3 = receiving between 800 and 2000 mm AAR but with DSC in excess of 400 mm; 4 = as 3 but DSC less than 400 mm.**

For example, we cannot state how greatly the frost risk would prejudice seed production over a large area of northern peninsular India, since we know neither how great the risk is nor how big a risk a still hypothetical seed industry could tolerate. Similarly, we cannot judge how seriously the marginally unsatisfactory rainfall distribution of extensive areas of central Brazil will interfere with production and long term stability in a seed industry which already exists there. All that we can say in either case is that, climatically, the prospects are better elsewhere.

Also, assessment on the present scale is

Table 8. **Climatic records of selected stations in Mexico and Central America (Derived from 10)*.**

Station No.	Name	Lat.	Long.	Alt.	T_1**	T_2**	AAR	DSC
		°N	°W	m	—— °C ——		—— mm ——	
1	Tuxtla Gutiérrez	16	93	500	27.2	20.7	900	170
2	Cintalapa	16	93	600	24.9	19.9	800	180
3	Colima	19	103	500	26.4	22.4	900	160
4	Ameca	20	104	1200	24.1	16.9	900	180
5	Ahuacatlan	21	104	1000	25.5	17.8	800	130
6	Acapulco	16	96	<10	28.8	26.7	1400	240
7	Salina Cruz	16	95	60	29.5	25.6	1000	160
8	Merica	20	89	20	27.8	23.0	900	330
9	Tampico	22	97	70	28.2	19.2	1000	330
10	Tegucigalpa	14	87	1000	23.1	19.3	800	360

* See Table 2 for explanation of terms

** T_1 refers to May or June, T_2 to January.

too coarse to take account of local climatic patterns where these vary greatly over short distances. We consequently find ourselves unsatisfactorily vague about the prospects, for example, of western peninsular India or sections of southern Mexico.

The reader must therefore beware of interpreting our conclusions too rigidly. He must use them as a starting point only, and make his own judgements about how appropriate they are to his particular requirements.

Our approach, in other words, is only a preliminary exercise. It identifies broad regions of high and low potential, and allows the planner to concentrate his attention (without wholly neglecting the marginal lands) on the limited areas of greatest promise. There he will find that, besides climatic details not revealed in the broad survey, he must take account of topographical, pedological, biological, social and economic factors. He must also start to consider individually each cultivar that is important to him. But at least he will be able to do so with the minimum dilution of resources and the maximum prospect of success at the end, provided he has made the correct initial choice of climatic range within which to operate.

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TROPICAL GRASS SEED PRODUCTION IN AFRICA, WITH PARTICULAR REFERENCE TO KENYA

Jos G. Boonman*

ABSTRACT

The role of sown pastures and seed production is described. Traditional concepts as regards the problems of grass seed production are discussed in the light of experimental evidence. Tropical grasses display a wide range, of many weeks, in (a) heading date between plants within varieties, (b) heading date between tillers within plants, and (c) flowering within heads. This lack of synchronization is the major cause of low seed yield. Seed yield, expressed in terms of pure live seed (PLS) yield, can be increased substantially by adequate and timely application of nitrogenous fertilizer which, coupled with appropriate close row spacing, leads to a larger amount of seed to mature within a shorter time. Harvest date should aim at the maximum recovery of yields of PLS, which is achieved at a date later than that of maximum spikelet yield. Weather conditions largely account for the wide fluctuation in annual PLS yields. Breeding, based on intra-variety variation, has produced selections with a marked improvement in seed and herbage yield characters. The impact of new recommendations and new selections on seed availability and seed prices is described.

THE ROLE OF SOWN PASTURES

The relevance of seed production depends on the extent to which use is made of sown pastures. However simple this observation may appear, it does explain why so little is done on seed production in most developing countries. Important as it is to have a viable commercial machinery for making seed available to the farmers, of overriding importance are the sheer economics of sown pastures. When development sets in and where the alternatives are either to utilize existing grazing resources or to replace the existing vegetation wholly or partly, the extent to which sowing is practiced depends largely on what values are attached to the ecological approach through range management. It is here that we find opposing views applied in different countries with similar climates and similar livestock industries. In South Africa emphasis is on veld management, while in Australia the policy has been to replace the vegetation with sown and fertilized grasses and legumes, often giving immediate and staggering increases in animal production. The latter policy is obviously more expensive and more risk prone in times and places of low livestock profitability, especially when the industry depends on external markets.

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In eastern Africa herbage seed production has been mainly to serve mixed-farming systems. *Chloris gayana* Kunth. cv. Katambora is widely used in Rhodesia and neighboring countries in rotation with tobacco to control root-knot nematode. In Kenya and the foothill areas of Mount Kilimanjaro, *C. gayana* cv. Tanzania and *Setaria anceps* Stapf. ex Massey cv. Nandi have been in general use in maize or wheat rotations. The Serere Agricultural Research Station in Uganda has shown that *C. gayana* and other grasses are effective in cotton rotations. Such pastures are less dependent on livestock profitability alone as they are considered essential to maintain the soil-productive capacity of the arable land on farms with generally constant numbers of livestock.

In spite of increased fertilizer use on crops, temporary pastures are still needed to maintain soil structure and to control noxious weeds in the arable rotation. Impressive records are on hand to show what the inclusion of temporary pastures achieves in terms of improved crumb structure, rainfall infiltration, reduced run-off and weed control (J.G. Boonman and P.M. Ahn, University of Nairobi Bulletin, in preparation). It has been suggested that such pastures contribute to the economy of the nation "more through the soil than through the rumen". This is a reflection of the fact that crop husbandry standards are generally better than those of livestock.

TRADITIONAL CONCEPTS IN TROPICAL GRASS SEED PRODUCTION

The history of tropical herbage seed production is a very young one. It started around the turn of the century in southern Africa and eastern Australia, and was pioneered by farmers along with the varieties they had brought into cultivation from the local flora or from accidental or purposeful introductions, many of which are still among the most popular up to the present day in these countries. Seed production research is of even more recent origin. Researchers have been reluctant to enter this enigmatic, obscure subject, which is neither pasture nor cereal science. Research reports have been few and scattered, often the fruit of first and once-only efforts of young graduates. To be relevant, seed production research requires a long-term exposure to day-to-day events in the field. It is not a subject for greenhouse studies as flowering is easily impaired. Sympathy must, however, be felt with pasture workers who feel compelled to devote part of their time to solving seed problems in support of their pasture improvement programs, yet are frustrated by the inconsistency of the results. Seed yield is more sensitive than herbage yield to what one does and in particular, to what one does wrong.

As a logical consequence of limited research some concepts and practices are still holding ground which have been hampering the development of seed production and sown pastures.

Tropical grasses have been said to be too wild and too undomesticated. True as this may be in the sense that one cannot see a clearcut distinction between cultivated and wild grasses, the same lack of domestication applies to temperate grasses, which present much fewer problems in seed production.

Meiotic irregularities and, particularly, apomixis which is widespread in tropical grasses were said to be active impediments to good seed yields. This concept was brought about by some cytological reports in the 1950s from India and the Americas. *Digitaria decumbens* Stent. is usually quoted as an example of a sterile interspecific hybrid. It would, however, be misleading to assume that an apomictic mode of reproduction necessarily leads to low seed yield. *Poa pratensis* L. and obligate apomictic temperate grass, produces good seed yields in temperate countries. *Melinis minutiflora* Beauv. and *Brachiaria ruziziensis* Germain & Evrard., which Bogdan (2) tentatively termed as apomictic at Kitale, are

no worse than the cross-fertilizing species in seed yield.

Full vegetative and generative development have been regarded as mutually exclusive. The view was held that, since grasses were chosen for their herbage value, low seed yields should be taken for granted. However, there is a considerable body of evidence now to indicate that it is not correct to generalize. Within species the best seed producing varieties are also the best herbage producers and, when compared at similar physiological stages, usually also the best in nutritive value (21). At the genus and species level, however, fodder type grasses such as *Pennisetum purpureum* Schumach. and grasses with strong colonizing ability (e.g. turf species of *Cynodon, Digitaria*) scarcely produce flowering heads, let alone seed.

Seed yields have been wrongly expressed only in terms of spikelet yields, with disregard to seed viability. Seed viability, expressed in % pure live seed (PLS), is a very variable character. Percentage of PLS can range from 0 to over 80 in good seeding grasses and what looks like a high yield may in fact be worthless because of no viability. When sown obvious disappointment will follow. Often as not there is a complete lack of a positive relationship between yield and percentage PLS. For instance, high N fertilizer levels increase yield but decrease percentage of PLS while increases in row width decrease % PLS in both *S. anceps* and *C. gayana* (5, 6). Maximum "spikelet yields" are obtained one week before maximum PLS yield and two weeks before maximum % PLS are achieved (8). Also in the breeding work a general lack of relationship (r = 0.09) was found between yield and % PLS in a population of *C. gayana* (10).

Purity tests are already a step in the right direction but pure seed of Kitale grasses may still give a range in % germination from less than 20 to over 80 in the best seeding grasses. Dormancy problems are no genuine reason to leave out germination tests as it should be easy enough to establish when dormancy is at its minimum.

In agronomy and breeding work we are basically interested in relative differences so that procedures can be employed which are quicker and simpler than the official seed testing standards. At Kitale all agronomy and breeding seed samples pass through germination tests, so that the actual PLS yields, i.e. the real value of the seed, can be determined.

Problems with seed production have led to the alternative use of vegetative propagation. In many countries use is made of species of *Pennisetum, Cynodon* and *Digitaria,* established vegetatively as no seeding varieties of these species are available. This is justifiable if these are far and away the best available. Whether mechanized or not, vegetative propagation is bound to be more expensive and troublesome. The Kenya experience is that vegetative propagation gives the small farmer a heavy labor burden which seems better spent on farm crops having peak labor requirements at the same time. Digging, transporting and planting readily require 25 man-days per ha. Side spacing is more convenient but increases the weeding load, especially if weed grasses are mistakenly, but often inevitably, transplanted with the main grass. Mortality of canes or splits can be high unless rain is received daily at the time of establishment. Perhaps unexpectedly, good seeding grasses such as *C. gayana* give a more rapid cover and herbage than vegetatively established grasses. Grasses than are easy to establish vegetatively are also the hardest to eradicate from temporary pastures in crop rotations. However, the most important argument calling for caution is that of the risk of diseases, as has been experienced with *D. decumbens* in the Caribbean region. Vegetatively propagated grasses are usually of a very narrow genotypic range, often only one clone. In Kenya, both *P. purpureum* and *Cynodon* spp. are under serious attack from a number of pests and diseases.

Supplementary to sown grasses, *P. purpureum* is a valuable fodder for the dry season and a selection program is underway to find resistance against *Beniowskia sphaeroidea, Khuskia oryzae* and other yet unidentified diseases (van Gastel, unpublised).

The argument is often adduced that the small farmer neither has the cash nor the mobility to acquire seed, if at all available. However, once the farmer has gone to collect the right grass, he may easily use part of it to grow a seed crop. In the small-farm settlement schemes near the Cherangani Mountains in Kenya this is an increasingly popular practice and a modest farm-to-farm trade has started to build up. Home-grown seed may be the answer also in hot and moist climates where storage-life of seed is too limited.

In seed production we have difficulty in coping with the ever increasing number of species and varieties which plant introduction officers and breeders find "promising". Sheer numbers do not, however, make up for lack of adequate knowledge about growth requirements and range of adaptation and more should be done to gain the knowledge required before seed production officers are asked to grow the seed. At the basis of it all is that there are so many alternative species available, yet we do not have the adaptive equivalent in the tropics of a *Lolium perenne* L. or a *Trifolium repens* L. of the temperate climates. Many introduction officers are out to find new material that is different from what is already available, e.g. successful chance introductions. The "species concept" has dominated pasture research in many countries at the expense of agronomic alternatives. Drought tolerant species have been sought too often where the obvious alternative would have been first to make hay of surplus growth. Hay making is a common practice in Kenya.

Cooperation is also needed from the physiologists to give answers to the basic question to what extent our grasses are responsive to daylength. Is it daylength or interplay of daylength, temperature and moisture factors? More information is also needed on tillering and reproductive development to reach a better understanding of the seed formation processes.

THE PRESENT STATUS OF SEED PRODUCTION

Seed production efforts have been limited to those countries which had viable pasture improvement programs. Yet, South Africa, Rhodesia and Kenya are the only countries in Africa with a grass seed industry viable enough to permit commercial seed exports. The presence of a surplus for export may be used here as a criterion to assess the viability of the activities in various countries. Zaire (1), Tanzania (12), Nigeria (15) Uganda (Newhouse and Waterhouse, unpublished) and Ethiopia (13, 14) have had ups and downs in seed production activities, rarely effective enough to have a lasting effect on the farming community. Aid programs designed to impose a seed industry from government level are also precarious. Various examples of these on the African continent have shown that it is easier to build a seed factory than a seed acreage.

The Kenya experience

Things began moving fast in Kenya, after a number of preliminary Government stations' efforts, when a number of grass seed growers bundled their efforts together and established the Kenya Seed Company in Kitale in 1956. A modest start it was but it soon became a focus of activity for research, extension and trade. Tropical grass seed and white clover were the first ventures, but sunflower, hybrid maize (now the main item), wheat and barley followed over the years. All these have seen rapid developments. Government breeders, seed growers and tradesmen now had their common meeting ground. It is this trinity with mutual cooperation that forms the essential basis of a good seed industry that is to achieve its ultimate goal: to supply the farmer with quality seed of the best

varieties. In the early 1970s a seeds authority and a seeds act came into being to regulate the smooth passing on of the varieties from the government breeders right down to the ordinary farmer.

The Kenya Seed Company, in which the Kenya Government has now acquired a major share, receives the basic seed from the National Agricultural Research Station, multiplies it one stage further on its own farm and then makes arrangements with a few dozen seed growers for the further multiplication to certified seed. Close guidance is provided to the grower. All the costs of seed, field operations, transporting, seed cleaning and packaging are the grower's, but he is assured of an agreed price, based on the full value of the seed, i.e. on the % PLS as determined by the Official Seed Testing Station in Nairobi. After processing the seed is distributed by the Kenya Seed Company via the normal commercial channels dealing with agricultural inputs. An elaborate system has been worked out to take seed in small packets to even the remotest villages. Grass seed sells at about US $15.00 per kg PLS. The seed rate to establish 1 ha is 1-1.5 kg PLS.

Varieties

The main grasses grown for seed are *S. anceps* cv. Nandi and varieties of *C. gayana* (Table 1). As for legumes, no seed of *T. repens* cv. Louisana or *Trifolium semipilosum* Fresen is produced any longer. *Desmodium uncinatum* (Jacq.) DC. was produced commercially in the 1960s following regenerated interest in legumes but the demand for seed was short-lived. The only fields still under production are those under my care at the Kitale station. *D. uncinatum* is doing well when grown with infrequently cut grasses (19), with cut or grazed *P. purpureum* and when oversown into native pasture (18). In mixture with *S. anceps* or *C. gayana* however, *D. uncinatum* does not stand up to the grazing pressure that farmers get from the companion grass under continuous or rotational grazing. The search for alternative legumes is continuing unabated, but it is feared that it may be difficult

Table 1. **Characteristics of the main Kitale varieties.**

Species and variety	Heading sequence*	PLS yield per crop*	Certified seed production**						
			1965	1967	1969	1971	1973	1975	1977
	weeks	kg/ha	ha						
S. sphacelata cv. Nandi	3	30	180	260	240	310	40	260	90
C. gayana cv. Mbarara	2	44	190	220	170	490	230	180	460
C. gayana cv. Elmba	1	90						10	40
C. gayana cv. Masaba	4-5	40	50	50	110	160	30	310	520
C. gayana cv. Boma	3-4	50						20	190
C. gayana cv. Pokot	6	24	5	50	470	530	50	160	0
P. coloratum cv. Solai	1	52	40	40	90	140	20	0	5
P. maximum cv. Makueni	1	25	5	5	15	15	20	1	1
B. ruziziensis	9	23	5	5	5	5	20	40	20
Seed yield of standard quality*** (kg/ha)**			75	64	77	91	102	95	101

* After Boonman and van Wijk, 1973, Table 3

** Data supplied by Kenya Seed Company and Kenya Inspection Service for Seeds

*** 25-30% PLS.

to find a suitable legume that will stand up to the grazing pressures to which short-term pastures on mixed farms are subjected. Unfortunately, we have very few exotic legumes naturalizing freely to any appreciable extent.

C. gayana is used from sea level to 2500 m altitude and also does well in the lower rainfall areas (750 mm). *S. anceps* cv. Nandi does well in the well-watered areas with an altitude range of 1000-2750 m. The best agricultural areas with mixed farming in Kenya are in the 1500-2750 m altitude range, receiving over 1000 mm rainfall and a mean annual temperature of 22 to 15°C, respectively, with little monthly variation. Above 2500 m temperate grasses are replacing *C. gayana* and *S. anceps,* use being made of *L. perenne, Festuca arundinacea* Schreb. and *Dactylis glomerata* L. About 75% of Kenya is below 1500 m and, with the exception of a narrow coastal belt, receives insufficient rainfall for sustained crop production. Very little use is made of artificial pastures in these areas.

In 1953 pasture research was started at Kitale which was considered to be the most representative of the high potential areas of the country. Following earlier work done by D.C. Edwards in Kabete, near Nairobi, R. Strange and A.V. Bogdan inititated an introduction program at Kitale of grasses and legumes which would exceed 4000 introductions by 1965, the year Bogdan left Kitale. Over 130 ecotypes of *C. gayana* and over 100 of *S. anceps* were introduced and screened (2), but equally as many entries were screened of *Cynodon* and *Cenchrus ciliaris* L. which proved to be less worthwhile. This introduction work was not entirely a novelty, although it yielded very valuable varieties (Table 1). Settler farmers had pioneered this field from the early days, introduced material from southern Africa or collected seed from attractive natural stands of *C. gayana,* took it to their farms and multiplied it. *C. gayana* cv. Nzoia and *M. minutiflora* cv. Kitale were probably introduced from South Africa (Bogdan, personal communication). Over the years both varieties have developed serious leaf diseases and this may well be connected with their foreign origin. Unlike Australia and South America, we have no record of other grasses which had been introduced from other countries or which had become naturalized before being taken into active cultivation. One would not anticipate this is a center of genetic diversity anyway, but neither does Kenya have examples of exotic legumes naturalizing to any appreciable extent.

Table 1 shows that there has been a move away from late-heading *C. gayana* varieties to early ones. Everything else being equal, early-heading varieties tend to be more popular, because their better seeding abilities result in cheaper seed. It has also been established now that for instance the late-heading *C. gayana* cv. Pokot lacks persistence and does not have the drought tolerance it was said to have.

Seed production practices

Until 1975 all grass seed was grown in the Kitale area, in close proximity to the Kenya Seed Company premises. Many of the large-scale farms in the Kitale area have now been split into smaller units, making seed production more difficult, and as a result some production has moved to the Nakuru area, halfway between Kitale and Nairobi. Both the Kitale and the Nakuru areas have long growing seasons from April to November, receiving 1000 - 1200 mm well distributed rainfall. The average annual temperatures are 17.5 - 18.0°C.

Seed is drilled in 90 cm rows, the standard row width of most implements set for maize cultivation, but preferably in 30-60 cm rows (Table 2). The standard seed rate is 1 kg PLS/ha. Phosphate fertilizer at a rate of 50 kg P_2O_5/ha is mixed with the seed at sowing.

The best time of sowing is at the start of the rains when the soil is still warm and of

Table 2. **Traditional vs research-based recommendations in grass production.**

Practice	Traditional	Research-based	PLS-yield increase
Time of sowing	After maize sowing and cultivation	At onset of the rains	variable
Seed rate	1-1.5 kg PLS	Same	-
Superphosphate	50 kg P_2O_5/ha in seedbed	Same	-
	50 kg P_2O_5/ha topdressed	None	-
Inter-row cultivation/ subsoiling	Yes	No	-
Chemical weed control	1 liter 2.4-D/1.5 - 2 liters MCPA	Same	-
Row width	90 cm (standard implement setting)	30-60 cm	30% (*S. anceps*)
Nitrogen fertilizer	50-60 kg N/ha	100 kg N/ha	50-100%
Time of N application	After maize sowing and cultivation	At onset of the rains	100%
Seed harvest time	At first shedding	At 30% shedding*	50%

* % relative to spikelets present at time of harvest.

good structure, but most growers wait until they have finished with the maize. The best seed bed is one that is freshly harrowed and rolled before sowing.

Dicotyledonous weeds are controlled with 2,4-D and MCPA, depending on the species involved, while annual grasses should be no problem on land which has been properly rotated. Where annual grasses are troublesome, no seed harvest is usually obtained in the year of establishment. Under normal circumstances, however, it is customary to have the first seed crop ready for harvesting in September-October, five to six months after sowing. A second and, on good land, a third flush of heads can be harvested in December and February, respectively.

Harvesting is done with sickles by hand and is therefore largely weather-independent. Experienced workers usually need 15 to 20 man-days/ha for all operations involving cutting, binding and stooking in the field. Top workers can cut and stook up to 0.20 ha/day/man. Even at lower work capacity, hand harvesting costs less than half compared with mechanized combine harvesting, were this at all feasible under the prevailing weather conditions. Stooking is, however, important as it permits unripe seed to mature on the stems. Combine harvesting has, thus far, given seed of low quality.

The first topdressing with nitrogenous fertilizer is given after the dry season, in April (Table 2). Harvesting will take place in June-July. If the aftermath herbage is cut a second topdressing may follow and a second harvest is ready by the end of the year. Many growers prefer not to have a second seed crop but to use the aftermath for hay. Most of them are too late with the early-season topdressing anyway leaving no time for a second crop to develop.

The same sequence can be repeated for a number of years, without any apparent decline in yield or an increased need of fertilizer. *C. gayana* seed fields tend to loose vigor on the poorer soils after four years and give way to invading weeds, but *S. anceps* seed fields can be kept productive for considerably longer.

Hay is a highly valued by-product of the seed production system.

FACTORS AFFECTING SEED YIELD IN TROPICAL GRASSES

Low seed yields

The complex of properties associated with low effective seed yields in tropical grasses can be assembled under two major headings: (a) low inflorescence (head) number and low spikelet weight per inflorescence (low crop index); and (b) low efficiency of available inflorescences and spikelets.

Tropical grasses have a very low crop index (ratio of seed yield to total herbage DM yield at seed harvest). Seed crops of Kitale grasses rarely have more than 350 heads per m². Spikelet yields of *S. anceps* cv. Nandi and *C. gayana* rarely exceed 150 kg/ha, whereas DM yields usually exceed 7500 kg/ha at the time of seed harvesting, thus giving a crop index of not more than 2%. This is reduced to 0.5-1.0 if only viable seed is considered. However, in temperate grasses crop index is often above 20% and in well developed cereals usually above 50%. This shows that the seed yield potential, as determined by head number and spikelet weight, of present-day varieties of tropical grasses is extremely low. These low head numbers and low spikelet weight set the upper limit to the potential seed yields of the available varieties.

The situation is further worsened by the low efficiency of the available heads and spikelets. The main reasons for the low efficiency are: (a) prolonged heading between plants within varieties (see below under "breeding"); (b) prolonged head emergence within plants, continuing for months (Fig. 1); (c) prolonged flowering within heads, continuing for weeks (Fig. 1); and (d) reduced flowering and seed set in late-emerging heads (Fig. 1).

In tropical grasses not only tillering but also heading is an extended process (Fig. 1). Daylength effects, which cause tillers of very different ages to elongate and head within a

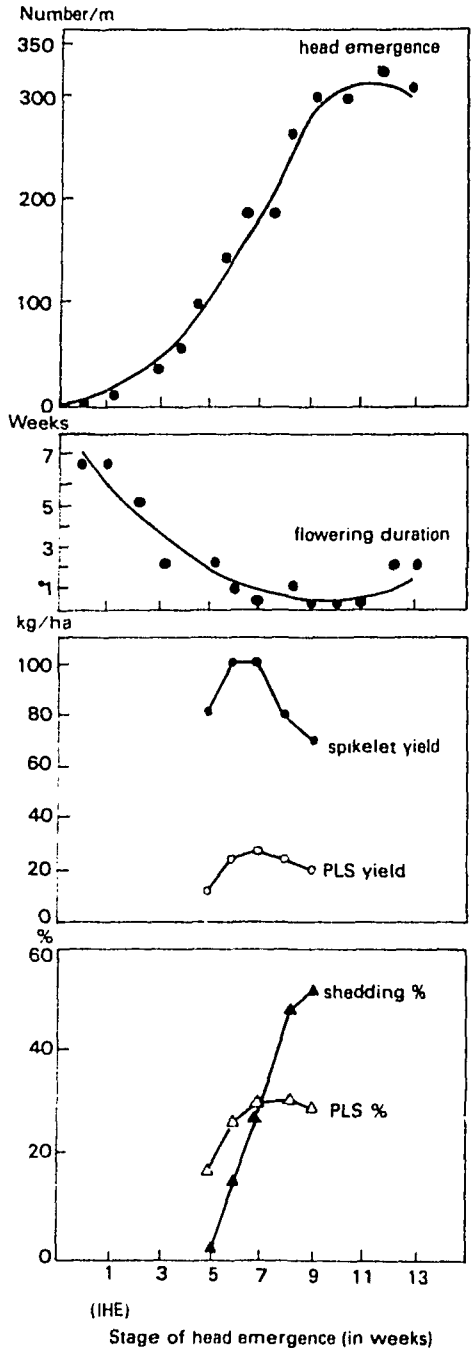

Figure 1. **Seed crop characteristics (4,8).**

matter of days in temperate grasses, are absent in equatorial regions and even beyond the latitudes of both tropics daylength effects are far from clearcut; except in a few grasses (17), daylength effects may well be confounded with temperature and moisture effects.

Consequently, seed maturation is not synchronized, which is aggravated by seeds shedding when over-mature. At any harvest date, only a fraction of potentially maturing heads are within the margins of either being overripe or underripe if at all having emerged. This causes the low yields of harvested seed. Secondly, of the heads which have contributed to the harvested seed there is a range of maturation in the seeds which have developed within the margins of shedding and underripeness. Thirdly, flowering and seed set decline progressively in later emerging heads, yet the unfertilized spikelets shrivel and detach all the same, even within a week or so after head emergence. This mixture of unripe and empty spikelets is responsible for the % PLS in the low yields already obtained.

Because of the large amount of shedding other workers have attributed the causes of low seed yield directly to shedding or to the low recovery of seed. It has been suggested that breeding for improved seed retention would go a long way to solving the seed yield problem. As pointed out above, however, shedding is a secondary event, depending primarily on poor synchronization and seed setting. A purity and germination test of the shed, unrecovered seed would, on the other hand, show that much of the normal shedding is seed of low or no value. Both the value of what is lost and what is retained can be assessed by no better method than a germination test. Similarly, a spikelet count to assess the seed set within an inflorescence is not complete without such a test.

Ways to increase seed yield

In accordance with the causes of low seed yield given above, it follows that seed yields can be increased through either or both of the following: (a) to enlarge the reproductive system, i.e. to increase the number of heads and the seed set per head. As seed yield is more sensitive to cultural techniques than is herbage yield, the crop index will rise also; and (b) to increase the efficiency of a standing seed crop.

Harvest date

The efficiency of a standing seed crop can be increased by the judicious choice of harvest date. Extensive studies carried out in Kitale in 1968-1971 have shown that, in general, the highest PLS yields are achieved when shedding of spikelets is about 30%, yet still some four weeks before maximum head numbers are reached (8). Both limits may be surprising as one would naturally be inclined to harvest at the first sign of shedding and, at least theoretically, want to wait for all heads to mature. Naturally, as harvesting is delayed shedding increases in an absolute sense and the losses incurred may be offset by additional maturation of underripe seed. This complication is avoided by determining the % shedding in a randomly harvested sample of heads, irrespective of their stage of maturity. Thus, much of the early shed seed is of low % PLS. Optimal harvesting time is usually some six to seven weeks after initial head emergence (IHE, 10 heads fully emerged per m^2) and usually shortly after peak emergence, i.e. the moment when most heads emerge per unit of time. However, it appears as if these heads are already too late to be efficient seed setters. The early heads —though perhaps not the very earliest which are always relatively short (5, 6)— are few but efficient, then head numbers grow rapidly but seed setting is progressively reduced until such a point where no more seed is set in youngly emerged heads.

Traditionally, growers used to harvest at the first sign of shedding. This is estimated to have resulted in PLS yields losses varying from 20 to 50%.

Harvesting techniques may be open to further improvement, e.g. by temperature treatments of the threshed seed (Hopkinson, personal communication).

Nitrogen and plant density

Having established how to harvest most of what is available it became important to find means of enlarging the reproductive system, i.e. the number of heads, the seed set per head, thereby increasing the total yield. Of particular interest was to find out whether a larger proportion of the heads could be made to emerge in a shorter time, thereby concentrating the flowering and maturation process. At the same time the total number of heads should be increased.

It was found in *S. anceps* (6) that this is possible by manipulating with tiller density and nitrogenous fertilizer. Tiller density should be such as to allow a large number of heads to emerge in a short time, thereby suppressing the development of late tillers. This requires extra N as many tillers are formed initially and a large proportion is to form a head. A row width of 90 cm was customary in traditional Kenya seed production (Table 2). This was too wide for tufted grasses such as *S. anceps*. Light penetration encourages late tillering and tillers tend to be too densely packed within the row. Wide row width also gives more problems with ecological control of weeds and volunteer seedlings, with mechanical cutting and removal of hay and with recovery after burning. The presence of a favorable climate and nitrogenous fertilizer were, however, the major attributes to make narrow row width a more attractive proposition.

Figure 2 shows the response of head numbers to N and row width levels (R). At N_0 initial head emergence (IHE) comes at the same time as at higher N levels but no increase in numbers is observed with time. With increases in N numbers were lowest at N_{130} R_{90}. Additional N had no effect at R_{90}, but had a marked effect at R_{30}. At the high N level head numbers nearly

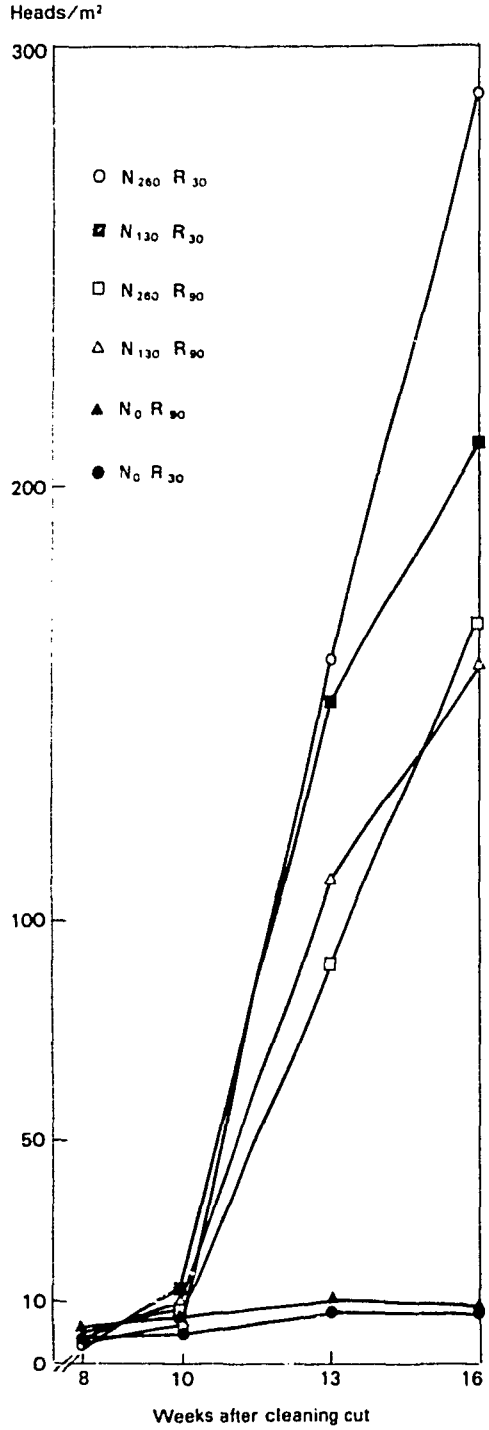

Figure 2. Numbers of heads at various levels of N and Row width (R).

doubled from R_{90} to R_{30}. Moreover, IHE was somewhat retarded by close row width. Hence, heading sets in later but then climbs faster to a higher level at close row width. This evidence of concentrated head emergence was also borne out in the PLS yields over seven consecutive seed harvests (Fig. 3).

At low N reasonable PLS yields were achieved at R_{90} but the best PLS yields were at R_{30} with the high N level. Thus, at close row width more N is required, whereas wide row width shows little response to extra N. This interaction is important to work out the optimal combination of row width and N levels against prevailing price ratios of seed and fertilizer. At current growers' prices 1 kg PLS pays for 10 kg N.

Of all variables that affect seed yield N and weather conditions (see below) are the most important. Without N seed can only be harvested economically in the year of sowing when soil-N is adequately available. In subsequent years PLS yields drop rapidly to 1-2 kg in *S. anceps* cv. Nandi and to 5-6 kg

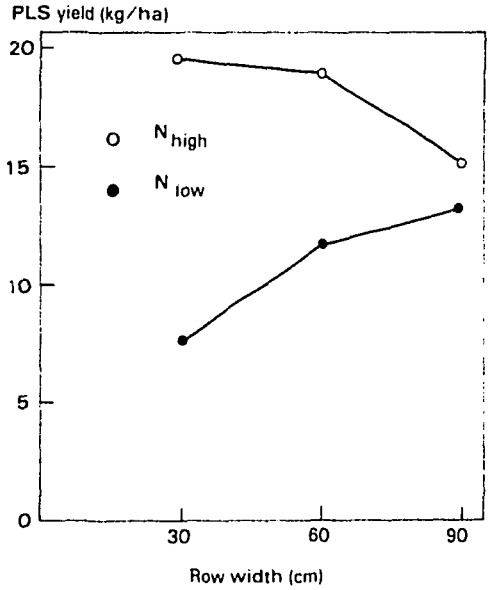

Figure 3. Influence of N regime on PLS yield of *S. anceps* cv. Nandi at various row widths. Means of seven harvests (5).

in *C. gayana* (5,6). These yields are increased seven-fold by the use of 100 kg N/ha.

Levels of N above 100 kg/ha tend to lead to a reduction in PLS yields in most seasons but are still effective in years with favorable growth conditions. The effect of high N is often to reduce both % purity and % germination, surprisingly independent of degree of lodging. N increases head length by up to a third and it is thought that longer heads have a more prolonged flowering. Evidence to support that head length is involved comes from the observation that under high tiller density shorter heads are produced giving seed of a higher % PLS (5).

Except from a little N applied in the seedbed along with the phosphate fertilizer, there is no need for topdressing in the establishment crop. First year crops develop well without N topdressing and they are often giving the best yields. This makes it the more important to achieve a good stand in the establishment year.

In subsequent years it appears as if grass seed crops need all their N fertilizer at once. Late applications only serve to encourage late, inefficient heads and are largely wasted. In the experiment concerned with the effect of split applications $N_{68/0}$ outyielded $N_{34/34}$ as well as $N_{68/68}$ (7). It is also essential to have an early cleaning cut and an early fertilizer application after the dry season when the soil is still warm and of good structure before the rains start building up. It was repeatedly observed that a delay in N-application of six weeks reduced PLS yields by more than 60% to levels close to N_0, although one would not have suspected this from the appearance of the crop at all. Herbage growth and head numbers were reduced to only a limited extent, but the main seed yield component reduced by late-applied N was the seed set per head.

Weather

Seed set and, consequently, PLS yield is also greatly affected by weather conditions,

especially rainfall. *C. gayanus* is at its best in moderately dry weather and shows PLS yield reductions when heading and maturation occur in particularly wet months. *S. anceps*, on the other hand, requires wet seasons with well-distributed rainfall. In unfavorable seasons with intermittent drought periods PLS yields may be less than 5 kg/ha, whereas in favorable seasons yields may exceed 70 kg PLS/ha (8). Again, this is largely unpredictable from crop appearance as the normal signs of a good growth —both herbage and head numbers— may well be present, when in fact PLS yields are going to be very low because of a poor seed set. Growers are advised to inspect the seed crop in good time for the presence of caryopses and to divert the crop to other purposes than seed harvesting if a low seed set is observed.

Other agronomic factors

Aspects of seed rate, phosphate fertilizer, inter-row cultivation, chemical weed control and burning have been looked into, but none seems to offer much scope for improvement anywhere near as radical as the factors highlighted above. Seed rate and phosphate have some effect only in the establishment crop (5, 6). Inter-row cultivation and subsoiling, practiced on some scale in the past, have been abandoned as unnecessary and, in fact, harmful to soil structure and the root system.

A search for herbicides with a broader spectrum and with better selectivity in the grass seedling stage has shown a number of interesting chemicals such as Ioxynil/Bromoxynil, Bentazon and Bromophenoxim, effective against broad-leaved weeds. Bentazon also suppresses *Cyperus rigidifolius*. Terbutryne and Metabenzthiazuron gave good results against the annuals *Digitaria velutina* and *Eleusine indica*. Endothal and Chlortoluron gave some control of annual *S. anceps* (20). The prices of the new chemicals are, however, too high in relation to those of 2,4-D and MCPA.

Burning experiments have been conducted with generally negative results. Burning leads to a rapid ingression of rhizomatous grass weeds (*Digitaria scalarum*) and can weaken the crop considerably in its regrowth. Burning is practiced in temperate regions to reduce the overcrowding of tillers. Little overcrowding is apparent in the seed crops under review as most tillers are formed after the dry season.

Impact of recommended practices

A summary of traditional and research based practices is given in Table 2, together with the anticipated PLS yield increases. The Kenya Seed Company and its growers have been swift in putting the new recommendations into practice. The limited number of seed growers and the guidance given to the growers enhanced the changeover. The immediate result was that the chronic seed shortages of the 1960s were transformed into the export surpluses of the 1970s. Equally important has been that seed prices have only seen an increase of 20% in all the years since 1965. The sample supply of seed also induced the Kenya Seed Company to introduce 1 kg seed packets for the benefit of the small farmer. One such packet is enough to sow ¼ ha. The same system had been applied successfully before with hybrid maize in the late 1960s along with a vigorous extension campaign so as to maximize the hybrid output through correct husbandry. Small-scale maize farming was rapidly revolutionized. The proof was given that the peasant farmer does take on innovations, if it is made clear to him that these are what he needs. Seeds bring change.

BREEDING

As pointed out previously, grass varieties display a prolonged range in heading date between plants within varieties. This has been observed in varieties of *C. gayana*, *S. anceps*, *Panicum coloratum* L. and *B. ruziziensis*. Even the last one, which has

been regarded to have an apomictic mode of reproduction, shows a marked range in heading date.

In the three commercial varieties of *C. gayana* Mbarara, Masaba and Pokot, a range was observed of six weeks between the first 5% of the plants to come into head and the last 5%, within each variety (9). Because of this wide variation it was normal to find almost complete shedding in the early heading plants by the time the last plants were just coming into head. Needless to say, such lack of synchronization in heading date is a major cause of low seed yield but also leads to varietal instability and shift over the generations of seed multiplication. The variation concerned is of a normal distribution and not the result of admixture but of evolutionary forces.

It was subsequently observed that the same plants also showed a wide range in vigor. The interesting finding was made that vigor and heading date were closely correlated. Vigorous plants were mainly composed of plants coming into head early and vice versa. Very few late heading plants were of high vigor (Fig. 4). The same had already been observed in *S. anceps* (11).

Of further interest was that individual plants varied also considerably in PLS yield, herbage yield, *in vitro* digestibility, drought tolerance and sward persistence (9). This seemed to offer some scope for breeding, but a pecularity arose when it was found that this variation was secondary, as it depended largely on the primary variation in heading date. The early heading plants were those with high seed yield, digestibility, drought tolerance and sward persistence. Late heading plants were progressively poorer in these characters.

The procedure that was followed was to classify the promising plants in maturity classes and subject these to further selection. The main objective was to select for PLS yield. Selection for herbage characters was to take second place as it was thought

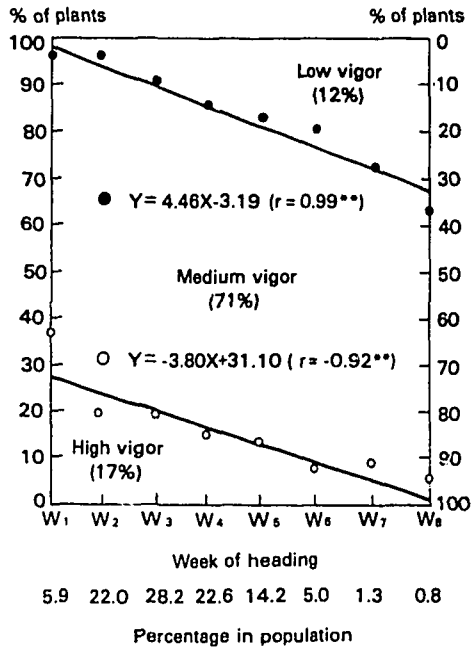

Figure 4. **Relationship between heading date and vigor in *C. gayana* plants.**

that these characters had already benefited extensively by natural selection over the thousands of years of heavy grazing pressure by herbivores in the savanna environment of East Africa. Nevertheless, efforts were made to improve these levels along with seed yield. Contrary to traditional belief that generative and vegetative improvements are mutually exclusive, it was found that simultaneous improvement is possible, provided that adequate precautions are taken.

However promising observed variability may appear, only variety trials can prove the worth of what are claimed to be the virtues of parent plants or selection procedures. A summary of the Kitale trials, 1974-1966, is given in Table 3.

The best selection with the highest overall response was Mbarara-Early, the early selection developed out of Mbarara, subsequently released under the cultivar name "Elmba": 127% gain in PLS yield; 75% gain in DM yield, three months after sowing

Table 3. **A comparison of selections and standard varieties of** *C. gayana*.

Original variety	Selection/ standard	Heading sequence*	PLS yield 1974-1976*	DM yield 1974-1976**	DM yield 3 months after sowing
		weeks	kg/ha		
Mbarara	Early	1.9	67	2900	2500
	Medium	2.9	48	3000	2200
	Late	4.2	36	2800	2000
	Very-late	5.5	28	2800	1700
	Standard	4.1	29	2600	1400
Masaba	Early	4.0	37	2700	2100
	Medium	4.4	35	2900	2800
	Late	5.7	27	2600	1600
	Very-late	6.2	17	2800	3000
	Standard	4.9	29	2600	1900
Pokot	Early	6.8	13	2900	1700
	Medium	6.9	9	2700	1700
	Late	8.1	7	2800	2300
	Very-late	8.4	5	2600	1500
	Standard	7.2	8	2400	1400
Source of variance					
Varieties		xx	xx	xx	x
Harvests		xx	xx	xx	-
Varieties x harvests		xx	xx	NS	-
$LSD_{0.05}$		0.5	7	200	900

* Mean of three harvests
** Mean of nine harvests
x, xx Significant at the 0.05 and 0.01 levels, respectively
NS not significant
LSD least significant difference.

(seedling vigor); 11% gain in overall DM yield; and 17% gain in DM yield under clipping (sward persistence).

Between themselves selections display a much wider range in heading date, 6.5 weeks, than did the standard varieties, 3.1 weeks (Table 3). Late-heading selections exceed the standards in DM yield, but their PLS yields were lower.

The current breeding work is concentrating on the early-heading sections of both early- and late-heading standards. Late-heading varieties are generally inferior, except in grazing systems where much flexibility is required in the ease of grazing management. On most mixed farms, however, over-grazing is serious and only early-heading selections can measure up to this.

As the original varieties were already popular, farmers are taking readily to the new selections. Those presently in commercial supply are:

Selection	Original variety
Elmba	*C. gayana* var. Mbarara

Boma	*C. gayana* var. Masaba
Nasiwa	*S. anceps* var. Nandi

DESMODIUM SEED PRODUCTION

Legumes are better dealt with seperately when it comes to discussing aspects such as seed production.

D. uncinatum is the only legume left with still a modest acreage under seed production at Kitale NARS (20 ha), which is a reflection of the low demand for legume seed. Seed sells at about US $8.00 per kg.

Establishment is slower than that of grasses and weed control problems are more serious. The results of pre-emergence herbicides have been disappointing. For post-emergence application 2,4-D, MCPA, Bentazon and Nitrofen were selective, but the best control was obtained with Bentazon and 2,4-D. If applied when *D. uncinatum* is young, 2,4-D is both selective and effective (20). Very good results have also been obtained by adding 1.6 kg Simazin to 0.7 liter of 2,4-D amine per ha.

Unlike in the grasses, weed control problems also continue to be serious in subsequent years. Both broad-leaved and perennial grass weeds (*D. scalarum*) are quick to invade and spread in the seed field. In Kitale we use mixtures of Dalapon (5 kg/ha), and Simazin and 2,4-D (1.6 kg and 0.7 liter, respectively) in April when *D. scalarum* is just beginning regrowth after the onset of the rains. This gives complete control but damage to *D. uncinatum* occurs if application is late.

Flowering begins in August and goes on until well into the dry season. Pods are seriously attacked by bollworm and spraying is necessary from early September onwards.

Harvesting is normally done in December and January. Handpicking is the cheapest method but this work is unpopular because of the difficulties of wading through the mass of vines with pods hooking easily to clothes. Direct combining with a powerful combine from partly dried-up stands gives the best yields. Cutting and windrowing prior to combining seems to give little advantage and, in fact, was found to slow down the movement of the combine. Desiccation of the standing crop with Diquat also gave no advantage and it was feared that pods hooked to the leaves would drop to the ground.

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EXPERIENCES IN TROPICAL PASTURE SEED PRODUCTION IN BRAZIL

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ABSTRACT

The author narrates his experiences as a businessman in legume and grass seed production on poor Cerrado soils in the state of Mato Grosso, near the Paraná River. Profitability and facility of production are the main aspects that should be taken into account when planning to embark on this type of enterprise. Grass production has fewer problems and is much more profitable than legume production since the only difficulty arises when harvesting and drying during rainy periods. On the other hand, legumes have many weeds and diseases, are difficult to harvest and, above all, their demand is very low. Thus 75% of the total area (1000 ha) will be sown with grasses. To illustrate this special type of operation, the author includes a two-year project for grass and legume seed production, in which first year sales should equal costs and second year sales should be at least as good, but with a 60% reduction in costs. The sequence of operations is as follows: (a) land cleaning and preparation; (b) sowing; (c) seed harvesting and sun drying (on concrete or earth patios); (d) seed cleaning (by means of vibrating screens, blowers and gravity tables); and (e) marketing. He considers himself as a kind of link between the researcher and the farmer. He multiplies the promising varieties on a commercial scale, which takes from two to three years, and sells them to farmers who keep him informed of the results on their farms. To date, his approach has been more that of a farmer than that of a corporation or a research center, and office staff and space have been minimal. In the immediate future, the objective is to sell grass seed premixed with legume seed in order to promote legume cultivation, which has been little accepted in Brazil up to now, until research demonstrates its utility and necessity in the short term. Finally, he suggests that the combined sowing of legumes and grasses should be established as a requirement for the approval of Government loans.

My interest in pasture dates from an early age and started from a fascination of the beauty of what today is called the symbiotic relation of legumes/grasses and came to me through the writings of Louis Bromfield from my home state of Ohio in the United States. However, I was not aware there was much activity with respect to tropical pastures until knowledge of the so-called "Revolution in Tropical Pastures" initiated by Australian research, reached me in 1964. Right away I started with as many of the new varieties of grasses and legumes as I could get samples of in my backyard and have been going strong ever since. The commercial part was actually necessary to support the hobby.

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TYPE OF OPERATION

My operation in Brazil has been described as "unique", so I present it as that. In broad terms I enter into an agreement with a property owner interested in pasture improvement or developing new lands for cattle, and form a 50-50 partnership in which we plant the land, or a portion of it, harvest several seed crops, then turn it over to the owner as an improved pasture ready for grazing cattle.

The profit margin can be high from seed production. This allows a better job of pasture establishment and management than might be possible counting only on profits from cattle. A better job includes thorough land clearing which is essential for harvesting with a combine, liming, fertilization, seeding, cutting, etc. I believe allowing the plants to mature in the beginning is good for the future pasture, too. In other words the seed enterprise is a vehicle for establishing pastures. Seed gives profit before cattle would, and pays for the development in a magnificent way.

A dependable source of seed of the best varieties at half the price is of course another factor for the property owner, which he can use in developing other areas of his holdings.

The region where I am presently located is in southeast Mato Grosso State near the Paraná River, which divides São Paulo State from the former at that point, about 20°S. The altitude is about 300 m and rainfall is about 1300 mm per year. The soil is of sandy texture running in general, from red sandy loam on crown areas down through successively less fertile, red sandy soil to grey sand of poor fertility on the lower part. Soil tests have average pH values between 4.5-5.0; available P, 1-2 ppm; available K, 14-25 ppm; Ca+Mg 0.4-0.8 meq/100 g and 0.5 meq exchangeable Al.

Natural vegetation consists of tall forest with good sized trees on what is considered good soil on crowns, down through "Cerradão", tall forest but thinner tree trunks and some difference in tree varieties, "Cerrado", a smaller scrubbier type, more or less open woodland, to "Campo Cerrado", an open natural grassland with scattered, stunted trees. The last two have more or less herbaceous growth depending on how open they are. Trees have blackened trunks showing signs of fires. There has been a definite selection by fire giving rise to typical "Cerrado" species with thick fire-resistant bark and/or strong ability for regrowth. The grass is usually a tough, narrow leaf, quick maturing type of low palatability. This quick maturing trait is very noticeable. Common management is to burn off this native range during the winter dry season for cattle to benefit from the succulent regrowth which is often already heading out before advent of the rainy season.

In my present situation on the Hofig property in Mato Grosso, this operation has been carried out almost entirely on the poor Cerrado soils of the ranch. We have concentrated our seed production efforts on these soils for three reasons. Firstly, this is the area that would need the biggest improvement to increase its productivity. Secondly, there is a problem of some infestation of *Panicum maximum* Jacq. cv. Colonião on better crown soils, this seed having been scattered over these better tall forest areas by plane in the past. *P. maximum* cv. Colonião would constitute a weed in areas where other varieties are grown for seed production. Thirdly, tall forest areas are much more expensive and time consuming to clear and get ready for mechanized combine farming.

OUTLINE OF TYPICAL OPERATION

Table 1 gives the species and varieties which might be planted this year. Grasses will occupy about 75% of the total area of 1000 ha. Grasses are easiest to produce and offer a higher profit margin if we give greater priority to those which are higher priced. You can see by the prices that is what has been done here.

Table 1. **Profile of seed production operations.**

Species and varieties	Area	Seed yield	Value	Gross income
	ha	kg/ha	US$/kg	US$/ha
B. humidicola	250	80	13.0	260,000
S. anceps cv. Kazungula	250	80	7.0	140,000
B. decumbens	125	120	3.0	45,000
Other grasses	125	80	7.0	70,000
Total grasses	750			515,000
M. atropurpureum	125	40	7.0	35,000
Stylosanthes spp.	50	40	7.0	14,000
Calopogonium mucunoides	25	40	4.0	4,000
Glycine wightii cv. Tinaroo	25	40	4.6	4,660
Other legumes	25	40	4.0	4,000
Total legumes	250			61,660
Grand total	1,000			576,660

By now, in Brazil, there is such widespread production of *Brachiaria* seed that it is down to the category of a more common grass such as *P. maximum* cv. Colonião or other grass varieties as to price with, therefore, a narrower profit margin.

Price of the seed or profit, however, is not the only factor to consider here. We must try as much as possible to level out the needs for harvesting machinery (combines). To stagger harvesting dates is very difficult with a single species or variety as seeding is mostly governed by hours of light. A little extra time may be gained by leaving cattle on a little longer, or cutting at precisely the right time. This is very risky and the time won is usually only a few days. So we must rely mostly on different varieties which have differing maturity dates.

You will note that about 15% of the total area is in "others", both grasses and legumes. Included here are two important but distinct activities, an introduction area and the first seed increase of newer species or varieties. The introduction area provides me with stimulation, pleasure and hopes for better things to come. When today's main varieties pass into the category of more common and therefore less profitable or fall by the wayside for other reasons, it is the newer varieties that keep me in business.

As shown in Table 2, projected first year sales should equal costs, second year harvests should be at least as good, with second year costs coming to only 40% of first year's costs. First year costs include such long-term investments as land clearing and liming. The property owner's first and perhaps largest profit is from the land appreciation due to this development and could be the most important factor influen-

Table 2. **Operating costs.**

Item	First year	Second year
	US$/ha	
Land preparation	160	13
Fertilizer + lime	160	80
Seed	77	-
Harvesting	72	72
Other	114	48
Total	583	213

cing him to enter into such a contract. Thus, the seed enterprise is essentially a vehicle for developing the land.

Fertilizers applied at planting may be 400 kg/ha of lime; superphosphate, 400 kg/ha; potassium chloride, 80 kg/ha; and of minor elements, copper sulfate 6.5 kg/ha, zinc sulfate 6.5 kg/ha, sodium molybdate 300 g/ha. Concentrated lime, I think, would be better than the regular product because of reduced transportation cost and as it could be handled and applied with our regular fertilizer equipment. A formula such as 0-16-10 or 0-18-6 including minor elements and in granulated form could be used also in place of the separate components. I use 400 kg/ha of ammonium sulfate for top-dressing grass crops 60 days before anticipated harvest.

Seeding rates would be about 4 kg/ha of all varieties, both grasses and legumes. Here I might explain that I include legumes in grass seed producing areas from planting time as they do not usually hinder grass seed harvest and when the area reverts to the cattle it already is a mixed pasture. Incidentally, I have found the N top dressing of 400 kg ammonium sulfate/ha has not negatively affected the legumes but rather has helped them.

Grass cannot be included in the legume seed producing areas as it would make legume seed harvest impossible. However, grass can be oversown in these areas after last contract harvest.

SEQUENCE OF OPERATIONS

Our sequence of operations consists of the chaining down of the scrub, using two crawler tractors traveling parallel about 30 to 50 m apart pulling a heavy anchor chain between them which pulls down everything in front of it. The tractors detour around some of the larger trees. The felled material is then piled or windrowed with bulldozers. These operations may go on all year round. Better results with chaining occur when the soil is moist. There are many firms which contract this work. We usually give the land three disskings with a heavy Rome plow with offset type disks.

Seed is broadcast mixed together with fertilizer using spinner equipment and the area is rolled. I would like to get this planting operation done by October. We would probably start in July. There is no need to wait for rain.

Areas will be hand-picked over for wood or stumps left over which could hinder combine harvest. A slashing with a rotary cutter is done from November to January to aid establishment and facilitate harvest.

Next would be the harvesting operation; summer (rainy season) for grasses and winter (dry season) for legumes. To be more specific, harvest of *P. maximum* cv. Green Panic would begin in December; *Brachiaria decumbens* Stapf. usually a few days before Christmas; *Brachiaria humidicola* (Rendle) Schweickt. in early January; *Setaria anceps* Stapf ex Massey cv. Kazungula mid January; *P. maximum* in April; *P. maximum* cv. Colonião in May. These are dates for second year established grass areas. First year harvests would be a couple of months later for the earlier season grasses but the same for *P. maximum* cv. Colonião. I have also found the harvesting dates can vary as much as 30 days from region to region.

Any given grass harvest usually starts when seed starts to shed. With most grasses we have a ten-day period when we can get a good yield. Although seed shedding has already started before we go in more green seed is also ripening during this time. After this ten-day grace period, the harvest can and often has to continue but the yield drops very fast. I have found this period of best yield is only five days for *B. humidicola* and it comes at the time of year of highest rainfall, to complicate things further. There is no second chance with *B. humidicola*, just one harvest. *P. maximum* cv. Green Panic may give as many as five harvests during season,

B. decumbens three, and *S. anceps* cv. Kazungula two.

In my experience, the first and last harvests of the season are usually the best yielders for *P. maximum* cv. Green Panic, the first is best for *B. decumbens* and the first without a doubt is best for *S. anceps* cv. Kazungula, the second sometimes not being worthwhile. This varies depending on weather conditions.

As to combine adjustments, ventilation is shut off as the driest material coming in is usually the ripest seed. Threshing does not have to be so violent as ripe seeds come off very easily and immature seed only makes more impurity to be eliminated later on. Screens are adjusted to carry out as much trash as possible without seed being taken out with it. Even so the material from the combine is very trashy.

So far I have not gone to artificial drying. We have been drying naturally in sun on paved floors and on earth floors (including part of an airstrip) with nearly equal results. This does not mean there are no problems. Every year there are times when seed requires from ten to 15 days to dry enough for bagging due to daily rains or cloudy weather, just as this risk can delay combine work in the field, too. But so far no substantial amount of seed has ever been lost.

On the whole, grass seeds can take more abuse than one would ever expect. When seed comes in from the field as bulk in wagons or trucks it is spread on the floor immediately, no matter what time it arrives or what the weather may be, even if it is raining. This essentially green material will heat up and exude oxygen very quickly if left heaped up. I would rather have it rained on than heating up under a tarp. The wetting will not spoil the seed but the heating or gas exchange will. Every year some batches of seed get successive partial dryings and wettings without spoiling. Seed spread on the drying flooor is stirred continually until ready for bagging which may be from 24 hours up to three or four days depending mostly on weather conditions. When seed is half dry and weather threatens rain, it is usually heaped and covered overnight and spread again next day to complete drying.

The next step would be seed cleaning done with vibrating screens, blowers, and a gravity table. Usually the last step, the gravity table, is not necessary to obtain a good enough pure live seed standard for the quality seed market. We usually have to throw out 30 to 70% of the material from the field. Our pure live seed content usually runs between 20 and 40%, that is purity times germination divided by 100. The economical factor is strong here as it is possible to clean a batch of seed right out of the market.

Now comes selling what we have gone to so much trouble and expense to produce. Fortunately the demand is strong in Brazil with so much land being opened up for cattle and our sales are mainly to the more pioneer areas. The older areas of São Paulo, Paraná, Minas Gerais, and Rio Grande do Sul are intensifying crop agriculture. However, that does not mean we can just expect buyers to shower down. We must promote, advertise, contact wholesalers, send out salesmen, etc. We do keep it to a minimum though. Through the years I have built up so many personal contacts and one of the reasons I choose prominent men for financial backers is the surprising amount of seed sold through their social and business contacts as most of these people are also developing land in pioneer country and need dependable seed. I have found that an article published in a farm journal either written by myself or as an interview about our operation brings much more response than a direct advertisement.

Field days and taking visitors around are important, too. It is actually more of an educational campaign than anything else. When I started not even *Macroptilium atropurpureum* (D.C.) Urb. was known here except to a very few. I had to teach what it

was and how to use it to sell it, the same with any other new species or variety. I think of myself as a link between research and the rancher. When a variety shows promise in research plots it must be increased for further research, grazing trials, plots in other regions, etc. Also I believe that the faster it is available to interested ranchers and planted in a diverse array of conditions the faster information on it will be obtained.

I realize there are two sides to this and a seed man could be criticized for touting new varieties as "Miracle Grasses" purely for commercial reasons and it may turn out to be a complete failure. In fact, I constantly warn against expecting "miracles". I tell how it performed for me, give any other information I may have on it along with what hopes I may have for it and that is all. In fact, I ask the buyer to let me know later on how it did in his region, as this is valuable information. I make a collaborator of him. The buyer takes it at his own risk.

I know of cases where a new release from a research center was also a failure. But I still think on the whole more can be gained than lost and society benefits more by early release, increase and wide distribution of new material. I also know of cases where a species stayed years in research plots without anyone paying much attention to it. But only when it finally was spread around, all of a sudden very much was learned about it.

In the two to three years it takes me to increase a promising new species or variety enough for commercial scale it goes without saying I learn very much about it too, more so considering the experience we can bring to bear.

I was asked for a "hard-nosed business" approach, but actually I am not a hard-nosed businessman. If I were I would be much better off financially than I am. In trying to analyze this I think it just comes down to a farmer's approach rather than a corporation or research center's. We have no large staff or expensive offices, etc., only a low overhead of non-productive expenses. We go about it just as any farmer anywhere in the world would. Some day we may need the office space and some staff but if and when, it will be because the production demands it.

PROBLEMS

As stated before, grass production has few problems and gives greater profit. Its problems would be harvesting and seed drying in rainy periods of the year. This keeps us jumping but so far no great seed losses have occurred because of this.

But legumes have many problems: weeds, diseases, harvesting difficulties, and biggest of all, lack of a strong demand. In virgin land a first crop may be harvested without too serious weed or disease problems. I have come to the conclusion that legumes, when grown for seed production, in most cases must be treated as an annual crop, both to break the disease cycle and to be able to incorporate a preemergence herbicide to take care of the grassy weeds. The area rarely needs replanting because legumes volunteer back, both from seed and from surviving mother plants to give a very good stand. When one has plenty of land to be developed in any case, the disked legume area may be overseeded to some good grass in the second year and this grass used for a seed crop. When the contract agreement is concluded this is another fine mixed legume/grass area for the property. Legumes for seed can be always planted on new land.

Legumes give more harvesting problems as usually we must cut low and the whole mass of plant material passes through the machine. This mass can be very voluminous and too much for the machine. The operator must learn to go slow, stop, maybe back up when things threaten to stop up the combine, and take a half or less width cut. Sometimes a few modifications on the machine may help the harvest of viney material. We have taken off most of the

retracting fingers to extend the auger on the forward platform to the middle. This eliminates twining of vines around the drum where the fingers were. Two fingers, one on each side, must be left on to feed the material into the thresher. Also the land should be somewhat level or leveled for legumes and much more carefully picked over or cleaned of stumps, roots, branches, etc., because of the lower cut. Any piece of wood coming into the machine can do quite some damage and the combine will miss nothing.

Due to disease problems or other troubles with nearly all commercial legume varieties, I have been seeking other options and some of the most promising have come from my own local collections. For instance *Stylosanthes capitata* Vog. is resistant to the most common stylo disease, antrachnose, and is a heavier seed producer than any commercial variety of *Stylosanthes* I know of, besides having other good qualities for a pasture legume. *Macroptilium panduratum*, which I collected on the very property, is much more vigorous than *M. atropurpureum* and has good (if not total) resistance to Rhizoctonia, my main problem with *M. atropurpureum*. A species of *Periandra* collected nearby has no disease problem to date, and is more vigorous and a more prolific seeder than *Centrosema pubescens* Benth., which has disease problems. *Teramnus uncinatus* (L) Sw. so far has no disease problems and the one collected on the property has a much broader leaf than the more common one which went the rounds many years ago. A large type *Aeschynomene americana* L. collected by Al Kretschmer and myself in the Pantanal region is the best nodulator I have ever seen and the harvest is easily mechanized.

However, the above are engineering or agronomical problems which usually have some solution as long as it is worthwhile to produce the seed. But, if besides having a higher cost of production, demand is weak, then it is very hard to justify the effort and expense.

As stated in the earlier part of this paper my first interest in agriculture stems in part from a fascination with the useful role of the legumes. Therefore, the lack of acceptance of legumes in pastures by the great majority of ranchers/cattlemen in Brazil is sad for me. Why this non-acceptance? Simply because so far it has not been irrefutably proven them that legumes are necessary, nor if a good mixture can be achieved then maintained over a long period. I know of no large scale generalized successes, although there are many isolated small scale successes, either a certain property, a field or pasture on a property, or just a part of one pasture. What I mean is I know of no generalized spectacular success over a region.

B. decumbens is now being planted on a very wide scale on second and third class soil throughout Brazil. It is a notoriously tough grass to get legumes to stay with. When I speak of legumes to customers, one of the more common questions is "Can a good legume association be had with *Brachiaria?*". I just do not know the answer. I am forced to mutter something about it being successful in some cases.

I think the ideal tropical legume has just not come along yet. I do not believe it possible to sell a less vigorous grass to the rancher simply because it is easier to get a legume association. A strong legume that can take the competition and requires no special management nor uneconomical amounts of fertilizer will have to be found. There are too many old pure grass pastures (with maybe a few native legumes here and there), maybe five or up to even 20 years old, still producing economically. This throws doubt as to whether it is necessary to plant legumes.

I keep hoping research will bring proof of the value of legumes in pasture to the rancher in such a way he will have to accept it. In the meantime I am thinking of selling grass seeds already mixed with legume seed according to where it is to be planted. I would

suggest we get a helping hand in this by the requirement that legumes be planted with grass for approval of government loans, as a further technical requirement for a loan approval. Why not this, too? At the present time the price of *B. humidicola* seed is higher than the average price of legume seed so in a mix the average price with legumes would be cheaper than the grass alone, thereby giving the illusion of lower price/kg. Of course the successful rancher is a highly intelligent businessman and would realize he is merely paying the average price of the legumes plus the grass seed and more total seed would be needed per area, too. But still he would console himself to the arm twisting by telling himself at least he is going along with the technical advice and doing things as he should. Besides, coming already mixed saves him that trouble.

Legumes would not be inoculated but how many graziers do that anyway? I do not believe it is particularly necessary with the legumes in common use in Brazil with so many native legumes and their rhizobacteria in the soil. In this way we will be making our own market for the legumes, and I believe a great deal more information would pour in after their more widespread use as has been stated before. Maybe we could start to find out why there are so many failures and find the key to success.

SYSTEMS OF PASTURE SEED PRODUCTION IN LATIN AMERICA

John E. Ferguson*

ABSTRACT

Five basic production systems by which seed of grass and legume cultivars arrive at the market are proposed and described. These are: 1. Traditional for grasses; 2. Legumes from plantation agriculture; 3. Legumes with physical support; 4. Grasses and legumes as pastures; 5. Grasses and legumes as crops. The particular species and countries where these systems presently exist are defined. The relative and future roles of these systems and the most pertinent areas for research are discussed thereby providing guidelines for future seed development strategies.

The availability and cost per kg of pure live seed to a beef producer frequently determines if the potential of a forage cultivar can be realized in terms of animal production. Even in Latin America where the predominant method of distribution and establishment of grasses has been by vegetative propagation, large scale pasture improvement within extensive cattle production systems is feasible only by means of seed. This is particularly the case with legumes and improved cultivars of grasses.

With the majority of tropical pasture species the production of seed is a relatively new endeavor, both commercially and from the viewpoint of scientific investigation. In Australia, Brazil, Colombia and Kenya, however, seed production has developed considerably in the last decade. The literature on pasture seed production is now expanding. The review of Humphreys (7), then Jones and Roe (8), provide the first comprehensive presentations of the classic components of seed production as applied to the present day range of species and cultivars. Numerous other publications relate either to the behavior and management of particular species, specific cultural practices or national summaries of seed production activities. Discussion of pasture seed production, however, is complicated by the number and diversity of species, either presently under commercial production or experimentation which may result in future release, and by the multiplicity of ways by which seed arrives at the market. Vicary (16) drew attention to the diversity of seed producing enterprises in northern Australia while Hopkinson (6) has described the progressive phases of build up of supply of a new cultivar.

This paper aims to provide a general description of how pasture seed is presently produced in lowland tropical Latin America but from the viewpoint of production systems. In addition, the role of research

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within each system and how these systems can respond to future needs is discussed.

SEED PRODUCTION SYSTEMS

A pasture seed production system is regarded as all the biological, technological and managerial components relating to a particular species and how these components interact in the production of seed as a marketable product.

In seeking to define such systems, emphasis has been placed upon: (a) the degree to which seed production is compatible with forage management for beef cattle or some other production enterprise. (b) The extent to which the biological requirements of the species for seed production are satisfied by: locating the crop in an appropriate geographic region and/or a specific site therein and/or applying cultural practices to various degrees of intensity and skill. (c) The grouping of species or cultivars receiving similar production components into the same system, aiming to minimize the number of systems but to avoid drastic generalitites.

Five basic seed production systems are proposed. These are:

System 1. Traditional for grasses
System 2. Legume from plantation agriculture
System 3. Legumes with physical support
System 4. Grasses and legumes as pastures
System 5. Grasses and legumes as crops.

System 1. Traditional for grasses

This system is confined to certain grasses, well naturalized in some livestock production areas, both in pastures and along roadsides. Their initital spread or establishment was either natural or for pasture, but not for the purpose of seed production. With the exception of limiting access of cattle after a certain date, the graziers apply no specific seed management practices. Flowering and seeding, however, are well synchronized with the termination of the wet season and in most years seed set is high and seed can be harvested as a cash crop.

Harvesting is conducted manually. It normally involves a contractual arrangement between the grazier and a traveling merchant who then subcontracts to local laborers to conduct the harvest. Some graziers, however, do organize and control their harvest. The main harvest method is to cut the flowering stems with a reaping hook or machete then construct orderly heaps with the stems arranged either horizontally or inclined upwards. The completed heap is covered with vegetative material. The heaps are constructed progressively in the field with the advance of the cutters through the field and only occasionally is the extra effort made to transport this material from the field to a shelter. After five to seven days the heaps are opened and the stems are threshed manually by being knocked against a stick or the ground. The detached seed mass is then bagged and transferred to shelter. Further cleaning is minimal and confined to removal of vegetative material. Final drying procedures are variable but normally involve exposure to the sun. An alternative harvest method is to simply enter an overmature crop and collect the fallen seed from the ground using rakes and brooms.

Commercial seed lots are extremely variable in all components of quality. The most obvious character of such seed is the high but variable contents of sand, soil, parts of leaves and stems and empty "seed". Conversely the seed technologist would describe the same seed lot as having low but variable purity (by the International definition) and a high inert matter content. Obviously the seed collected from the ground will have the highest sand and soil fraction. On the other hand particular seed lots can be almost free of sand, soil and vegetative material. The constant variable is the proportion of seed-like structures con-

taining a caryopsis, i.e. the content of pure seed by the International definition. Germination, too, is highly variable relating to the content of pure seed, the proportion of inmature seed and post-harvest handling, especially time and conditions in the heaps, the rate of drying and storage conditions.

Seed yields are highly variable and estimates are complicated by the difficulty in measuring area of harvest and the weight and purity of the final product.

Seed sales are essentially local and without any standard definitions or estimates of quality. In particular regions seed is traded commercially and may move across adjacent national borders, i.e., from Colombia to Venezuela.

This system has developed and functions without any governmental assistance or research input. While the product is unrefined and variable, this system produces the largest volume of pasture seed and it is the most widespread grass seed production system throughout Latin America. Species, countries and yields are summarized in Table 1. By far, the greatest total production occurs in Brazil and Colombia.

Aspects of production and development of this system have been described by several authors (1, 5, 9, 12, 15). Examination of the basic nature of this system would indicate that to improve firstly quality and then quantity of production, an intensive research effort is not required but more the application and extension of available technology. Research efforts to understand more of the effects and control of the sweating phase, i.e. while the harvested material is kept moist in heaps (14), and to develop more appropriate seed processing equipment (11) should be continued.

Table 1. **Distribution and seed yields of grasses in the traditional grass system (System 1).**

Species	Country	Seed yield*
		kg/ha
Hyparrhenia rufa (Nees) Stapf.	Brazil, Colombia, Costa Rica, El Salvador, Guatemala, Mexico Panamá, Perú, Venezuela	100-200 (1 harvest)
Panicum maximum Jacq.	Brazil, Bolivia Costa Rica, Colombia, Ecuador, Mexico, Venezuela	50-100 (1-2 harvests)
Dichanthium aristatum (Poir.) C.E. Hubbard	Colombia, Venezuela	75-150 (1-2 harvests, often irrigated)
Melinis minutiflora Beauv.	Brazil, Colombia Costa Rica, Venezuela	75-150 (1 harvest)
Cenchrus ciliaris L.	Colombia, Mexico, Venezuela	50-100 (1 harvest, without heaping)

*Unrefined seed of variable but generally low purity.

The system could be improved in the following ways:

1) Refined on-farm, post-harvest management. Firstly, more understanding and control of the sweating phase. Secondly, the use of cheap plastic sheeting and inclined scalping screens during the threshing phase to reduce the proportion of inert matter. Thirdly, more emphasis upon slow, natural drying under shade.

2) Off-farm mechanical seed processing to improve the purity of marketed seed. This could be provided either by a national institution or private individuals organizing a processing facility within a major production area. Equipment required may include a pre-cleaner or a scalper, an adjustable hammer-mill or a debearder and air-screen cleaner and a gravity table.

3) Developing an increased understanding of seed quality. The first requirement would be a standard definition and measurement of seed purity for each species, then the development of a seed testing service facility. The latter would be best provided by a national institution. Also required would be an educational program to emphasize the roles of purity, germination, pure live seed content and their relationship to seeding rates.

4) Encouraging particular land owners to engage more seriously in seed production. This would involve a commitment to the selection of uniform, weed-free pasture seed production areas and more intensive management. In some mixed crop and cattle production regions, it should be possible to use slashing and combine harvesting with specific adjustments or adaptations of equipment used for food crop production.

Several large commercial seed companies are entering into contractual arrangements with graziers; therefore, this system is likely to be more productive in the future. It should be noted, however, that a high degree of refinement of this system would constitute a transition to System 4.

System 2. Legumes from plantation agriculture

This system is confined to legumes capable of providing stable ground cover under perennial tree plantations in the humid tropics. Plantations for rubber, palm oil and coconuts are developed obviously where ecological conditions favor these particular crops. The legume provides a living mulch for control of erosion and weeds and becomes progressively under partial shade. Seed production from the legume is not an initial objective, but is an occasional secondary cash crop.

Grazing is not a part of the management system in rubber and oil palm plantations. The legume is manually cut away from the base of the trees and may be defoliated occasionally either manually or mechanically. Pre-harvest management of the legume is essentially minimal or zero.

Within a minority of plantations and only in some years, seed set of the legume may be relatively prolific in parts of the plantations. Some managers divert labor to manual seed harvesting, generally the wives and children of permanent workers. Harvested pods are sun dried and threshed manually.

The marketed product is of high purity but with variable germination which is related to seed age and storage conditions. Seed supply from this system is obviously irregular. Seed moves into national markets, but also moves internationally because of the marketing contacts of the plantation industry. At present within Latin America only *Pueraria phaseoloides* (Roxb.) Benth var. *javanica* (Benth) Bak. is produced from within African oil palm or rubber plantations (Table 2). It is important to note, however, that other legumes, such as *Centrosema* spp., and *Desmodium ovalifolium* Vahl. could be produced within this system.

The seed yield potential of *P. phaseoloides* without physical support is not well defined in Latin America. At Carimagua in eastern

Table 2. **Distribution and seed yields of *P. phaseoloides* within the plantation agriculture system (System 2).**

Species	Country	Seed yield
		kg/ha
P. phaseoloides with African oil palm or rubber	Brazil, Colombia, Ecuador, Guatemala	10-50 (1 harvest)

Colombia (4°N), Raúl Pérez (personal communication) has recorded hand-harvested yields between 5 and 80 kg/ha from pure stands. At CIAT's headquarters, (3°N) yields of 500 and 340 kg/ha were recorded from hand and direct combine harvesting, respectively. The species, therefore, does have an attractive seed yield potential essentially unexploited at present in Latin America.

As large areas of *P. phaseoloides* presently exist and will expand consistent with the growing plantation industry, means to increase the volume of *P. phaseoloides* seed, or of other species, within this system should be examined. These include:

1) Improved laison between the plantation and pasture seed industries as regards definition of demand, production potential and methodology and sharecropping agreements.

2) Purposeful selection of specific geographic regions where the legume would consistently produce reasonable seed yields. Included here are considerations of: latitude, as *P. phaseoloides* has a short-day flowering response, lowland low latitude areas have a lower yield potential, but yields should be attractive above 8° latitude even at low altitudes; rainfall distribution relative to daylength, in particular the requirement for a marked change to a consistent dry season combined with shorter photoperiods; radiation levels, avoiding areas with consistently high cloud cover throughout the year.

3) Selection of specific areas within plantations which are located within optimal geographic regions. These areas would have: minimum shading either because of young trees, low tree density or old diseased tree populations; light soil types, promoting moisture stress in the dryer season; flat topography, preferably with complete land clearing to facilitate mechanized crop management.

4) More intensive management of these selected areas for seed production. Included here may be: fertilizer application for the legume, especially to fulfill requirements for P, S, K, Mg, Zn or Mo; insect control, if and when needed; determination of harvest method related to availability of labor or the potential for a direct combine harvest, possibly on a contractual basis; the benefit of a cheap partial support system to facilitate a hand harvest.

System 3. Legumes with physical support

This system is confined to legumes with a twining growth habit. Areas of legume are established and then a support system is erected and the stems encouraged to climb the supports. The support system is usually a bamboo and wire combination, or may be simpler and more variable using plant stakes or old stems without interconnection.

Seed production is the primary objective. No specific consideration is made for selection of an appropriate geographic location, in fact, a lack of climatic adaptation for seed production in the particular location may be partially compensated for by the support system.

The support system negates alternative use by grazing, facilitates the obligatory hand harvest but restricts the size of the production area. Management is semi-intensive and may include fertilization, insect control and irrigation to promote high yields and thereby compensate for the cost of the support system. Pods are harvested manually and repetitively, normally on a programmed sequence. Pods are simply sun dried and threshed manually or by simple mechanical means, i.e. a stationary thresher. Seed yields can be very high. Purity and germination are normally high. Seed is often used on the same property or sold locally. The species most frequently involved are listed in Table 3.

Lotero (10) reported high yields with *Calopogonium muconoides* Desv. producing 800 kg/ha, *P. phaseoloides* 838 kg/ha and *Glycine wightii* (R. Grah. ex Wight & Arn.) Verdc. 622 kg/ha in Medellín, Colombia. Farfán (4) reported yields at Porto Viejo, Ecuador, with *Centrosema pubescens* Benth. yielding 950 kg/ha, *Macroptilium atropurpureum* (D.C.) Urb. 267 kg/ha and *Macrotyloma axillare* (E. Mey.) Verdc. 280 kg/ha. At Santander de Quilichao, Cauca, Colombia, *Centrosema* spp., have yielded 650 kg/ha in the first year.

This system is efficient and practical only on a limited scale with valuable material where labor is cheap and readily available. These limitations, dictate a primary and transitory role for this system because if demand or costs for a particular species continue to rise, significant expansion of production can only occur by a transition to either System 4 or 5.

Research within this system should be directed towards assisting this transition by the identification of cultural practices and appropriate geographic regions such that mechanical harvesting is economic. Another line of research could investigate the use of low cost support systems, (including multiple crop combinations which could be mechanically harvested) and chemical growth regulators.

In the future this system will be used to initiate seed increase of promising germplasm within national institutions producing seed for experimental purposes and provide high and rapid multiplication rates to both seed producers or graziers initiating production of a new variety where initial seed supply is either restricted or expensive.

System 4. Grasses and legumes as pastures

This system can involve both grasses and legumes. The species or cultivars involved are relatively new. The geographic region involved is one where the species is well adapted for forage production, and in most years, also in terms of seed set. Initital establishment is for the purpose of developing improved pastures, either in pure or mixed stands. While the initital objective of

Table 3. **Distribution and seed yields of legumes grown in the physical support system (System 3).**

Species	Country	Seed yield
		kg/ha
C. pubescens	Colombia and	over 100
G. wightii	Ecuador	over 100
P. phaseoloides		over 100
C. mucunoides		over 100

the grazier is to produce forage for cattle production, he is attracted into becoming a seed producer either by high seed prices or the recognition that he can harvest his own seed for further property development. Seed production is therefore a secondary cash crop.

In the years when seed production is an objective, the grazier restricts grazing in particular areas and generally without any further input, this area is left to flower and set seed. These areas may have been fertilized to exploit the forage yield potential of new or improved cultivars. Harvesting is conducted by contract by either manual or mechanical means. The tendency however, is definitely towards combine harvesting. Seed is sun-dried on the property, but is generally transported to a processing facility where seed is cleaned and classified. The quality of final seed lots is variable but can be high. Seed yields are variable and generally moderate for the species. Total seed volume, however, is sufficient to significantly affect national supplies and prices as the areas involved increase.

This system is obviously intermediate between Systems 1 and 5. Some may even argue that it is not a discrete system. At present it is not common in Latin America, certainly not with legumes, but this reflects the scant number of relatively new pasture cultivars recently available (Table 4). This system is not promoted by research and development but tends to evolve naturally in response to strong economic demand for seed recognizable by progressive graziers within the same region. It is a relatively low cost method of seed production and if it develops on any scale, it negates the need for the development of System 5, for the particular cultivars involved within that particular country. The problem is however, that it is unlikely to develop rapidly enough for some cultivars and not at all for others, especially legumes in low latitude regions. The producers in this system are innovative entrepreneurs who move in and out of seed production depending upon the balance between seed prices and the need for forage. Some, however, are attracted into the enterprise and may become specialist producers*. The system, therefore, contributes both seed and seedsmen and is a bridging mechanism to the process of national seed improvement.

System 5. Grasses and legumes as crops

This system can include both grasses and legumes and the cultivars involved may be traditional or new. The principal objective is the production of seed, with limited emphasis upon production of forage. Land areas are selected and seed crops are established and managed towards this primary goal. A seed crop of a pasture

* See Hayman's chapter in this book. (Editor's note).

Table 4. **Distribution and seed yields of species in the pasture system (System 4).**

Species	Country	Seed yield
		kg/ha
Brachiaria decumbens Stapf.	Colombia, Venezuela and Brazil	5-50 (1-2 harvests)
P. maximum (cv. Colonião, Green Panic, etc.)	Brazil	50-100 (1-2 harvests)
M. atropurpureum	Brazil	20-50 (1-2 harvests)

species may form part of a food or fiber crop rotation and also provide secondary income from hay (especially with legumes) or limited grazing (especially with grasses).

This system develops within, or in time evolves towards, geographic regions best suited for the production of seed. In some cases specific climatic and edaphic ecologies are purposely sought out to locate seed crops. Such regions may be distinct and distant from the regions where the seed is used in pasture establishment.

A further dimension is the degree of management skill which is introduced by producers more inclined to apply specific cultural practices, mechanical ingenuity and concentration of effort.

Most producers have invested in specialized equipment, such as combines, artificial dryers, slashers, cultivating implements, seeders and seed processing machinery. Perhaps also land, irrigation equipment and sprayers are purchased. The need for large capital investment may lead to the involvement of corporate organizations, alone or linked to governmental agencies.

The full spectrum of conventional seed crop cultural practices are applied to the pasture seed crops as required; in particular, complete land preparation, high seeding rates, fertilizers, defoliation, integrated weed control (including cultivation and herbicides), insect control and appropriate efforts to maintain genetic purity. Irrigation may be applied to some species. The majority of crops are mechanically harvested, generally using conventional crop combines but the system may include manual harvesting. Seed processing is complete, and is conducted either on the same property or at centralized processing facilities. Seed is stored in appropriate sites.

Seed yields respond to the more intense management and more optimal environments, and are therefore higher and more consistent. Seed quality is generally higher reflecting both improved seed processing and storage conditions and quality control standards regulated by national agencies. Seed is marketed more systematically, both nationally and internationally.

This system is the most intensive and specialized. At present within Latin America it is not well developed or widespread as indicated by the species, countries and especially yields (Table 5). However, this system does offer greater opportunities for viable commercial production, higher yield and quality potentials, more consistent market availability and lower prices for many species. It is particularly appropriate for species or cultivars which either (a) have specific climatic, edaphic, pollination and/or isolation requirements to produce economically viable seed yields, (b) difficult maturity, harvesting or quality characteristics, or (c) constitute new cultivars, developed either by introduction or plant improvement programs. Ultimately only this system will resolve future demands for many legume species or will reduce prices to the consumer as the number of independent producers and areas under crop increase.

The developmental research by several authors (2, 3, 4, 13), the Instituto de Pesquisas IRI in Brazil, and the coordinating and publishing efforts of the Instituto Interamericano de Ciencias Agrícolas (IICA), have contributed significantly to the initiation of commercial production in various countries.

Research programs within national institutions are required to contribute towards the development and efficiency of this system. While these institutions tend to be naturally involved in inititating production, it must be stressed that ultimately production is most efficient in the hands of semi-autonomous organizations or independent operators. Research therefore, must be progressively modified to be responsive to their particular needs. Initially research

Table 5. **Distribution and seed yields of species in the crop system (System 5).**

Species	Country	Seed yield
		kg/ha
B. decumbens	Colombia, Bolivia Brazil	10-100
Brachiaria humidicola (Rendle) Schweickt.	Brazil	10-50
P. maximum	Bolivia, Brazil	20-50
Setaria anceps Stapf. ex Massey	Brazil	20-50
G. wightii	Bolivia, Brazil	100-300
Lablab purpureus (L.) Sweet	Bolivia	500-1200
M. atropurpureum	Brazil	30-100
Stylosanthes capitata Vog.	Brazil	50
Stylosanthes guianensis (Aubl.) Sw.	Brazil	30-75

should emphasize the definition of appropriate geographic regions for each species, regions with sufficient local diversity to accomodate various species, seed yields therein, the major determinants of seed yield and quality and the provision of basic seed stocks for potential producers. In time research should focus on the progressive refinement of economic production systems for a particular species, and/or general problems of the growers in a particular region.

Resources applied to seed production should be applied to adapted cultivars or promising germplasm. Both commercial seed producers and researchers need to be related closely to germplasm development and evaluation programs to ensure that this genetic prerequisite is fulfilled.

CONCLUSIONS

The availability and cost of seed of each pasture cultivar is the result of a production system, the major components of which are: the particular species and its reproductive mechanisms; the geographic region where it is grown for the production of seed; and the management practices applied. The five basic systems described here are by no means rigid but overlap and interrelate in the progressive development of seed supplies of any one cultivar. The descriptions are incomplete, especially as regards exact location of production regions within countries and precise production data which is simply not available in the literature.

Of fundamental importance for the development and economics of commercial seed production and any research effort to support this enterprise, is the definition and identification of appropriate geographic regions for seed production. Such regions provide favorable combinations of climatic, edaphic and management factors to consistently promote high yields and high quality of seed of a number of species and thus allow the growth of a viable seed industry. As national needs will always involve a number of species which could differ in seed production requirements, a given country will need at least one production region with a diverse array of local ecologies or several separate regions. These regions may be separate and distant from

livestock areas inferring the need for organized seed movement.

The value of these partly conceptual seed production systems is in the analysis of how future seed needs can be fulfilled and the most appropriate role for the scant research resources available. Definition of the demand potential of proven adapted cultivars is the starting point for a seed production effort. Obviously each country can have different cultivars and volume requirements. If Systems 1 and 2 exist, their production potential should be closely examined. While System 4 suggests an ideal situation it cannot be assumed that it will develop rapidly enough to satisfy demand and it is unlikely to cater for many legumes especially in low latitude regions. System 5 will therefore be required to ensure sufficient rapid and consistent availability of seed at reasonable cost of many cultivars, especially existent and new legume cultivars. A research effort and specialized producers are both needed to develop this system, which will only be viable within particular geographic regions.

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PART VI

TRANSFER OF TECHNOLOGY

SOME COMMON CAUSES OF FAILURE OF TROPICAL LEGUME/GRASS PASTURES ON COMMERCIAL FARMS AND SUGGESTED REMEDIES

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ABSTRACT

The widespread belief that grazing animals live on grass and grass alone is responsible for most failures of tropical legume based pastures. Its corollary —that legumes are only there to supply N to the grass— leads to management practices which favor grass growth to the detriment of the associated legumes and their eventual elimination. Common examples of such practices are: (a) Mixing legumes and grasses which are not compatible with each other. (b) Using seed mixtures which contain too much grass seed and insufficient legume seed. (c) Burning or slashing to get rid of uneaten grass and to promote more palatable regrowth. (d) Using N fertilizer on legume/grass pastures to increase grass yields. (e) Failure to supply elements such as Mo which are essential to the legume/*Rhizobium* symbiosis but have little or no direct effect on grass yields. (f) Overstocking during the growing season to try to utilize as much of the grass as possible before it becomes overmature. (g) Rotational grazing systems which are designed to force cattle to eat all the pasture on offer. It has been demonstrated in many tropical environments that animal production increases as the legume percentage of the pasture increases. Pure legume pastures, however, are unstable and subject to weed invasion. The grass prevents weed invasion, utilizes soil N from legumes and provides bulk and carbohydrates for cattle. It is argued that the prime components of mixed tropical pastures are the legumes, as they supply protein essential for a high level of growth and reproduction. Various management strategies based on this proposition, which have been applied on commercial farms with apparent success, are discussed.

Most tropical grasslands have been subjected to regular burning, either intentional or accidental, for thousands of years. This has led to the dominance of fire resistant grasses and elimination of most of the better indigenous legumes —partly because they are either less fire resistant or recover more slowly after burning than the grasses; partly by selective grazing pressure; and partly, perhaps, due to lack of S which is essential to the legume/*Rhizobium* symbiosis but is lost in burning (22).

This dominance of the grasses has apparently led to the widespread belief throughout the tropics that grass is the only feed for grazing cattle— as indeed it literally is in many places, due to management practices which favor grass growth but which rapidly eliminate the legumes.

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This "grass-mentality" is so strong amongst many cattlemen that they do not recognize valuable pasture legumes when they are present. Some even class them as weeds and treat them accordingly. It is not surprising, therefore, that adoption of mixed legume/grass pastures has been slow and failures have been many.

When grass-conscious cattlemen do decide to introduce a legume into their pastures their objective is usually to promote grass growth by supplying it with cheap N manufactured by the legume. To relegate tropical legumes to this secondary role is to seriously underestimate their value as high quality forage plants which will produce faster liveweight gains per head than tropical grasses.

Throughout this paper the term "legume/grass pastures" has been used, in preference to the more usual "grass/legume pastures", to emphasize the relative importance of the legume. It is considered that until all those who are responsible for pasture management accept this order of priority they will continue to use management practices which favor grass growth to the detriment of the legume.

Some common examples of such practices are discussed below, together with alternative management strategies which have been tried in a wide range of climates from humid sub-tropical to wet equatorial, and on soils ranging from relatively fertile Alfisols formed on basalt to infertile Ultisols and Oxisols derived from shales and sandstones.

ESTABLISHMENT

The most common mistakes in establishing legume/grass pastures are: (a) using species which are not well-adapted to the area; (b) choosing legume and grass species which are not compatible with each other; and (c) suppressing the legumes in the seedling stage by including too much grass seed in the mixture.

Well-adapted species

There is a very wide range of adaptation to various levels of soil acidity and fertility in both legumes and grasses (26). It is essential that the basis of any pasture mixture in acid infertile soils should be those species which are most likely to persist under these conditions. As a gradual buildup in soil fertility may be expected under a well managed legume/grass pasture, there is a good case for including in the mixture some species which will perform better as fertility increases. There is not likely, however, to be any general decrease in acidity, so there is no point in including any of the few species which are intolerant of acid conditions—unless a cheap source of lime is available, and it seldom is in the tropics.

Compatibility of legumes and grasses

When planning a pasture mixture it may seem logical to combine the highest yielding grass with the best adapted legume species which are available. Unfortunately this approach often fails because the tropical pasture legumes at present available are not capable of competing with many of the highest yielding grasses.

Assessment of species is frequently done by cutting and weighing samples from small monoculture plots. Dry matter (DM) production of the best grasses may be of the order of two to four times greater than that of the best legumes. The highest yielding grasses usually have a very tall or very dense growth habit combined with fast regrowth after grazing. It is almost impossible for the slower growing legumes to compete with fast growing grasses which are very tall, such as *Pennisetum purpureum* Schumach., or very dense, such as *Digitaria decumbens* Stent. and *Brachiaria decumbens* Stapf. and grazing management of such mixtures is extremely difficult. However, grasses which combine fast growth rates with medium height and an open growth habit, such as the shorter cultivars of the *Panicum maximum* Jacq.

family, will combine well with legumes provided they are more palatable than the legumes during their period of most active growth. Cattle will selectively graze such grasses, keeping them in check and giving the legumes a competitive advantage.

Characteristics other than relative palatability which help legumes to maintain a stable association with a faster growing grass are: (a) shade tolerance (e.g. *Desmodium intortum* (Mill.) Urb.), (b) ability to withstand defoliation (e.g. *Stylosanthes guianensis* (Aubl.) Sw.), (c) resistance to damage from trampling (e.g. *Desmodium heterophyllum* D.C.), and (d) ability to regenerate from seed (e.g. *Macroptilium atropurpureum* (D.C.) Urb. cv. Siratro), stolons (e.g. *Glycine wightii* (R. Grah. ex Wight & Arn.) Verdc.), or crowns (e.g. *S. guianensis* cv. Oxley). These characteristics can only be assessed in plots containing a mixture of legumes and grasses which are grazed by cattle.

Assessments based on cutting and weighing can be most misleading. Pure grass pastures without N fertilization may yield considerably more DM than the most stable legume/grass mixtures, at similar levels of soil fertility. Yet, whenever comparisons have been made in grazing trials, animal production has invariably been higher from the legume/grass pasture (28). The relationships which have been established between DM and animal production for temperate pastures have no validity for tropical pastures and attempts to predict animal performance based on DM production of tropical pastures has led to some spectacular failures.

In general, if several legume species are included in the mixture their chances of survival are increased, but using two or more species of grass reduces the chances of legume survival. An exception to this is the use of a non-aggressive grass such as *Melinis minutiflora* Beauv. as a pioneer together with a more productive grass in situations where soil fertility is initially too low to get full production from the better grass. As fertility builds up the more productive grass will replace *M. minutiflora.*

Seeding rates

It is quite meaningless to specify seeding rates unless the pure live seed (PLS) percentage of each species in the mixture is known. For instance, in Australia seeding rates of 2-6 kg/ha are usually recommended for *P. maximum* which complies with the minimum prescribed standards of 25% germination and 40% purity (= 10% PLS). In many countries, where there are no prescribed standards, seeding rates of *P. maximum* are normally of the order of 20 kg/ha or more. The poor germination of grass seed commonly available in many humid tropical countries is often due to dormancy or poor storage conditions. It is essential to make a germination test prior to sowing so that the correct seeding rates may be determined.

As a general rule, the tendency is to use too much grass seed, with the result that the grass seedlings suppress the slower growing legumes very early in the life of the pasture. It is better to err on the side of too little grass and too much legume seed. Grasses will soon thicken up from their own seed, but with most species it is extremely difficult to increase the proportion of legume in the pasture if there are not sufficient legume plants there in the first place. As a rough rule of thumb, the aim should be to establish at least as many legume seedlings per unit area as grass seedlings, and preferably more.

Inoculation with an effective strain of *Rhizobium,* to ensure early nodulation of the legumes, will greatly increase their ability to compete with the grass in the early stages. This is particularly important for species which are slow to establish, such as *Centrosema pubescens* Benth., *G. wightii* or *Leucaena leucocephala* (Lam.) De Wit.

Early grazing to control height of grass

Legume seedlings usually emerge before the grass seedlings but then grow very

slowly for the next few weeks until they nodulate. During this period the grass seedlings overtake them and, if not checked, will suppress them by competing strongly for light, moisture and nutrients. Fortunately, at this stage the grasses are usually more palatable to cattle than the legumes, so a competitive balance can be maintained by introducing a few cattle as soon as the grasses start to overtop the legumes. Damage to the legumes will be kept to a minimum if a small number of cattle are left in the paddock, adjusting numbers as necessary to ensure that they keep the grass down but not eat too much of the legumes. It is often recommended that a large herd be used to complete this early grazing in a short time but this can be dangerous. A great deal of damage can be done to the legumes in a short time if cattle are left in the paddock too long —as frequently happens when grazing management is controlled by people who are inexperienced in managing legumes.

The objective should be to achieve legume dominance as early as possible in the life of the pasture, and then keep it that way. Legume dominance is defined here as being the stage where legumes have overtopped the grass to the point where there are more legume leaves than grass leaves visible.

Effect of mowing, burning and herbicides

Unlike cattle, mowers are not selective and most types only work well close to ground level. Consequently, mowing a pasture will give the grass a competitive advantage over climbing and more upright tropical legumes and may do more harm to them than it does to faster growing weeds.

Pastures which contain tropical legumes should only be mown at the end of the dry season, before legumes have commenced new growth, to remove weeds and uneaten grass. Burning for this purpose should, of course, never be done.

Most of the weeds which appear in newly established pastures are annuals and a vigorous pasture will soon smother these if it is not overgrazed. Tall growing perennial weeds should be hand-pulled when young, hoed out, or spot sprayed with herbicide. Woody perennials should be cut near ground level and the butts painted with a mixture of 2,4,5-T and diesel fuel. All pasture legumes are more less susceptible to damage from herbicides so blanket sprays should never be used, particularly in mixtures of 2,4,5-T and Picloram.

FERTILIZATION

Effect of nitrogen fertilization

Although N is obviously deficient in acid tropical soils, N should not be applied to legume/grass pastures. Henzell (8) has estimated that effectively nodulated legumes will supply 62-180 kg/ha annually to the associated grass; Whitney and Green (30) reported DM yields from a *D. intortum/D. decumbens* pasture equivalent to yields from a pure *D. decumbens* pasture receiving about 250 kg/ha of N fertilizer, and crude protein yields equivalent to pure *D. decumbens* plus about 450 kg/ha of N; Chadhokar (3) in Papua New Guinea obtained increased DM yields by oversowing *S. guianensis* into *Imperata cylindrica* equivalent to *I. cylindrica* alone plus 240 kg/ha of N. Any attempt to obtain additional grass production by applying N fertilizer will place the legume at a competitive disadvantage and, if persisted with, will lead to elimination of the legume (Fig. 1).

Cultivation will usually mineralize sufficient N and K for establishment of grasses. Deficiency of soluble phosphate may be a more serious limitation to some of the better grasses (e.g. *P. maximum)* than it is to legumes.

The role of phosphorus, sulphur and molybdenum

Much of the success of tropical pasture legumes in Australia can no doubt be attributed to the ready availability of

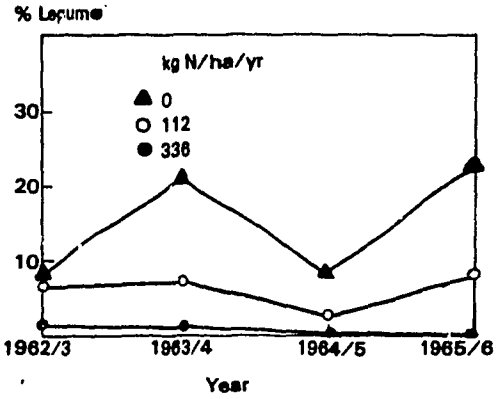

Figure 1. Effect of annual N fertilizer on percentage of legume *(M. atropurpureum)* in a *M. atropurpureum/S. anceps* pasture over four years (11).

molybdenized SSP. Conversely, many failures of legumes both in Australia and elsewhere are undoubtedly due to lack of P, S and/or Mo. That these elements profoundly affect legume survival and productivity is well documented, but providing them is difficult in many tropical countries.

Some increases in animal production can be obtained in the short term by using legumes, such as some of the *Stylosanthes* spp., which are able to make use of soil P of low availability. Sooner or later, however, additions of P to the soil will have to be made or animal production must decline. Ozanne *et al.* (24) have recorded near linear responses in body weight gains, by sheep, at phosphate fertilizer rates up to about three times those needed for maximum pasture yield. These gains were attributed to greater voluntary intake and digestibility of feed from the fertilized pasture. The same rates of gain could not be obtained by substituting an inorganic supplement to give the same intake of P. They concluded that "the responses obtained were not necessarily due to phosphorus *per se* but possibly to some other unmeasured constituent of the feed which varied with phosphorus level". There is some evidence that these findings also apply to cattle fed on tropical pastures (D.J. Minson, pers. comm.).

Jones and Andrew (15) and Mears (19) found that P increased yield of grass more than legume in the establishment year. In Malaysia, Kerridge (17) found that *S. guianensis* could be established on a P deficient soil by the application of 500 kg/ha of ground rock phosphate but *P. maximum* required a more soluble form of phosphate —200 kg/ha TSP. Both species could be maintained by annual applications of rock phosphate. This suggests that in some legume/grass mixtures there may be scope for manipulating the ratio of legume to grass if alternative sources of P fertilizer are available.

S and Mo are essential for good N fixation by legumes (1). In addition to incorporating Mo in fertilizer, it can also be applied as a seed coating when sowing, or by spraying it on to an established pasture. Sufficient S may be mineralized by cultivation for establishment of legumes and SSP contains sufficient quantities for maintenance requirements in most soils. Unfortunately, SSP is unobtainable in most tropical countries. As the swing towards the manufacture of TSP will probably continue, it can be expected that poor performance of legumes due to S deficiency will increase in the future unless a satisfactory alternative form of S fertilizer can be found (9).

THE EFFECT OF HIGH STOCKING RATES ON LEGUMES

Stocking rate is the most important factor affecting the stability and long term productivity of a legume/grass pasture. Overgrazing will lead to a decline in the proportion of legume in the pasture and this will be followed by a sharp fall in animal production.

This is illustrated in Figure 2, which is based on a grazing experiment by Jones (11, 13). At a stocking rate of 1.11 animals/ha, after three years there was a stable association of approximately 50% legume and 50% grass with practically no weeds (Fig. 2a). At the high stocking rate of 2.96 animals/ha the legume had been reduced from 23% to 6% after three years, with 46% weeds (Fig. 2b).

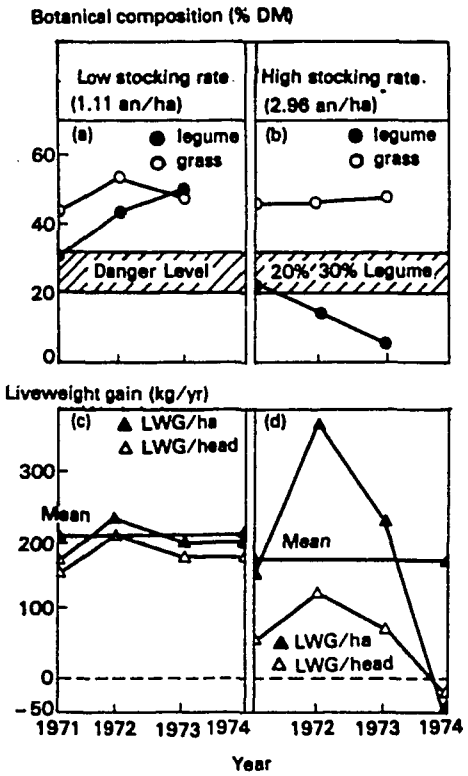

Figure 2. Performance of a *D. intortum/S. sphacelata* pasture over four years at two stocking rates (11, 13).

The effect of these botanical changes on animal production is shown at the bottom of Figure 2. At the lower stocking rate liveweight gains per head and per ha remained fairly constant over the four years of the experiment, with mean annual liveweight gains of 200 kg/ha and 180 kg/head (Fig. 2c).

At the higher stocking rate there was a steep increase in liveweight gain in the second year, but this was accompanied by a decline in legume percentage, which in turn led to dramatic falls in liveweight gains in subsequent years. In the fourth year there was practically no legume left in the pasture and the animals actually lost weight (Fig. 2d). Over the four year period the mean annual liveweight gain at this stocking rate was only 178 kg/ha and 59 kg/head.

At the higher stocking rate, production over the four year period was 88 kg/ha lower than it was at the low stocking rate and production per head was not satisfactory at any stage. Not only had there been a loss of production but the legume component of the pasture had been eliminated at the high stocking rate and further falls in production would be inevitable.

This situation is very common in practice and is brought about because most cattlemen, when determining stocking rates, base their decisions on an assessment of the condition of the cattle and the amount of grass in the pasture. On this basis the high stocking rate of 2.96 animals/ha in 1972 would not appear to be excessive, as there was plenty of grass in the pasture and the cattle were doing well. This, therefore, is obviously not a satisfactory guide —as indicated by the disastrous fall in production over the next two years.

The most useful parameter for determining stocking rate is the amount of legume in the pasture.* As soon as a decline in legume content is observed grazing pressure must be reduced. Recovery will be most rapid in the latter half of the growing season, when grasses have matured but legumes are still growing actively, and every effort should be made to keep stocking rates down at this time.

In the example given above, legume percentage had fallen to 16% in 1972 (Fig. 2b), well below the danger level which is probably of the order of 20 to 30% depending on species and the time of the year. If the stocking rate had been reduced at this time the legume could have recovered and again formed a stable, productive pasture. But by

* There are a few exceptions to this general rule. For instance, in Malaysia it has been found that if a pasture of *S. guianensis* and *P. maximum* is grazed too short, *P. maximum* declines more rapidly than *S. guianensis* leading to a temporary increase in the proportion of legume even though the stocking rate is too high. Stobbs (27) reported a similar occurrence in a *M. atropurpureum/P. maximum* pasture in Uganda. This can be avoided if the pasture is not grazed too short during the growing season, as described later under "Grazing Management".

1973, when the decline in animal performance became apparent the damage had already been done and it was too late to save the legume, which by then had been reduced to only 6%.

It should also be mentioned here that overgrazing of the legume component of a pasture can occur in some circumstances even though the overall stocking rate is not too high. Examples of this are: (a) Rotational grazing systems, with long rests between grazings, which allow the grass to become overmature and relatively less palatable than the legume. (b) Crash grazing programs which are designed to force cattle to utilize as much as possible of the feed on offer, thus robbing the legume of the protection conferred on it by its relative unpalatability during the early growth period.

GRAZING MANAGEMENT

It is not surprising that grazing management of tropical legume based pastures is poorly understood, as most of the legumes have only been in use as pasture plants for a short time. There is very little published information on management and some of it is misleading as it is based on the assumption that management practices which are beneficial for temperate legume based pastures (principally clovers) will also be beneficial for tropical legume based pastures.

This has not always worked out in practice, due to fundamental differences between the growth characteristics of temperate and tropical grasses and legumes. These are, chiefly, the high growth rates, high DM yields and poor nutritional value of rapidly maturing C_4 grasses and the growth habit of the most commonly used tropical legumes.

Various management techniques which have been developed to overcome the nutritional deficiencies of tropical grasses (e.g. burning, slashing, crash grazing, N fertilization) are all damaging to the pasture legumes which are currently available. This no doubt accounts for the scarcity of indigenous legumes in pastures which have been subjected to any of these practices for a considerable length of time.

Similarly, techniques which improve utilization of temperate grasses and encourage the spread of low growing clover plants, such as rotational grazing and high pressures, soon lead to elimination of climbing and more upright tropical legumes due to overgrazing and, to a lesser extent, trampling.

Legume classification

For the purposes of grazing management it is more practical to classify legumes according to their behavior under grazing rather than as temperate or tropical species, which is not a very clear division anyway.

It is suggested that most legumes fall into broad categories:

(a) **Prostrate legumes,** which perform best under high grazing pressures, such as *Trifolium* spp., *Lotus pedunculatus, Lotononis bainesii* Baker, *Desmodium canum* (J.F. Gmel.) Schinz. & Thell. and *D. heterophyllum.*

(b) **Climbing legumes** such as *D. intortum, Desmodium uncinatum* (L.) Sw., *G. wightii, M. atropurpureum* cv. Siratro and *C. pubescens,* and upright types like *S. guianensis* and *Stylosanthes hamata* (L.) Taub., all of which perform best under low grazing pressures.

There is also a third, smaller, group consisting of:

(c) **Very palatable legumes,** which tolerate defoliation quite well but are so palatable that they will soon be grazed out if animals have unrestricted access to them. *Medicago sativa* L. is the most widely used and best understood legume in this group but more recent introductions include *Vigna luteola* (Jacq.) Benth and *L. leucocephala.*

The first and third groups include temperate, subtropical and tropical species. Efficient management techniques have been developed for the temperate species and there seems to be no reason to doubt that these methods would also be appropriate for the tropical species in those groups.

On the other hand, the second group of climbing and more upright types does not include any widely used temperate species but it does include all the tropical species most widely used at present. It is the grazing management of this group of legumes which presents the most problems and these are discussed below.

Pasture height and grazing pressure

The legume group is comprised of climbers and shrubs which must not be grazed too low. If insufficient leaves are left after cutting or grazing they will be slow to recover and yields will be reduced (Fig. 3). Frequent severe defoliation will seriously reduce their vigor and ability to compete with other species (14) and will eventually lead to their elimination. This also applies to some tropical grasses, particularly *P. maximum* (27).

In practice it has been found that the most useful guide to maintaining the necessary number of leaves and growing points to ensure good production and persistence of these legumes is the height of the pasture. This will vary somewhat according to the species but for a typical *S. guianensis/C. pubescens/P. maximum* mixture the height should be kept within about 30 to 60 cm during the growing season. This is short enough to keep the grass growing actively but long enough to keep the legume from being completely defoliated.

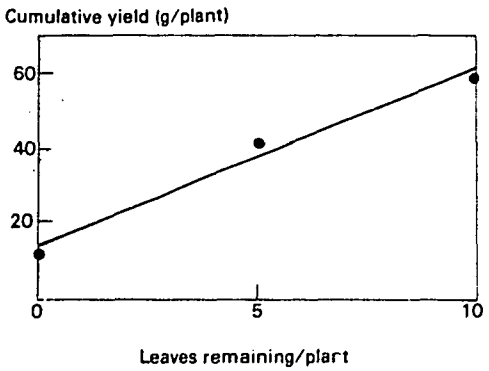

Figure 3. Relation between total cumulative plant yield and the number of leaves remaining on the plant after cutting *M. atropurpureum* every four weeks (12).

Above this height cattle will have difficulty in harvesting the pasture efficiently (29) but it may be necessary to exceed this height towards the end of the growing period to ensure that sufficient feed will be available to carry the stock through the dry season in good condition. By that time the pasture will, of course, be shorter than 30 cm but the legumes will soon recover if there is a good ground cover of woody stems to provide plenty of growing points.

For most legumes in this group it is suggested that, as a general rule of thumb, during the growing season the pasture should be kept at between one quarter and one half of the mature height of the associated grass. Under these conditions a layer of raw organic matter (OM) soon accumulates on the soil surface and builds up the O horizon that is so often missing from tropical grassland soils. This layer is an important route for return of nutrients to the soil, it moderates fluctuations in soil moisture and temperature, it protects the soil from erosion and, by acting as a cushion, it reduces trampling damage to the stems of legumes.

By maintaining the pasture within these height limits it is not difficult to achieve and maintain legume dominance. The rather loose term "legume dominance" is used deliberately because, for the practical cattleman who must make decisions on stocking rate, it is not much help to know that it is desirable to maintain a mean annual legume content of, say, 30% because he has no way of measuring this, other than visually, and visual assessments of legume/grass ratios can be grossly mis-

leading. In a tall pasture the percentage of legume may be as low as 10% but it appears to be more because most of the legume leaves are at the top and are more easily seen than the grass leaves (19). Also, there are very wide seasonal variations in legume percentage on a DM basis even in pastures which have a quite high proportion of legume plants (5). Where there is adequate legume in the pastures the legumes have large healthy leaves of good color and texture probably because plant food reserves are never seriously depleted. This suggests that a size reduction in the legume leaves could be a useful indication that grazing pressure should be reduced.

One warning sign that a tall legume based pasture is being overgrazed is the appearance of annual weeds or low growing pasture species. It is necessary to have some sort of easily recognizable warning sign as it is extremely difficult to convince most cattlemen that the stocking rate should be reduced while there is still 30 cm of pasture standing in the paddock.

VARIABLE CONTINUOUS GRAZING

To maintain tropical legume based pastures within height limits favorable to the legume it is necessary not only to choose the correct stocking rate but also to devise a grazing system which allow grazing pressure to be manipulated and so preserve the balance between legume and grass.

In rotational grazing systems each paddock tends to alternate between too short and too tall unless rotations are very rapid, and even in a simple two paddock system of rotation the stocking density is doubled in the paddook which is being grazed —with a resultant increase in damage to the legume from trampling, and pugging of the soil in wet weather. There is always a danger that cattle will be left too long in a paddock and eat out the legume.

Continuous grazing appears to be a more successful system for climbing and upright tropical legumes (18, 27) provided the correct stocking rate is selected. In practice, however, this is difficult to achieve due to seasonal and annual fluctuations in pasture production. Consequently, rigid set stocking patterns usually lead sooner or later to overgrazing and damage to the legume component which is difficult to rectify.

A variation of the put-and-take system, known as Variable Continuous Grazing, has successfully maintained climbing legumes for nine years at average stocking rates of about 1.5 animals/ha at "Lochburn", a commercial farm near Murwillumbah in northern New South Wales, lat. 27° 30' S (25). In this system there are normally some cattle in every paddock at all times, but the number in each paddock will vary from time to time according to the availability of feed. Cattle are never completely removed specifically for the purpose of promoting pasture regrowth —although they may be removed at times for other reasons, such as to allow one or more of the pasture components to set seed, or for animal husbandry purposes. The stocking rate is continuously varied as necessary to maintain a stable equilibrium between legume and grass —increasing the grazing pressure favors the grass, decreasing it favors climbing legumes— provided well-adapted and compatible species were chosen in the first place.

Because climbing and upright legumes are so sensitive to overgrazing, and because it is not usually practical to vary stocking rates by buying or selling stock, other areas of pasture must be provided which will not be damaged by temporary overstocking. This "safety valve" may consist of unimproved grasslands or special areas of stoloniferous pastures which can withstand heavy stocking densities. These two types of pasture have completely different animal production characteristics which complement each other in an integrated pasture system of this nature.

Tall legume based pastures

These contain climbing or shrubby

legumes as described earlier. Animal production will be in direct proportion to the amount of legume present (6, 23) but pure legume pastures are unstable and subject to weed invasion. They may also be difficult for cattle to harvest efficiently (29). An important role of the grass, therefore, is to keep out weeds and provide feed in spring when legume regrowth is slow. The legume is regarded as being the main source of high protein feed and stocking rates are continuously adjusted to keep the legume/grass ratio as high as possible. Although there is always a grass component, for convenience these are referred to as legume based pastures.

The characteristics of such pastures are high production per head but comparatively low carrying capacity (Fig. 4). They are used for rapidly fattening cattle and, in frost-free locations cattle can be finished right through the dry season when prices for fat cattle are highest.

Short grass pastures

These may be of two kinds; sward forming grasses which may include a prostrate legume, or which may be top-dressed with N as necessary to provide additional feed in emergencies. The grasses must be stoloniferous species which will take heavy grazing pressure, e.g. *Axonopus affinis* Chase, *Pennisetum clandestinum* Hochst. ex Chiov. or *B. decumbens*. They will not be damaged by high stocking densities but production per head will be low unless N inputs are high, either from an associated legume or from fertilizer (Fig. 5). This is not important, however, as their function is to act as holding paddocks from which to channel a steady stream of store cattle into the fattening paddocks and to act as "sacrifice" paddocks during periods of feed shortage. Their main attribute is that stocking rates may be varied within very wide limits without doing permanent damage to the pasture. This is more fully discussed later under the heading "Integration of tall legume based and short grass pastures". For convenience they are referred to as grass paddocks although they may include prostrate legumes which are tolerant of high grazing pressures.

WHAT IS THE OPTIMUM STOCKING RATE?

The acknowledged low carrying capacity of tall legume based pastures has led many cattlemen to reject them, apparently in the belief that carrying capacity is closely correlated with profitability. This is probably reinforced by some confusion over what is the "optimum" stocking rate.

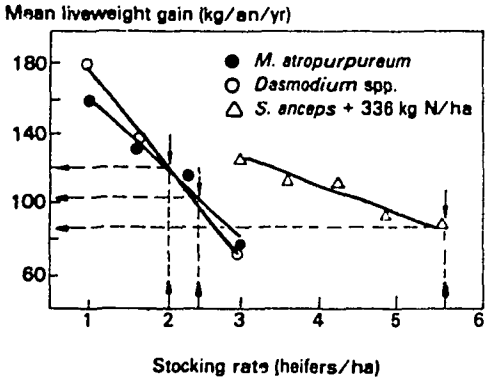

Figure 4. The relation between animal liveweight gain and stocking rate for three tropical pastures over a three year period, 1969/70-1971/72. Arrows indicate stocking rate for maximum gain/ha and the gain/an at this stocking rate (13).

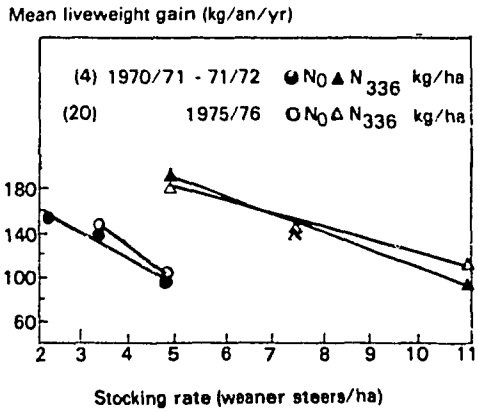

Figure 5. The relation between animal liveweight gain and stocking rate on naturalized pastures with and without N fertilization (4,20).

Mott's model of the relation between stocking rate (S/R) and animal product per head and per ha (Fig. 6a) has been widely used and this indicates an "optimum" S/R very close to maximum production per ha. It implies that lower stocking rates would be less profitable because production per ha drops rapidly as S/R is reduced but there is very little compensating gain in production per head. For example, a reduction of 30% in S/R would decrease production per ha by approximately 25% and increase production per head by only about 10%.

More recently Jones and Sandland (16) have proposed a model (Fig. 6b) which indicates an "optimum" S/R at the point of maximum liveweight gain per ha (LWG/ha) but this point is not nearly as critical as in Mott's model. In Jones and Sandland's model a reduction in stocking rate of 30% would decrease LWG/ha by only 10% and increase LWG/head by about 30%. This does not take into account, however, differences in the monetary value of the LWG at different S/R's, or the increased costs associated with higher stocking rates.

Figure 7a illustrates the results of a grazing trial conducted by Jones at Samford,

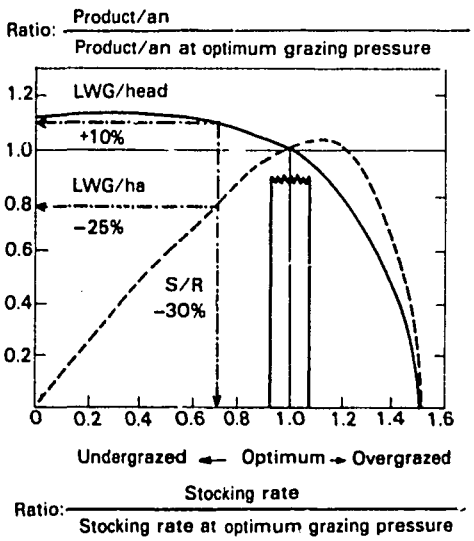

Figure 6a. The effect of reducing stocking rate by 30% on LWG/head and per ha, based on the model of Mott (21).

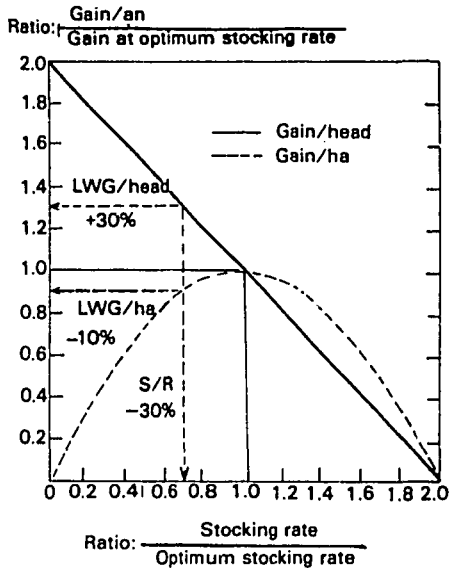

Figure 6b. The effect of reducing stocking rate by 30% on LWG/head and per ha, based on the model of Jones and Sandland (16).

southeastern Queensland, on a *S. anceps/M. atropurpureum* pasture at four stocking rates. The percentage of legume in the pasture (13) has been superimposed on the figure illustrating the relation between gain per animal and gain per ha which was published by Jones and Sandland (16). Note how closely gain per animal was related to the mean percentage of legume for the first three years and also that in the third year the percentage of legume was declining at the higher stocking rates. In Figure 7b the gross value of meat produced per ha (a) has been plotted, on the assumption that the heaviest animals (at the lowest S/R) would be worth 10% more per kg than the lightest animals (at the highest S/R). It is stressed that this increase in value has nothing to do with any so called improvements in meat quality, such as "marbling", which does not attract a premium price in most tropical countries. It is entirely due to the fact that, for pasture fed animals of the same age, the heavier animals will yield a higher proportion of lean meat than the lighter ones, i.e. the ratio of muscle to bone, hide and offal will be greater. It should also be noted that this increased value applies to the total liveweight of the animals, not just to the

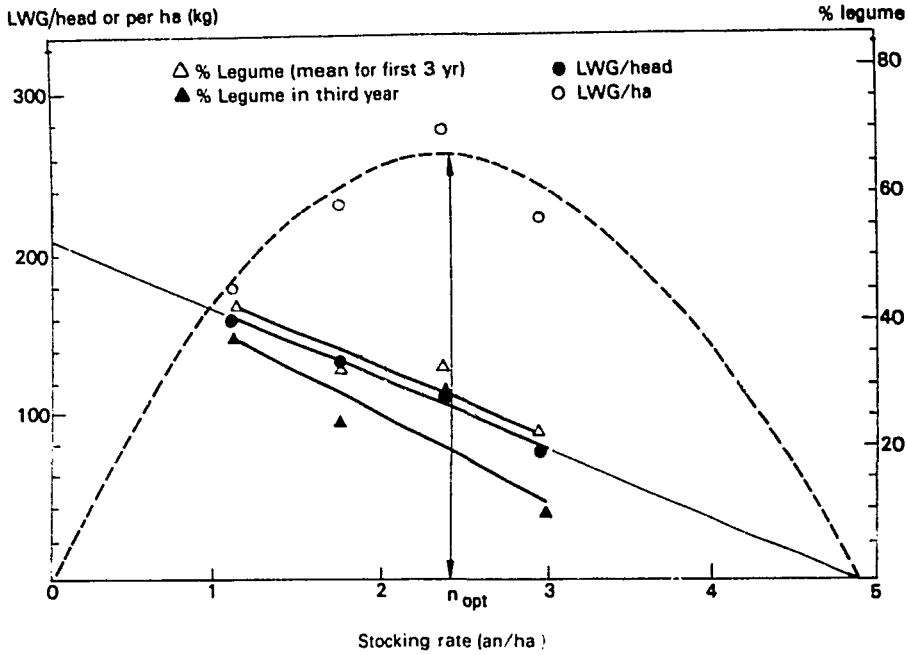

Figure 7a. The relation between gain/animal and gain/ha in response to increasing stocking rate for a *S. anceps/M. atropurpureum* pasture (16).

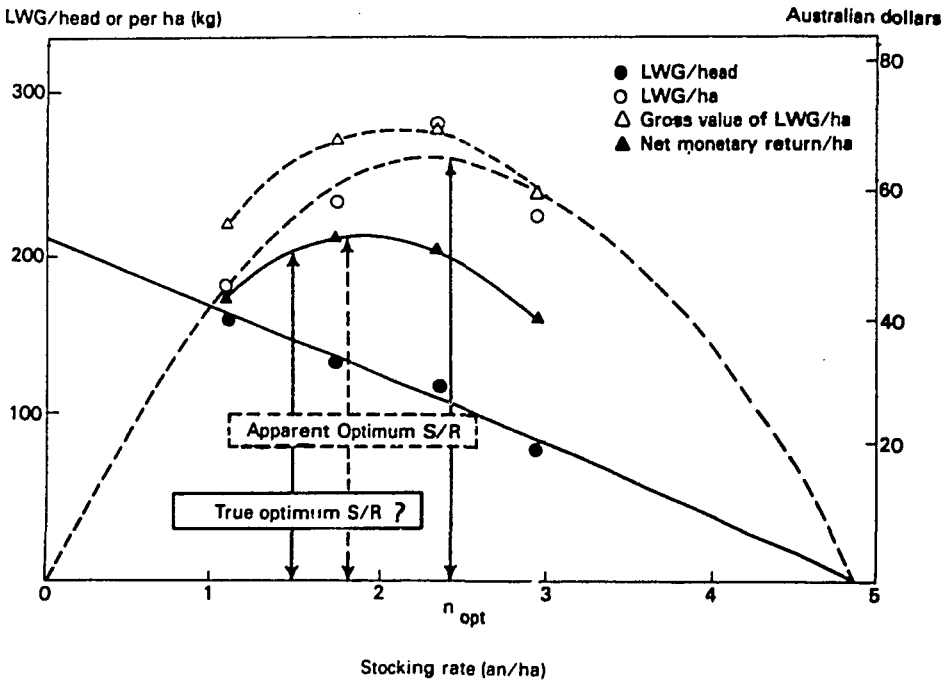

Figure 7b. Gross value of LWG/ha and net monetary value per ha after deducting costs which are directly related to stocking rate, based on animal production data in Fig. 7a.

weight gained during the experimental period.

From the figures thus obtained for gross value of meat produced per ha, (a) have been deducted the costs which are directly related to S/R, i.e. interest on capital invested in stock, costs per head associated with animal health, transport, losses by death, etc. It has been assumed that these costs amount to 10% of the value of the animals, and this percentage is not very sensitive to changes in market value as its chief component is interest on capital invested in stock. Plotting the figures thus obtained produces a curve (b) which approximates net monetary return per ha and it is suggested that the economic optimum S/R is indicated by the highest point of this curve provided no hidden costs are being incurred by damage to the pasture at this S/R.

The botanical changes which occurred during the first three years of the experiment appeared to indicate that the pasture was stable at S/R's of 1.73 and 2.35 animals/ha (Fig. 7a) but the legume contribution was only of the order of 23-29% at these stocking rates against 37% at 1.11 animals/ha. Since then, however, the legumes have been eliminated from this pasture at the intermediate S/R's of 1.73 and 2.35 animals/ha, emphasizing the importance of long term grazing trials for assessing botanical changes and their effect on optimum stocking rates (27).

In practice it has been found that similar pastures have remained stable for periods of at least nine years at S/R's of about 1.5 animals/ha and there does not appear to be any point in risking a reduction in legume content by pushing the S/R beyond this point, as the curve for net monetary return per ha is comparatively flat in this area.

It is contended that the true optimum stocking rate for tall legume based pastures lies closer to the point of maximum production per head than it does to the point of maximum production per ha. The fact that they cannot withstand heavy grazing pressure and, therefore, carrying capacity is comparatively low, does not entail any significant economic penalty provided alternative pastures with high carrying capacity are available for use in times of feed shortages.

Attention is drawn to the sharp drop in net monetary return per ha at stocking rates above 2.3 animals/ha in this example. To buy additional animals to increase the stocking rate beyond this point is obviously a bad investment, quite apart from any adverse effect it may have on the pasture. Nevertheless, failures of newly established pastures are frequently caused because funds which should have been used for pasture maintenance (e.g. weed control and fertilization) are diverted to purchase additional cattle, in an attempt to "fully utilize" the pasture and get a quicker return on capital.

It might be argued that the light animals at the higher stocking rate in the above experiment would not, in practice, be sold at that age but would be carried through until they reached the same slaughter weight as the heavier animals at the lower stocking rates. Provided this weight was reached in a period of a year or less there would only be a small difference in the yield of saleable meat from the younger carcases (N.M. Tulloh, pers. comm.) and consequently the monetary value of the liveweight gain would be about the same in each case, wiping out the 10% premium at the lowest stocking rate shown in Fig. 7b.

There would, however, be another economic penalty—probably of greater magnitude. The slower growing animals would have consumed a much greater amount of pasture for maintenance purposes only and, consequently, a smaller proportion of their total feed consumption would have been used for producing meat. A two year old animal might be as much as 40% more efficient than a three year old at similar weight because of less labor and time involved and less feed eaten (F.J. Mikan, pers. comm.).

INTEGRATION OF TALL LEGUME BASED AND SHORT GRASS PASTURES

The animal production characteristics of grass pastures

Figure 8 is based on results of a grazing trial conducted by Mears (20) at Wollongbar in northern New South Wales. The pastures were originally a mixture of *P. clandestinum, A. affinis, Paspalum dilatatum* Poir and *Trifolium repens* L. very similar to the short grass pastures at "Lochburn" described under "Grazing Management" earlier in this paper.

The main characteristic of these pastures is the very flat slope of the line for animal production per head in the N_0 treatment. At the low S/R, LWG/head is not particularly high but the S/R can be increased considerably without much reduction in LWG/head. This is in contrast to the much steeper slope of this line for a tall legume based pasture (Fig. 7a) and it is the reason why these short grass pastures are so suitable for use in conjunction with tall legume based pastures. (No direct comparison of the animal production in Figs. 7b and 8 should be made, however, as climatic conditions are more favorable and soils much more fertile at Wollongbar than at Samford).

The flexibility of these short grass pastures is demonstrated by the way in which the slope of the LWG/head line changes in the N_{336} treatment; at a S/R of 4.9 animals/ha,LWG/head was increased from 142 to 191 kg by addition of 336kg/ha of N; alternatively, the S/R could be increased from 4.9 to 7.4 animals/ha without

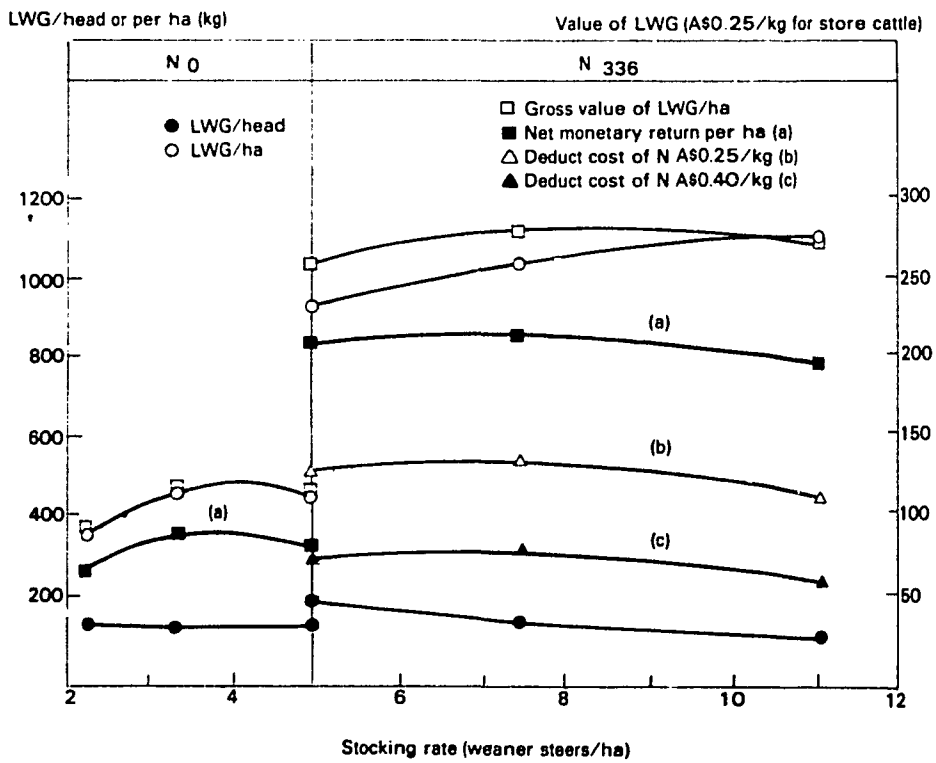

Figure 8. Gross value of liveweight gain per ha and net monetary return per ha after deducting: (a) Costs which are directly related to stocking rate, (b) cost of N fertilizer (A$0.25/kg N), and (c) cost of N fertilizer (A$0.40/kg N.). Based on animal production data of Mears (20).

any loss of LWG/head using the same amount of N.

In Figure 8 the cost of N at two levels has been deducted from the net monetary return/ha. In 1970-72, when these results were obtained, the cost of N at Wollongbar was about 25¢/kg and the N_{336} treatment was more profitable than the N_0 treatment. On present costs of about 40¢/kg N, the N_{336} treatment is slightly less profitable than N_0, and these relative levels of profitability are very sensitive to changes in the price of animal products (7).

An enterprise which is mainly dependent on grass plus fertilizer N is therefore risky, but the flexibility of this system makes it ideal for providing a "safety valve" in an integrated system based mainly on production from tall legume based pastures.

Integrating legume based and grass pastures

The ratio of legume based pastures to grass pastures should be varied according to the nature of the enterprise, being highest for fattening or dairying, lowest for breeding. In the example given under "Variable Continuous Grazing", above, for a commercial fattening enterprise near Murwillumbah, the ratio is about three to one. A common cause of failure on other properties in this area has been because this ratio has been far too low, resulting in over-utilization of the legume based pastures.

By planning the layout of paddocks so that the grass pastures are located at the points of greatest stock concentration, e.g. around stockyards and dairy buildings, there will be a transfer of N by cattle from the legume/grass paddocks to the grass paddocks, thus reducing or obviating the need for N fertilization to keep the grass pasture productive.

It has also been shown that keeping the grass pastures short leads to an invasion of indigenous and naturalized short growing legumes, such as clovers, and this can be encouraged by fertilizing with superphosphate.

It is believed that by integrating legume based and grass pastures in this way it is possible to obtain greater animal production than would be possible from either type of pasture alone. The increases in production come from improved feed quality, resulting in better calving percentages, faster growth rates and higher turn-off of beef per year; or higher milk production with less dependence on concentrate feeding in a dairy enterprise.

As far as is known this system has not been tested experimentally, and it may not be possible to do so, as its chief merit lies in its flexibility and this would probably be lost in any experimental design which would fulfil the requirements of statistical analysis (2).

CONCLUSIONS

It is considered that, although there is much room for improvement in methods of establishing tropical legume based pastures, the majority of failures occur at a later stage due to improper management practices.

These failures are attributed to over-emphasis on the importance of tropical grasses as a source of feed for cattle and a lack of appreciation of the major role which tropical legumes can play in increasing animal production. This "grass-mentality" leads to attempts to fully utilize the large quantities of low quality fodder produced by tropical grasses but these management practices lead to elimination of the legumes.

It is argued that the prime components of a mixed tropical pasture are the legumes. An important role of the grass is to prevent weed invasion and utilize N accumulated in the soil by the legume. On a quantitative basis the grass may contribute more to the diet of the cattle than the legumes but on a

qualitative basis the legume is indispensable. This is of paramount importance because feed quality, rather than quantity, has always been the main factor limiting animal production in the tropics.

It is contended that increases in animal production can best be achieved by adopting management practices which favor legume growth and persistence, thereby increasing the ratio of legume to grass in the pastures, with a resultant increase in the quality of the feed on offer. The aim should be to achieve legume dominance rather than merely legume survival. Anything less is inviting failure.

These changes can only be brought about by controlling stocking rates and giving the animals every opportunity to select for themselves a high quality diet. It is suggested that animal production would be higher from an integrated system of tall legume based pastures and short grass pastures than could be obtained from either type of pasture alone.

With this system, pasture utilization would be quite low by temperate standards but the unconsumed pasture is not considered to be wasted —in the tropics very large quantities of OM must be returned to the soil to preserve and build up the fertility on which the whole system depends.

The return to the soil of large quantities of unconsumed pasture in this manner is seen as a better short term investment than trying to utilize it all as cattle feed, and in the long term it could eventually reverse the steady decline in productivity of tropical grasslands which is evident throughout the world.

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EXPERIENCES IN REGIONAL DEMONSTRATION TRIALS IN BRAZIL

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ABSTRACT

Regional trials on improved natural pastures and established cultivated pastures on cleared fields, were conducted in the Cerrado region of Brazil, to evaluate three factors influencing cattle productivity: (a) methods and costs of establishing pastures; (b) management systems and pasture evaluation through animals; and, (c) economic analyses of production systems. The program was successful in its objectives of demonstrating to farmers, on their own farms and with their participation, the costs and benefits of technically established, adequately managed pastures. Also studied were the effects of different maintenance fertilization levels on the persistence of the grasses and legumes and on animal production. Results obtained in the Brazilian Cerrado demonstrate that it is possible to increase production per unit area using associations of grasses and tropical legumes. CONDEPE conducted the trials until 1976 and they are now coordinated by EMBRATER and its affiliates EMATER in the different states of central Brazil.

The Special Demonstration and Pasture Technology Evaluation Program in central Brazil established demonstration and/or verification areas in that region aimed at testing, at farm level, the technical and economic results obtained in previous experiments. The information generated in these trials provided answers on which to base technical recommendations to the region's beef cattle producers. Through these verification areas the following factors influencing cattle productivity were assessed: (a) pasture establishment methods and costs; (b) pasture evaluation and management; and, (c) economic analysis of production systems.

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THE SPECIAL PROGRAMS

Pasture Establishment Technology Program

This program was established in 1971 at the request of the Central Bank of Brazil; its implementation and coordination were assigned to CONDEPE (Conselho Nacional de Desenvolvimento da Pecuária). Its basic objective was to test, under farm conditions and at low risk to the farmers, some techniques already developed for the improvement and management of pastures. These techniques included correcting soil acidity and fertilization, associations of grasses and legumes and grazing systems.

The Central Bank of Brazil subsidized the cooperators in the program through free amendments, fertilizers and seed as well as

the provision of a 7% rate of interest on investment loans. Financing was for five years with a two-year grace period; later, these periods were extended to seven and three years, respectively.

At first the regional trials had a size of 25 ha, but later they were expanded to 100 ha. Cooperators in the program were required to: (1) permit program personnel and farmers to visit the areas so that the techniques and ideas could be diffused more effectively; (2) provide the Central Bank of Brazil with financial data of the farm enterprise; (3) implement all the recommendations contained in a "Simple Plan" approved by CONDEPE; and, (4) reimburse the value of products received, subject to a 15% annual interest rate, and to cancel all financing, if for any reason the cooperator had to leave the program. Data in Table 1 show the number of farms and hectares planted to improved pastures by this program.

The program demonstrated to the farmers, on their own farms and with their participation, the costs and benefits of technically-developed and adequately-managed pastures. Knowledge about forage legumes and grasses other than the traditional ones (*Hyparrhenia rufa* (Nees) Stapf., *Melinis minutiflora* Beauv. and *Panicum maximum* Jacq.) were widely introduced to these areas. In addition, farmers had the opportunity to observe and adopt the benefits of fertilized and well-managed legume-based pastures—technological innovations introduced for the first time on their farms.

Follow-up Program

A second program, entitled "Evaluation and Adaptation of Technology and Project Methodology" was created in 1974 under a constitutional law presented by the Central Bank of Brazil.

The basic objectives of this program were: (a) to evaluate the impact of various technological factors, proven and introduced by CONDEPE, on the productivity and profitability of farms provided with technical and financial assistance; and, (b) to refine the practices introduced in demonstration trials in order to define the technology for improving and managing pastures in the central region of Brazil.

Table 1. **Area planted and number of farms involved in the "Special Program for Pasture Establishment with Modern Techniques".**

Specification	Mato Grosso	Goiás	Espíritu Santo Minas Gerais	Total
Pastures established from 1971 to 1973				
Number of pastures (units)	27	25	114	166
Area benefited (ha)	907	1,262	2,736	4,905
Pastures established in 1975				
Number of pastures (units)	-	-	17*	17
Area benefited (ha)	-	-	1,066	1,066
The program as a whole				
Number of pastures (units)	27	25	131	183
Area benefited (ha)	907	1,262	3,802	5,971

* Pastures established in the State of Minas Gerais.

To meet these objectives, the program gave priority to the following factors: (a) selection of grasses and legumes for the pastures of the principal economic regions; (b) nutrient requirements of forage plants on different soils (or great groups of soils); (c) study of the introduction of tropical legumes with phosphate fertilizer on degraded pastures, to increase their production and stabilize their nutritional value; (d) determination of the most adequate use of legume-grass associations during the dry season and the systems of management to assure their persistence; (e) introduction, at a low cost, of tropical legumes in natural vegetation; and, (f) economic evaluation of the relation between inputs and production on farms of different sizes in the principal ecological regions.

The program was carried out successfully by a team consisting of three consultants, four coordinators, 14 officers and two assistants.

These days, these special pasture programs are coordinated by EMBRATER and their operation is supervised by the branches in the different states. The data in Table 2 illustrate the growth during 1974-75 and 1975-76, in central Brazil.

Considering the two programs together, a total of 240 demonstration fields were established totaling 10,342 ha of improved pastures.

THE REGION

The program area is located between latitudes 15° and 23°S and encompasses parts of five states forming the central and southern regions of the country: Espíritu Santo, Minas Gerais, southern Goiás, southern Mato Grosso and northwestern São Paulo.

According to Köppen, this region is characterized by two main types of climatic classifications: the hot humid savanna (Aw) and the sub-tropical or mesothermic (Cw). Mean annual temperature ranges from 20° to 22°C over most of the region and average annual rainfall is from 1000 to 1500 mm, with the exception of some mountainous areas of Minas Gerais where higher rainfall is recorded.

Table 2. **Area planted and number of farms involved in the "Program for the Evaluation and Adaptation of Technology and Project Methodology".**

Specification	São Paulo	Mato Grosso	Goiás	Espiritu Santo	Minas Gerais	Total
Pastures established						
1974-75						
Number of pastures (units)	-	4	10	5	13	31
Area benefited (ha)	-	350	807	313	763	2,233
Pastures established						
1975-76						
Number of pastures (units)	5	5	5	3	7	25
Area benefited (ha)	387	444	494	162	651	2,138
The program as a whole						
Number of pastures (units)	5	9	15	8	20	57
Area benefited (ha)	387	794	1.301	475	1,414	4,371

The region has a dry season that varies from four to six months. During these months (April to October) only sporadic rains are recorded and these normally do not total more than 20% of the annual rainfall.

The vegetative cover is composed of distinct types of formations, generally by forests, pastures and the native Cerrado, with the last one being the main form.

The great majority of the soils have moderate to low fertility levels; they are generally deep and of good texture. Soils with Latosolic B horizons (Oxisols), with all their variations and characters, are predominant in the region. Also found in the region but in less representative areas are other soil types such as the Red Yellow Podzolics (Ultisols), Regosols (sandy Entisols) and the Lithosolic (shallow Entisol) soils. As can be seen, the Cerrado occupies almost all the area covered by the program and part of the 1,339,250 km² (about 16% of the land surface of the country) forms 59, 37 and 35%, respectively of the states of Goiás, Minas Gerais and Mato Grosso. In these states are found 77% of the total Cerrado and 42% of the nation's beef population (10).

The Cerrado is utilized for intensive grazing. Productivity always depends on the level of technology adopted. This level varies from grazing the native savanna, without any investment, up to its complete substitution for cultivated pastures, employing land clearing, soil preparation, use of lime, fertilizers and planting forage species.

In its native state, the Cerrado does not offer adequate forage during the entire year and the best nutritional levels are found during the forage regrowth stage, after the annual burnings. The low productivity indices of the herds —with calving rates of not more than 50%,slaughtering of steers at around five years of age and first breeding of heifers at more than 40 months—and the low carrying capacity (0.2 to 0.4 AU/ha) are due to poor quantity and quality of the negative Cerrado vegetation as a forage.

The best lands of the region were previously covered with forests and cerradão. Pastures of *P. maximum* and *H. rufa* were established there but today these are degraded, especially in São Paulo and Minas Gerais, where exploitation has occurred for a longer time. Because of the low levels of fertility to which these soils have been reduced, their renovation requires similar efforts of soil preparation and fertilization to those already tested in Cerrado areas.

Most of the areas of central Brazil have a favorable relief for intensive agriculture; however, the Oxisols under Cerrado vegetation generally are acid and of excessively low fertility so that satisfactory production is impossible without applying lime and fertilizers. It is in this phase aspect that one finds the principal production problems of these immense, unproductive areas. However, it is still necessary to clearly define the fertility problems of the principal soil types of the Brazilian Cerrado, in order to recommend liming and fertilization practices to bring about an efficient and rational development of this extensive area (2). Of all the elements limiting production on Cerrado soils, P appears to be, without a doubt, the most important limiting factor for establishing and adequately developing forage species in pastures. Its deficiency in these soils is generalized and widely known.

Simple superphosphate (SSP) is the recommended source, because in addition to P, it contains a sufficient quantity of S. Other P sources, especially naturally occurring ones, have provided excellent results in central Brazil (8) and could be utilized economically, if S, Zn and Mo are also added (3). The use of lime on pastures in Brazil is a recognized necessity proven by results from many experiments (5, 7). Liming alleviates the toxicity caused by Al and Mn, increases the solubility of P and Mo and supplies the Ca and Mg to the soil.

METHODOLOGY

One of the major problems in developing a

technology transfer program on beef production is to find the most appropriate technology for a given region. Available information on the establishment and management of pastures is still lacking, and knowledge about the ecology for the selection of grass and forage species is just becoming available.

The different types of soils, the topography of the land, the climatic conditions, the physical resources of the property, etc., present and create a diversity of situations that require equally different methods and practices.

Nevertheless, some technology has resulted basic and fundamental to the implementation of the program such as, soil correction with lime, the use of P and the association of grasses and legumes, as well as the criteria used for selecting who will receive the loans, the selection of the area and the methodology for evaluating pastures.

The selection of the farms that will be benefited by the program is based, among other criteria, on the ecological conditions of the region, physical resources of the property, ease of access and the leadership potential of the farmer, so that he can assist spreading the results.

Once the areas are chosen, detailed studies are done for the identification and reconnaissance of the boundaries, slope, water resources, type of soils, its apparent level of fertility and potential use. The technical team assigned to choose the forage species and establishment methods analyzes this information.

At the same time as site selection and land preparation, other precautions of a technical and administrative nature are taken. A very important aspect is the calculation of quantities of lime and seed needed. A study of the market, the availability of the products and their prices as well as the transport system to the farm are aspects that should be closely studied so that planting can be done during the recommended season. In addition, a rain gage is installed in each area to measure rainfall.

RESULTS

Of the 57 pasture paddocks established in all the states participating in the program, in about 70% production and botanical composition are being evaluated in detail. In the others, evaluations are less exact, being limited in some cases to controlling the entrance and exit of animals into the pastures and/or weighing cattle to determine increases in liveweight.

Improved natural pastures

"Campo Limpo" (Treeless savanna)

The botanical composition and liveweight gain were determined in an improved pasture of treeless savana ("Campo Limpo"), under continuous grazing. The area was representative of the physiographical zone of Alto São Francisco, Minas Gerais. The soil is a Dystrophic Lithosol (lamina of hard clay) with low levels of P, K, Ca, Mg, Mo and high in Al. The mean annual rainfall was 1209 mm and the average maximum and minimum temperatures were 29° and 19°C, respectively. Vegetation was composed mostly of native grasses.

Pasture improvement consisted of manually clearing weeds and opening furrows with a Caterpillar tractor and with animals. Fertilization consisted of 76 kg P_2O_5/ha as thermophosphate, applied by hand in the furrow. Then, *Stylosanthes guianensis* (Aubl.) Sw. cv. Endeavour and *M. minutiflora* were manually sown in the furrow at rates of 4 and 2 kg/ha, respectively. After this, the vegetation was composed principally of native grasses, *S. guianensis* and *M. minutiflora*.

Table 3 shows that stocking rates altered the botanical composition of the pasture. At the high stocking rate (0.7 AU/ha) a larger decrease in botanical composition was observed in *S. guianensis* (47% over the

Table 3. **Average botanical composition of native pastures in "Campo Limpo" on Litosolic soils, under three stocking rates.**

Stocking rate	Botanical composition				
	Native grasses	*S. guianensis*	*M. minutiflora*	Weeds	Dead vegetation
A U/ha	%				
0.3	59.7	17.7	9.8	2.5	10.3
0.5	56.4	13.6	8.0	14.0	7.8
0.7	53.0	10.9	6.7	22.8	6.3

whole period and 51% in the rainy season) and in *M. minutiflora* (39 and 36%) than in the native grasses (13 and 14%).

At all the stocking rates used, the native grasses were less accepted by the animals, and/or less accessible, and most resistant to trampling than *S. guianensis* and *M. minutiflora*. Independently of the stocking rate, percentages of native grasses, *M. minutiflora* and *S. guianensis* decreased 11, 30 and 38%, respectively.

The average liveweight gains by the Zebu (Gir) steers in 364 days in the improved area were 358 and 76 g/day at the low and high stocking rate, respectively (Table 4). At a rate of 0.5 AU/ha, which provided the highest liveweight gain per ha, the daily gains averaged 258 g/day and the increase per ha, 101 kg/yr. The daily weight increases per day and per ha with the stocking rate of 0.2 AU/ha, were 116 g/day and 20.4 kg/ha/yr, respectively, in unimproved native Campo Limpo. Consequently, by improving the pasture, an increase of 80.5 kg/ha/yr of liveweight was obtained compared to the natural vegetation. The best annual liveweight gain in the control areas was below the annual average of the state of Minas Gerais of 48 kg/ha (1).

With the highest stocking rate, animals lost weight during September, October and December. This could be because of the quantity of available forage in those months.

Cerrado

Botanical composition and liveweight gains were determined for improved pastures in a Cerrado vegetation, under a system of continuous grazing. The pasture was seeded on a Dark Red Latosol (Oxisol),

Table 4. **Liveweight gains of animals grazing improved native grass and "Campo Limpo" for 364 days, under three stocking rates.**

Pasture	Stocking rate	Daily gains/ animal		Annual gains/ha		
		Rainy season	Dry season	Rainy season	Dry season	Annual
	AU/ha			kg		
Improved	0.3	0.502	0.210	64.8	18.8	83.6
	0.5	0.365	0.150	78.6	22.4	101.0
	0.7	0.122	0.030	36.7	6.2	43.0
Campo Limpo	0.1	0.204	0.106	9.6	3.8	13.5
	0.2	0.162	0.070	15.3	5.0	20.4
	0.3	0.102	0.007	14.5	0.7	15.2

representative of the physiographic zone of Alto São Francisco, Minas Gerais. The average annual maximum and minimum temperatures recorded during the trials were 31° and 14°C, respectively. The annual rainfall was 952 mm.

The Oxisol had low levels of P, was high in Al and intermediate in K, Ca and Mg. Vegetation was characteristic of the Cerrado physiognomic type, with many varied species of trees, and shrubs overlying a grass canopy.

Pasture improvement consisted of a mechanical clearing of brush and weeds and one harrowing. Fertilizer applied was 80 kg P_2O_5/ha and then *S. guianensis* cv. Endeavour (2 kg/ha) and *Macroptilium atropurpureum* (DC.) Urb. (2 kg/ha) were seeded mechanically. Afterwards, the vegetation was composed mostly of *M. minutiflora, S. guianensis,* weeds and bushes, native grasses, *M. atropurpureum* and *H. rufa* (Table 5).

The percentages of *M. minutiflora* and *S. guianensis* tended to decrease at all the stocking rates used, compared with the two initial periods.

Comparing the botanical composition between the highest and the lowest stocking rates, *S. guianensis, M. minutiflora* and *H. rufa* (the latter in small quantity) suffered decreases of 22, 20 and 31%, respectively. However, increases were observed for native grasses (111%), *M. atropurpureum* (143%) and weeds and bushes (175%). These results can be interpreted as a consequence of greater or lesser acceptance and/or the ease of access to the plants by the animals as well as varying resistance to trampling.

In the improved area the average percentages of crude protein of the available forage, with the lowest or highest stocking rate, were 10 and 10.8%, being higher (12.8 and 12.9%) during the rainy season and lower (9.5 and 9.9%) in the dry season.

The average liveweight gains in 364 days for crossbred steers in the improved area were 376 and 200 g/day at the lowest and highest stocking rates (Table 6). With a stocking rate of 1.0 AU/ha, which produced the highest liveweight gain per ha, 311 g/day and 228 kg/ha/yr were obtained. In the native pasture, at the rate of 0.3 AU/ha, the daily gain was 363 g/day and the annual production 78 kg/ha.

No weight loss was observed in animals in the improved area during the dry season, even at the highest stocking rate. This result is probably due to the quality of forage available in that season. Therefore, improved Cerrado provided 150 kg more liveweight/ha/yr, compared to the unimproved area.

Cultivated pastures

Cerradão

The effects of associated grass-legume pastures were studied to determine the

Table 5. **Annual average botanical composition of improved native grass of Cerrado under three stocking rates.**

Stocking rate	Botanical composition						
	M. minutiflora	*S. guianensis*	*H. rufa*	Native grasses	*M. atropurpureum*	Shrubs and weeds	Dead vegetation
AU/ha	%						
0.8	43.2	30.5	3.6	3.8	2.9	6.4	9.3
1.0	38.3	27.4	2.8	5.3	5.3	13.6	7.0
1.2	34.3	23.7	2.4	8.1	7.2	18.0	6.1

Table 6. **Liveweight gains of animals grazing improved native grass of Cerrado for 364 days under three stocking rates. (Rainy season = 196 days; dry season = 168 days).**

Pasture	Stocking rate	Liveweight gains					
		Rainy season	Dry season	Total	Rainy season	Dry season	Total
	AU/ha	kg/an			kg/ha/yr		
Improved	0.8	98.2	36.8	135.0	161.9	50.1	212.0
	1.0	86.2	26.9	113.1	177.8	50.8	228.6
	1.2	62.7	10.1	72.8	155.1	19.6	174.7
Cerrado	0.2	131.1	32.0	163.1	51.6	9.5	60.9
	0.3	114.7	23.7	138.4	67.7	10.6	78.3
	0.4	77.4	10.9	88.3	61.0	6.5	67.5

liveweight gain and carrying capacity under continuous grazing.

The initial vegetation was representative of the Cerradão physiognomic type and had been interplanted with a pasture of *H. rufa* that was several years in use. The soil had medium levels of K, Ca, Mg and OM, and was critically low in P only with an average content of 4 ppm. The soil contained no native Al.

The pasture was established on a Red Yellow Latosol (Oxisol) with a sandy clay loam texture. The region was representative of the micro physiographical region "Cerrado Caiapó", of the state of Goiás.

Pasture improvement consisted of complete preparation of the soil —clearing of the area, plowing, and harrowing— and then fertilization with SSP (80 kg P_2O_5/ha) and potassium chloride (30 kg K_2O/ha). A mixture of seeds of *P. maximum* var. Trichoglume (7 kg/ha), *S. guianensis* cv. Endeavour (2.5 kg/ha) and *Centrosema pubescens* Benth. (3.5 kg/ha) was mechanically seeded. Annual rainfall in the area was 1330 mm in 1976 and 1400 mm in 1977. The area of the legume-based pasture covered two paddocks of 27 ha and the control area consisted of two paddocks of 11 ha each.

The botanical composition of the pasture (Table 7) shows the performance of legumes subjected to consecutive grazings over several years. A strong decrease in the population of *S. guianensis* can be seen, in contrast to what happened with *C. pubescens* which increased considerably after the second year. This occurred despite the small initial population of *C. pubescens* (2.4 plants/m²) in relation to 20 plants/m² of

Table 7. **Botanical composition of pastures during the first grazing years.**

Date	*P. maximum*	*S. guianensis*	*C. pubescens*	Weeds residues
	%			
May, 1975	35.6	15.7	4.1	44.4
May, 1976	72.9	10.3	4.2	12.4
May, 1977	53.3	3.3	28.7	14.5
Feb, 1978	77.6	2.7	14.5	5.0

S. guianensis. The percentage of weeds tended to decrease after grazing the area.

The increase in liveweight/ha obtained with Nellore and crossbreds (Nellore x Chianina) steers, during the first year (367 days) was approximately 550 kg/ha, of which 146 kg occurred in the dry season and 404 kg, in the rainy season (Table 8). These levels are extremely high when one considers the averages obtained in the control area of *H. rufa* in the dry and rainy seasons (34 and 144 kg/ha, respectively)

Comparing the yields of the second dry season with those of the first one, a strong decrease was noted in the liveweight gains/ha and in carrying capacity. This can be attributed to the fact that the area still had not received maintenance fertilization.

However, considering the same period, practically the same differences were maintained between the yields from the associated pasture and the control, a fact attributed to the presence of legumes in the cultivated area.

The nutritional analyses of the forage species which were done separately, revealed a high content of crude protein in the legumes during the critical dry season period (June) as follows: *P. maximum*, 8.6%; legumes, 17%; and *H. rufa* (control), 5%.

Cerrado

Under continuous grazing, liveweight gains were determined for *P. maximum* pastures associated with *C. pubescens* and *Calopogonium mucunoides* Desv. on a Dark Red Latosol (Oxisol) representative of the physiographical region of Rio Vermelho, state of Goiás. The vegetation was typical of low Cerrado, with a predominance of trees and bushy species.

The chemical analyses of the soil, before liming and fertilization, showed the following results: P, 2 ppm; K, 31 ppm; Ca + Mg, 0.8 meq/100 g; Al, 0.6 meq/100 g; and OM, 1.3%. Soil pH was 5.3. Mean annual rainfall for the area was 1305 mm. The experimental area was composed of three paddocks of 33 ha each. The botanical composition of the pasture shows almost complete predominance of *C. mucunoides*, after the second year of establishment. This dominance is, to a certain extent, due to low consumption by the animals, especially during the rainy season (Table 9).

After land clearing, cleaning, plowing and harrowing of the area, soil pH was increased

Table 8. **Stocking rate per season, liveweight gain per ha, and daily average gain of Nellore steers grazing associated and control (without legumes) pastures.**

Season	Legume-based pasture			Control		
	Stocking rate	gain/ha	gain/an/day	Stocking rate	gain/ha	gain/an/day
	AU/ha	kg		AU/ha	kg	
First dry (196 days)	1.8	146	0.35	1.0	34	0.175
Second rainy (171 days)	3.8	404	0.65	2.0	144	0.420
Second dry (201 days)	1.5	125	0.42	0.8	50	0.319

Table 9. **Initial plant population (plants/m²) and botanical composition of forage crops (%).**

	P. maximum	*C. pubescens*	*C. mucunoides*	Residues
Plant population January, 1976	70.7	2.1	3.0	4.3
Composition June, 1977	21.4	9.8	51.5	17.1
Composition January, 1978	26.3	3.6	55.6	14.3

with dolomitic lime (2.8 t/ha)and fertilized with SSP (100 kg P_2O_5/ha), potassium chloride (60 kg K_2O/ha) and sodium molybdate (0.2 kg/ha). A mixture of *P. maximum* (20 kg/ha), *C. pubescens* (3 kg/ha) and *C. mucunoides* (1.5 kg/ha) along with a small quantity of superphosphate was broadcast mechanically.

Table 10 shows the yields obtained with crossbred steers (based on Zebu) during three consecutive periods. Considering the two seasons (dry and rainy), and for 364 days of grazing, liveweight gains were 92 and 128 kg/ha/yr, respectively. These results were inferior to those obtained on other areas with identical conditions. However, comparing them with the results of the control *H. rufa* pasture established on soil of medium fertility, it is evident that the daily liveweight gains and the increases per hectare are rather superior, especially during the dry seasons.

The low yields of the associated pasture can be attributed to the little *P. maximum* available. It suffered attacks from spittlebugs and the spontaneous predominance of *C. mucunoides*. On the other hand, it was observed that the animals did not consume this legume during the rainy season, and when it was grazed at the beginning of the dry season it suffered considerable loss of leaves caused by lack of moisture and by animal consumption.

Maintenance fertilization

An attempt was made to determine the effect of the levels of maintenance fertilization on liveweight production and the persistence of associated pastures formed with *P. maximum, S. guianensis* cv. Endeavour and *M. atropurpureum* and established on a Yellow Latosol (Oxisol) on the Campo Cerrado physiognomic stage of vegetation.

Table 10. **Liveweight gains per ha and daily gains of steers grazing associated and control pastures during different seasons of the year.**

Season	Legume-based pasture			Control		
	Stocking rate	Daily gain/an	gain/ha	Stocking rate	Daily gain/an	gain/ha
	AU/ha	kg		AU/ha	kg	
Dry (167 days)	1.78	0.311	92.1	1.04	0.191	33.1
Rainy (179 days)	1.23	0.530	128.4	1.07	0.425	89.6
Dry (167 days)	0.85	0.300	42.0	0.69	0.047	5.5

Initially, the soil showed low levels of P, K, Ca, Mg, OM and high Al. Its texture was classified as clay loam. Average maximum and minimum temperatures recorded during the experiment were 29° and 16°C, in 1975, and 30° and 17°C, in 1976. Annual rainfall recorded was 996 mm in 1975 and 1012 mm in 1976.

After clearing the Cerrado, dolomitic lime (2 t/ha) was applied followed by plowing and harrowing. Corrective fertilization was made with thermophosphate (100 kg P_2O_5/ha), potassium sulfate (70 kg K_2O/ha) and FTE-Br-10 (25 kg/ha).

The grass seed (15 kg/ha) and the legumes (2 and 3 kg/ha of seed of *S. guianensis* and *M. atropurpureum)* were sown mechanically at the time of fertilization.

After the corrective fertilization, OM remained at the critical level, P, K, Ca and Mg were at medium levels and Al was at a low level. In subsequent years after pasture establishment, applications of SSP (20 and 40 kg P_2O_5/ha) were made each February.

The pasture that received no maintenance fertilization (zero level) showed smaller percentages of *P. maximum* and legumes and more weeds, bushes and *M. minutiflora*, compared to those that received fertilization (Table 11).

It was verified that in the first year, the increase in the total forage yield (dry and rainy season) was 12 and 18%, while in the second year it was 46 and 78%, respectively, for fertilizer levels of 20 and 40 kg/ha, compared to the zero level. This variation between the first and second year was due to the time of application of fertilizer and the marked decrease in the forage yield at the zero level. In terms of forage yield, it appears that 20 kg/ha as a maintenance rate tends to keep production of introduced species stable, while the 40 kg/ha rate tends to increase it.

The fertilization level used modified the bromatological composition of the forage (Table 12). On the other hand, the greater crude protein, K, Ca and P contents found in these forage species are due to the fertilizers used and/or a greater proportion of legumes in the samples collected in these treatments.

The fertilization levels used did not affect the quality of the forage, according to the conversion of total digestible nutrients (kg of TDN/kg of increase) during the first year (Table 13).

Generally, during the second year, fertilizers modified the carrying capacity of the pasture considerably, while the daily increase varied only in those pastures that received the lowest level.

Annual liveweight gains during the first year were 298, 339 and 376 kg/ha, for the 0, 20 and 40 kg/ha of fertilization, respectively. During the second year the yields were 169, 339 and 449 kg/ha, respectively, for the three levels considered. Comparing the gains of the second year with that of the first, it can be seen that the 20 kg/ha level tends to maintain production, the 40 kg/ha level tends to increase it (19%) and the 0 level tends to decrease it (15%).

The best liveweight gain obtained in the second year (449 kg) is slightly superior to that obtained by Quinn *et al.* (9), with 200 kg of N and 175 kg P_2O_5/ha as maintenance fertilization in 269 days for *P. maximum*, and less than that obtained by Lima *et al.* (6), with 200 kg/ha of N, also for the grass *P. maximum*, on fertile red soils.

CONCLUSIONS

Regional trials in Brazilian Cerrados demonstrate that it is possible to increase the beef production per unit area. Undoubtedly, the utilization of forage resources ought to constitute the basic factor for increasing the productivity of the area. The results expressed here are those of producers that adopted and amplified the new technology on their own properties.

Table 11. **Botanical composition of associated pasture** *(P. maximum, M. minutiflora, S. guianensis* **and** *M. atropurpureum)* **per season and per treatment.**

Season	Fertilization P_2O_5	Fertilization K_2O	*P. maximum*	*M. minutiflora*	*S. guianensis*	*M. atropurpureum*	Weeds and shrubs	Dead vegetation
First dry	0	0	49.2	12.1	10.0	5.8	9.5	13.4
(165 days)	20	20	47.7	12.3	10.4	6.0	9.8	13.8
	40	40	47.7	12.6	10.2	5.5	9.9	14.1
First rainy	0	0	57.7	8.5	6.0	6.3	10.8	10.8
(196 days)	20	20	61.5	7.9	8.0	6.6	8.8	7.2
	40	40	69.5	6.0	12.5	7.1	4.0	0.9
Second dry	0	0	37.3	15.8	7.0	5.8	19.1	15.0
(168 days)	20	20	50.3	13.6	14.0	4.7	9.0	8.4
	40	40	58.1	11.3	14.1	7.1	3.8	5.6
Second rainy	0	0	40.1	20.3	4.5	5.0	22.1	8.0
(196 days)	20	20	63.5	8.2	9.6	6.6	5.6	6.5
	40	40	70.1	5.0	11.6	8.7	3.6	1.0
Averages	0	0	46.0	14.1	6.8	5.7	15.3	11.8
	20	20	55.7	10.5	10.5	5.9	8.3	8.9
	40	40	61.3	8.7	12.1	7.1	5.3	5.4

Table 12. **Nutrient composition of grass** *(P. maximum* **and** *M. minutiflora)* **and legume** *(S. guianensis* **and** *M. atropurpureum)* **forages per season and treatment.**

Season	Fertilization P_2O_5	Fertilization K_2O	Crude protein	Ca	P	K
	kg/ha		%			
First dry	0	0	9.61	0.40	0.14	1.91
(168 days)	20	20	9.56	0.41	0.15	1.86
	40	40	8.99	0.39	0.14	1.93
First rainy	0	0	14.63	0.51	0.19	2.15
(196 days)	20	20	14.94	0.56	0.26	2.30
	40	40	15.41	0.58	0.28	2.40
Second dry	0	0	8.60	0.34	0.11	1.60
(168 days)	20	20	9.81	0.50	0.18	1.70
	40	40	10.25	0.56	0.20	1.95
Second rainy	0	0	12.53	0.47	0.18	2.10
(196 days)	20	20	14.81	0.58	0.27	2.60
	40	40	15.61	0.61	0.29	2.80

Table 13. **Stocking rate, average liveweight gain per animal and per ha, and total digestible nutrients per kg of gain, per season and per treatment in an associated pasture** *(P. maximum, M. minutiflora, S. guianensis* **and** *M. atropurpureum).*

Season	Fertilization P_2O_5	Fertilization K_2O	Stocking rate	Daily gain/an	gain/ha	kg TDN/kg of gain
	kg/ha		AU/ha	kg		
First dry	0	0	0.86	0.339	78.37	15.01
(168 days)	20	20	0.90	0.315	76.21	14.96
	40	40	0.85	0.330	75.40	15.10
First rainy	0	0	1.51	0.600	220.50	10.15
(196 days)	20	20	1.90	0.572	263.02	10.85
	40	40	2.15	0.579	301.19	10.78
Second dry	0	0	0.68	0.271	50.95	18.11
(168 days)	20	20	0.92	0.305	76.96	15.10
	40	40	1.15	0.338	105.33	14.50
Second rainy	0	0	0.99	0.480	119.01	12.81
(196 days)	20	20	1.88	0.585	262.92	10.88
	40	40	2.45	0.600	343.98	10.36

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REGIONAL PASTURE TRIALS IN ACID INFERTILE SOILS OF COLOMBIA*

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ABSTRACT

ICA's Pasture and Forage Research Program started regional trials and demonstration work in 1964. More than 200 regional trials have been conducted in different regions of Colombia, away from experimental stations. About 21% of these trials have been located on very acid, low-fertility soils, corresponding to the Llanos Orientales and to the intermediate mountainous zones of the Western, Central and Eastern Cordilleras. There have been three types of studies: (a) adaptation of forage grasses and legumes; (b) agronomic trials, mainly on the response of pastures to NPK fertilization, and the addition of lime; and (c) trials with animals to evaluate stocking rate and animal production of the most promising species. This paper discusses the grasses and legumes best adapted to the different thermic levels and ecological regions with acid, infertile soils. Forage species respond differently to the application of fertilizers, up to the point that some pastures such as *Melinis minutiflora*, do not respond to fertilization while others, such as *Panicum maximum*, need high amounts of nutrients in order to be used as a pasture feed. The pasture which has shown the best adaptation and production since 1966, when the first trials were done in the Llanos Orientales is *Brachiaria decumbens*. Regional trials on adaptation and management of legumes are scarce, mainly because of the lack of material for testing. So far three legume genera appear promising—*Pueraria*, *Stylosanthes* and *Desmodium*. Trials with animals, although limited, show the superiority of introduced or adapted pastures over native pastures. In the Piedmont area (San Martín) and at the Carimagua Center (San Pedro de Arimena), *B. decumbens* has supported a stocking rate of 2.5 an/ha throughout the year when managed under a paddock rotation system. This stocking rate is in sharp contrast to that of native pastures, which support only about 0.2 an/ha. At the experimental level it has been possible to increase meat production per ha in the Llanos up to 15 times, using introduced species and with adequate management of pastures and animals. In conclusion, several alternatives exist for utilizing pastures with animals, which have been proven in experimental centers. These must be validated and then disseminated directly at the cattle ranch level.

Systematic studies of the adaptability and performance of pastures were first carried out in Colombia in the 1930's by the Ministry of Agriculture, with special emphasis on cool highland areas of Colombia. The present Pasture and Forage Program began

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in 1955 under the Division for Agricultural Research (DIA) of the Ministry of Agriculture. This has now become part of the research division of the Instituto Colombiano Agropecuario (ICA).

The purpose of the program is to obtain information which will provide solutions and alternatives to the livestock producer so that he can maximize the use of his land, his time and his capital. More specifically, its objectives are to increase production of meat, milk and wool per unit area throughout the year, by improved establishment and management of forage species.

Up to 1964 the program was conducting primarily research. It was then concluded that the results obtained from adaptation, establishment, and pasture management research were quite encouraging, and that it was possible to do further studies on cattle ranches, mainly to demonstrate and put the research results into practice. Thus in 1965, work was started on activity no. 7, Regional Trials and Demonstrations. Since then, several transfer of technology activities in the field at different levels, field trips, publications, etc, have been completed.

It is felt that the trials and results obtained at the experimental level should be validated and demonstrated on farms. The purpose of the Program is to obtain the support and cooperation of livestock companies and individual farmers throughout the country, and to disseminate the results which have been proved in experimental centers. The Program also increases the knowledge of problems related to animal feeding using forages, so that research priorities can be planned and physical, human and financial resources used in a more rational way. The Program also includes comparative trials of different species and varieties of forages, demonstrations on the correct agronomy for growing pasture and forage, and demonstrations using animals and different alternatives for the management of pastures (2).

LOCATION OF REGIONAL TRIALS

The trials have been carried out on soils located in very hot, moderately hot, medium, cool and exceedingly cold climates. As for ecological regions (3), the trials and the research carried out in the experimental centers represent coverage of approximately 95 million ha, equivalent to 83% of the total area of Colombia (Fig. 1).

Most of the trials have been done in the Llanos Orientales (Eastern Plains) of Colombia, primarily south of the Meta River. It is estimated that there are approximately 21 million ha of land in the Llanos, consisting of Piedmont (12%), Floodable Savannas (26%) and High Plains (62%). Native pastures, which are the only feed source for the cattle, are found mainly on the plateaus and terraces. In the Piedmont area, the main activity is fattening cattle, and introduced or adapted pastures are more frequent.

This paper reviews the most important results obtained in local trials on acid soils of very low fertility, relatively poor in N, P, K, Ca and Mg, with high levels of exchangeable Al and with climates characterized by high temperatures and/or high rainfall (Table 1). These features are found in the first three thermal layers mentioned earlier, e.g. between sea level and 2000 m altitude, where mean annual temperatures range between 18° and 28°C. The ecological regions studied are tropical dry forest (T-df), tropical dense rain forest (T-drf), sub-tropical rain forest (ST-rf), and sub-tropical dense rain forest (ST-drf). These areas have an average annual rainfall between 2000 and 5000 mm.

These are some legumes and grasses which are generally unproductive and of low quality under these ecological conditions. Coupled with poor management of animals, pastures and native grasslands, their use results in the lowest stocking rates in the country (6 ha/an), daily weight increases of about 200 g/an, low calving rates (30-40%) and high mortality rates (10-15%) both in

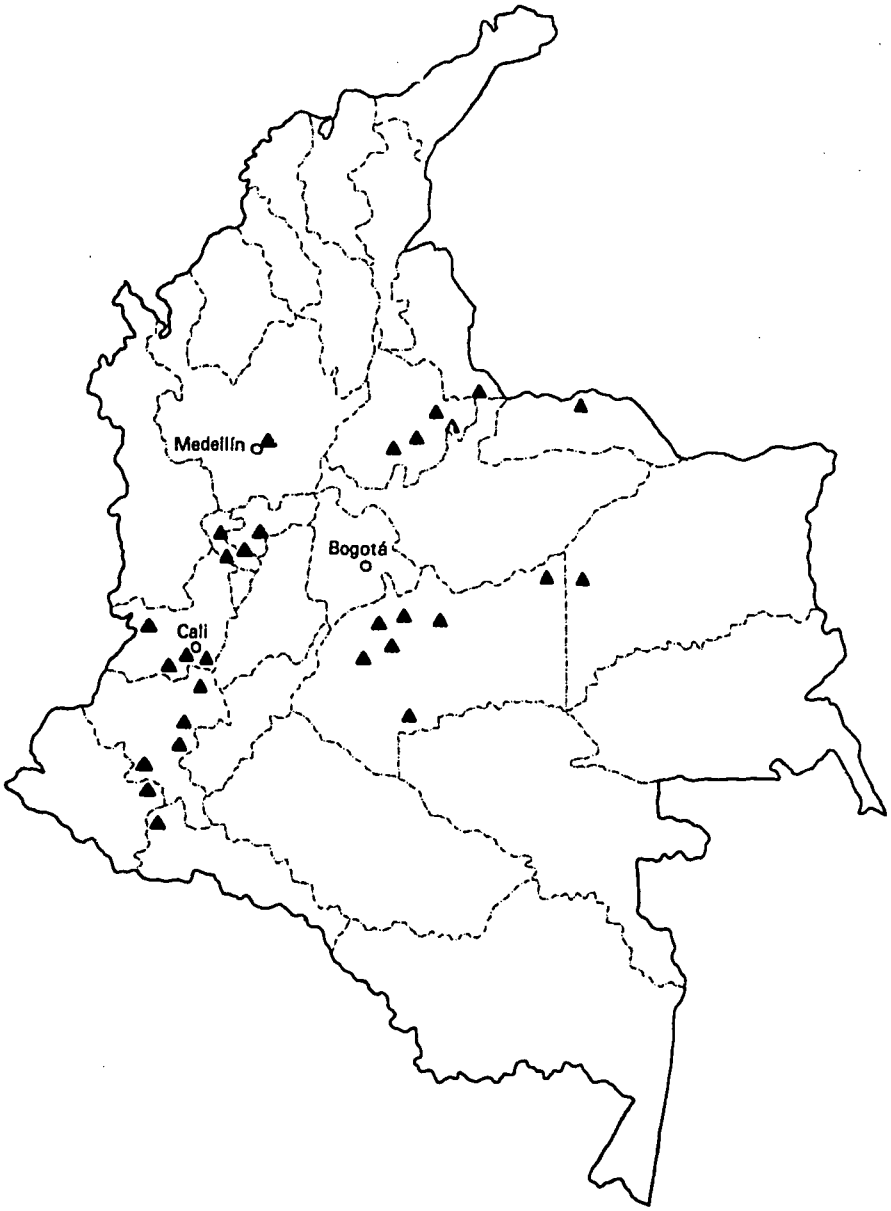

Figure 1. Regional trials on adaptability, utilization and management of pastures in Colombia, on acid, infertile soils.

young and adult cattle. Meat production per ha is consequently low in this area.

The most common native grasses are of the genera *Andropogon, Axonopus, Digitaria, Homolepsis, Paspalum, Setaria, Imperata, Panicum, Trachypogon* and *Leersia.* Spontaneously growing legumes are of the genera *Desmodium, Eriosema, Galactia, Zornia, Centrosema, Phaseolus,*

Stylosanthes, Clitoria, Leucaena and *Indigofera* (13).

With the exception of legumes, these genera are characterized by low production of poor quality forage, mainly with regard to digestibility, Ca, P and crude protein content (CPC) (5, 6, 11). Some, however, allow acceptable growth by cattle. For example, on well-drained soils cattle graze *Paspalum plicatulum* Michx., *Axonopus purpusii* (Metz) Chase, *Leersia hexandra* Sward, and *Trachypogon plumosus* Nees, all of which are considered quite important. There are some other species, such as *Andropogon bicornis* L. and *Paspalum virgatum* L., which are quite abundant and which are only eaten by cattle when in early growth stages.

In other parts of Colombia there are also infertile and acid soils, mainly in the humid sub-tropical forest, sub-tropical perhumid forest and sub-tropical rain forest. These zones include the coffee growing area along the Central and Western Cordilleras, which cover approximately 11 million ha of mostly mountainous land. Cattle ranches are numerous, and most are family enterprises. There are fewer native pastures than in the Llanos Orientales. The most common grasses, some of them native and some adapted, include the genera *Paspalum Axonopus, Hyparrhenia, Eragrostis, Digitaria, Ixophorus, Panicum, Melinis* and *Tripsacum*. The most important native legumes include the genera *Centrosema, Desmodium, Leucaena, Phaseolus* and *Calopogonium*. The carrying capacity of these pastures is relatively low, and cattle grazing most of them have a daily rate of weight gain below 400 g. Some of the chemical properties of these soils appear in Table 1. Although slightly superior to the soils of the Llanos, they also have a low pH and an average-to-low content of most of the primary and secondary elements. Deficiency of P is evident in these soils. It is important to emphasize that eroded soils are found quite often as a result of high rainfall and the steepness of the land.

METHODOLOGY OF THE REGIONAL TRIALS

Table 2 shows locations in Colombia where regional trials have been conducted, and indicates the type of trial at each place. Approximately 40 trials were carried out, mainly on the Piedmont and in the Llanos Orientales, on intermediate zones, like the coffee growing areas, and on some locations in the Cauca Department (1).

The trials in acid, infertile zones included three well-defined components. First of all, the adaptation of introduced species were compared with the most common grasses and legumes native to the locality. Collections were made in several places, and growth of the pastures under natural conditions was compared with their

Table 1. **Chemical properties of typical soils in the areas where regional trials were carried out.**

Location	pH	Total OM	Total N	Available P (Bray II)	Exchangeable cations K	Ca	Mg	Na	Al	ECEC	Source
		%		ppm	meq/g of soil						
Llanos Orientales	4.3	3.7	0.1	2.7	0.12	0.60	0.11	0.07	4.0	8.0	(12)
Popayán Plateau	4.8	8.0	0.3	8.0	0.24	2.00	0.30	0.50	2.5	20.0	Data Bank, Soils Program, ICA, 1978.

Table 2. **Location of regional and demonstration trials of the Pasture and Forage Program on acid, infertile soils, and type of trial carried out in each location.**

Location		Type of trial[a]		
Municipality and ICA Region	Department	Adaptability[b]	Agronomic[c]	With animals[d]
Region No. 4				
Rionegro	Antioquia		+	+
Urrao	Antioquia	+		+
Region No. 5				
Popayán	Cauca	+	+	
Patía	Cauca		+	
Puerto Tejada	Cauca		+	
Ricaurte	Nariño	+		
Mercaderes	Nariño		+	
Bajo Calima	Valle	+		
Jamundí	Valle			+
Queremal	Valle	+		
Restrepo	Valle	+		
Sibundoy	Putumayo		+	
Region No. 7				
Socorro	Santander	+		+
Enciso	Santander	+		
Arauca	Arauca	+		
Region No. 8				
San Martín	Meta	+	+	+
Villavicencio	Meta	+	+	+
Guacavia	Meta	+	+	
Planas	Meta	+		
Trinidad	Meta	+		
Puerto López	Meta		+	
Acacias	Meta	+		
San Pedro de Arimena	Meta	+	+	+
San José del Guaviare	Vaupés	+		
Gaviotas	Vichada		+	
Yopal	Casanare	+		
Region No. 9				
Manizales	Caldas	+		
Chinchiná	Caldas	+		
Pereira	Risaralda		+	
Santa Rosa de Cabal	Risaralda		+	

[a] In some locations more than a sample was necessary for the respective types of trials

[b] Collections of forage grasses and legumes

[c] Establishment and cropping practices, mainly fertilization

[d] Evaluation of pastures with grazing animals.

development under fertilization, mostly with Ca and P. Calcium was applied in sufficient quantity to try and neutralize 50% of the exchangeable Al; P was applied at rates from 50 to 200 kg P_2O_5 ha. The most common sources of these elements were commercial lime, rock phosphates, basic slag and, in some cases, complete 10-20-20 or 10-30-10 fertilizers.

The second component studied was the agronomic evaluation of pastures, with emphasis mainly on the response of the species to fertilization using N, P, K and lime. Pasture growth after applications of N as organic or inorganic fertilizers was also studied. The most frequently used design was randomized plots with factorial arrangements and three or four replications. Experimental plots were set up in existing farm paddocks and pastures were sown whenever necessary.

The third component was pastures utilization under grazing. The number of trials conducted with animals on infertile soils in places other than experimental stations was fairly limited. While this represented the main activity in other parts of Colombia such as the Cauca, Patía and Antioquia Valleys these trials are not discussed here.

Grazing trials were done with different species, bearing in mind the standard of management of the farm so as to demonstrate that good management practices can increase production. For example, if the ranch had a system of continuous grazing and the paddocks were invaded by weeds, the first step was to demonstrate that a rotational system of grazing, fertilizing and irrigation was not necessary, but to show first that weed control could increase the amount of available forage and thus, animal production. Later it was possible to demonstrate the benefits of a different or alternative grazing system, working up to the most sophisticated ones.

Because of these factors, trials with grazing animals vary among regions and among ranches. Together with recommendations on pasture management, an effort was made to convince farmers of the advantages of good animal husbandry. This was done mainly using well-adapted pastures and animals, adequate health and management practices, and feed supplements based on salt and minerals.

Certain aspects which may have an impact on the evaluation of the trials and/or the dissemination of results, must be observed: (a) trials were done away from experimental stations, and were, therefore, not under permanent control and attention, both from a physical as well as a statistical point of view, as they would have been in the centers; (b) some farms had very difficult access; (c) in some cases, the farmer although receptive and ready to cooperate, did not guarantee the normal development of the trials, and at times trials were not completed; and, (d) the people in charge of the trials were technicians who had been trained mainly as research workers.

Despite these drawbacks this work has been gratifying because much experience has been gained for directing future research. The results have been disseminated, and both farmers and research workers have begun communicating with each other.

RESULTS AND DISCUSSION

Species adaptation

One of the first steps in studying forages is to determine which grasses and legumes are better adapted to the conditions of a given region. Although most native species are of low quality and production, sometimes an increase in cattle production is achieved when substituting one for the other. At farm level, the introduction of new pastures, although not necessarily the first step, does help when other alternatives do not produce encouraging results. This is the case in the Llanos Orientales of Colombia. The introduction of suitable pastures can

sometimes multiply meat and milk production on a farm or in a region several times.

Table 3 shows suitable species for different locations studied. These are evaluated on the basis of such criteria as initial growth vigor, growth habit, height, forage production, time of flowering, seed production, presence of insects or diseases, and persistence after several forage crops.

Several years ago it was found that native species of the Llanos Orientales could be replaced with pastures such as *Melinis minutiflora* Beauv., *Hyparrhenia rufa* (Nees) Stapf. and, especially, *Brachiaria decumbens* Stapf. Later work has shown that the first two, besides permitting a greater stocking rate during the rainy season, produce better weight increases than native pastures.

B. decumbens deserves special attention. This species has shown the widest range of adaptability in Colombia. It grows well from sea level up to nearly 2000 m, both in high fertility soils and in poor ones, and it responds to management and fertilization. After introducing *B. decumbens* it is possible to increase the stocking rate several times, year-round. This grass pasture is presently considered to be the best alternative for feeding animals during the dry season although it does not grow well in poorly-drained areas, and its quality can be questioned as weight increases are not very high.

In warm and medium climates in the coffee growing areas, the Popayán plateau and generally on valleys of the Eastern and Western Cordilleras, the following grasses have been classified as promising for grazing: *H. rufa, B. decumbens, Axonopus micay* (Fluegge.) Hitchc. var. Telembí and clone 72, *Chloris gayana* Kunth. The most adaptable species for cutting have been *Pennisetum purpureum* Schumach. var. Merker, Patiño, and H. 534 and *Axonopus scoparius* (Fluegge) Hitchc. var. 60 and 70. Promising grazing species have increasingly replaced pastures mainly consisting of *Paspalum notatum* Fluegge and *Paspalum conjugatum* Michx. The cut forage grasses already mentioned have shown better recovery and forage production than a sugar cane adapted as a forage, *Tripsacum laxum* Nash and the common *A. scoparius.*

It must be mentioned that the greatest difficulty in all areas has been to find legumes which develop well and are persistent under intensive management. However, *Pueraria phaseoloides* (Roxb.) Benth. var. javanica Benth., *Stylosanthes guianensis* (Aubl.) Sw., *Cajanus cajan* (L.) Millsp. and species of the genera *Desmodium* and *Centrosema* have shown a permanent and acceptable development in the Llanos. In mountain regions, *P. phaseoloides, Desmodium intortum* (Mill.) Urb., *C. cajan, Vigna sinensis* (L.) Hassk., *Stizolobium deeringianum* Bort., and *Bohemeria nivea* Gauch. from the Urticacea family, have been outstanding. The development of new types and varieties in experimental centers should be given priority so that all promising material can be evaluated in regional trials.

To summarize, the use of introduced legumes continues to be limited in the Llanos Orientales region. *P. phaseoloides* and *S. guianensis* appear to be the most suitable, but require good fertilization to sustain growth and production. In mountainous regions, *P. phaseoloides* is the most widely used and, during the last few years, adaptation trials with *B. nivea* have influenced the spread of this forage, mainly as a source of protein.

Fertilization studies

As the chemical conditions of the soils being studied are probably the most limiting factor to forage production, trials have been mostly directed at studying the most appropriate nutrient sources and their correct dosages for establishment and production of pastures.

Table 3. **Forage grasses and legumes better adapted in some areas of acid, infertile soils in Colombia, which can be recommended as animal feed.**

Municipality and ICA Region	Department	Altitude	Ecological formation	Better adapted species	
				Grasses	Legumes
		masl			
Region No. 5					
Popayán	Cauca	1760	ST-rf*	*A. scoparius, P. purpureum, D. decumbens, A. micay, P. clandestinum, B. decumbens*	*D. intortum*
Queremal	Valle	1460	ST-rf	*B. decumbens, C. gayana, D. decumbens, P. purpureum, P. clandestinum*	
Bajo Calima	Valle	195	T-drf**	*B. ruziziensis, A. micay, P. plicatulum, B. decumbens, A. micay* var. Telembí, *P. purpureum.*	
Region No. 7					
Socorro	Santander	1100	ST-rf	*S. vulgare* var MN1022, *P. purpureum, P. maximum, B. decumbens, C. gayana.*	*C. cajan, S. deeringianum, D. lablab, P. vulgaris, P. phaseoloides.*
Arauca	Arauca	280	df/T-rf***	*B. decumbens, B. ruziziensis, H. rufa, M. minutiflora, P. plicatulum, P. purpureum, E. polystachya.*	*C. mucunoides, P. phaseoloides*
Region No. 8					
Gaviotas	Vichada	285	T-df	*M. minutiflora, H. rufa*	*P. phaseoloides*
Region No. 9					
Manizales	Caldas	2153	ST-drf	*A. micay, A. scoparius, D. decumbens, M. minutiflora, P. maximum*	*M. lathyroides, M. sativa, T. pratense, Desmodium* spp.
Chinchiná	Caldas	1400	ST-df	*D. decumbens, C. gayana, B. decumbens, P. maximum* var. Pajarita y Postrada, *A. micay* var. Telembí, *P. purpureum.*	*P. phaseoloides, V. sinensis, Desmodium* spp., *S. deeringianum, B. nivea.*

* Sub-tropical rain forest
** Tropical dense rain forest
*** Dry forest/tropical rain forest.

One of the main factors studied has been pasture response to applications of lime, N, P and K in different combinations. The sources studied have been Calfos (basic slag) and agricultural lime to correct acidity; rock phosphates (20% P_2O_5 and 35% CaO), triple superphosphate (46% P_2O_5), basic slag (18% P_2O_5 and 42% CaO) as sources of P and complete fertilizers high in P. N sources used were urea (46% N), ammonium sulphate and organic fertilizers such as cow and chicken manure. The most important results are described below.

Several trials were done at Iraca, San Martín, in the Piedmont area. The two most important experiments were a comparative study of *B. decumbens* and *P. plicatulum* and the evaluation of *H. rufa, P. maximum* and *M. minutiflora* (1). Table 4 shows responses of *B. decumbens* and *P. plicatulum* to three levels of P, two of K, two of N and two of lime. Both grasses produced similar amounts of DM without fertilization and responded to fertilization. The influence of P and lime was most noticeable in *B. decumbens,* which produced nearly 2.5 t/ha more with 200 kg P_2O_5/ha and 4 t/ha of lime, compared with the control treatment. When comparing the application of the three principal elements plus lime with a similar trial receiving in addition 400 kg $MgCO_3$/ha no favorable effect from Mg was observed. After several forage harvests, it was concluded that at the time of sowing *B. decumbens* it was possible to apply 350 kg/ha of 10-30-10 fertilizer plus 4 t/ha of lime. This treatment yields 5 to 6 t/ha of dry forage per cutting, every four or six weeks during the rainy season and at longer intervals during the dry season.

Responses of *H. rufa, P. maximum* and *M. minutiflora* were also compared with three levels of P, two of K and the presence and absence of lime, in San Martín during the rainy season. Table 5 shows the DM yield per cutting for each grass. *M. minutiflora,* well-adapted in the Llanos Orientales, produced more DM with and without fertilizers, thus demonstrating its excellent ability to grow on acid, infertile soils. *P. maximum* yielded lowest, demonstrating that although it grows under Llanos Orientales conditions, it can not stand intensive management and needs fertilization with more than 100 kg P_2O_5/ha and 2 t/ha of lime in order to tolerate frequent defoliations. *H. rufa* was intermediate in performance. This grass can be fertilized with amounts similar to those mentioned for *B. decumbens.* At Campoalegre ranch, near Villavicencio, similar results were obtained when comparing *B. decumbens, H rufa* and *M. minutiflora.* The latter produced the greatest yields of forage without fertilizers or with minimum levels of nutrients.

It is evident that the highest-yielding pastures in the Piedmont areas are *M.*

Table 4. **Effect of N, P, K and lime applications on DM production by *P. plicatulum* and *B. decumbens* at Iraca, San Martín.Cuttings done on average of every six weeks.**

Treatment				DM Yield	
N	P_2O_5	K_2O	Lime	*P. plicatulum*	*B. decumbens*
kg/ha				t/ha	
0	0	0	0	4.3	4.7
50	100	100	0	4.5	6.4
50	100	100	4	5.9	6.8
50	200	100	4	6.8	7.1
50	100	100	4 + 400 kg $MgCO_3$	5.8	6.4

Table 5. **Effect of N, P, K and lime applications on DM production by *H. rufa, P. maximum* and *M. minutiflora* at Iraca, San Martín. Cuttings done on average of every six weeks.**

Treatment				DM Yield		
N	P_2O_5	K_2O	Lime	*H. rufa*	*P. maximum*	*M. minutiflora*
kg/ha				t/ha		
50	0	0	0	2.6	2.5	3.7
50	0	0	2	3.0	2.2	3.8
50	50	50	0	2.9	2.2	4.1
50	50	50	2	4.7	3.3	3.6
50	100	50	2	3.7	2.9	4.2

minutiflora and *B. decumbens.* The former, although it can not stand dry weather, does not justify fertilization from either the agronomic or the economic point of view. The latter tolerates drought and responds to fertilization. *P. plicatulum* and *H. rufa* yielded better than *P. maximum,* which is not a suitable species for Piedmont conditions in the Llanos Orientales.

At hacienda El Piñal, located in San Pedro de Arimena, in the high plains, adaptation and response to combined applications of Ca and P was observed for *P. purpureum, A. scoparius, M. minutiflora, A. micay, B. decumbens, H. rufa* and *P. maximum* (1). Table 6 shows average DM yields per cutting of the grasses evaluated. Several aspects of this trial must be emphasized. *P. maximum* produced the lowest levels of forage as it did on the Piedmont. Amongst grazing grasses such as *A. micay, H, rufa, M. minutiflora* and *B. decumbens,* the greatest yields were obtained with the last two. Once again *M. minutiflora* did not respond to applications of P. *A. scoparius* and *P. purpureum,* grasses for cutting, responded to fertilization in a different way. Forage production of *A. scoparius* (2.5 t/ha) contrasts with that of *P. purpureum* (1.8 t/ha) planted without fertilization, indicating the better adaptation of the former to acid soils. The response of *P. purpureum* to lime (2 t/ha) was very good, yielding nearly 3 t/ha more DM with this

Table 6. **DM production by various grasses under two systems of fertilization, at Hacienda El Piñal, San Pedro de Arimena, Meta.**

Fertilization	Forage production						
	P. purpureum	*A. scoparius*	*A. micay*	*M. minutiflora*	*B. decumbens*	*H. rufa*	*P. maximum*
	t/ha/cutting						
Control	1.8	2.9	1.0	1.9	1.3	1.2	0.7
500 kg/ha of basic slag	1.9	3.3	1.8	1.6	2.0	1.5	1.0
2 t/ha of lime + 300 kg/ha of 10-20-20	4.5	3.5	1.7	2.1	2.0	1.3	1.2

amendment. These results have corroborated studies at La Libertad Station, where it has been difficult to cultivate *P. purpureum* without neutralizing at least 75% of the exchangeable Al.

At the same Hacienda El Piñal, forage production of the introduced grasses *B. decumbens, H. rufa* and *M. minutiflora* was compared under three levels of P and K and two of lime with native species *Trachypogon vestitus* Anderss and *A. purpusii* (Mez) Chase (Table 7). *M. minutiflora* and *B. decumbens* yielded better than native pastures. Among these, *A. purpusii* gave the lowest production and was the least persistent. Introduced pastures generally showed similar responses to P, K and lime as those found at Icará, San Martín. In the case of *B. decumbens* and *H. rufa,* 300 to 350 kg/ha of a complete fertilizer like 10-30-10 and at least 2 t/ha of lime can be applied at seeding.

Similar studies were carried out at Guacavia, Gaviotas and Puerto López, and with small variations, results were quite similar. With these trials it was possible to observe the great potential of *B. decumbens,* which not only responded to fertilization, but, unlike *M. minutiflora,* produced high yields and tolerated the dry season. *M. minutiflora* is another pasture of older introduction which shows excellent adaptation. Unfortunately, it did not respond to fertilization, at least at treatments used. *H. rufa* produced less than the others just mentioned, especially on savanna soils, but it also responded to fertilization. From these trials it was possible to conclude that *P. maximum* is not recommended for Llanos Orientales' conditions, and that to obtain acceptable results with these grasses, controlled grazing and high doses of fertilizers are necessary.

As for legumes, a comparative study at Guacavia showed adaptation and response to P and to lime of *P. phaseoloides, C. cajan* and *D. intortum.*

In regions other than the Llanos Orientales trials have also been done on pasture fertilization (1). For example, effects of several rates and sources of P on the yield of *P. purpureum* were studied in Santa Rosa de Cabal (Risaralda). Triple superphosphate (TSP) was better than rock phosphate and pastures responded satisfactorily to additions of several levels of P.

In Chinchiná, Caldas, *P. notatum, A. scoparius* and *A. micay* did not respond to fertilizers. *P. purpureum* H-534 and *B. decumbens* responded slightly after the first year of harvesting at frequent intervals. On

Table 7. **DM production of various pastures under different fertilization levels at Hacienda El Piñal, San Pedro de Arimena.**

Treatment				Forage production				
N	P_2O_5	K_2O	Lime	*B. decumbens*	*M. minutiflora*	*H. rufa*	*T. vestitus*	*A. purpusii*
kg/ha			t/ha	t/ha/cutting				
50	0	0	0	3.1	4.4	1.9	2.3	1.3
50	0	0	2	3.9	4.3	2.7	3.3	1.7
50	50	0	2	5.5	5.4	3.6	3.9	1.9
50	50	50	2	5.9	6.2	3.9	4.1	2.0
50	100	100	0	4.3	6.0	3.9	4.3	1.4
50	100	100	2	7.0	5.9	4.3	4.1	1.5

the other hand, pastures such as *C. gayana* and *B. decumbens* must be fertilized with P and K at least once a year.

N is essential for increasing and maintaining uniform pasture production. A trial on seasonal N fertilization in *D. decumbens* was done at El Tigre Ranch, Pereira (10). The soil was brought to normal conditions of pH and principal nutrients. N was applied as urea at rates of 50 and 100 kg/ha after each cutting and at the end of the rainy season. Response to N varied with presence or absence of moisture and after six cuttings, similar yields were obtained with 50 kg N/ha after each cutting and 100 kg N/ha at the end of the rainy season (Table 8). The difference is because 300 kg/ha were applied with the first treatment of N and 200 kg/ha, with the second.

A trial to compare two organic sources of N and three inorganic sources of P on forage yields of *A. scoparius* var. Telembí (6) is being done at the Hacienda Las Guacas, on the Popayán plateau, in collaboration with the ICA Soil Program. It was thought that adding OM could improve P availability from slightly soluble sources. Several treatments have been made including two lime rates (0 and 2 t/ha), rock phosphate, basic slag and TSP (0 to 150 kg P_2O_5/ha).Lime and organic fertilizers are added to the soil five weeks before sowing and at sowing, K and phosphate fertilizers are added.

Results to now indicate that lime alone does not increase forage production significantly, but the opposite has happened when organic fertilizers are added. Preliminary results (Table 9) show that TSP and rock phosphates have a similar effect, but over two or more years, the latter source provides greater forage production. Basic slag has a higher initial effect, but with time and after three or more cuttings, it loses its residual value causing reduced DM yields.

Trials with animals

The last step in research on forage species is their evaluation in terms of animal production. The carrying capacity of a pasture depends on its DM yield. Production per animal reflects the nutritional value of that forage.

Until now evaluation trials with animals of pastures on poor soils have been fairly limited, compared to many such trials done in other places (1). Table 10 shows the results of four of these trials on the Piedmont plains and on the savanna soils of the Llanos Orientales.

Because of the limited data available, the different locations of the trials, and the diverse systems of pasture management, only a few practical comments can be made. Native pastures and *P. plicatulum* provided less carrying capacity than introduced species *(H. rufa* and *B. decumbens).* No attempt was made to introduce a rotation system for native pastures, because this is not traditional in the Llanos and it involves expensive management methods. The experience gained at La Libertad Station influenced the use of rotations in introduced pastures. Possibly the good adaptation of these species, their growing habits and the management may result in a greater carrying capacity.

An important consideration is the low liveweight increase obtained on native grasslands —200 g compared to 500 or 600 g on other pastures. It must be emphasized that these increases are greater than those obtained in experiments during the rainy season at La Libertad (Villavicencio) and Carimagua experimental stations. Also, the weighing of animals is perhaps less controlled on private farms than in experimental centers. On native pastures it is difficult to expect more than 30 kg beef/ha at least during the eight months of rains.

Results in Table 10 show that differences exist between pastures, management methods and location, for beef production in the Llanos Orientales. In other words, different pasture management methods can be used for feeding cattle in this region.

Table 8. **Effect of seasonal application of N on DM yield by *D. decumbens* in Pereira (10).**

N rates	Total N applied	Cuttings						Total production	Average production
		23-V-67[a]	7-VII-67[b]	18-X-67[c]	23-XI-67[d]	21-XII-67[b]	29-II-68[c]		
kg/ha		t/ha							
0	0	0.8	0.2	0.5	0.7	0.1	1.0	3.2	0.5
50[e]	300	2.7	0.7	1.9	2.4	0.8	3.7	12.0	2.0
50[a]	100	2.5	0.3	0.9	2.6	0.2	0.9	7.4	1.2
50[d]	100	1.2	0.3	1.8	1.0	0.1	3.0	7.4	1.2
100[d]	200	1.3	0.4	2.9	1.1	0.1	5.8	11.6	1 9

[a] At the beginning of the rainy season
[b] During the dry season
[c] During the rainy season
[d] At the end of the rainy season
[e] At each cutting.

Table 9. **Effect of the two organic sources of N and four sources of P on DM yield by *A. scoparius* var. Telembí on the Popayán plateau during 1976-1977. Average of five cuttings.**

OM	Rock phosphate*	Basic slag*	TSP	$\bar{X}$
t/ha	kg/ha			
0	11.8	10.3	12.6	11.6
Chicken manure**	13.9	12.4	13.2	13.2
Cow manure**	13.2	11.9	12.2	12.4
$\bar{X}$	12.9	11.5	12.7	

* 150 kg/ha of available P_2O_5

** 5 t/ha.

Regional trials with animals have not been tried yet, but the time has come to start these on the basis of results obtained at La Libertad and Carimagua. Without mentioning specific experiments and without trying to define beef production in the Llanos, the expertise and the results obtained by ICA at La Libertad and by ICA and CIAT at Carimagua can be used to develop some alternatives for evaluation on cattle ranches (Table 11).

These systems have already been studied experimentally, over two or more years, and can now be tried at the regional level. Some cattle owners have already put several alternatives into practice, and of course, Numbers 1 and 2 are traditional in the Llanos. However, it is necessary to quantify the results. Other alternatives exist which have only been partly studied, and whose results are not very favorable at the experimental level. One example is rotation grazing on *M. minutiflora*.

Trials would be constructed to obtain data on stocking rates, animal growth, forage production and chemical composition. As well as the biological evaluation, it would be essential to make an economic evaluation. Animal health, genetic constitution of the animals, and other factors should constantly be reviewed.

Profitability analysis should have special priority. It is very difficult to get a cattleman to adopt pasture and cattle management techniques different from those used at present, unless it can be proved that they are feasible and profitable. Perhaps some of

Table 10. **Regional trials conducted in the Llanos Orientales to measure effects of pastures on the stocking rate and the liveweight increase during the rainy season.**

Municipality	Farm	Pasture	Cattle	Stocking rate	Liveweight increase	Grazing system
				AU/ha	kg/day	
San Pedro de Arimena	El Piñal	Native	Criollo	0.5	0.20	Continuous
Villavicencio	Villaflor	*P. plicatulum*	Criollo	1.9	0.60	Continuous
Villavicencio	La Esmeralda	*H. rufa*	Criollo	2.2	0.60	Rotational
San Martín	Iraca	*B. decumbens*	Zebu	3.5	0.60	Rotational

Table 11 **Alternatives to be evaluated in on-farm trials with animals.**

Pasture type	Management system	Season
1 - Native species	Without burning	Rainy season - dry season
2 - Native species	With burning	Rainy season - dry season
3 - Native species	Sequential burning	Rainy season - dry season
4 - *M. minutiflora*	Continuous grazing	Rainy season
5 - *H. rufa*	Continuous grazing	Rainy season - dry season
6 - *B. decumbens*	Continuous grazing	Rainy season - dry season
7 - *H. rufa*	Rotational grazing	Rainy season - dry season
8 - *B. decumbens*	Rotational grazing	Rainy season - dry season

these trials should be carried out not as isolated analytical experiments but as "production systems". These systems would combine two or more of the alternatives just mentioned; for example, comparing the use of *M. minutiflora* during the rainy season and *B. decumbens* during the dry season with *B. decumbens* all the year.

Some observations are available on native pastures and their carrying capacity, which under grazing conditions in the Llanos varies from 0.12 to 0.2 an/ha (4). Likewise, studies done by ICA at La Libertad and Carimagua with *B. decumbens* indicate that the carrying capacity of this pasture under a paddock rotation system fluctuates between 2 and 3 an/ha (Table 12) (8, 9).

Beef production/ha/yr can be increased 15 times by replacing native pasture with *B. decumbens*. This possibility, as well as other intermediate steps, should be verified as soon as possible at the farm level.

CONCLUSIONS

General conclusions and recommendations based on results of regional trials on acid, low fertility soils are as follows:

1. Growth and production patterns of several species of grasses have been identified. Some of these grasses have replaced native species very successful-

Table 12 **Potential beef production in the Llanos Orientales, using forage according to the extreme alternatives 2 and 8 of Table 11.**

Alternative	Factor		
	Stocking rate	Weight increase	Live-weight
	an/ha	kg	kg/ha/yr
Native pasture with burning	0.2	0.3	22
B. decumbens under rotational grazing	2.3	0.4	335
Times each factor would increase by	11.5	1.3	15.3

ly, for example *B. decumbens* and *M. minutiflora* in the Llanos. Studies on adaptability must continue, because ICA does not have experimental centers at the intermediate zone level. In the Llanos it is necessary to carry out adaptability studies on low terraces and river bed soils.

2. So far it has been impossible to find legume species, lines or varieties with good agronomic features which can be used consistently in cattle feeding. A greater effort must be made in the search for forage legumes. This is the main question mark regarding availability of new species.

3. As a result of these factors, agronomic trials are indispensable. The results of agronomic trials, together with the research support in experimental centers, provide guidelines for fertilization for the establishment of pastures on acid, infertile soils. It would be much easier to implement methods for establishing pastures at the same time as fertilization practices.

4. Evaluation of pastures with grazing animals should be intensified at the regional level. It might be advisable to start studying production systems, mainly in the Llanos Orientales. These systems would permit the profitability of cattle ventures to be determined and would also identify possible problems which might have an impact on the low cattle output of these regions.

5. There are still serious unknowns about pasture growth and production on poor soils, and on forage consumption by animals. The experimental centers have, however, generated technology which should be tried at the regional level, under farming conditions.

6. Experience gained so far shows that well-trained people are needed to carry out these kinds of tasks, not only from an academic but from a human relations point of view. The ideal would be to have a team of people responsible for this work who know the relaticnships between soils and pasture, pasture and animal, management and health, who are also knowledgeable of economics.

7. The effort being made by the Pasture and Forage Research Program at ICA on regional trials is not exhaustive. The results, however, are encouraging and can be considered as a preliminary stage in the development of technology, which must take place in the future in regions with acid, infertile soils.

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PASTURE RESEARCH AND TECHNOLOGY TRANSFER IN TWO LATIN AMERICAN CATTLE DEVELOPMENT PROGRAMS: ECUADOR AND PANAMA

Luis E. Tergas*

ABSTRACT

Experimental results on pasture and forage production and utilization show that it is possible to obtain about 450 g/animal daily liveweight gains in steers in relatively fertile soils with good water retention capacity, which is the case in the Coastal area in Ecuador between Quevedo and Santo Domingo. With stocking rates up to 3 animals/ha, it is possible to obtain gains of 1.5 kg/ha/day, or 500 kg/ha/yr, enabling animals to reach slaughter weight before 2.5 years of age. Adequate reproductive levels with 80% effective weaning is possible both for adult cows and first calving heifers before the age of 3 years. On the other hand, test results in acid, infertile soils with low moisture retention capacity, such as those prevalent in the Pacific Region of Panama, do not seem promising at this time. This justifies the need for further research on these soils. The comparative advantages of using fertile soils for the more profitable crop production must be considered as well. With respect to technology transfer to cattlemen, although it is true that there is no adequate model that can be applied to all possible circumstances in Latin America, experiences in Ecuador and Panama suggest the need to develop research with practical, well-defined goals related to livestock development programs supported by credit projects. Furthermore, validation of technology and demostrations at the producer's level should form an integral part of research activities, as should training young professionals and designing techniques for evaluating, adapting and adopting new technology in light of socio-economic conditions of the livestock industry.

Pasture and forage production capacity has been considered one of the advantages of the Tropics for economical beef cattle production. However, the present use of these resources under grazing conditions is far from being efficient, mainly due to production restrictions during the dry periods and variations in forage quality on offer in the humid-dry regions with acid, infertile soils.

Results reported during this seminar have shown the production potential of these areas, and how nutritional problems of livestock production under grazing conditions could be solved despite the above-mentioned deficiencies. However, a number of unsuccessful attempts on technology transfer in Latin America have also been mentioned (24), especially those related to introducing new forage species with higher potential than native species, in which, due to higher costs of establishment and management, a change in the existing

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pasture structure was not justified. In relation to that, it has also been pointed out (4) that some forage species, especially grasses, have been introduced by ranchers themselves. On the other hand, it must be recognized that the existing technology is far from being applied at the farm level at a sufficient rate to cause impact on beef production, promising a serious delay in tropical livestock development.

Even though the importance of research on pasture and forage production and utilization in tropical, acid, infertile soils must be recognized because of the possible impact of the results on economical beef production it has been suggested (19) that perhaps it is also important first to adapt and to test results at the regional level before transferring technology to the producers.

Nevertheless, in the case of livestock production, we still do not have a technological package similar to that for crop production in the "Green Revolution", which could be applicable to livestock production. Basic to any beef production program in Latin America, efforts must be made to develop a methodology to facilitate technology flow from researcher to producer.

The objectives of this paper are to present results of research in tropical forage and pasture production and utilization based on the experience of livestock development programs in the tropical coastal regions of Ecuador and the Pacific Coast of Panama, and to discuss the possibilities for developing technology transfer models at the farm level.

CHARACTERISTICS OF THE TROPICAL REGIONS OF COASTAL ECUADOR AND THE PACIFIC COAST OF PANAMA

These are two typical regions in Latin America where beef production plays an important role in the agricultural development of each country, not only because of its importance in food production, but also because of its contribution to the economics of the nation. Available natural resources for beef production present certain marked differences which are reflected in the production and utilization of pastures and forages, the approach to research and the technology transfer methodology applicable to each region.

Climate

Annual rainfall and distribution throughout the year do not seem to differ in the two regions (Fig. 1). Approximately 80 to 90% of the annual rainfall occurs during the rainy season and affects seasonal forage production. Due to the difference in latitudes, the rainy and dry seasons occur at different times of the year in each region.

Soils

Differences between both regions are being determined by this natural resource. In Ecuador, only 23% of the soils are classified as Oxisols or Ultisols (2), and most of the estimated 8.6 million ha are located in the eastern, humid, tropical region and the northern part of the Coast. In Panama, 3.6

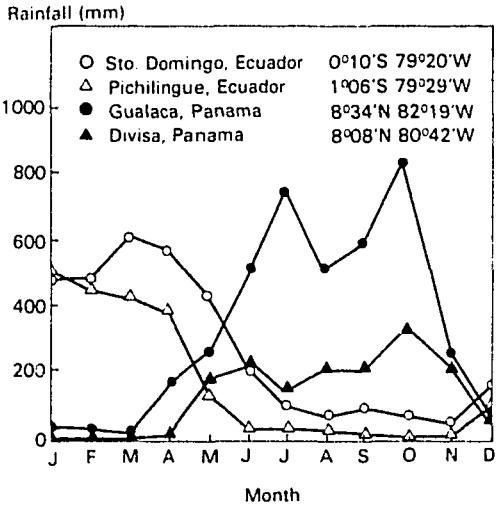

Figure 1. Rainfall distribution in representative sites of the Ecuadorian coast and the Pacific Region of Panama (Servicio Nacional de Meteorología e Hidráulica of Ecuador and Servicio Interamericano de Cooperación Agrícola of Panama).

million ha, comprising 63% of the country, are found throughout the nation both in humid and humid-dry regions.

Table 1 shows soil chemical characteristics of each region. In general, the Ecuadorian coastal soils, especially from Pichilingue to Santo Domingo, are highly fertile which allows high yields of annual food crops such as rice, maize soybean, etc. (5). On the other hand, low soil fertility has been considered the main limiting factor in Panama for forage production, hence, food crops.

The moisture retention capacity of coastal Ecuadorian soils—mostly Inceptisols, Alfisols and Vertisols—is generally good, with moisture equivalents of 30 to 40%, which allows continued forage growth for some time after the end of the rainy season. On the other hand, ocean currents greatly influence prevailing winds and air temperatures in the region leading to lower evapotranspiration rates during the dry season (12). In Panama, water holding capacity of most Ultisols and Oxisols is relatively low, independent of texture and OM content. During the dry season actual evapotranspiration is 80 to 90% higher than rainfall (18). Therefore, low soil moisture content in addition to low natural fertility levels are more critical for pasture and forage production and utilization in the Pacific Coast of Panama than in the Ecuadorian coast.

Forage species

Panicum maximum Jacq. (31) is the most common grass in the Ecuadorian coast where it has been naturally adapted to soil and climatic conditions ranging from sea level to an altitude of approximately 1100 m. This forage species has been recognized as excellent (32) because of its yield and adaptation to all climatic and soil conditions in the Tropics and it is considered (37) the highest yielding grass under grazing conditions in Puerto Rico. In Panama, 84% of the pastures are established with *Hyparrhenia rufa* (Nees) Stapf. (27); hence, livestock production, mainly during the dry season, is limited due to its low yield and nutritional value, even after N application near the end of the rainy season (35).

METHODOLOGY

The first activities in Ecuador and Panama were related to ecological survey of the target area within the beef development programs to get acquainted with the available resources for pasture and forage production, and, above all, to identify limiting factors which should be emphasized in the study (33, 34). The scheduled visits to many beef ranches, representing different types and levels of productivity, helped in analyzing animal production factors directly related to nutritional and socio-economic aspects involved in technology development and transfer to producers.

Table 1. **Characteristics of representative soils from the Ecuadorian coast and Pacific region of Panama.**

	pH	OM	P (Bray II)	Exchangeable cations Ca	Mg	K	Al	Source
	— % —		ppm	— meq/100 g —				
Santo Domingo, Ecuador	5.7	5.3	5	3.0	0.6	0.3	0.0	Tergas*
Pichilingue, Ecuador	6.1	5.6	28	13.0	2.4	1.6	0.0	(12)
Gualaca, Panama	5.1	7.5	1	1.3	0.5	0.3	1.8	(8)
Coclé, Panama	5.4	4.6	2	8.6	2.1	0.3	1.3	(8)

* Unpublished data

As to finding practical and economical solutions to the problems of pasture and forage utilization and production, the following methodology was adopted: (a) screening of forage species adapted to the prevalent ecological conditions (soils and climate) in the area; (b) development of acceptable pasture establishment and maintenance practices for the specific socio-economical conditions of the beef industry in each country; and (c) personnel training, within the program, in validation and technology transfer techniques.

Research work in Ecuador was conducted directly with a technical assistance program of the University of Florida (U.S.A.), in association with the Instituto Nacional de Investigaciones Agropecuarias (INIAP) with headquarters at the Estación Experimental Tropical de Pichilingue (EETP) in Quevedo (financed by the Central Bank's Livestock Development Program ECU 222 through a loan from the International Bank for Reconstruction and Development (World Bank)). A research program was set up including conventional agronomy studies of forage plants under cutting and grazing conditions on the Ecuadorian coast. Technology transfer carried out through the Centro de Capacitación Ganadera (Livestock Training Center) in the experimental station where theoretical-practical courses on basic animal production aspects are offered to extension and credit agents and selected producers.

The Panama study was carried out directly with the Panama National Bank's Livestock Development Program PAN 901, financed through a World Bank loan. Activities of testing on adaptation and validation of technology at a farm level were supported by the pasture and forage research program of the Instituto de Investigaciones Agropecuarias de Panamá (IDIAP), with headquarters at the Gualaca's Experimental Station which is technically assisted by the Animal Husbandry Department of the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) of Costa Rica. The mechanisms used for technology transfer involved direct technical assistance to producers and field demonstrations.

The training of technological personnel assigned to these programs was designed to provide: (a) knowledge for identification of forage utilization and production problems related to nutritional needs of the herds; (b) technical skills in validation and adaptation of new technology according to the available natural and financial resources and administrative capacity of the enterprise; and (c) communication and agricultural extension methods. In Ecuador, greater attention was placed on the research aspects and in Panama, to the financial ones, for obvious reasons.

RESULTS AND DISCUSSION

Most of the research and technical assistance efforts were focused on the dry season, due to the fact that most restraints concerning pasture and forage utilization and production in terms of dry matter (DM) production and nutritive value are found during this critical period.

Research

Dry matter

Screening results on *P. maximum* accessions which were adapted to the ecological conditions of the Ecuadorian coast showed no ecotype with better DM production during the dry season (Table 2). There were also no significant differences among the best varieties introduced and common ecotypes in terms of DM digestibility and crude protein content (CPC) (36).

Table 3 summarizes dry season average DM yields of pasture species and varieties adapted to the Ecuadorian coast under cutting conditions every 21 and 35 days. In general, common *P. maximum* was outyielded only by species of *Brachiaria*, varieties of *Pennisetum purpureum* Schumach., varieties of *Glycine wightii* (R. Grah. ex Wight and Arn.) Verdcourt especially Malawi, and *P. maximum* variety EETP 307*;

* Accession number from the Estación Experimental Tropical, de Pichilingue, INIAP, Ecuador.

Table 2. **DM yields* of naturalized *P. maximum* and introduced, well-adapted varieties under grazing conditions** (15, 16).**

Varieties	1975 Dry season	1976 Rainy season	1976 Dry season	Total 18 months
	t/ha			
Common	3.15	10.19	5.37	18.72
Improved	2.62	6.99	3.74	13.35
EETP 307	3.64	8.84	4.49	16.97
Introduced***	4.28	8.78	4.76	16.83
Average	3.42	8.70	4.59	16.72

* Dry weight basis 45°C, 24 hours
** Grazed at 21 and 42 day intervals during the rainy and dry season respectively
*** Average of 10 best introduced varieties

however, performance of the latter variety under grazing conditions was not consistent as shown in earlier tables.

Dry season production of non-fertilized *H. rufa* in Panama (27) was 1.05 t/ha, representing 14.6% of the total annual production; meanwhile the average yield of improved species without fertilizer applications was 1.16 t/ha, and 2.97 t/ha when fertilized annually with 900 kg N, 400 kg P_2O_5 and 120 kg K_2O/ha. However, dry season yields represented only 12% of the total annual production. *H. rufa* is considered suitable only for extensive production systems, due to its poor response to N application during the rainy season. Among the grasses selected and recommended for intensive use they considered *Digitaria decumbens* Stent., *Brachiaria ruziziensis* Germain & Evrad, *Brachiaria decumbens* Stapf., *Brachiaria radicans* Napper, *Hemarthria altissima* (Poir.) Stapf. & Hubbard var. Tetraploid and some *Axonopus*, *Cynodon* and *Pennisetum* species and varieties. The following legumes were considered promising: *Pueraria phaseoloides* (Roxb.) Benth. var. Javanica (Benth.) Bak., *Desmodium ovalifolium* Vahl., *Desmodium intortum* (Mill.) Urb., *Centrosema* spp., *Stylosanthes guianensis* (Aubl.) Sw. and *Macroptyloma axillare* (E. Mey.) Verdc.; although dry season yields were only recorded for the most productive species (*B. decumbens*, *Cynodon* sp. var. Estrella and *B. ruziziensis*).

Table 3. **DM yields* of naturalized species and varieties and introduced, well-adapted pasture species under cutting conditions during the 1975 dry season at INIAP (34).**

Species and varieties	Cutting intervals 21 days	Cutting intervals 35 days
	t/ha	
Common *P. maximum*	2.63	3.34
Improved *P. maximum*	2.91	3.61
P. maximum EETP 307	8.05	11.93
Cynodon spp.	3.83	3.96
Brachiaria spp.	7.05	8.36
C. ciliaris	3.56	4.34
Setaria spp.	3.01	5.64
P. purpureum	8.42	16.84
C. wightii	7.75	5.66
G. wightii var. Malawi	10.59	8.12
Average	5.78	7.18

* Dry weight basis 45°C, 24 hours.

P. purpureum yield levels of DM obtained in Panama (18) towards the end of the rainy season ranged from 6.3 to 10.3 t/ha using up to 1.400 kg N/ha/year and from 4.5 to 8.0 t/ha when grown in association with *P. phaseoloides* with P, K and gypsum applications. DM yields ranging from 58 to

66 kg/ha/day were recorded by IDIAP (14) for non-fertilized *Saccharum sinense* Roxb. and 68 to 82 kg/ha/day when fertilized with 100 kg N/ha/yr. This grass has shown good drought resistance and response to low P levels in P deficient soils.

Nutritive value

DM *in vitro* digestibility averages of the best-adapted *P. maximum* varieties in the Ecuadorian coast taken at 21 and 56 days during the dry season, decreased from approximately 61 to 52% as the plant matured (Fig. 2). There were no significant varietal differences when compared with common *P. maximum* (36). Among the grasses, only *Brachiaria* species and *P. purpureum* varieties proved of any importance regarding DM digestibility and were slightly better than *P. maximum* varieties. Legume species maintained digestibility levels above 60%, despite the plants' stage of maturity.

Average CPC in grass species and varieties in Ecuador decreased with maturity (between 21 and 56 days of growth) whereas CPC remained over 25% in legume species (Fig. 3). Furthermore, the performance of *P. purpureum* varieties was slightly better; however, in all cases overall CPC was above 10%, an adequate level for growing ruminants, and for beef production. No significant CPC differences were found during the rainy season (36).

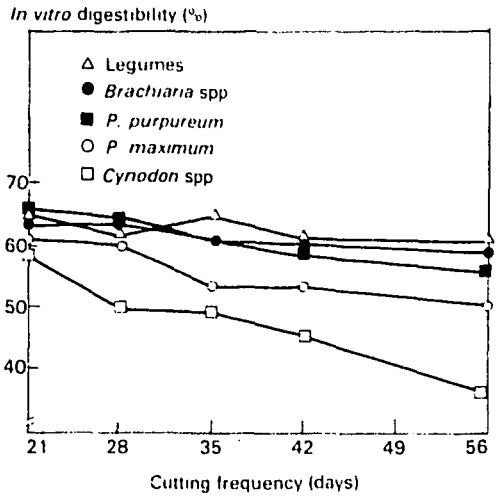

Figure 2 **Effect of cutting frequency on *in vitro* digestibility of tropical pasture species and varieties adapted to the coast of Ecuador. INIAP-Pichilingue, dry season, 1975 (34).**

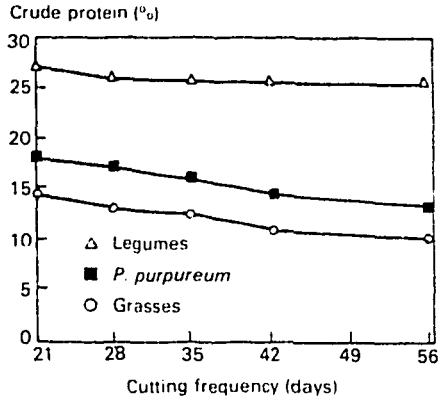

Figure 3 **Average crude protein content of tropical pasture species and varieties adapted to the coast of Ecuador. INIAP-Pichilingue, dry season, 1975 (34).**

In Panama (27) average CPC of samples from 13 species and varieties of grasses was 13.7%. Materials were selected according to environmental adaptability, cut at three-day intervals between 12 and 42 days of growth and fertilized with 360 kg N, 240 kg P_2O_5 and 60 kg K_2O/ha. In comparison maximum CPC was 9 to 10% for *H. rufa* fertilized with 600 kg N/ha/yr during the rainy season and 4 to 6% during the dry season.

Crude protein levels of almost 11% (18) were found in *P. purpureum* towards the end of the rainy season without N application, while *S. sinense* levels fluctuated between 8 and 11.5% (14) when N was applied at a rate of 200 kg/ha/yr.

Digestibility and nutritional level parameters for the selected grasses were not reported, except for P content in P-treated soils.

Animal production

Tables 4 and 5 show daily liveweight gain/animal and per area in Ecuadorian

Table 4. **Liveweight gains per animal with several grass species and varieties under different treatments in the Ecuadorian coastal Plains.**

Species and varieties	Treatment	Liveweight gains				Source
		No. of days	Dry season	Rainy season	Annual average	
		g/animal/day				
Common *P. maximum*	Non-fertilized*	180	-	423	-	(15)
	Non-fertilized**	491	307	411	359	(15)
	In association with *P. phaseoloides***	491	331	468	399	(15)
Improved *P. maximum*	Non-fertilized	280	317	597	457	(25)
	Non-fertilized	180	-	353	-	(15)
	100 kg N/ha/yr	336	485	674	579	(28)
	In association with *C. pubescens*	224	243	744	493	(7)
*B. dictyoneura**	Non-fertilized	180	-	394	-	(15)
G. wightii var. Tinaroo*	Non-fertilized	180	-	607	-	(15)
Average		282	336	519	457	

* Pichilingue
** Santo Domingo

coast tests with different grass species and varieties, mainly common and improved *P. maximum* varieties, under different treatments. Despite the short duration of these trials, in general, animal production averages of 457 g/animal/day and 1.46 kg/ha/day throughout the year are very good. This provides liveweight gains of over 500 kg/ha/yr and enables steers to reach slaughter weight (450 kg) before 25 months of age when weaned at not less than 180 kg (1). These results are 52% higher than averages found in an economic survey of farms within the Livestock Development Program in the Area of Santo Domingo and Quevedo (19). This production rate is comparable to that presented in a summary on animal performance on N-fertilized tropical grasses and pasture and legume associations (23), and higher than that recorded in Mexico for *D. decumbens* and *H. rufa* when fertilized with 100 kg N/ha during the rainy season (11) and in Venezuela (6) for *Cynodon* sp. var Estrella, *D. decumbens* and *P. maximum* receiving N applications. However, results from Pichilingue show that average daily gains per animal during the dry season are only 65% of those obtained during the rainy season. This is due to the effect of lower quality grasses which leads to a 50% reduction in beef production/ha/day even despite high stocking rates over the entire year.

In Panama, in trials (18) with stocking rates of nearly 2.5 animals/ha, the highest daily gain per animal on non-fertilized *H. rufa* under rotational grazing conditions was 200 g while 310 to 450 g gains were obtained with complete fertilization of *Brachiaria* spp. and *D. decumbens*. In another trial in Gualaca (14), daily animal gains of up to 838 g were obtained in 180 days on N-fertilized *H. rufa* pastures. However, economic evaluations showed the system to be economically unfeasible due to current beef and fertilizer prices. The same study shows that *H. altissima* var.Tetraploid fertilized with 300 kg N/ha/yr produced weight gains of up to 502 kg/ha during the initial stage of the study, compared with 417, 407 and 390 kg/ha for *D. decumbens, Cynodon* sp. var. Estrella and *B. radicans,* respectively. These production rates are

Table 5. **Liveweight gains per unit area with several grass species and varieties under different treatments in the Ecuadorian Coast.**

Species and varieties	Treatment	No. of days	Stocking rate***	Liveweight gains: Dry season	Liveweight gains: Rainy season	Liveweight gains: Annual average	Source
			an/ha	kg/ha/day			
Common *P. maximum*	Non-fertilized*	180	- /3.1	-	3.20	-	(15)
	Non-fertilized**	491	3.8/3.3	1.22	1.17	1.20	(15)
	In association with						
	P. phaseoloides	491	4.8/3.4	1.40	1.38	1.39	(15)
Improved *P. maximum**	Non-fertilized	280	1.4/1.7	0.65	1.65	1.15	(25)
	Non-fertilized	180	- /2.8	-	2.68	-	(15)
	100 kg N/ha/year	336	3.3/3.3	1.60	2.22	1.91	(28)
	In association with						
	C. pubescens	224	1.7/3.3	0.95	2.33	1.64	(7)
*B. dictyoneura**	Non-fertilized	180	- /3.6	-	2.90	-	(15)
G. wightii var. Tinaroo*	Non-fertilized	180	- /2.6	-	2.81	-	(15)
Average		282	3.0	1.16	2.26	1.46	

* Pichilingue
** Santo Domingo
*** Dry/rainy season average.

relatively low compared to production rates resulting from *H. rufa* experiments in non-fertilized, but more naturally fertile soils in Ecuador (29), and from *H. rufa* and *S guianensis* associations in acid, infertile soils in Pucallpa, very similar to those in Panama (20).

Animal reproduction

Results obtained in Ecuadorian coast trials show that effective weaning averages of over 80% are possible with average 160 kg weights (adjusted to 205 days of age) for males and females by utilizing mineral supplementation and breeding herd management, without changing the common *P. maximum* pastures in the region (Table 6). These averages are much higher than those found on Ecuadorian Livestock Development Program ECU 222 farms in Santo Domingo and Quevedo, where the maximum average growth rate of the herd is only 1.2% (9). Regarding development and reproduction performance, results show that it is possible to obtain a 36% higher calf crop when first calving heifers graze separately from the adult herd (15).

In Panama, calving rates increased from 62 to 73% when P was supplemented to the animals or by fertilizing *H. rufa* at a rate of about 80 kg P_2O_5/ha (14). On the other hand, in studies conducted in the humid tropics of Peru (30), mineral supplementation was found to have a greater effect on reproductive performance of heifers than superphosphate applications of up to 500 kg/ha on *H. rufa* and *P. phaseoloides* associations. These results suggest that mineral supplementation with P could have a greater effect on reproductive performance than pasture improvement, as has been found in the Llanos Orientales in Colombia (2).

Technology transfer

Centro de Capacitación Ganadera

Table 7 shows the number of participants in the pasture and beef cattle management courses offered at Pichilingue from 1975 to the present. A total of 376 trainees, including a balanced number of producers from the Coastal region and technical research and assistant staff members from the Livestock Development Program have received training. The information provided during the courses is based on research results Field demonstrations are carried out at the experimental station, followed by regional trials on selected farms owned by participating ranchers. Up to now these experiments have been concentrated on reproductive improvement in a region of low animal population rates and high grassland availability.

Table 8 shows the alternatives offered to cattlemen and participants in the improved pasture establishment and management courses, for increasing beef production during the dry season. It is interesting to note that the option with the best expected

Table 6. **Reproductive performance of beef herd grazing on common and improved *P. maximum* varieties (15, 16, 17).**

	1975		1976		1977		
	Common	Improved	Common	Improved	Common	Improved	Average
Calving (%)	92	95	80	80	80	80	84
Birth weight (kg)	28	29	28	29	29	29	28
Weaning (%)	92	95	80	80	80	80	84
Weaning weight (kg) (205 days)	159	160	159	168	156	166	162

Table 7. **Number of participants, by levels, in the beef and pasture management courses at the Centro de Capacitación Ganadera (15, 16, 17).**

Level	1975	1976	1977	Total
Technicians*	65	90	47	202
Producers**	45	49	80	174
Total	110	139	127	376

* Research technicians, credit and technical assistance agents, and selected university students

** From the Ecuadorian Coast

benefit ratio, when compared with establishment and management costs, is the use of common *P. maximum* complemented with *Eriochloa polystachya* H.B.K. and another species well-adapted to the many floodable low-land coastal areas, and *P. purpureum* from cutting and grazing under extreme drought conditions.

Associations of common *P. maximum* and *P. phaseoloides* in established pastures seem to be a promising option for low fertility soils or areas where soil fertility is declining. These data are available (15) and results could be transferred to cattlemen in a relatively short period of time. First, however, the persistence of the species under present management systems in the area must be validated, and the need of whether to modify or not the present systems which include burning and continuous grazing must also be studied. Furthermore, it is important to consider the possibility of reducing establishment costs, especially availability and seed price, and to define P and S fertilizer maintenance requirements. The other option, substituting common *P. maximum* for some *Brachiaria* species, is

Table 8. **Analysis of possible alternatives based on research carried out on improved pasture management and establishment to increase dry season beef production in common *P. maximum* pastures of the Ecuadorian Coast.**

Alternatives offered (management)	E.B. [a]	E.E. [b]	M.D. [c]	E.M.C. [d]	E.B./E.M.C.
P. purpureum *E. polystachya* (Supplemented)	>	≤		≥	>
P. phaseoloides *G. wightii* (In association)	>	?	?	?	?
B. decumbens *B. dictyoneura* (Replacement)	=	<	=	>	<

[a] Expected benefits
[b] Ease of establishment
[c] Management difficulties
[d] Establishment and management costs

not promising in the long run, because, although these species seem to be better adapted to low-fertility soils and compete better with weeds under these conditions, their productivity gradually decreases due to soil N deficiencies and a legume-grass association would be much more difficult to establish.

Technical assistance and demonstrations

A total of 311 visits were made to cattle ranches in Panama between the end of the rainy season in 1975 and the first semester of 1977. Table 9 shows the objectives, number and distribution of calls. At the beginning of the study several non-participating ranches were visited so as to diagnose pasture and forage production and utilization problems in the area and to observe some of the better-managed holdings. Later, most activities were concentrated on ranches associated with the credit program

Technical assistance at the farm level focused on improved forage establishment and management, mainly to increase the nutritional level of feed provided during the dry season. As a result of these visits, almost 1000 ha of improved pastures and seed plots of the recommended species were established on almost every participating ranch. Field demonstrations were used to train the program's technical staff on improved pasture establishment and management practices (i.e. species identification and screening, forage utilization and preservation, etc.) so that through the learning process the communication methodology and agricultural extension work could be more effective. Toward the end of the second year, the sub-projects were evaluated according to the new technology's effectiveness, economic impact and acceptance. Evaluation was extended to the training of the technical personnel. The evaluations were concentrated on farms selected as models within the sub-region, the majority of which were less than 300 ha in size and with so-called dual purpose, dairy-beef operations. Economic evaluations of these farms are in progress at the present time.

Specific technical recommendations are based on the analysis of the options presented in Table 10. These options would be presented to cattlemen according to the study results and socio-economic aspects of the beef industry. It is not feasible to increase production during the dry period by improving *H. rufa* management, although the relative importance and productivity of this grass during the rainy season was noted. A promising short range option that solves some nutritional problems is the establishment of relatively small areas, at the beginning, of *B. decumbens* or *B. radicans* in low-fertility soils, *E. polystachya* in lowland floodable areas, and *S. sinense* as cut grass for supplementing *H. rufa* during the dry period. The gradual substitution of *H. rufa* by *Brachiaria* species and the establishment of *Cynodon* in higher fertility areas were considered feasible, yet there is no

Table 9. **Number and distribution of visits to cattle ranches in different regions in the Pacific Coast of Panama. Livestock Development Program PAN 901-Banco Nacional.**

Objectives	1975	1976	1977	Total
Problem diagnosis	69	10	0	79
Technical assistance	8	111	19	138
Demonstrations and training	0	13	0	13
Sub-project evaluation	0	25	56	81
Total	77	159	75	311

Table 10. **Analysis of possible alternatives based on research carried out on improved pasture management and establishment to increase dry season beef production in *H. rufa* pastures of the Pacific Coast of Panama.**

Alternatives offered (management)	E.B. [a]	E.E. [b]	M.D. [c]	E.M.C. [d]	E.B./E.M.C.
Brachiaria spp. *S. sinense* *E. polystachya* (Supplemented)	>	≦	=	>	>
P. phaseoloides *S. guianensis* (In association)	>	?	?	?	?
Brachiaria spp. *cynodon* spp. (Replacement)	>	<	=	>	?
P. purpureum *S. sinense* (Silage)	?	<	>	>	?
D. decumbens *Cynodon* spp. (Hay)	=	≦	>	>	<
By-products Molasses + urea (Supplemented)	>	=	>	>	?

[a] Expected benefits
[b] Ease of establishment
[c] Management difficulties
[d] Establishment and management costs.

information on expected benefit ratios compared to additional establishment and management costs. On the other hand, both systems tend to degrade with time due to decreases in soil fertility leading to reductions in animal production. Another possibility would be to include forage legumes such as *P. phaseoloides* and *Stylosanthes* spp. native to the area in *H. rufa* pastures, since this seems to have been effective in certain tropical areas, including some isolated areas in Panama. However, experimental results have not been tested sufficiently in commercial operations, and lack of seeds of adapted species and varieties limits the work on technical adaptation at the regional level.

The preservation and use of forage as silage or hay for beef production was not found to be economically feasible due to high production costs (34) and losses during storage (21). Finally, the use of agricultural by-products such as sugar cane and bagasses, rice hulls, etc., was considered with some good biological results (14). Their

use depends on the availability of a commercial molasses mix with 2% urea content, at localized subsidized prices, much lower than in the international market, which can be justified only to maintain animals under extreme drought conditions or high pasture and forage scantiness.

CONCLUSIONS

Test results on pasture and forage production and utilization in the Tropical Coastal area of Ecuador between Quevedo and Santo Domingo on fertile soils with adequate moisture, indicate that there is enough information available to improve livestock production which is based on acceptable and ready to transfer technology on improved forage establishment, consisting mainly of management of the available natural resources with minimum investment costs. However, the situation varies in low-soil-fertility areas with moisture retention problems as is the case of the Pacif Coast of Panama, where forage production is low during most of the year. On the other hand, any livestock development program must consider the comparative advantages of higher soil fertility areas for the more profitable crop production.

Though it is true that, based on these experiences from Ecuador and Panama, an ideal technology transfer model for cattlemen can not be designed, we can however confirm the important role of research as a source of new technology as long as it is related to well-defined goals in the livestock development programs.

A common error in Latin America (4) is the lack of relevance of the work carried out at experimental stations to the cattleman's problems in the region. Recommended, therefore, is the establishment of a livestock training center within the experimental station, such as that at INIAP in Pichilingue, Ecuador.

Frequent contact among producers, extension agents and research workers—with the support of development and credit agencies—is essential if research results are to be applied at the producer level. This contact does not necessarily guarantee results, but does serve as a stimulus, which is the case of Australia and other tropical countries throughout the world (13).

Training in economical production and efficient utilization of pastures and forages, and in communication and technology transfer techniques is important in order to maintain a good flow of information between research workers and the beef industry, due to the limited number of persons in the developing countries in Latin America capable of interpreting and transmitting the technology developed at research stations (22). Research projects related to any Latin American livestock development program should include training for technical personnel, especially young college graduates.

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FAO'S TRAINING COURSES ON TROPICAL PASTURES

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ABSTRACT

The Grassland and Pasture Crops Group of the Plant Production and Protection Division of FAO has been conducting a series of short-term courses on Tropical Pastures and Range Management since 1972 in response to identified needs of developing countries. At present only two areas are covered (the Far East and the Pacific Islands and the English speaking countries south of the Sahara), but a new program for French speaking countries south of the Sahara is in preparation. The objectives of the training program, number and duration of the courses carried out, prerequisites for selection of candidates, factors affecting the selection of the locality where the course will take place, and the financing institutions are mentioned. Emphasis is placed on the practical and demonstrative component, and on how the students learn to profit from the scarce facilities available at their home countries. Thanks to the backing offered by the governments and to the satisfactory results obtained, the present program in Africa will continue without major modifications

Since 1972, the Grassland and Pasture Crops Group of the Plant Production and Protection Division of FAO has been conducting short term courses on Tropical Pastures and Range Management. These courses form part of the main activities with the tropical pasture development program which includes technical assistance to field projects, technical publications and regional research programs.

The need for these courses was identified as a result of many years of activities in developing countries dealing with pasture-livestock development in the tropical and sub-tropical zones.

At present two distinct geographical areas are covered. (a) Far East and the Pacific Islands funded by the Australian Freedom from Hunger Campaign and (b) English speaking countries of Africa south of the Sahara with a financial contribution from the Swedish International Development Authority. A new program for French speaking countries south of the Sahara is in preparation, with bilateral funding.

Up to the present time, there have been three courses in the Far East Region (1972 Malaysia, 1975 Thailand, 1978 Sri Lanka). Students from Burma, India, Indonesia, Laos, Malaysia, Papua New Guinea, Philippines, Samoa, Seychelles, Sri Lanka, Thailand and the Solomon Islands (UK) have participated in these programs.

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In Africa, one course was held in Kenya 1975 and in June-August 1978 the second will be held in Tanzania with participants from Botswana, Cameroon, Gambia, Ghana, Kenya, Lesotho, Malawi, Nigeria, Sierra Leone, Tanzania, Uganda and Zambia. There is only one main difference between the Far East Program and the African courses: in that the first has a duration of four weeks and gives greater emphasis on cultivated pastures. The African courses are split into two parts, one dealing with cultivated pastures mainly for the so-called higher potential areas and the other with range improvement for dry and very extensive pastoral systems. The same students attend both sections, with a duration of four weeks for each part.

For the African courses we have initiated the follow-up activities which consist mainly in the provision of seeds, fertilizers, inoculants and other inputs which are not available, or otherwise difficult to come by in their home countries.

The courses are offered for graduates and sometimes diploma holders are accepted. Each country is asked to nominate candidates and a selection is made. It should be emphasized that the main prerequisite for selection is that the candidate be actually engaged in pasture/animal production research and extension activities. The courses are not designed for administrators. The majority of participants have a Bachelor's Degree in Animal Sciences—Livestock and Veterinary Science and Agricultural Science. Occasionally we have a Master's Degree or Ph.D. Selection also takes into consideration the geographical area of the country and institution involved; some come from University, Government research stations, livestock development programs.

The location of a course is decided after reviewing the existing facilities where the courses may be held, generally in the Department of Agriculture at a particular university, or research institute. In many cases, the FAO ongoing field programs may also be a decisive factor in the selection of a country.

The aims of the training program are to provide in a relatively short time an intensive training that will strengthen and update the knowledge of the participants or the principles of soil-plant relationships, factors affecting tropical pasture species, growth and pasture yield; a study of species adaptation, the management of these species and animal production from tropical pastures. Within this framework, the training course aims to define problems and limitations to tropical pasture production, with special emphasis on the improvement of productivity.

It is an important characteristic of these courses that students are taught to do by themselves valid research and field investigations within limited type of facilities and equipment which nevertheless can provide valuable and accurate data which will be useful for their pasture and livestock development programs. It is not unusual to see tropical agronomists trained in developed countries who have had considerable difficulties in adjusting themselves to the very basic facilities given in their home countries.

The training courses are designed with a large practical and demonstration component, which is of major importance and probably the key factor of the success of the program. The participants rarely have the opportunity or need before these courses, to carry out all of their own practical experimental work either in the field or laboratory.

Field plots, glasshouse experiments and laboratory demonstration are prepared by students in order to get first hand knowledge of the methods and techniques of laying out and organizing experiments, with all the practical details. Obviously, these may not be harvested during the short period of the course and therefore use is made of

replicate experiments: omission trials, fertilizer trials, effects of inoculation, shading effect, defoliation, sowing methods, etc., which have been previously established by the course demonstrators, so timed as to be ready for harvesting by the students during the course. In this way the whole experimental period can be concentrated in o a four-week course.

On many occasions it is necessary to provide funds to improve the local facilities of the host institute, such as a low cost glasshouse made for laying out pot trials, benches, hand harvesting equipment, electronic calculators, glassware, etc.

The program of lectures is combined with the corresponding practicals, field excursions, films and seminars which the students have been requested in advance to prepare, dealing with some of their pasture development research and extension problems found in their home countries.

A series of textbooks relevant to the courses is provided for each student as well as reference material on the subjects being dealt with during the course.

We now have a team of staff basically from Australia—the Department of Agriculture, University of Queensland and from the Department of Primary Industries, Queensland. For Range Management, we utilize staff members of FAO located in the area. If local lecturers in the region are available an effort is made to have their services for specific topics.

It is felt that for the present there is no need to vary much the present program. We shall continue the regional approach as the fact is that in many countries there is still no more than a handful of professionals dealing with tropical pasture research. The same duration will also be maintained as it is difficult enough to obtain students for four or eight week periods at present.

The evaluation carried out last year by an independent consultant of the African courses summarized the evaluation by saying that nowhere in Africa was there a similar opportunity being offered to students and the program was well warranted and also well received by the students and participating government institutions.

PART VII

SEMINAR CONCLUSIONS

TROPICAL PASTURE RESEARCH IN ACID, INFERTILE SOILS OF LATIN AMERICA: PRESENT STATUS AND NEEDS FOR THE FUTURE

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One of the main conclusions of the seminar on the "Potential to Increase Beef Production in Tropical America" held at CIAT five years ago was the need to increase efforts in tropical pasture research in order to bring it in line with efforts on animal management and health (2). An in-depth review of pastures and forages research in the region, published by Crowder (1) in 1974 showed that there were significant, but largely scattered pasture research efforts throughout tropical Latin America, few of which had any real linkages to soil constraints or to animal productivity. The purpose of this Seminar is to review the present state of knowledge, five years after those two reviews. This chapter attempts to summarize what is known and what is still unknown, drawing from the papers presented, the question and answer periods, and the general discussion sessions. The author is grateful to the chairmen of the general and discussion sessions**, for providing valuable summaries, on which many of the following comments are based.

PRESENT STATE OF KNOWLEDGE

Conceptual

Three major conceptual themes emerged from the Seminar. First, in order to increase beef production an integrated attack on the constraints affecting the soil-pasture-animal continuum is needed. To accomplish this an interdisciplinary team is required both to develop improved beef production technology and transfer it to the users. Second, the Seminar participants agreed that the main constraint preventing increased beef production is animal nutrition caused by insufficient pasture both in terms of quantity and quality. Many scientists involved in major research efforts which have concentrated on improved animal breeding or health have gradually realized that notwithstanding the importance of adequate management and health of tropical beef cattle, poor pasture production is by far the most limiting factor in marginal soil areas. The third major theme is the growing ecosystem focus on acid infertile soils, which cover about 51% of tropical America. A number of national and international institutions are giving top priority to savanna and jungle Oxisol-Ultisol regions as the areas with the greatest potential to increase beef production in our continent, where unlike tropical Asia and Africa, beef is a major component of the diets of poor urban and rural Latin Americans. The Oxisol-Ultisol regions are rapidly developing and almost invariably, land settlement starts with extensive, pasture-based beef production. If productive and persistent pasture technologies are developed to withstand the acid soil infertility and

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climatic stress, many of the better soils located close to markets, presently used to produce beef, can be used more efficiently for intensive food crop production.

The ecosystem

Many of the Seminar authors have carefully described the climate, soil and native vegetation of the areas in which they work, revealing their awareness of ecosystem differences, which may limit the extrapolation of results to other regions. In broad terms, Alvim describes the potential of the Amazon region for pasture-based beef production and makes use of actual experience to put into perspective the excessive pessimism of those who fear that the opening up of the tropics will result in "catastrophic" ecological disasters. The report of Serrão and coworkers from Eastern Amazonia that pastures significantly reduce the rate of soil fertility decline after clearing and burning tropical forest has major ecological implications. Toledo and Morales further show that beef production in the Amazon can reach very high levels.

Cochrane's paper presents a systematic way to synthesize available information on climate, soil, landscape and vegetation into land systems, units small enough to allow quantification of variability and implications for livestock production. Similar considerations are also needed for identifying ecosystems with high potential for tropical pasture seed production, which as Hopkinson and Reid indicate, are usually not the same areas where pastures are to be grazed.

The quest for adapted forage germplasm

The unifying theme of the Seminar is the continuing need for improved ecotypes of both grass and legume pasture species, which are better adapted to Oxisol-Ultisol regions of tropical America, and to subtropical regions of North America and Australia.

While there are few well adapted, productive grass species, only two of them cover much of the improved pastures area in the acid soils of tropical America: *Brachiaria decumbens* in the more stressful soils, and *Panicum maximum* in the somewhat better soils. *B. decumbens* is threatened in some areas by spittlebug attacks, particularly in the more humid regions, while *P. maximum* disappears with time when its nutritional needs are not adequately met. Other major species such as *Hyparrhenia rufa* are productive only in areas with better soils or at higher levels of fertilizer and lime applications, which are probably uneconomical in much of the Oxisol-Ultisol regions.

The need for expanding the germplasm base of tropical pasture grass species is obvious, but it is greatly overshadowed by the lack of appropriate pasture legumes. All grasses need nitrogen, which in this energy short world, should be fixed from the air at low cost by legume-*Rhizobium* symbiosis. No lasting impact can be expected until persistent and productive grass-legume pastures are developed for the Oxisol-Ultisol regions of Latin America. Hutton's paper reports almost no successes in persistent grass-legume pastures in acid, infertile soils of this continent to date. Very encouraging results with grass-legume pastures are reported during the first year or two, but the legumes tend to disappear afterwards, due to a variety of reasons such as poor adaptation to acid soils, tolerance to insect and disease attacks, inadequate mineral nutrition, and overgrazing.

Paradoxically, Latin America is the richest source of tropical forage legume germplasm in the world. Australian Scientists collected many ecotypes decades ago, selected them for adaptation to their conditions and developed the only large-scale, legume-based beef

production in the tropical world. The papers by Hutton, Teitzel, Evans, and Roberts describe and update this achievement.

Until recently, pasture legume work in Latin America has consisted largely of repatriation of the Australian cultivars back to their center of origin. Sánchez and Isbell point out the fundamental differences in climate and soils between the tropical pasture regions of Australia and Latin America, which largely limit the transferability of results from one continent to the other. Since in tropical Australia the soils are generally not acid and the climate is characterized by long and cool dry seasons, much of the adapted germplasm has failed when introduced into acid soil regions of Latin America. Also they are subjected to devastating disease and insect attacks, which are unimportant in Australia. The successful transfer of Australian cultivars is limited to high latitude, high soil pH regions with cool, long dry seasons, but not to low latitude, hot, humid tropical America.

Fortunately, new and coordinated efforts are underway for collecting, cataloging and evaluating the forage germplasm resources of Latin America, as Schultze-Kraft and Giacometti describe. Hecht's report emphasizes the potential value of browse species, which traditionally have been of more interest to botanists than cattle producers. It is clear that tropical pasture scientists in Latin America are beginning to master their continents' forage germplasm resources.

Technology components

The processes of testing new germplasm for adaptation, productivity and persistence in acid soil regions involves a series of technology components, some of which rely heavily on purchased inputs and some of which require only minimum inputs. Both approaches are well illustrated in many papers of this Seminar, and such differences are expected in a region with countries having widely different economic, social and political conditions. In spite of these differences, the Seminar papers indicate a rapid transition from classic, temperate region research emphasizing the elimination of stresses by heavy fertilization, liming, irrigation, pest control, hay making, silage, and concentrate supplementation, to attempts to overcome, and in some cases, take advantage of acid soil infertility.

Several papers describe components of low input technology aimed at adapting the forage species to acid soil stresses. Spain's paper shows the abundance of grass and legume pasture species which tolerate high levels of aluminum saturation in the soil, in sharp contrast to most crop species and many commercial tropical forage species such as *Chloris gayana, Hyparrhenia rufa* and *Glycine wightii.* The use of aluminum tolerant species such as *Brachiaria decumbens, Stylosanthes guianensis* and many others, effectively eliminates the need of liming, although in soils with extreme calcium deficiency, this nutrient has to be supplied.

The paramount limiting nutrient, however, is phosphorus which is not only costly to apply but is subject to chemical fixation in clayey Oxisols and Ultisols. The review by Fenster and León shows that very important differences exist among and within forage species in their ability to grow well at low levels of available soil phosphorus. Also their paper indicates that if the soils are kept acid and aluminum tolerant pasture species are grown, low reactivity rock phosphates are as efficient as superphosphate in supplying phosphorus to the pasture, but as a fraction of the cost. By keeping the soil acid, the high energy requirement of superphosphate manufacturing plants can be replaced by the chemistry of acid soils. Tropical America is blessed with vast rock phosphate deposits of low reactivity. Their use in

the Oxisol-Ultisol regions could make a major contribution towards overcoming this major limiting factor in pasture nutrition.

After phosphorus deficiency is overcome, nitrogen is commonly the next most serious limiting factor. Pure grass pastures run out of nitrogen with time and as Hubbell points out, the possibility of associative symbiosis between free living N-fixing bacteria such as *Spirillum lipoferum* and tropical grasses is of no practical significance. The use of nitrogen fertilizers on grass pastures is severely limited by their high cost to very special circumstances as Teitzel, Evans, Kretschmer and Snyder and Toledo and Morales point out. The best alternative is nitrogen fixation by legume-*Rhizobium* symbiosis. Halliday's results show significant advances in obtaining effective symbiosis in acid-tolerant tropical pasture legumes, by the systematic selection of strains and pelleting practices. The concept that most tropical pasture legumes nodulate freely in acid soils is now discarded.

Other essential nutrients are limiting in acid soil regions; their identification and correction is essential to guarantee persistent grass-legume associations. Very little is known about the nutrient status of Oxisol and Ultisol regions of Latin America in relation to the requirements of both grass and legume pasture species. Teitzel describes the Australian approach to identify such limitation based on geology, native vegetation and missing element trials, and several papers from Latin America follow this approach to a limited extent. Most Latin American countries, however, have well equipped soil testing laboratories which could develop site-specific recommendations if the nutritional requirements of the pastures were known. Of major importance to our region are potassium, sulfur and magnesium deficiencies, and among the micronutrients zinc, boron, copper and molybdenum seem to be the most widely limiting ones.

One of the major themes of the Seminar was that the nutritional requirements of grass and legume species must be met in order to have persistent pastures. These requirements must be identified and corrected in the most economical way, particularly if the species are tolerant to aluminum toxicity and to low levels of available soil phosphorus.

Conventional pasture establishment techniques have been developed for savanna and jungle regions but they are generally costly. The paper by Nores and Estrada, and economic data presented in others suggest very strongly that improved pasture establishment costs should be reduced to the greatest possible extent in order to make these practices more profitable. Some promising alternatives have been identified such as low density plantings, described in Spain's paper, and methods for gradually improving the native savanna. Another is the use of crops as precursors of pasture establishment, a practice already in use in Brazil, Peru and other countries and described in papers by Kornelius *et al.* and Toledo and Morales. Burning the native savanna or the tropical rain forest is an integral component of most pasture establishment methods, and in both cases, an ecologically sound one.

The availability of sexual seed of the improved pasture species is another essential technology component for increasing beef production. Ferguson provides a practical classification of the main pasture seed production systems in tropical America and summarizes the present status. Rayman describes his very interesting experiences as a commercial seed producer in Brazil. Much can be learned from the grass seed production experiences in Africa described by Boonman, and of legumes in Australia described by Hopkinson and Reid. Low latitudes is a major constraint in forage seed production particularly in countries that have limited areas with latitudes of less than 10°, such as Costa Rica, Panama, Colombia, Venezuela, Guyana, Surinam, Ecuador, and most of Peru.

The application of technology

An overview of the productivity of pasture-based beef production systems in tropical Latin America, was given in the papers by Garza, Barcellos *et al.*, Paladines and Leal, Nores and Estrada, Rolón and Primo, Alarcón, Kornelius *et al.*, Serrão *et al.* and Toledo and Morales. As a whole they show that the productivity of native savannas is extremely low, but it can be drastically increased by the introduction of improved grasses such as *Brachiaria decumbens, Panicum maximum* and *Hyparrhenia rufa* in order of increasing native soil fertility. In the case of jungle areas, beef production per unit area is higher than in savannas because of a better rainfall distribution and the fertilizer value of the ash. Nevertheless the productivity of jungle pastures seem to decline more rapidly because of fertility decline and weed invasion. In all cases but one, the introduction of legumes have not been successful for more than a year or two. Thus, the next breakthrough in tropical pasture productivity on acid soils of Latin America is expected to be a result of the strategic use of productive and persistent grass-legume pastures.

Transfer of technology activities through regional trials and training activities are in operation in Latin America, as shown by the summaries from Colombia, Brazil, Ecuador and Panama by Alarcón, Rolón and Primo, Tergas, and Riveros. Progress has certainly been made, but none of the Seminar participants considered these efforts sufficient to close the gap between technology development and technology transfer. The Australian experience of both successes and failures, described by Roberts, is certainly food for thought for pasture specialists in this hemisphere.

AREAS THAT NEED STRENGHTHENING

The most important knowledge gaps identified in this Seminar, either explicitly or implicitly, can be summarized in the following paragraphs.

1. Collection of both grass and legume germplasm should be intensified and better coordinated among the different countries. Given the disease and insect stresses of germplasm near its center of origin, collection of legumes in acid soil regions of Southeast Asia and the Pacific, and of grasses in similar areas of Africa should be intensified for use in Latin America. Of particular concern is the genetic vulnerability of *Brachiaria decumbens* and other species with only one or two ecotypes diffused over the entire continent. Emphasis should also be given to legume browse species, given their importance to animal nutrition in both savanna and jungle areas.

2. As the collecting efforts begin to bear fruit, the breeding of tropical grass and legume species should gain in importance. Breeding for disease and insect tolerance, improved nutritional quality, and tolerance to acid soil stresses are the highest priorities. The limited variability in tropical grass species can be vastly increased when apomixis is broken, such as the case of *Panicum maximum.*

3. The extremely limited knowledge about the nutritional requirements of forage grass and legume species in relation to the soil's native fertility must be increased. Critical nutrient levels for the establishment phase should be determined and quantified in terms of soil tests or plant analysis data on a routine basis. Critical levels developed for crop species are not likely to be useful for pasture species. Forage germplasm should be classified according to its nutritional requirements and grouped into classes defined quantitatively and not, as "adapted to somewhat more fertile soils".

4. Almost nothing is known about weed control in pastures growing in acid infertile soils, including jungle regrowth, as Doll's paper points out. Low input technologies must be developed to cope with these and other causes of pasture degradation.

5. Site-specific work is needed to develop low-cost pasture establishment methods, including improving the native savanna.

6. Very little is known about the maintenance requirements of improved grass-legume pastures, particularly their fertilization needs under different grazing pressures and management systems.

7. There is also very little hard data on animal productivity from improved grass-legume pastures. Liveweight gain trials should be conducted for a sufficient number of years to ascertain persistence and productivity in a meaningful way. Long term trials require good planning, and a commitment of financial resources for several years.

8. Improved grass-legume pastures are expected to cover a certain percentage of the total grazing area. This proportion ranges from 5 to 10% for strategic use in breeding herds to almost 100% in fattening operations close to the markets. Herd management studies are needed to determine the optimal proportion of improved pastures and its relationship to mineral supplementation and other important animal management and health practices.

9. Transfer of technology activities, such as regional trials and training should be intensified and coordinated in a way that the different countries share the experiences of the other ones. Technology transfer begins with technology validation in specific sites and should be strengthened by follow-up contacts between trained personnel, as part of an overall tropical pasture research network.

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GLOSSARY OF PASTURE SPECIES MENTIONED

GRASSES

Scientific name	Spanish	English	Portuguese
Andropogon			
bicornis L.	Rabo de zorro		
gayanus Kunth.	Azul de Rodesia; Carimagua	Gamba grass	Capim gamba
Aristida			
pallens			Capim barba de bode
Axonopus			
affinis Chase	Carpeta; zacate amargo	Carpet grass; narrow-leaf carpet grass; nat grass	Grama tapeta; grama jesuita
compressus (Swartz) Beauv.	Grama trenza; cañamazo; trencilla; zacate amargo; pasto alfombra	Carpet grass; broadleaf carpet grass	Capim-cabayu; Missionera; grama tapeta
micay H. García-Barriga	Pasto micay; pasto chato; cañamazo dulce		
purpusii (Mez) Chase	Guaratara o Guarataro		
scoparius (Flügge) Hitchc.	Pasto imperial	Imperial grass	Capim imperial; Capim Columbia

Scientific name	Spanish	English	Portuguese
Brachiaria			
brizantha (Hochst. ex A. Rich.) Stapf.	Estrella de Africa; señal; pasto alambre	Palisade grass; signal grass	
decumbens Stapf.	Braquiaria; pasto alambre	Surinam grass; signal grass; sheep grass	Braquiária
humidicola (Rendle) Schweickt.		Creeping signal grass; coronivia grass	Quicuio da Amazonia
mutica (Forsk.) Stapf.	Yerba del parral; pasto malojillo; Egipto; Nilo; admirable; pasto de laguna; gramalote	Pará grass; Mauritius grass; Angola grass; penhalonga grass	Capim roxo; capim angola. capim fino
radicans Napper	Tanner	Tanner grass	
ruziziensis Germain & Evrard.	Gambutera	Congo signal grass; congo grass; ruzi grass; Kennedy ruzi	
Cenchrus			
ciliaris L.	Buffel: pasto bufel	Buffel grass; African foxtail	Capim bufel
Chloris			
gayana Kunth.	Pasto rodes; grama Rhodes	Rhodes grass	Rhodes
Cynodon			
aethiopicus Clayton & Harlan		Star grass; giant star grass	
dactylon (L.) pers.	Pasto, zacate o yerba Bermuda; pasto Argentina; zacate agrarista; pata de perdiz; gramilla brava; uña de gato	Star grass; Bermuda grass; wire grass; couch grass; Dog's tooth grass	Grama rompedeira; grama seda; grama paulista; capim de burro; capim fino
nlemfuensis Vanderyst		Star grass	

Scientific name	Spanish	English	Portuguese
plectostachyus (K. Schum.) Pilger	Estrella; pasto estrella	Giant star grass; Naivasha star grass	Grama da cidade; grama inglesa; grama campista
Dactylis *glomerata* L.	Pasto azul orchoro; pata de gallo; ovillo; dáctilo ramoso	Cocksfoot; orchard grass	Capim dos omares; capim pé de galinha
Dichanthium *aristatum* (Poir.) C.E. Hubbard		Angleton grass	
Digitaria *decumbens* Stent.	Pangola	Pangola grass; finger grass	Pangola
scalarum (Schweinf.) Chiov.		African couch grass; thangari	
Echinochloa *polystachya* (H.B.K.) Hitchc.	Pasto alemán; zacate alemán	African wonder grass	Capim angola; capim caiana; capim de Pernambuco; canarana verdadeira; capim da praia; capim de feixem; capim navalha
Echinolaena *inflexa*			Capim flexilha
Eleusine *indica* (L.) Gaertn.	Grama de camino; guaratara; grama de caballo	Goose grass; fowl-fout grass; rapoka grass	Capim pé de galinha
Eragrostis *curvula* (Schrad.) Nees	Pasto llorón; pasto amor; pasto llora amor	Weeping lovegrass	Capim chorão

Scientific name	Spanish	English	Portuguese
Eremochloa			
ophiuroides (Munto) Hack.	Cienpiés	Centipede grass	
Festuca			
arundinacea Schreb.	Festuca alta	Tall fescue	
Hemarthria			
altissima (Poir) Stapf. & Hubbard	Pasto clavel; gramilla canita	Limpograss	Capim gamalote
Heteropogon			
contortus (L.) Beauv. ex Roem. & Schult.	Pasto enredo	Spear grass; black spear grass; tangle grass	
Hyparrhenia			
rufa (Nees.) Stapf.	Puntero; yaraguá; jaguayano; faragua	Jaragua; yaragua	Jaragua; capim próvisorio; Sapé gigante, capim vermelho
Leersia			
hexandra Sw.	Lambedora; arroz bravo	Barit; Clubhead; cutgrass	Capim andrequicé
Lolium			
multiflorum L.	Ballico italiano; ballico anual o doméstico	Annual ryegrass; Italian ryegrass	Azevem italiano
perenne L.	Ballico inglés o perenne	Perennial ryegrass	Joio; erva castelha; azevém vivaz
Melinis			
minutiflora Beauv.	Pasto gordura o chopin; yaraguá peluda; yerba melado	Molasses grass; wynne grass	Capim-gordura; capim-catingueiro meloso; capim melado; gordura roxo

Scientific name	Spanish	English	Portuguese
Panicum			
coloratum L.	Macaricari	Coloured Guinea grass; Kleingrass; Makari kari grass	Macari cari
maximum Jacq.	Hierba de India; privilegio; zacatón; pasto guinea o india; hoja fina; zacate de guinea; castilla; saboya; zaina.	Guinea grass	Capim colonião (cv.); capim sempreverde (cv.); guiné; capim murumbu
repens L.	Grama portuguesa	Torpedo grass	Capim de castella portuguesa; canarana rasteira; capim de praia
Paspalum			
conjugatum Swartz.	Torurco o pata de gallina; gengibrillo; pasto hilo; pasto amargo; pasto horqueta	Sour grass; sour paspalum; bitter grass	Capim amaroso
dilatatum Poir.	Pasto miel; pasto dalis; gramalote	Dallis grass	Capim-alema; capim-comprimido; grama das rocas
notatum Flügge	Pasto bahía, pasto trenza; pasto horqueta; grama dulce; gramilla blanca	Bahia grass	Forquinha; capim bahia
plicatulum Michx.	Pasto negro; gamelotillo; conejito	Plicatulum; brown seed paspalum	Capim colchão; coqueirinho de garapuava; pasto negro
virgatum L.	Maciega; cortadera; caguazo; paja cabezona; talquezal; pajón; remolina	Vasey grass; bull paspalum	Mihão grande; capim salgado; capim milha roxo; palha branca

Scientific name	Spanish	English	Portuguese
Pennisetum			
americanum (L.) K. Schum.		Pearl millet; bulrush millet	
ciliare (L.) Link.	Pasto buffel	Buffel grass	
clandestinum Hoschst. ex Chiov.	Kikuyu; pasto kikuyo; zacate alfombra	Kikuyo (kikuyu) grass	Capim kikuyu; kikuiu
purpureum Schumach.	Pasto elefante; napier (cv.) o gigante; merker (cv.); merkerón	Elephant grass; napier grass; napier's fodder; elephant merker	Capim elefante
Phalaris			
arundinacea L.	Pasto cinta; zacate de listón; falaris de los bañados; alpiste de forraje	Reed canary grass	Capim amarelo; alpiste dos prados; caniço malhado
Poa			
pratensis L.	Pasto azul de Kentucky; poa de los prados	Kentucky blue grass; Smooth-stalked meadow grass	Poa
Rhynchelytrum			
roseum (Nees.) Stapf. & C.E. Hubbard	Pasto ilusión; favorito; grama seda; pasto natal	Natal grass; redtop natal grass	Capim favorito; capim natal; capim de tenerife; capim rosado; capim bandeira
Saccharum			
sinense Roxb.	Caña de uva	Uba cane; king grass	
Sehima			
nervosum (Rottb. ex Willd.) Stapf.		Sain grass	
Setaria			
anceps Stapf. ex Massey	Setaria	Setaria grass; Nandi (cv.)	Napierzinho

Scientific name	Spanish	English	Portuguese
Sorghum			
halepense (L.) Pers.	Pasto Johnson; zacate de Johnson; sorgo de Alepo, pasto ruso; canutillo	Johnson grass; Sorgho d'Alep	Capim mexicano; sorgo de allepo; arroz bravo; capim aveia
vulgare Pers.	Sorgo forrajero; millo criollo; maicillo; mijo; maíz millo	Sorghum; sweet sorghum	
Sporobolus			
poiretii (R. & Scholt.) Hitchc.	Liendrillo	Smutgrass	Cabeça de negro; capim mourão
Themeda			
australis (R. Br.) Stapf.		Kangaroo grass	
Trachypogon			
plumosus Nees	Paja peluda	Steek grass	Capim lanceta
vestitus Anderss	Paja llanera o peluda		
Tripsacum			
laxum Nash.	Pasto Guatemala	Guatemala grass	Capim Guatemala
Tristachia			
chrysothrixe			Capim flexa
Urochloa			
mosambicensis (Hack.) Dandy		Little para	
	LEGUMES		
Aeschynomene			
americana (L.)	Tamarindillo; yerba rosario	Joint vetch	Sensitiva mansa; carrapicho

Scientific name	Spanish	English	Portuguese
Alysicarpus vaginalis (L.) DC.	Trébol Alicia; Maní cimarrón; yerba de contrabando	Alyce clover; one-leaf clover	
Bohemeria nivea Gauch.	Ramio	Ramie	Ramí
Cajanus cajan (L.) Millsp.	Guandul; gandul fríjol de palo; chícharo de árbol; quinchoncho; fríjol gandul; guandú	Pigeon pea; Red gram;	Guandú; andú
Calopogonium mucunoides Desv.	Calopogonium; rabo de iguana; fríjol velludo; bejuco; napta	Calopo	Calopogonio
Centrosema plumieri (Pers.) Benth.	Patitos; chorreque; paticos	Butterfly pea	Fava de vaca
pubescens Benth.	Centro; chancho; bejuquillo; centrosema peluda; bejuco de chieve; gallinita; conchita	Centro	Jitirana; centrosema
Clitoria ternatea L.	Cuña; deleite; campanilla clitoria	Cordofan pea; Asian pigeon wings	Cunha; piquita de cunha
Desmodium barbatum (L.) Benth.	Barbadiño	Tick clover	Barbadinho
canum (J.F. Gmel.) Schinz & Thell.	Pega pega	Kaimi; Kaimi clover; beggar weed	
discolor Vog.	Mermelada de caballo		Marmelada de cavalho; capparicho

Scientific name	Spanish	English	Portuguese
heterocarpon (L.) DC. *(D. ovalifolium* Vahl.)		Florida Carpon Desmodium (cv.)	
heterophyllum DC.	Trébol japonés	Japanese tickclover; Spanish clover	
intortum (Mill.) Urb.	Desmodio; pega-pega; cadillo; amor seco	Greenleaf desmodium; desmodium	
tortuosum (Sw.) DC.	Mozotón; kintán	Florida beggar weed	Carrapicho
uncinatum (Jacq.) DC.	Platero	Spanish clover; tick clover; silver-leaf desmodium	Trevino do campo
Dolichos			
lablab L.	Dolicos; fríjol jacinto; gallinazo blanco; poroto de Egipto; chimbolo verde	Hyacinth bean. lablab; Egyptian bean	Mangalo; ervilha japonesa
Glycine			
wightii (R. Grah. ex Wight & Arn.) Verdc.	Soya perenne; soja	Glycine	Soja perene
Indigofera			
hirsuta L.	Indigo peludo; Añil velludo	Hairy indigo	Anileira cabelluda
Lablab			
purpureus (L.) Sweet		Lablab bean; Hyacinth bean; Bonavista bean	
Leucaena			
leucocephala (Lam.) de Wit	Barba de león; zarza; campeche; acacia bella rosa; leucaena huaxin; guaje	White popinac; leucaena; Ipil-ipil (Phillippines); Koa-kaole (Hawaii)	Caola; leucena
Lotononis			
bainesii Baker		Lotononis; Mites lotononis	

Scientific name	Spanish	English	Portuguese
Lupinus			
angustifolius L.	Lupino azul	Narrow-leafed lupin; blue lupine	Tremoço das folhas estreitas
luteus L.	Lupino amarillo	Yellow lupin	Lupino amarelo; tremoço amarelo; tremócilha
Macroptilium			
atropurpureum (DC.) Urb.	Siratro (cv.)	Siratro (cv.)	Siratro (cv.)
lathyroides (L.) Urb.	Fríjol de los arrozales; habichuela parada	Phasey bean	
Medicago			
sativa L.	Alfalfa	Lucerne; alfalfa	Alfalfa; luzerna
Mucuna			
pruriens (L.) DC. var utilis (Wall) Burck.	Pica pica	Velvet bean	
Pueraria			
phaseoloides (Roxb.) Benth. var Javanica (Benth.) Bak.	Kudzú tropical	Tropical kudzu; Puero	Kudzu tropical
Stizolobium			
deeringianum Bort.	Fríjol terciopelo; poroto aterciopelado; terciopelo; haba terciopelo	Velvet bean; Bengal bean	Veludo; mucuna rayada
Stylosanthes			
guianensis (Aubl.) Sw.	Stylosanthes; stylo; alfalfa del Brasil; trifolio	Stylo; finestem stylo	Meladinho; alfalfa do nordeste; estilosantes; pegajera; melosa
hamata (L.) Taub.		Caribbean stylo; verano (cv.)	

humilis H.B.K.	Stylo pequeño; alfalfa de Townsville	Townsville stylo; Townsville lucerne	
scabra Vog.		Shrubby stylo; seca (cv.)	
viscosa Sw.			Vassourinha
Teramnus			
uncinatus (L.) Sw.	Juanita; bejuquillo; cresta de gallo		Amendoim de veado; faveira; farinha de capoeira; alfalfa paulista
Trifolium			
alexandrinum L.	Trébol egipcio; trébol de Alejandría; trébol bersim	Berseem clover. Egyptian clover	Bersim
cherleri L.		Cupped clover	
hirtum All.	Trébol rosa	Rose clover	
pratense L.	Trébol rojo	Red clover	
repens L.	Trébol blanco; trébol ladino; carretón	White clover	Trevo branco
semipilosum Fresen		Kenya white clover	
subterraneum L.	Trébol subterráneo	Subterranean clover; subclover	Trevo subterráneo
Vicia			
sativa L.	Veza común	Common vetch	Ervilhaca común
Vigna			
luteola (Jacq.) Benth.	Fríjol maravilla	Dalrymple	Feijão da praia; batatarana
sinensis (L.) Hassk.	Caupi; chicharo de vaca	Cowpea	Caupi; ervilha de vaca; feijão da China

Scientific name	Spanish	English	Portuguese
Zornia diphylla (L.) Pers.	Cargadita		

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