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Pastures for the Tropical Lowlands

CIAT's Contribution

CIAT Centro Internacional de Agricultura Tropical

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CONTENTS

INTRODUCTION

R. R. Vera*

This document will explain the **objectives** and **strategies** of the Tropical Pastures Program (TPP) between 1986 and 1991. The strategies underwent a process of gradual evolution during that time period.

The overall **goal** of the TPP is "to contribute to increased beef and milk production in the acid, low-fertility soils of tropical America's lowlands by using improved grass-legume pastures."

In pursuing this objective, the TPP sought to contribute to improved human nutrition, social welfare, and economic growth. It was also evident from the very beginning of the TPP that successful legume-based pastures would contribute to the development of more productive tropical farming systems.

During the period under review, and as a consequence of changes in both the external and internal environments, the TPP developed new strategies to accomodate changing circumstances.

The initial emphasis in the early 1980s on increased livestock production on marginal soils so as to release fertile lands for crop production has remained a dominant theme throughout the period.

It is postulated that the research strategy of concentrating on the poorest soils has paid off in terms of identifying species that are well adapted to those extreme conditions but that retain the ability to respond to environmental improvements, as other chapters in this volume will demonstrate.

We pursued this objective mainly through a very significant effort of collection and exchange of germplasm, while confining our breeding activities to highly selected cases. This will also be illustrated in other chapters.

Likewise, we had to develop low-input management techniques to get the selected materials established, reducing risks to the extent possible. This also implied using minimal external inputs, whether fertilizers or herbicides, depending upon the ecosystem and farming system considered.

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Later in the 1980s, the need to develop a more mechanistic understanding of the processes underlying adaptation, persistence, and production of tropical pastures was recognized. Consequently, the development of an understanding of soil-plant-animal interactions was incorporated as an important Program strategy. It should be noted, however, that this new strategy was only made possible by the existence of persistent and productive species, thanks to many years of pioneer work in screening thousands of accessions. Progress in pursuing this new strategy is examined by R. Thomas et al. and I.M. Rao et al. (Chapters 8 and 9, respectively).

In a similar vein, the TPP also identified the need to progress beyond the formal, on-station stages of pasture evaluation, incorporating feedback from graziers' perspectives. Intimately related to this new challenge was the concern about the lack, in most countries, of institutional means to deliver emerging pasture-related technologies effectively. This deficiency was most notable in the seed sector. The initiatives undertaken to address these issues meant that the TPP began to explore the limits of orthodox research, and even overlap with some areas more closely linked to development. Our advances along these lines are summarized by J.E. Ferguson (Chapter 7).

As is common for the rest of CIAT's programs, we aimed at strengthening the ability of national institutions to conduct research. This was done through a combination of formal and informal training events, both at headquarters and in the countries, and through a very successful networking effort, crystalized in what is today a very large network of 95 Latin American institutions in 22 countries called the Red Internacional de Evaluación de Pastos Tropicales (RIEPT). This is in stark contrast to the situation at the beginning of the 1980s, given the almost total absence of tropical pasture research in many countries at that time.

The documents that follow form part of the TPP's participation in CIAT's Annual Program Review. Not one of these articles reflects research carried out by a single scientist. Rather, they are the product of teamwork.

First, J. M. Spain and M. A. Ayarza (Chapter 1) provide an overview of the TPP's target environment. Then, the core of the TPP's activities, namely, those related to germplasm evaluation throughout the mandate region, will be examined. An initial and general analysis of germplasm across ecosystems is made by J. W. Miles and S. L. Lapointe (Chapter 2), and some of the methodological implications are discussed by C. E. Lascano and J.M. Spain (Chapter 3). This is followed by in-depth discussions of two specific cases by S. L. Lapointe and J. W. Miles (Chapter 4) and P. J. Argel and E. A. Pizarro (Chapter 5).

The physical integration of improved pastures with other resources, mainly native vegetation, is addressed by M.J. Fisher et al. (Chapter 6). J.E. Ferguson (Chapter 7) deals with the difficult issue of bridging the gap between traditional research and development, thereby bringing in other institutional players. This attempts to deal with some of the issues in interinstitutional integration.

Papers on the empirical and mechanistic processes underlying tropical pasture production (R. J. Thomas et al., Chapter 8) and adaptation (I.M. Rao et al., Chapter 9) and some of the implications for other potential farming systems components follow.

After the conclusions, a bibliography of publications by the TPP and its members from 1985 to 1991 is presented.

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CHAPTER 1

TROPICAL PASTURES TARGET ENVIRONMENTS

J. M. Spain and M. A. Ayarza*

Introduction

A physiographic map of Central and South America serves as a basis for a geologic overview of the region, which is dominated by three major features. The Guyana shield to the north and the Brazilian shield to the east are among the oldest surfaces in the world and represent extremes of geologic weathering. In contrast, the Andean uplift, extending along the western rim of the continent and through Central America, is a recent and continuing geologic event. The sub-Andean depression runs along the eastern base of the Andes, and extends north and east through the Orinoco basin, east along the Amazon, and south along the Paraguay and Plata rivers. These basins are filled with sediments, mostly derived from the Andean uplift. Almost all of the lowlands in tropical South America are humid to perhumid, low elevation, and low latitude, with continuous high temperatures, thus leading to very rapid weathering of soil material. It is therefore not surprising to find that most of the region is characterized by deep, heavily leached, highly weathered soils which are strongly acid and infertile.

Well-drained Savannas

The initial focus of the Tropical Pastures Program (TPP) was on the well-drained neotropical savannas. Field activities began in 1970 with a collaborative arrangement with the Instituto Colombiano Agropecuario (ICA) in the Eastern Plains (Llanos Orientales) of Colombia. The major research and screening site was Carimagua. In 1977, a second screening site was established at EMBRAPA's Cerrados Center (CPAC) near Brasília. The rationale for the initial focus was multiple. The Colombian savannas were close to CIAT headquarters and appeared to offer a very large potential for expanded livestock and crop production with minimum ecological risk. National institutions were actively looking for international collaboration in developing a research effort for this important resource base. The savannas were being managed extensively, with low management input and very low levels of production. There are approximately 240 million hectares of well-drained savannas in South

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America, with over 200 million ha in Brazil, 12 million ha in Colombia, and another 10 million ha in Venezuela.

Well-drained neotropical savannas have a number of important advantages, along with some severe limitations. The Oxisols which dominate all three major savanna areas (Table 1) are generally deep and well structured, with little or no physical barrier to deep root development. Rainfall distribution results in adequate to excess moisture during six to eight months of the year. Topography ranges from very low relief and gently rolling landscapes to some heavily dissected regions. The areas are relatively easily accessible and the cost of road building is low compared to other humid tropical regions. The land is easily mechanized for intensive cropping. The most important limitations on the use of tropical savannas include the prevalence of allic, infertile soils in which aluminum is the dominant exchangeable cation and almost all the major nutrients and micronutrients are deficient. Another strongly negative factor is the high P-fixing capacity of most Oxisols due to their high iron content. Savanna regions are subject to very severe dry seasons, ranging in duration from four to seven months (Figure 1). This results in problems of forage quantity and quality during the dry season and extreme nutritional stress on grazing animals.

The savannas are subject to extreme biotic stress. Fungal and bacterial diseases are endemic and extremely virulent for many crop and pasture species. Leaf-cutter ants and other insects are also a hazard to both crops and pastures, especially to the latter during the establishment phase.

The lack of transportation and marketing infrastructure has severely limited development of savanna regions. This situation has changed radically in the last 25 years and both Brazil and Venezuela now have good infrastructure in most of the savanna regions (Table 2). The distance to markets is still a major economic factor. Many soybean-producing regions in western Brazil are over 2000 km from ports where the grain enters international trade.

In a discussion of land use and socioeconomic factors, it is convenient to separate traditional land use which still predominates in Colombia and many more remote regions in Venezuela and Brazil from the much more intensive land use systems which have evolved in many regions of Venezuela and Brazil. Traditional land use is characterized by extensive cow-calf and feeder operations. The large ranches which dominate are generally held by absentee owners and production is characterized by low management input and almost no purchased inputs, with correspondingly low productivity. Population densities in regions characterized by this traditional land use are very low.

In the last 25 years, impressive land use changes have occurred in both Brazil and Venezuela. Over 40 million hectares have been planted to pastures and 12 million hectares to annual crops (Figure 2). This has resulted in rapid expansion of both grain and cattle production (Table 3). As the area planted to pastures has expanded, the

Table 1. Soil orders by ecosystems (% of area).

Soil	Ecosystem			
	Llanos	Cerrados	Seasonal rain forest	Evergreen rain forest
Oxisols	68	96	52	31
Ultisols	2	3	39	43
Entisols	21	—	6	3
Inceptisols	1	—	1	14
Others	8	1	4	9

SOURCE: Cochrane, 1985.

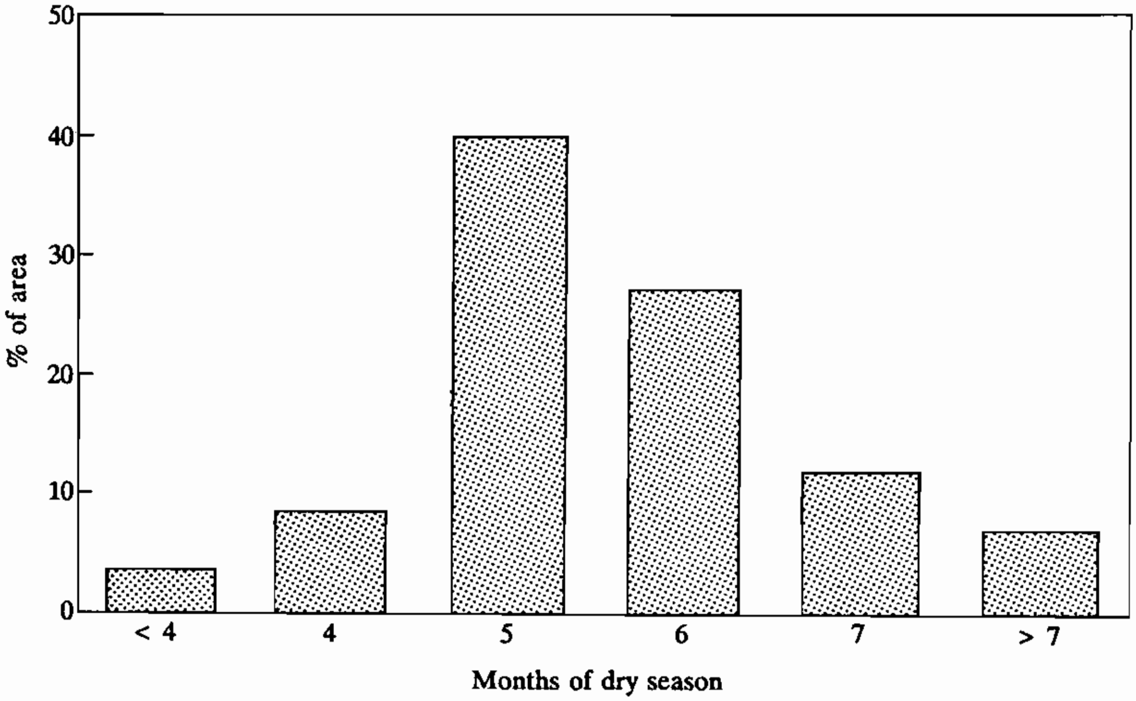

Figure 1. Brazilian Cerrados: distribution by number of dry-season months. (Adapted from Adámoli et al., 1985.)

Table 2. Road length density in neotropical savanna regions.

Region	Paved roads (km/1000 km^2)
Venezuelan Llanos	50.9
Brazilian Cerrados	5.7
Colombian Llanos	0.1

SOURCE: Vera and Seré, 1985.

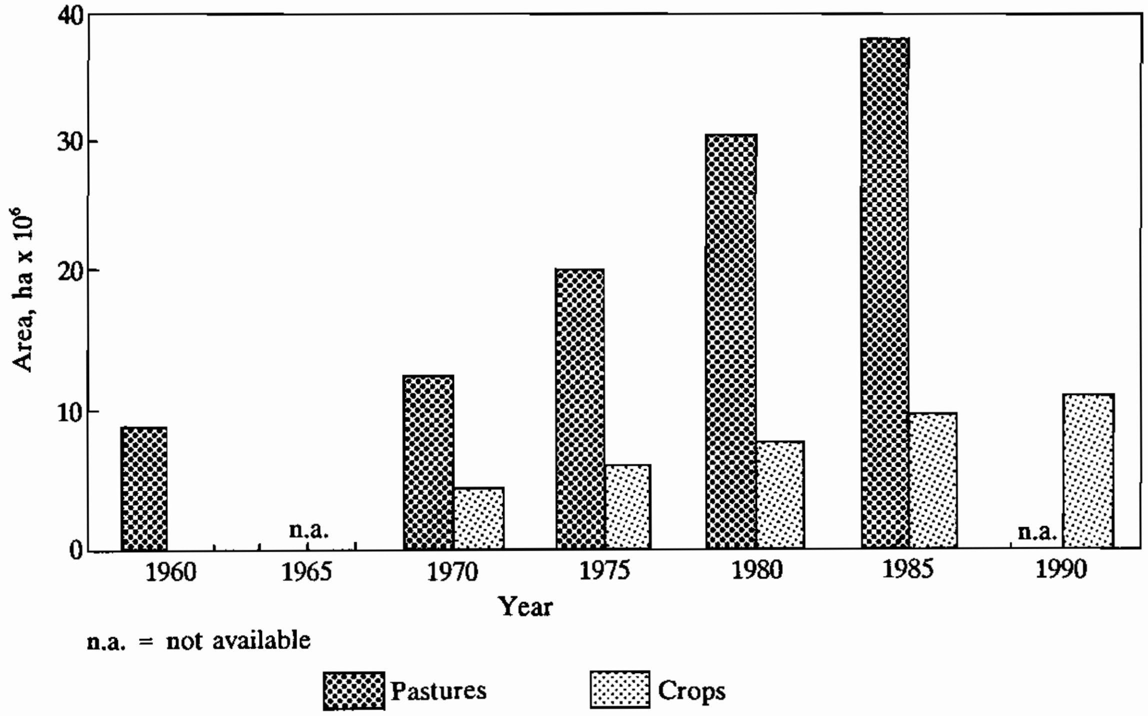

Figure 2. Expansion of area planted to crops and pastures in the Brazilian Cerrados, 1960-1990. (Adapted from IBGE, 1981; CPAC, 1990.)

Table 3. **Amount of increase in different production factors for savannas from 1970 to 1990: from fertility deserts to tropical breadbaskets.**

Component	Amount of increase in production
Arable crop area (ha)	12,000,000
Grain (tons/year)	20,000,000
Planted pastures (ha)	40,000,000
Cattle (head)	45,000,000

proportion of degraded pastures has also increased alarmingly. It has been estimated that 80%-90% of planted pastures in the Brazilian Cerrados are in advanced stages of degradation. In some cases, serious erosion is occurring on sloping pasture lands. Intensive tillage for annual crop production has also resulted in soil degradation, beginning with the disaggregation of the surface soil, leading to severe compaction in the profile and to rapid crusting of the surface, with a corresponding increase in runoff and erosion. Under continuous cropping, weeds, diseases, and insects also increase and result in declining yields.

Forest Margins

In the early eighties, the TPP came under increasing pressure to expand into forest margin regions where soils cleared from forest were rapidly degrading. CIAT's administration and the TPP were confronted with a major dilemma. On the one hand, if the TPP developed germplasm/management packages that were highly productive and stable, would it contribute to accelerated forest clearing? On the other hand, if nothing were done, would current management, which leads to rapid degradation and low productivity, accelerate clearing even more? We knew from our experience with the Red Internacional de Evaluación de Pastos Tropicales (RIEPT) that we had germplasm well adapted to many tropical forest environments. Our colleagues in national programs were conducting pasture development and management research and were avid to have more active participation from CIAT in their research efforts.

CIAT's management and Board of Directors decided that there were valid and convincing arguments for a limited initiative in the forest margins. The first screening site was established in 1985 near Pucallpa, Peru, with strong collaboration from IVITA and INIAA, and other local institutions in the Pucallpa area. In 1987, additional sites were identified and established in Costa Rica in collaboration with the Ministry of

Agriculture and Livestock, IICA, and CATIE. The initiative in Costa Rica was important in providing a base from which to meet the needs of collaborators in Central America and the Caribbean.

The forest margin ecosystem has a number of advantages and certain limitations. It is generally favored by more even rainfall distribution and less severe or shorter dry seasons. There is less biotic stress on many species in the forest ecosystem than in the savannas. This is reflected in the wide range of forage legumes adapted to the forest ecosystem. Both upland and flooded rice also experience less severe disease pressure than in the savannas.

Among the important limitations are the dominance of allic, infertile soils in a landscape which is much more variable in topography and drainage than the savannas. Forest ecosystems are generally characterized by high weed potential and they are difficult to mechanize because of topography and poor drainage in low-lying areas. Stumps and logs left after the clearing operation also inhibit mechanization. Many regions are far-removed from markets and suffer from lack of infrastructure, both regional and local. The presence of many endemic diseases, including yellow fever, malaria, and, more recently, cholera, result in great human suffering in areas where health services are deficient if available at all.

With regard to land use and socioeconomic factors, smallholders in forest margins are almost always poorly capitalized. Large holdings are often held by absentee owners. The major sources of income are timber extraction, subsistence agriculture, and dual-purpose cattle. Many areas of colonization suffer from extreme poverty and ever increasing population density as landless people migrate from other regions.

Hillsides

The TPP has made a very modest investment in expansion into hillside regions in the past five years. This involvement was the result of strong demand from other commodity programs within CIAT and from national and regional institutions desperately looking for assistance in confronting a crisis situation in the management of natural resources. The initial effort was local and low-profile in the departments of Valle del Cauca and Cauca, with strong institutional collaboration from ICA, CVC, and the Fondo Ganadero.

Hillside regions have several advantages. Most of the Andean hills were initially covered with forests and native soil fertility was better than in savanna or forest ecosystems. Soils are less acid; it is estimated that less than 50% are allic. Many areas are close to population centers and markets and there is a reasonable road and market infrastructure in most areas.

The extreme limitations of hillside regions are mostly related to topography. The areas are characterized by steep and irregular slopes, and often thin soils which are highly erodible, except in volcanic areas. Many soils are already in advanced stages of degradation, with most of the topsoil already gone. These regions are obviously very difficult to mechanize and most tillage operations are either manual or with animal traction.

The main economic activities in hillside areas include subsistence agriculture and livestock production systems, timber extraction in more remote areas, and market-oriented dual-purpose cattle and vegetable crop production near population centers. Smallholders are poorly capitalized, with the poorest usually relegated to the most marginal lands. These areas are characterized by high population density and high land pressure.

Expanding Global Mandate

The TPP has responded to increasing demands from national and international partners on other continents to share germplasm and technology in ecosystems that are similar to our target environments in Latin America. These partners stand to benefit from our large and active germplasm bank focused on forage species which have been selected specifically for acid, infertile soils of the humid tropics. CIAT's response has been modest, beginning in 1989 in West Africa and continuing in 1990 in Southeast Asia. The TPP has a liaison scientist stationed in each region to facilitate the flow of germplasm to and from CIAT and to screen this germplasm at key sites and through regional trials.

Conclusions

Just as the TPP has evolved over time and expanded to include new target environments, the environments themselves are changing. Edaphic conditions change as soils are managed more intensively under annual crops with major inputs of lime and fertilizers. The germplasm available has changed radically with the development of new lines of rice (Figure 3), sorghum, soybeans, maize, and an increasing number of options of well-adapted forage legumes and grasses.

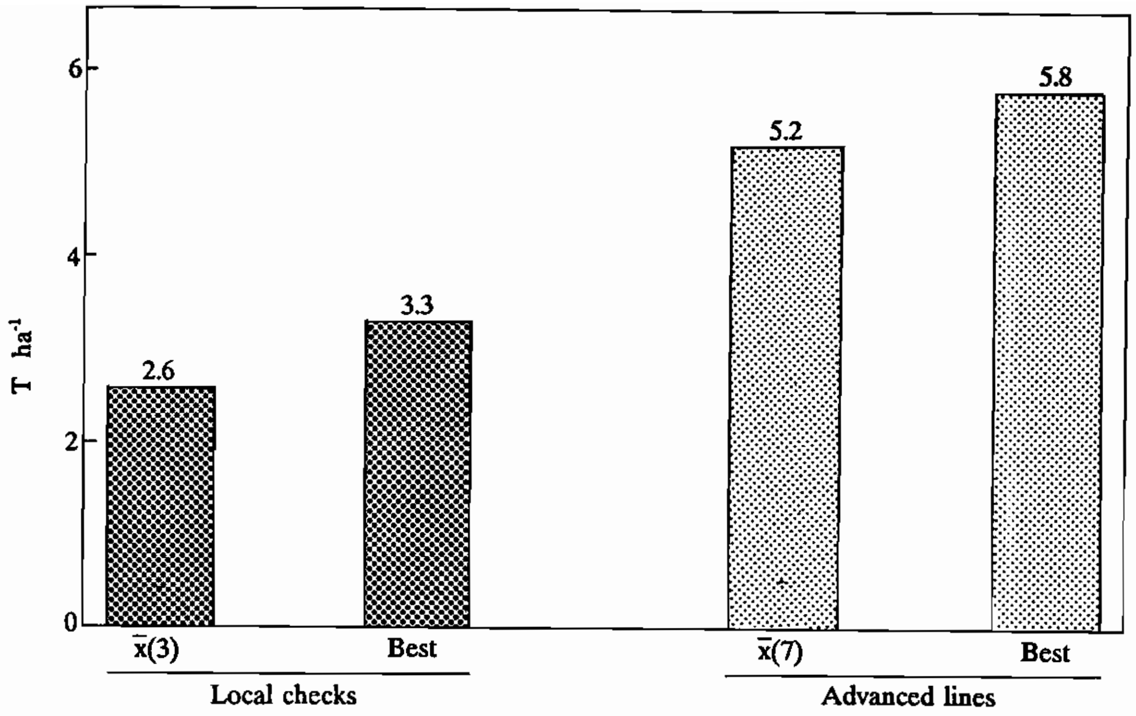

Figure 3. Grain yields of local checks and "savanna" rice lines in Mato Grosso, Brazil, 1989. (Adapted from CIAT report, 1990.)

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CHAPTER 2

REGIONAL GERMPLASM EVALUATION: A PORTFOLIO OF GERMPLASM OPTIONS FOR THE MAJOR ECOSYSTEMS OF TROPICAL AMERICA

J. W. Miles and S. L. Lapointe*

The Tropical Pastures Program (TPP) aims to develop grass and legume pasture plants for the complex target environment discussed in a companion article (Spain and Ayarza, Chapter 1) defined by the presence of acid, infertile soils in the lowland tropics. This general definition, however, covers wide diversity in terms of other environmental factors such as soil attributes other than pH, climate, pests and diseases, topography, socioeconomic conditions, and production systems.

This highly diverse target environment implies that no single germplasm solution will be adequate to fill all environmental niches. Instead, we seek a set or portfolio of germplasm options—species and genera with different adaptations, fitting particular species to specific niches.

The strategy adopted by the TPP in the face of this extreme target area diversity is one of decentralized, regional germplasm evaluation at major screening sites in four important ecosystems, with subsequent testing through numerous regional trials conducted by national program collaborators, through the International Tropical Pastures Evaluation Network (RIEPT). These major target ecosystems are the well-drained, isohyperthermic savannas (Llanos); well-drained, isothermic savannas (Cerrados); humid tropics; and subhumid tropics (Central America).

The purpose of the present document is to describe the current status of germplasm development by major ecosystem and then to present and document several important cases of ecosystem-specific pasture plant adaptation.

The major germplasm screening sites and institutional collaborators are listed in Table 1. They cover the well-drained, isohyperthermic savannas (Llanos of Colombia and Venezuela); the well-drained isothermic savannas (the Brazilian Cerrados); the humid tropical forests (Amazonia and humid forest sites of Central America); and the subhumid tropical forests (Central America).

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* Plant breeder and entomologist, respectively, Tropical Pastures Program, CIAT. The authors would like to thank P. Argel, E. Pizarro, G. Keller-Grein, D. Thomas, R. Schultze-Kraft, B. Grof, and J. E. Ferguson for their contributions to this work.

Table 1. Major screening sites.

Ecosystem	Sites and collaborators
Llanos	CNI Carimagua (Instituto Colombiano Agropecuario)
Cerrados	CPAC (EMBRAPA)
Humid tropics	Pucallpa (IVITA, INIAA) San Isidro, Costa Rica (COOPEAGRI, Ministerio de Agricultura) Guápiles, Costa Rica (Ministerio de Agricultura)
Subhumid tropics	Atenas, Costa Rica (Escuela Centroamericana de Ganadería)

The important environmental attributes of the TPP's major screening sites are listed in Table 2. Altitude of the sites ranges from 200 to 1000 m.a.s.l., average annual precipitation varies from approximately 1600 to over 4000 mm, and the number of dry months ranges from zero to six.

Germplasm evaluation has been conducted by the TPP at Carimagua since 1972, while three sites in Central America have been developed only since 1988. Large volumes of germplasm in Category II (see Table 3 for definition of germplasm evaluation categories) have entered the evaluation process between 1986 and 1991. More than 1000 grasses and more than 1000 herbaceous legume accessions have entered the screening process. Many have been screened at more than one site. A small but growing number of accessions of woody shrub or tree legume species are now being evaluated (Table 4).

In Tables 5-8, promising species are listed by ecosystem. The large number of commercial materials for the Llanos ecosystem is a reflection primarily of the longer history of pasture plant germplasm evaluation in this environment. An additional large number of species are at earlier stages of the evaluation process. These include several promising woody species such as *Desmodium velutinum* and *Flemingia macrophylla.*

For the well-drained isothermic savannas (Cerrados), there are fewer commercial cultivars, reflecting in part the more recent initiation of pasture plant germplasm evaluation in this ecosystem, and in part simply the more difficult environmental conditions—longer dry season, lower dry-season temperatures, and greater biotic stresses.

Table 2. Principal environmental characteristics of the TPP's major screening sites.

Characteristic	Carimagua	CPAC	Atenas	Pucallpa	San Isidro	Guápiles
Ecosystem	Isohyperthermic savanna	Isothermic savanna	Subhumid tropics	Tropical forest	Tropical forest	Tropical forest
M.a.s.l.	200	1000	200	250	700	250
Temperature (°C)	26.5	24.0	23.7	26.4	22.8	24.6
Precipitation (mm)	2240	1578	1600	2048	2950	4260
No. dry months	5	6	5.5	2	3	0
Soil	Oxisol	Oxisol	Inceptisol	Ultisol	Ultisol	Inceptisol

Table 3. Evaluation categories of promising germplasm.

Category	Type of evaluation
I	Introduction garden
II	Small-plot monospecific clipping trial
III	Small-plot grazing in association (grass/legume)
IV	Animal performance trial
V	Pre-release
VI	Released cultivar

Table 4. Germplasm evaluation at major screening sites of CIAT's TPP, 1986-1991, according to number of accessions.

Site	Year evaluation initiated	Grasses	Legumes	
			Herbaceous	Shrubby
Carimagua	1972	1028	1018	285
CPAC	1978	398	1104	141
Pucallpa	1986	275	644	148
Costa Rica*	1988	430	427	208

* Three sites

Table 5. Promising species for the well-drained isohyperthermic savannas (Carimagua, Colombia).

Category	Grasses	Legumes
III	*Panicum maximum* (5)	*Desmodium velutinum* (1)
	Brachiaria brizantha (5)	*D. strigillosum* (1)
		Stylosanthes guianensis var. *pauciflora* (3)
		Dioclea guianensis (1)
IV	*B. brizantha* (1)	*Flemingia macrophylla* (1)
	B. humidicola (1)	*Desmodium ovalifolium* (1)
		Centrosema acutifolium (1)
V		*Arachis pintoi* (1)
		C. brasilianum (1)
VI	*B. decumbens* cv. Basilisk	*S. capitata* cv. Capica
	B. dictyoneura cv. Llanero	
	B. brizantha cv. La Libertad	*Pueraria phaseoloides* cv. "Common"
	B. humidicola cv. "Common"	
	Andropogon gayanus cv. Carimagua 1	

Table 6. Promising species for the well-drained isothermic savannas (Cerrados).

Category	Grasses	Legumes
III	*Paspalum plicatulum* (2)	*Centrosema* hybrids (4)
	Brachiaria dictyoneura (1)	*Stylosanthes guianensis* var. *vulgaris* (4)
IV		*C. acutifolium* (1)
V	*Panicum maximum* (1)	*C. brasilianum* (1)
		S. capitata (1)
		S. macrocephala (1)
		S. guianensis var. *pauciflora* (1)
VI	*Andropogon gayanus* cv. Planaltina	*Calopogonium mucunoides* cv. "Common"
	Brachiaria brizantha cv. Marandú	
	B. decumbens cv. Basilisk	

Table 7. Promising species for the humid tropics.

Category	Grasses	Legumes
III	*Brachiaria brizantha* (3)	*Arachis pintoi* (1)
	B. humidicola (2)	*Centrosema acutifolium* (2)
	B. jubata (2)	*C. pubescens* (2)
	Panicum maximum	*Pueraria phaseoloides* (2)
		Desmodium ovalifolium (1)
		Cratylia argentea (1)
		Desmodium velutinum (1)
IV		*C. macrocarpum* (mixture "Ucayali")
V	*B. dictyoneura*	*Arachis pintoi* (1)
		P. phaseoloides (1)
		C. macrocarpum (1)
VI	*B. decumbens* cv. Basilisk	*D. ovalifolium* cv. Itabela
	Andropogon gayanus cv. San Martín	*Stylosanthes guianensis* var. *vulgaris* cv. Pucallpa
	B. brizantha cv. Marandú	*P. phaseoloides* cv. "Common"
	B. humidicola cv. "Common"	*C. pubescens* cv. "Common"

Table 8. Promising species for the subhumid tropics (Atenas, Costa Rica).

Category	Grasses	Legumes
III	*Panicum maximum* (4)	*Stylosanthes guianensis* var. *vulgaris* (2)
	Brachiaria decumbens (2)	*Centrosema brasilianum* (1)
		C. macrocarpum (2)
		Leucaena leucocephala (1)
		Cratylia argentea (1)
		Flemingia macrophylla (1)
IV	*Andropogon gayanus* (1)	*S. guianensis* var. *vulgaris* (1)
	B. brizantha (2)	
	B. dictyoneura (1)	
	B. humidicola (1)	
V		
VI	*B. decumbens* cv. Basilisk	

In spite of a relatively short period of germplasm evaluation in the humid tropics, a large number of promising species have already been identified. Lower drought stress and somewhat more fertile soils permit a wider range of species to perform well in this environment.

For the subhumid tropical forest ecosystem, only *B. decumbens* is commercial. However, a large number of promising species have been identified, and these are moving through the germplasm evaluation process.

Promising pasture plant species are listed in Tables 9 and 10. It will be noted that, in general, the grass species are more broadly adapted than the legumes. Of eight promising grass species, four are promising across ecosystems. In contrast, none of the 17 legumes listed in Table 10 is considered promising across all four major ecosystems.

Commercial releases between 1986 and 1991 are listed by species and country of release (Table 11). A number of materials are expected to be released formally in 1992 (Table 12).

We shall attempt to briefly summarize the positive attributes of nine promising pasture plant species and indicate the salient factors which limit or constrain the range of adaptation of each species.

A. gayanus's (Table 13) utility in the Colombian-Venezuelan Llanos is commonly limited by the species' high susceptibility to leaf-cutter ants of the genera *Atta* and *Acromyrmex*. Ant populations increase rapidly in *A. gayanus* pastures, while they tend to decrease in pastures of the resistant *B. humidicola* (Figure 1). Likewise, at low-latitude sites (generally in the Colombian Llanos), *A. gayanus* flowering is poorly synchronized and consequently quality of seed produced at low-latitude sites is poorer than that of seed produced at higher latitude sites (Table 14). *A. gayanus* introduced by the TPP to tropical America originated at Shika, Nigeria, at approximately 11° N lat., and apparently requires a greater range in photoperiod over the year than is perceived at very low latitude sites in the Colombian Llanos to induce uniform, abundant flowering.

A very promising species, *Arachis pintoi* (Table 15), is dealt with in another article in this volume (Argel and Pizarro, Chapter 5). Briefly, in spite of several positive attributes, *A. pintoi* exhibits poor leaf retention under prolonged drought conditions.

A number of *Centrosema* spp. have been identified by the TPP as showing promise on acid soils. *C. acutifolium* (Table 16), however, does not persist well under grazing on heavy-textured soils, and has poor seed yield at many sites because of late flowering and disease susceptibility. Data from a grazed pasture on a heavy-textured soil at Carimagua (Figure 2) show *C. acutifolium* disappearing from the pasture while *A. pintoi*, in spite of wide seasonal variation, is maintained under grazing.

Table 9. Promising grass species by ecosystem.

Grasses	Ecosystem			
	Llanos	Cerrados	Humid tropics	Subhumid tropics
Andropogon gayanus	+/-[a]	+	+	+
Brachiaria brizantha	+	+	+	+
Brachiaria decumbens	+	+	+	+
Brachiaria dictyoneura	+	-	+	+
Brachiaria humidicola	+	-	+	+
Brachiaria jubata	-	-	+	-
Panicum maximum	+	+	+	+
Paspalum plicatulum	?	+	?	?

a. + = adapted to the ecosystem; - = not adapted to the ecosystem.

Table 10. Promising legume species by ecosystem.

Legumes	Ecosystem			
	Llanos	Cerrados	Humid tropics	Subhumid tropics
Arachis pintoi	+[a]	-	+	-
Centrosema acutifolium	+	+	+	-
Centrosema brasilianum	+	+	-	+
Centrosema macrocarpum	-	-	+	+
Centrosema pubescens	-	-	+	-
Calopogonium mucunoides	-	+	-	-
Cratylia argentea	+	-	+	+
Desmodium ovalifolium	+	-	+	-
Desmodium strigillosum	+	-	-	-
Desmodium velutinum	+	-	+	-
Dioclea guianensis	+	-	-	-
Flemingia macrophylla	+	-	+	+
Leucaena leucocephala	-	-	-	+
Pueraria phaseoloides	+	-	+	-
Stylosanthes capitata	+	+	-	-
Stylosanthes guianensis var. *pauciflora*	+	+	-	-
Stylosanthes guianensis var. *vulgaris*	-	+	+	+

a. + = adapted to the ecosystem; - = not adapted to the ecosystem.

Table 11. Forage grasses and legumes evaluated in RIEPT that have been released in different countries (1986-1991).

Species	CIAT No.	Cultivar	Year	Country
Grasses				
Andropogon gayanus	621	Llanero	1986	Mexico
		Andropogon	1988	Cuba
		Veranero	1989	Costa Rica
		Otoñero	1989	Honduras
		Gamba	1989	Nicaragua
Brachiaria brizantha	26646	La Libertad	1987	Colombia
Brachiaria brizantha	6780	Brizantha	1987	Cuba
		Gigante	1989	Venezuela
		Insurgente	1989	Mexico
Brachiaria decumbens	606	Brachiaria	1986-87	Cuba
		Chontalpo	1989	Mexico
		Señal	1989	Panama
		Pasto Peludo	1991	Costa Rica
Brachiaria dictyoneura	6133	Llanero	1987	Colombia
Brachiaria humidicola	679	Aguja	1989	Venezuela
		Humidicola	1989	Panama
		Chetumal	1990	Mexico
		Humidicola	1990	Colombia
Panicum maximum		Vencedor	1990	Brazil
		Tanzania-1	1990	Brazil
Legumes				
Centrosema acutifolium	5277	Vichada	1987	Colombia
Stylosanthes guianensis	184	Zhuhuacao	1987	China
Desmodium ovalifolium	350	Itabela	1989	Brazil
Pueraria phaseoloides	9900	Jarocha	1989	Mexico
Clitoria ternatea		Thehuana	1988	Mexico
		Clitoria	1990	Honduras
Centrosema pubescens	438	Centrosema	1990	Honduras
Arachis pintoi	17434	Amarillo	1990	Australia

Table 12. Forage grasses and legumes evaluated in RIEPT that will be released in the near future by different countries.

Species	CIAT No.	Cultivar	Year	Country
Grasses				
Brachiaria dictyoneura	6133	—	1992	Panama
		—	1992	Venezuela
			1992	Costa Rica
			1992	Mexico
			1992	Peru
Legumes				
Arachis pintoi	17434	Maní forrajero	1992	Colombia
Centrosema brasilianum	5234	—	1992	Venezuela
Centrosema macrocarpum	5713	—	1992	Venezuela
Leucaena leucocephala	17492	—	1992	Venezuela
Stylosanthes capitata	10280	—	1992	Venezuela

Table 13. Positive attributes and ecosystem-specific constraints of *Andropogon gayanus*.

Positive attributes	**Ecosystem-specific constraints**
Spittlebug resistance	Llanos
Deep rooting	Susceptibility to leaf-cutter ants (*Atta* & *Acromyrmex*)
Drought tolerance	At low latitudes
Recovers quickly after drought	Asynchronous flowering
High dry-matter yield	Poor seed quality
Excellent edaphic adaptation to low-fertility soils	
Responds to higher fertility	

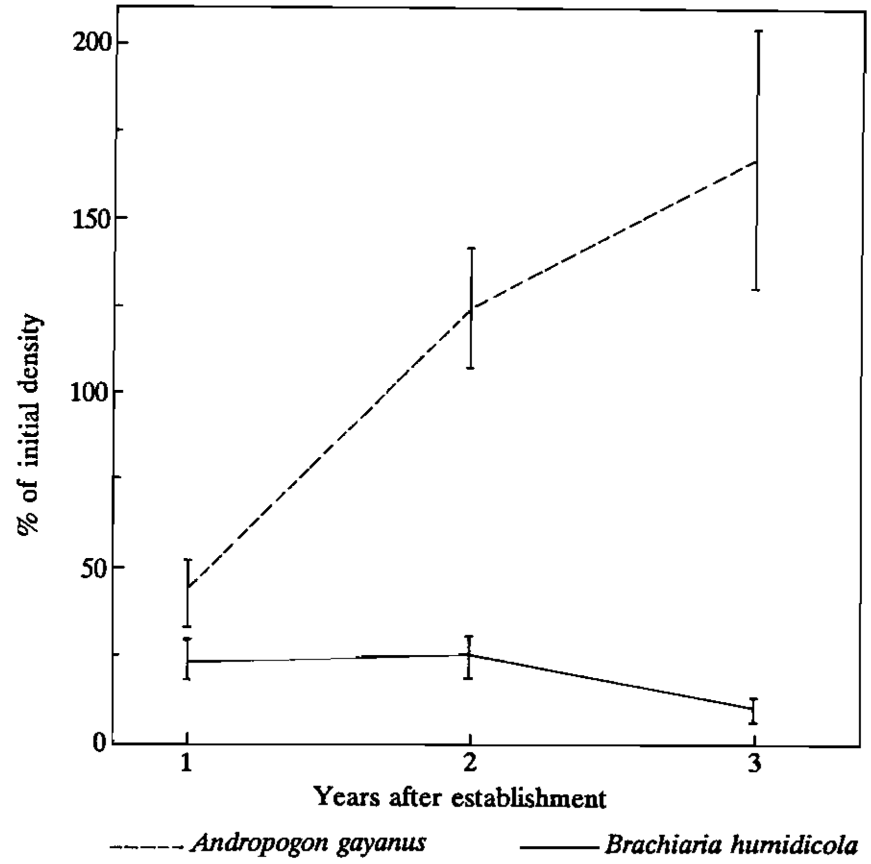


Figure 1. Colonization of swards (30 x 60 m) of *A. gayanus* and *B. humidicola* by the leaf-cutter *Acromyrmex landolti* yearly since establishment at Carimagua. Bars are standard deviation, N = 6.

Table 14. Seed size and germination in six seed lots of *Andropogon gayanus* from locations in Colombia and Brazil.

Quality component	Means	
	Colombia (3°N lat.)	Brazil (15°S lat.)
Unit weight (mg/100)		
Caryopses	85	105
Full spikelets	295	317
Germination (%)	27	68

Table 15. Positive attributes and ecosystem-specific constraints of *Arachis pintoi*.

Positive attributes	**Ecosystem-specific constraints**
Stoloniferous growth habit	Cerrados and subhumid tropics
Persistence under grazing	Poor leaf retention under prolonged drought
Excellent forage quality	

Table 16. Positive attributes and ecosystem-specific constraints of *Centrosema acutifolium*.

Positive attributes	**Ecosystem-specific constraints**
Drought tolerance	Poor persistence on heavy-textured soils
Good adaptation to low-fertility soils	Llanos
High nutritive quality	Disease susceptibility

Centrosema brasilianum (Table 17) has excellent adaptation to low-fertility soils and high seed yields. However, in wetter environments such as the Colombian Llanos, susceptibility to *Rhizoctonia* foliar blight is a serious limitation on performance. Table 18 shows the greater disease rating recorded on *C. brasilianum* at Carimagua compared with accessions of two other *Centrosema* species.

A third *Centrosema* species, *C. macrocarpum* (Table 19), has excellent forage yield, drought tolerance, and nutritive quality. However, its adaptation to very low fertility soils is poorer than that of other promising pasture plant species. Forage yield doubled in response to higher fertilizer or fertilizer and liming treatments on a low-fertility soil at Carimagua (Table 20), while yields of *S. capitata* or *D. ovalifolium*, two highly adapted species, were not affected, or actually declined at higher fertilizer levels. Likewise, forage yield was approximately three times greater for *C. macrocarpum* CIAT 5713 on a fertile soil in the Valle del Cauca (ICA, Palmira) as compared with a low-fertility soil in the Colombian Llanos (El Capricho) (Table 21).

As we have seen, *D. ovalifolium* (Table 22) is well adapted to low-fertility soils. It is a vigorous legume with a strongly stoloniferous growth habit conferring excellent persistence under grazing. However, as with *A. pintoi*, leaf retention during prolonged periods of water stress is poor. This is reflected in low dry-season forage yields of *D. ovalifolium* at sites with long (5-6 months) dry seasons compared with forage yields at sites with less prolonged (2 months) dry seasons (Table 23).

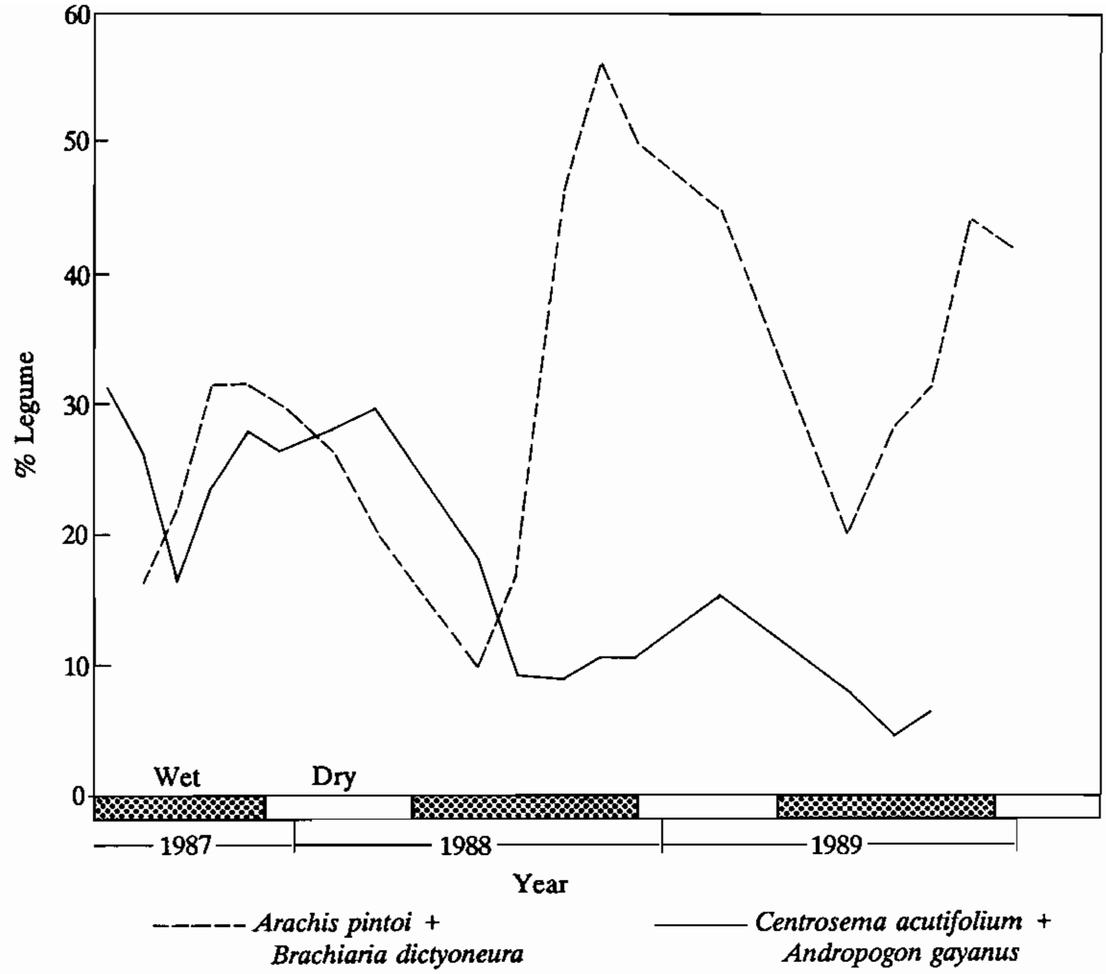


Figure 2. Change in pasture composition of two grass-legume associations on a heavy soil at Carimagua.

Table 17. Positive attributes and ecosystem-specific constraints of *Centrosema brasilianum*.

Positive attributes	**Ecosystem-specific constraints**
Excellent drought avoidance	Susceptibility to *Rhizoctonia* in wetter environments
Excellent edaphic adaptation to low-fertility soils	
High seed yield	

Table 18. *Rhizoctonia* foliar blight reaction of three *Centrosema* species at Carimagua.

Species	Disease score[a]
C. brasilianum	3.2 a
C. acutifolium	2.8 b
C. macrocarpum	2.8 b

a. Visual rating on scale of 1 to 5, where 1 = healthy leaves and 5 = dead leaves. Numbers followed by the same letter do not differ significantly ($\alpha = 0.05$).

Table 19. Positive attributes and ecosystem-specific constraints of *Centrosema macrocarpum*.

Positive attributes	**Ecosystem-specific constraints**
High forage yield Drought tolerance Seedling vigor High nutritive quality	Poor adaptation to very low fertility soils

Table 20. Yield response (kg/ha)[a] to fertilizer level of three tropical forage legume species.

Species	Fertilizer level[b]		
	Low	High	High + Lime
C. macrocarpum	915	1299	1856
S. capitata	1695	1298	1594
D. ovalifolium	5030	4238	4226

a. Accumulated yield over five harvests at two-month intervals.

b. Low: 20 P, 20 K, 12 S, 12 Mg, 0 N, 0 Zn, 0 lime; high: 50 P, 100 K, 20 S, 12 Mg, 80 N, 5 Zn, 300 lime (Ca + Mg); high + lime, same as high but with 2000 lime.

Table 21. Dry-matter forage yield[a] of *Centrosema macrocarpum* CIAT 5713 on soil of contrasting natural fertility.

Location	Season Min. precipitation	 Max. precipitation	Mean
	(kg/ha)		
El Capricho, Col.	223	1115	669
ICA, Palmira, Col.	1907	2414	2161

a. 12-week regrowth.

Table 22. Positive attributes and ecosystem-specific constraints of *Desmodium ovalifolium*.

Positive attributes	**Ecosystem-specific constraints**
Excellent edaphic adaptation to low-fertility soils	Cerrados and subhumid tropics
Good seed yield	Poor leaf retention under prolonged drought
Stoloniferous growth habit	
Persistence under grazing	
Excellent ground coverage	

Table 23. Dry-season forage yield of *Desmodium ovalifolium* at sites with contrasting dry-season duration.

Location	Duration of dry season (months)	Forage yield (kg/ha/12 weeks)
Chetumal, Mexico	6	1394
Lomabonita, Mexico	6	20
Carimagua, Colombia	5	800
Mean		738
Leticia, Colombia	2	6085
Guachi, Venezuela	2	1456
Tibú, Colombia	2	3393
Mean		3636

Stylosanthes capitata (Table 24) is another legume with excellent adaptation to very low fertility acid soils, particularly light-textured soils. It has high seed yield, easy establishment, and good forage quality. However, it tends to persist poorly on heavier textured soils relative to other species such as *S. guianensis*. In a glasshouse experiment, dry-matter yield rankings between *S. capitata* and *S. guianensis* were exactly reversed on a light-textured soil (17% clay content) as compared with a heavy-textured soil (37% clay content) (Table 25). Persistence under grazing was related to soil texture (sand content) (Figure 3).

Stylosanthes guianensis var. *vulgaris* (Table 26) is a productive, well-adapted species, with good dry-season performance. However, in the Llanos ecosystem, its use is severely constrained by high susceptibility to anthracnose disease (caused by *Colletotrichum gloeosporioides*). Among a collection of accessions of *S. guianensis* var. *vulgaris* or *S. guianensis* var. *pauciflora* tested at Carimagua, over 90% of the var. *vulgaris* accessions were classed as susceptible to anthracnose while 60% of the var. *pauciflora* accessions were found to be resistant (Table 27).

Stylosanthes guianensis var. *pauciflora* (Table 28) is a promising replacement for *S. guianensis* var. *vulgaris* in environments with heavy anthracnose pressure. This botanical variety of *S. guianensis* has many of the same positive attributes of *S. guianensis* var. *vulgaris*, with outstanding green leaf retention during prolonged dry periods. However, in locations with lower disease pressure, forage dry matter and seed yield of *S. guianensis* var. *pauciflora* are inferior to those of *S. guianensis* var. *vulgaris* (Table 29).

The important point illustrated by these examples is that while a particular species has been selected for its outstanding performance in a specific ecosystem with a particular set of environmental conditions, for many species performance is limited in other ecosystems due to their special, different environmental conditions. Hence, rather than one or a few germplasm selections, the TPP seeks to provide a number of options, each particularly suited to one set of environmental conditions.

Promising forage germplasm options can be offered for a series of environmental scenarios, as exemplified by Tables 30-32, where we list a number of promising grass or legume options for crop-pasture rotations in three major ecosystems.

Now, it would be premature to infer from the foregoing that the job of germplasm acquisition, evaluation, and selection is finished. Even for the herbaceous species for lowland ecosystems, more germplasm is needed. For example, a glaring deficiency is our very small collection of *Arachis pintoi*—only eight accessions. However, in addition to herbaceous species for lowland ecosystems, the Tropical Pastures Program, as it evolves into the Tropical Forages Program, will face an expanded germplasm mandate. The new Program is assuming responsibility for germplasm distribution and initial evaluation in West/Central Africa, through WECAFNET, and in Southeast Asia, through SEAFRAD. Furthermore, the

Table 24. Positive attributes and ecosystem-specific constraints of *Stylosanthes capitata*.

Positive attributes

- Excellent adaptation to very acid, low-fertility, light-textured soils
- High seed yield
- Good forage quality
- Seedling vigor and ease of establishment

Ecosystem-specific constraints

- Low yield and poor persistence on heavier textured and higher fertility soils relative to other species

Table 25. Shoot dry weight (g/m² soil surface) of two species of *Stylosanthes* on a heavy- or a light-textured soil.

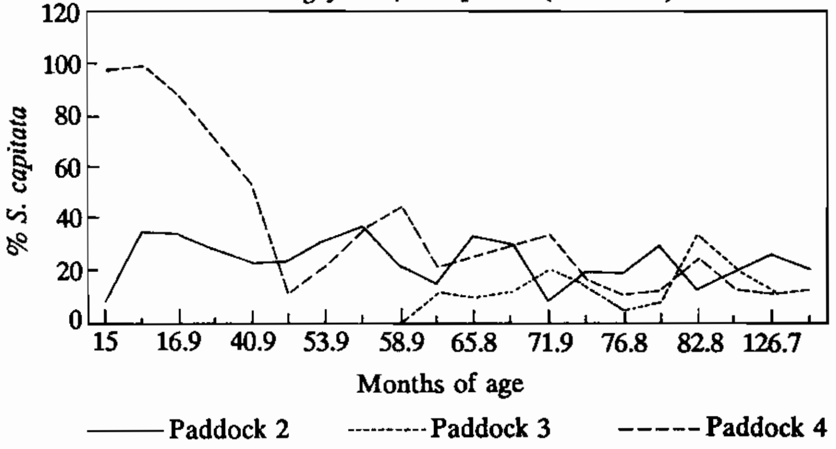
Species	Soil texture	
	Light[a]	Heavy[b]
S. capitata	143.3	126.0
S. guianensis	128.7	141.7

a. 17% clay content.
b. 37% clay content.

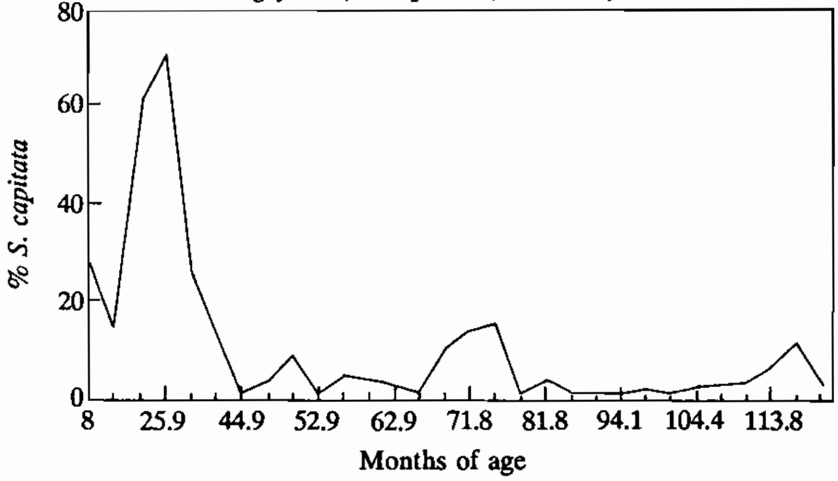
Table 26. Positive attributes and ecosystem-specific constraints of *Stylosanthes guianensis* var. *vulgaris*.

Positive attributes	**Ecosystem-specific constraints**
High forage yield	Llanos
High seed yield	Anthracnose susceptibility
Excellent edaphic adaptation to low-fertility soils	
Ease of establishment	
Seedling vigor	
Leaf retention during drought	

El Viento - *A. gayanus/S. capitata* (38% sand)



Leonas-*A. gayanus/S. capitata* (17% sand)



El Paraíso - *A. gayanus/S. capitata* (28% sand)

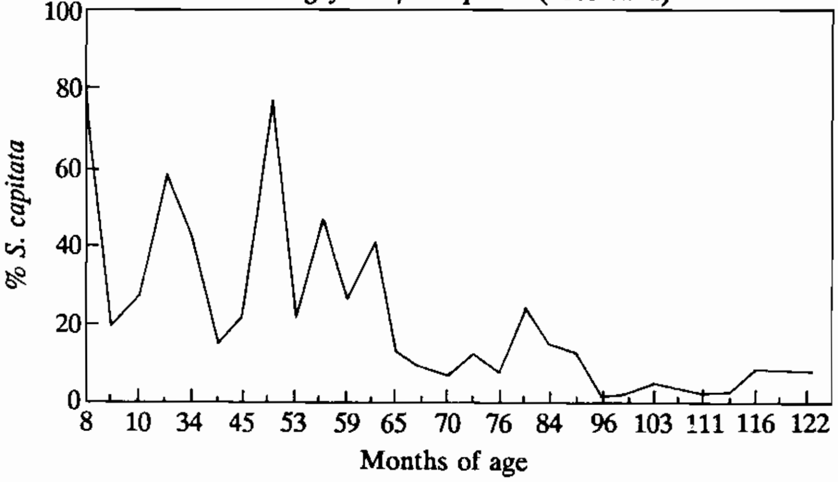


Figure 3. Persistence of *Stylosanthes capitata* in grazed pastures as related to soil sand content.

Table 27. Proportions of accessions of two botanical varieties of *Stylosanthes guianensis* resistant or susceptible to anthracnose at Carimagua.

Botanical variety	Resistant (%)	Susceptible (%)
var. *vulgaris*	8.4	91.6
var. *pauciflora*	60.6	39.4

Table 28. Positive attributes and ecosystem-specific constraints of *Stylosanthes guianensis* var. *pauciflora*.

Positive attributes	**Ecosystem-specific constraints**
Anthracnose resistance Excellent edaphic adaptation to low-fertility soils Ease of establishment Seedling vigor Leaf retention during drought	Lower forage yield compared with var. *vulgaris* where anthracnose is not limiting

Table 29. Forage yield (tons/ha) of promising accessions of two botanical varieties of *Stylosanthes guianensis* under low anthracnose pressure.

Botanical variety[a]	Guápiles	Atenas	Mean
var. *vulgaris*	30.8 a	21.6 a	26.2 a
var. *pauciflora*	11.8 b	11.3 b	11.5 b

a. Values at individual sites are means of two accessions for each botanical variety.

Table 30. Germplasm options for crop-pasture rotations in the Llanos.

Grasses	**Legumes**
Andropogon gayanus	*Centrosema acutifolium*
Where leaf-cutters are not limiting	Light-textured soils
	Centrosema macrocarpum
Responds to higher fertility	Better soils
Spittlebug resistant	*Stylosanthes capitata*
Panicum maximum	Low-fertility, light-textured soils
Responds to higher fertility	*Arachis pintoi*
Spittlebug resistant	Heavy-textured soils

Table 31. Germplasm options for crop-pasture rotations for reclamation of degraded pastures in forest margins.

Grasses	**Legumes**
Brachiaria dictyoneura	*Stylosanthes guianensis*
Brachiaria decumbens	Adaptation to low-fertility soils
Brachiaria brizantha	Ease of establishment
Spittlebug resistant	Seedling vigor
All are highly competitive against weeds, resistant to trampling	*Desmodium ovalifolium*
	Very low fertility soils
	Excellent ground coverage
	Pueraria phaseoloides (kudzu)
	Competes with weeds
	Rapid growth rate
	Rapid establishment

Table 32. Germplasm options for crop-pasture rotations for the Andean hillsides.

Grasses	**Legumes**
Brachiaria decumbens	*Desmodium ovalifolium*
Rapid ground cover	Very low fertility soils
Dense sward	Excellent ground coverage
Brachiaria humidicola	*Arachis pintoi*
Dense sward	Higher fertility soils
Stoloniferous	Highly persistent
	Dense sward
	Excellent ground cover, e.g., under coffee
	Centrosema macrocarpum
	Better, not highly degraded soils

Program's ecosystem mandate will expand to include mid-altitude Andean hillsides to 1800 m.a.s.l. The Program will place increasing emphasis on multipurpose woody tree and shrub legumes, to find persistent, perennial species fitting into sustainable, tropical agricultural production systems. All these new initiatives imply the need for an even broader germplasm portfolio in the future.

In summary, the Program's aim has been, and will increasingly continue to be, to find not one or a few promising species, but rather to assemble a diverse portfolio of germplasm options, including species adapted to acid, infertile soils and exhibiting particular adaptation to fit specific environmental or production system niches within the Program's broad ecosystem mandate. The fundamental strategy adopted to achieve this end is decentralized germplasm evaluation and selection at major screening sites representing the predominant ecosystems comprising the target environment, and regional trials conducted by collaborating national research institutions, members of the RIEPT.

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CHAPTER 3

METHODOLOGICAL CHALLENGES IN PASTURE RESEARCH

C. E. Lascano and J. M. Spain*

Introduction

The special nature of pasture research needs to be recognized, particularly when compared with research on short-cycle crops. Research in tropical pastures deals in most cases with perennial plants, and thus is of a long-term nature. Pasture researchers also deal with many genera and species of which there are large numbers of accessions, in many cases with no established knowledge base.

The Tropical Pastures Program (TPP) has emphasized a pasture technology based on grass-legume associations, which poses further complexity to researchers, since tropical grasses and legumes have different photosynthetic pathways that result in inherently different growth rates. In addition, grasses and legumes compete with each other for nutrients, water, and light when they are in association.

Pastures are intermediate products of no intrinsic value except when converted to the final animal product such as beef, milk, or wool. Therefore, in the research sequence, pastures must be evaluated with grazing animals to assess animal performance under different management options. In the process of pasture evaluation, the researcher must recognize that grazing animals select different plant species and plant parts and thus affect growth and stability of the planted species.

Finally, pastures have to be evaluated with a production systems perspective, which in some cases implies large-scale grazing experiments aimed at assessing this effect on herd performance.

The complexity of the grazed pasture environment has implications for research methodology as discussed in this chapter under the following topics: (1) methodologies for germplasm and pastures evaluation for researchers in RIEPT; (2) advanced techniques for forage germplasm evaluation and enhancement developed by CIAT's Biotechnology Research Unit; and (3) methodological challenges facing the TPP in evaluation of forage germplasm and pastures.

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* Animal scientist and soil scientist, respectively, Tropical Pastures Program, CIAT. The authors would like to thank W. Roca and J. W. Miles for their contributions to this work.

Methodologies to Support RIEPT

Pasture research in tropical areas of Latin America was characterized by large introduction gardens, with very little flow of germplasm to advanced stages of pasture evaluation under grazing. In many cases, this was attributed to the lack of methods and strategies for pasture research. As a consequence, one of the TPP's objectives has been to backstop national institutions within RIEPT through the adjustment of research methodologies which are extended to national institutions, in the form of manuals together with training of pasture researchers.

In a series of meetings of RIEPT's Technical Advisory Committee, manuals of methodology were produced dealing with:

1. Collection, preservation, and characterization of tropical forage germplasm resources.

2. Agronomic evaluation to determine germplasm adaptation to edaphic, climatic, and biotic factors, and to determine seasonal dry matter yields (RTA and RTB).

3. Small-plot grazing evaluation to determine the effect of management on productivity and persistence of selected grass-legume combinations (RTC).

4. Grazing experiments to evaluate potential animal production and management responses of selected grass and grass-legume pastures (RTD).

5. Support experimentation on:

    Adjustment of fertilizer requirements
    Rhizobiology
    Pest and disease reaction
    Seed multiplication

Undoubtedly, the methodologies produced for RIEPT researchers have contributed to the evolution we have seen in the type and number of regional trials conducted in tropical areas with acid soils. In a five-year period, the number of grazing experiments has doubled and the number of support trials has more than tripled (Table 1).

Advanced Research Methodologies

With the creation of CIAT's Biotechnology Research Unit (BRU), a number of collaborative projects with the TPP have developed or refined very useful techniques for:

Table 1. Evolution of regional trials conducted in RIEPT, 1986-1991.

Type of trial	Year 1986	 1988 (no. of trials)	 1991	Increment (%)
Agronomic	138	218	274	99
Grazing	40	71	84	110
Support*	16	63	75	369

* Fertilizer adjustment, inoculation, seed multiplication.

1. Identifying genetic variability through fingerprinting techniques using isozymes and seed protein electrophoresis. Now, the BRU and TPP have begun work towards the construction of a molecular genetic map of *Brachiaria*.

2. Handling germplasm accessions through an in vitro micropropagation technique, which was used to import *Brachiaria* germplasm from Africa and to distribute this germplasm to major screening sites of the TPP in Latin America.

3. Plant regeneration for *Stylosanthes guianensis*, *S. capitata*, and *S. macrocephala*. Very recently, plant regeneration of *B. humidicola* and *B. ruziziensis* has also been achieved by the BRU.

The regeneration of *S. guianensis* has allowed the BRU to produce:

1. **Somaclonal variation** useful for studies on mechanisms of plant adaptation to acid soils. Somaclonal lines of *S. guianensis* tested in the field and glasshouse have shown through various generations:

   Root and shoot biomass production superior to that of the control.

   Ploidy and morphological variants: bushy plant habit, chlorotic foliage, 1-2 leaflet leaves, and several tetraploid lines.

2. **Genetically transformed plants of *S. guianensis*.** The first genetic transformation of a plant at CIAT has been achieved by the use of several markers, including a gene for herbicide resistance. DNA analysis of transformed plants provided

evidence of physical transfer of DNA. In addition, a test of rooted cuttings of transgenic plants showed tolerance to herbicide applied at two to four times the recommended commercial dose.

Examples of Methodological Challenges in Germplasm and Pasture Evaluation

Different sections of the TPP and support units, principally the Data Services Unit in its two areas of responsibility, biometrics and research data bases, have contributed to or have made progress in the development of methodologies relevant to pasture research. In order to illustrate the methodological challenges facing the TPP, we will present some examples for germplasm and pasture evaluation with grazing animals.

Germplasm evaluation: Screening large numbers of accessions

The traditional methodology for evaluating forage germplasm in early stages of selection is to plant the accessions in monospecific plots with clean-cultivated borders. Under these conditions, forage yield and reaction to pests and diseases are assessed in an artificial environment, very different from that found in a grazed pasture. In a pasture, the presence of associated species and grazing subjects the germplasm to inter- and intraspecific competition, selective defoliation, and trampling, in addition to disease and insect pressure and edaphic and climatic stresses.

An alternative methodology is being tested for the concurrent evaluation and natural selection of forage germplasm under grazing. The objective of the methodology is to allow the natural selection under grazing of heterogeneous populations derived from mixtures of numerous accessions of a promising species for:

1. Disease and insect tolerance
2. Plant vigor
3. Competitive ability
4. Seed production
5. Adaptation to the soils and climate of a specific ecosystem

We anticipate that the natural-selection methodology will contribute a broad genetic base to key legume species released for acid soils. However, we recognize that the potential to obtain a genetically dynamic population with the capacity to adapt to the biotic, physical, and management environment will depend on the following aspects of the species:

1. Mode of reproduction
2. Degree of outcrossing
3. Perenniality
4. Rate and success of seedling recruitment in stand maintenance

The proposed methodology includes two phases:

Phase 1: (1) Population formation. Seed of numerous accessions of a promising legume species is mixed. (2) Pasture formation. The resulting heterogeneous population of genotypes is sown with a common grass to form a pasture, which is then grazed with an appropriate system to favor grass-legume balance. (3) Seed harvesting. Grazing is suspended in the second year after planting, and each year thereafter, to permit flowering and seed production of the legume.

With each successive cycle, seed harvested should increasingly be of the genotypes best adapted to the selection environment.

Phase 2: Populations derived from phase 1 would then be compared in grazing trials with pure lines resulting from conventional screening to determine legume persistence and animal performance.

Natural selection projects. To test the hypotheses on which the proposed methodology of natural selection is based, three experiments are under way at different locations:

1. Natural selection of *Centrosema macrocarpum* in the piedmont of Colombia's Llanos

    292 accessions

    Sown in 1990 with *Brachiaria dictyoneura* cv. Llanero as a common grass and currently under grazing

2-3. Natural selection of *Centrosema brasilianum* in the savannas of Colombia (Carimagua) and Venezuela

    200 accessions

    Sown in 1990 with *Brachiaria dictyoneura* cv. Llanero as a common grass and currently being standardized

Germplasm evaluation: Screening wild species

In most cases, researchers in the TPP have to work with forage species, particularly legumes, about which very little is known. Consequently, it is important to define at an early stage the potential forage value of such species. The early assessment of forage value includes:

1. Acceptability to grazing animals
2. Potential nutritive value

To determine the relative acceptability of forage species, we conduct cafeteria-type trials under grazing. Initial studies indicated that short-term, prior exposure of the test animals to the individual forage species under study affected the magnitude of acceptability indices of the more palatable species, but not the overall ranking of species. Subsequent cafeteria trials have shown that accessions of some legumes such as *Rhynchosia reticulata*, *Flemingia macrophylla*, and *Phyllodium pulchellum* are very unpalatable, even to the point of being totally rejected by the animals and thus having limited forage value (Table 2).

Crude protein (CP) has been used traditionally to assess the nutritive value of forage species, since there is generally a good relation between CP in the diet and rumen ammonia necessary for bacterial protein synthesis. However, results obtained by the TPP show a poor correlation between rumen ammonia levels and CP in the diet of animals grazing pastures with legumes high in tannins, such as *Desmodium ovalifolium* (Figure 1). Subsequently, **in situ** studies have shown that the protein of certain legumes (e.g., *Calliandra grandiflora* and *Flemingia macrophylla*) is overprotected by tannin to the point of escaping degradation by rumen microorganisms (Figure 2).

Ammonia production in vitro has proven to be a good method to determine the potential contribution of forage legumes to rumen fermentable nitrogen (Figure 3). This method includes measurement of ammonia production with forage legumes incubated in vitro, together with a blank, for 1, 2, 4, and 6 hours. This simple method could be useful in evaluating herbaceous and shrubby legumes with variable levels and types of tannins.

Pasture evaluation: Animal selectivity

Animal selectivity is an important factor controlling the balance between grass and legume in a grazed pasture. Diet selection by grazing animals has commonly been measured by examining extrusa samples collected by esophageal-fistulated steers. Now, Australian researchers have proposed an alternative method to measure legume in the diet of grazing animals. The method uses the ratio of natural ^{13}C and ^{12}C isotopes of carbon in feed and resultant feces. Results are expressed as the difference ($\delta^{13}C$) in the ratio of the number of atoms of ^{13}C to the number of atoms of ^{12}C in a standard.

In collaboration with CSIRO in Australia, legume selectivity was measured in different pastures at Carimagua using two methods:

1. Stereoscope hit-point reading of the extrusa collected from esophageal-fistulated steers, which is the old standard method.

2. $\delta^{13}C$ in the feces of intact-resident animals.

Table 2. Relative acceptability of legumes in cafeteria-type trials under grazing, Quilichao, Colombia.

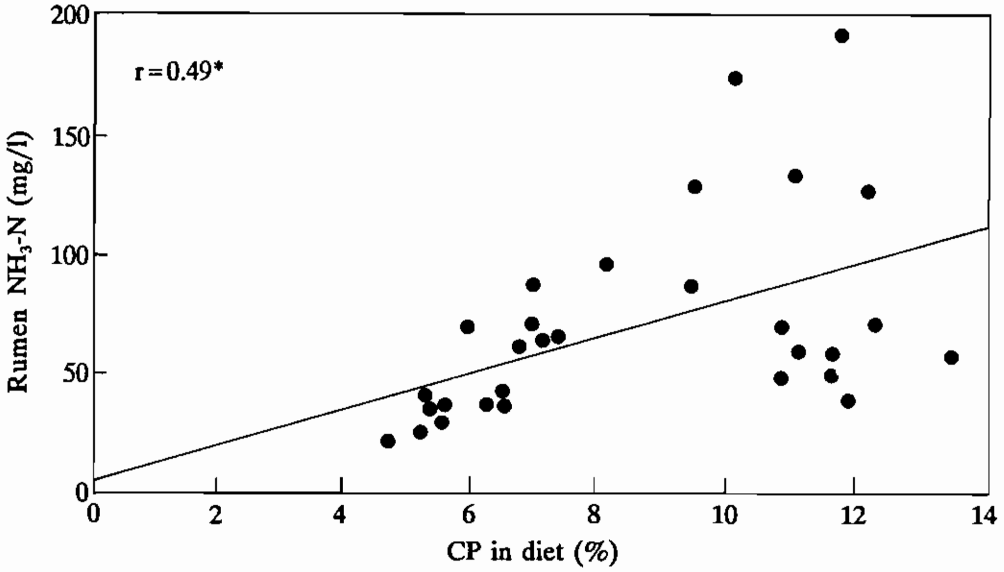
Legumes (CIAT no.)	Season (PI)[a] Dry	Rainy
Study A		
Centrosema macrocarpum (5065)	3.1 a*	2.3 a
Centrosema arenarium (5236)	0.6 b	1.0 b
Dioclea guianensis (9311)	0.4 b	0.6 b
Rhynchosia reticulata (8193)	0.1 c	0.1 c
Study B		
Centrosema acutifolium (5568)	3.0 a	3.5 a
Desmodium velutinum (13213 + 13215)	1.3 b	0.7 b
Stylosanthes viscosa (1353 + 1538)	0.5 c	0.7 b
Flemingia macrophylla (17403)	0.8 c	0.1 c
Study C		
Centrosema acutifolium (5277)	3.1 a	3.7 a
Desmodium ovalifolium (13289 + 13305)	0.8 b	0.9 b
Tadehagi triquetrum (13274 + 13276)	0.6 b	0.4 b,c
Phyllodium pulchellum (13248 + 13290)	0.3 b	0.1 c

a. PI = Preference Index (observed frequency of eating ÷ expected frequency of eating).

* Numbers in the same column followed by the same letter do not differ significantly ($P>0.05$).

The correlation between the percentage legume in the diet, measured with hit-point reading of extrusa and $\delta^{13}C$ in feces, was low (Table 3). The difference between methods could not be explained by errors in the hit-point reading of extrusa, because estimates with the hit-point method were highly correlated with $\delta^{13}C$ measurements in the same extrusa.

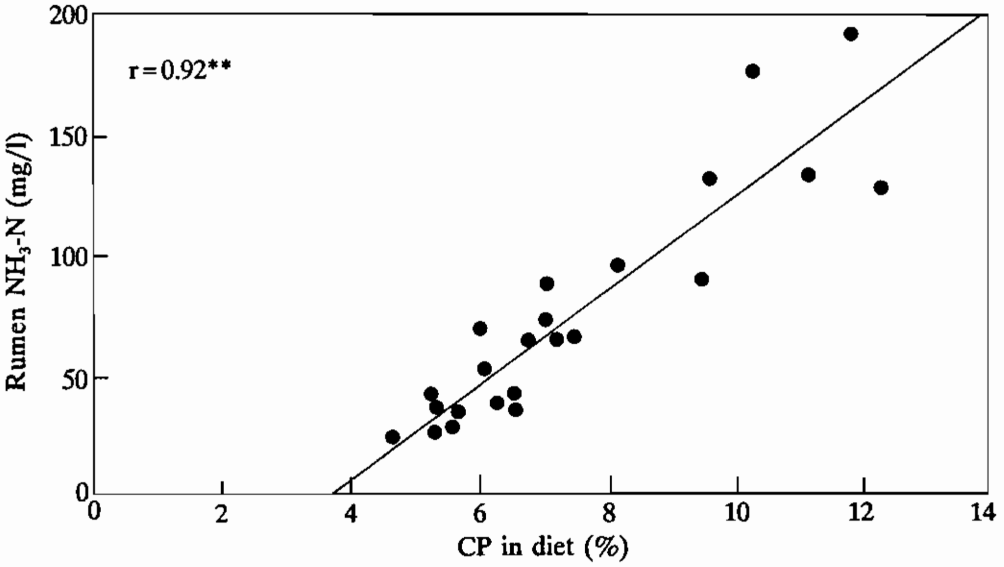
In another study at Carimagua, animal selectivity was measured in a pasture of *A. pintoi-B. dictyoneura* using esophageal-fistulated steers previously accustomed to the pasture and intact-resident steers. Results presented in Table 4 indicated:



*P<0.05

4 pastures

B.h.
B.h.-D.o.
B. dic.
B. dic.-A.p.



**P<0.01

3 pastures

B.h. *B. dic.* *B. dic.-A.p.*

Figure 1. Relationship between rumen ammonia and dietary crude protein. (*B.h.* = *Brachiaria humidicola*, *D.o.* = *Desmodium ovalifolium*, *B. dic.* = *Brachiaria dictyoneura*, *A.p.* = *Arachis pintoi*.)

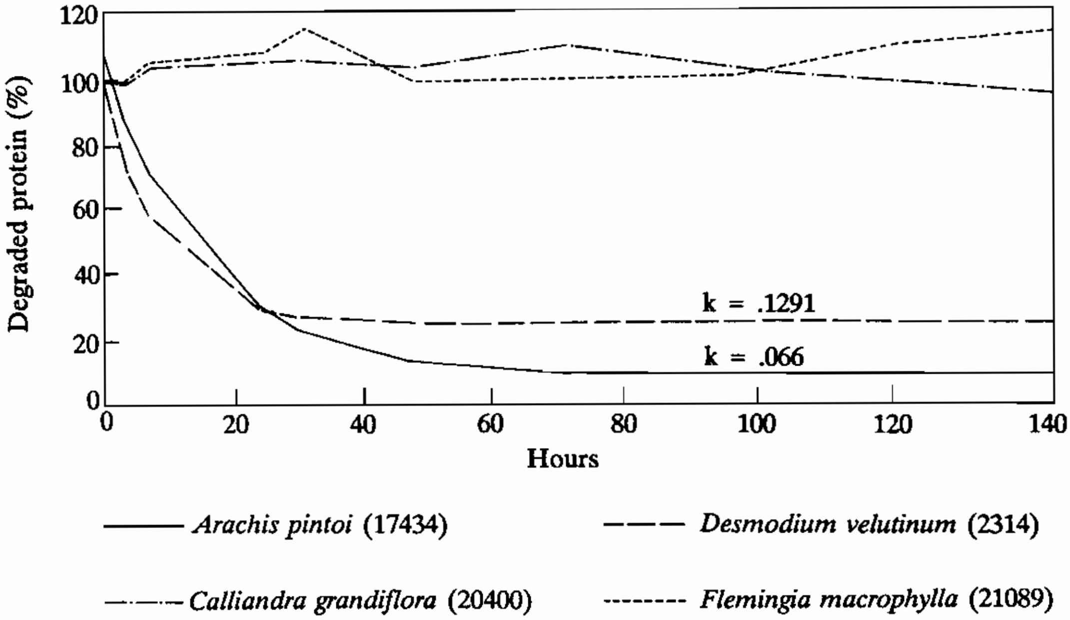


Figure 2. **In situ** rate of protein degradation of some tropical legumes (k = rate of degradation).

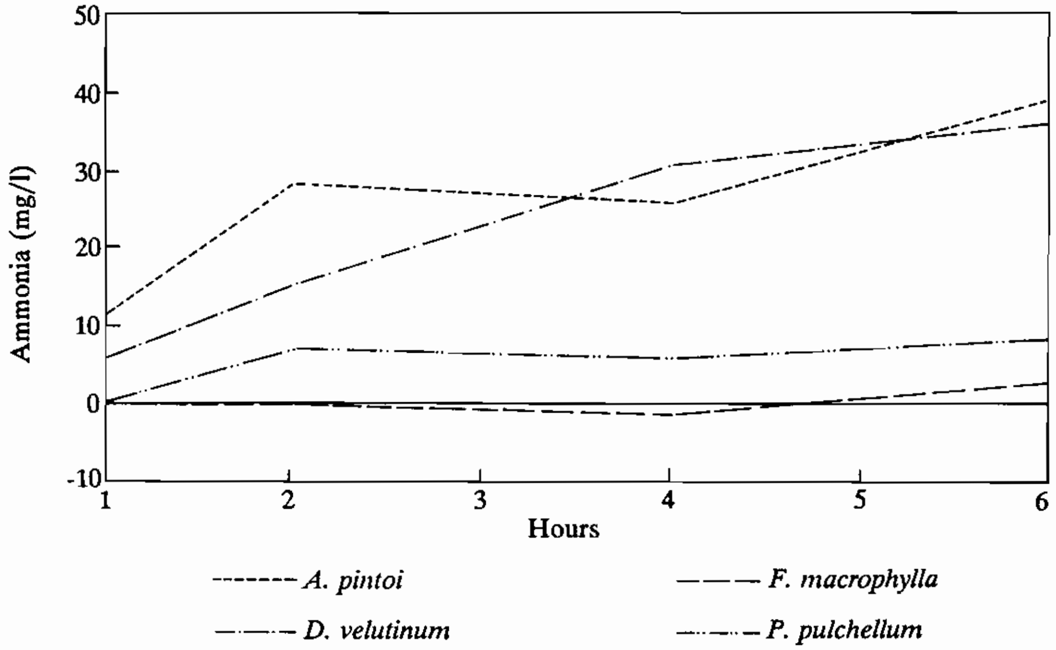


Figure 3. In vitro ammonia production.

Table 3. Proportion of legume in the diet selected by esophageal-fistulated and intact-resident steers in grass-legume pastures, Carimagua, Colombia.

Pastures	Legume in diet (%)	
	Fistulated (Extrusa)[a]	Intact-resident ($\delta^{13}C$ in feces)
Brachiaria dictyoneura-Arachis pintoi	51.7 ± 9.6[b]	1.3 ± 0.9
Andropogon gayanus-Centrosema acutifolium	11.5 ± 7.8	25.3 ± 4.5
Brachiaria humidicola-Desmodium ovalifolium	29.7 ± 10.0	9.2 ± 3.8
Brachiaria decumbens-Pueraria phaseoloides	84.7 ± 10.2	27.7 ± 3.8
Correlation fistulated vs. intact-resident = 0.13 (NS)		

a. Hit-point reading.

b. Standard deviation.

Table 4. Correlation between animals and methods used to estimate legume selectivity under grazing in *Arachis pintoi*-based pastures.

Animals	Method	r	Significance
Fistulated vs. Permanent	$\delta^{13}C$ in feces $\delta^{13}C$ in feces	0.42	NS
Fistulated vs. Fistulated	Reading extrusa $\delta^{13}C$ in feces	0.44	NS
Fistulated vs. Fistulated	Reading extrusa $\delta^{13}C$ in extrusa	0.95	(P<.01)

1. Low correlation between estimates of legume in the diet of esophageal-fistulated and intact-resident steers with $\delta^{13}C$ in feces.

2. Low correlation between estimates of legume in the diet of esophageal-fistulated steers with $\delta^{13}C$ in feces and hit-point reading of extrusa.

3. High correlation between estimates of legume in the diet between $\delta^{13}C$ in extrusa and hit-point reading of extrusa.

These results have very important methodological implications:

1. Extrusa samples collected from esophageal-fistulated animals for 30-40 minutes each day during 3 or 4 consecutive days do not seem to give an accurate estimate of the overall diet. Obviously it is better to abandon esophageal-fistulated animals and go entirely to $\delta^{13}C$ in feces of permanent animals when it is feasible to do so. However, not many national programs have mass spectophotometers, so if the technique with esophageal-fistulated animals can be improved, then we will make a big advance in technology for national programs. Therefore, to improve the sampling procedures with esophageal-fistulated animals, future studies need to define the extent to which diet selection changes during a day and between days.

2. Esophageal-fistulated animals and permanent animals to which inference is to be made should be managed similarly.

Pasture evaluation: Grazing management

The advanced evaluation, under grazing, of tropical forage germplasm is an essential step in the process leading to selection and release of new forage plant cultivars. The traditional methodology used for pasture evaluation has either been:

1. Set stocking under continuous or rotational grazing. With this methodology, the true potential of new grass-legume pastures may be underestimated, since set stocking does not recognize the dynamics of species (grasses and legumes) in the pasture as they interact with climate, soils, and biotic factors.

2. Put and take. With this methodology, researchers have attempted to estimate the production potential of the pasture under one or more constant grazing pressures (biomass on offer/kg liveweight grazing the pasture) without regard to species balance.

An alternate methodology to evaluate tropical grass-legume pastures has been developed by the TPP. Each association under evaluation is to be managed in a flexible manner, such that stocking rate and grazing frequency are adjusted depending on two pasture parameters:

1. Forage on offer. Stocking rate is adjusted when grazing pressure reaches selected lower or upper limits (e.g., 3 and 6 kg DM/100 kg LW/day) (Figure 4). When the amount of forage on offer exceeds the upper limit, stocking rate is increased, and when it reaches the lower limit, stocking rate is decreased.

2. Legume content. Grazing frequency is adjusted when legume proportion in the pasture reaches selected limits (e.g., 15% and 50%). When the legume reaches the upper limit, the rest period is increased, and when the legume reaches the lower limit, the rest period is reduced (Figure 4).

Validation of flexible management. A number of grazing experiments in small plots have been carried out to test the assumptions of the flexible management methodology. Results from Quilichao with contrasting grass-legume associations indicate that, when pastures are not overgrazed and the species are well adapted to the location, frequent grazing favors the legume. Similar results have been obtained in experiments conducted in a contrasting humid forest environment.

In a grazing experiment in a humid forest ecosystem in Bahia, Brazil, grazing frequency had a greater effect on legume content in *B. humidicola-D. ovalifolium* pastures than stocking rate (Table 5). Continuous grazing favored legume in the pasture, particularly at the intermediate and high stocking rates, whereas a rotational system of 7 days on and 56 days of rest favored the grass.

In a current grazing experiment in the Cerrados of Brazil, grazing system has had a large effect on legume content in the pasture. A 14/42 (days on/days rest) rotational system has resulted in gradual loss of *S. guianensis* in association with *A. gayanus*. In contrast, an alternate flexible system and a 7/21 (days on/days rest) rotational system have maintained acceptable levels of legume in the pasture.

The importance of grazing management of grass-legume pastures for animal performance was documented in the Cerrados of Brazil. The association of *A. gayanus-S. guianensis* cv. Bandeirante was initially evaluated with set stocking and continuous grazing. With this management, low individual and per hectare weight gains were recorded as a result of low legume content in the pastures. In a subsequent experiment, the same association managed with a flexible system has produced two times more gain per animal and per hectare, largely due to good legume content in the pastures. By adjusting stocking rate during the wet season, a standing grass hay + legume is available during the dry season, which allows animals to gain or at least maintain weight during this critical period. Pastures are rested during the early wet season to allow grass and legume recovery. During the time the pasture is spelled, animals graze native vegetation which has been burned and has good-quality regrowth.

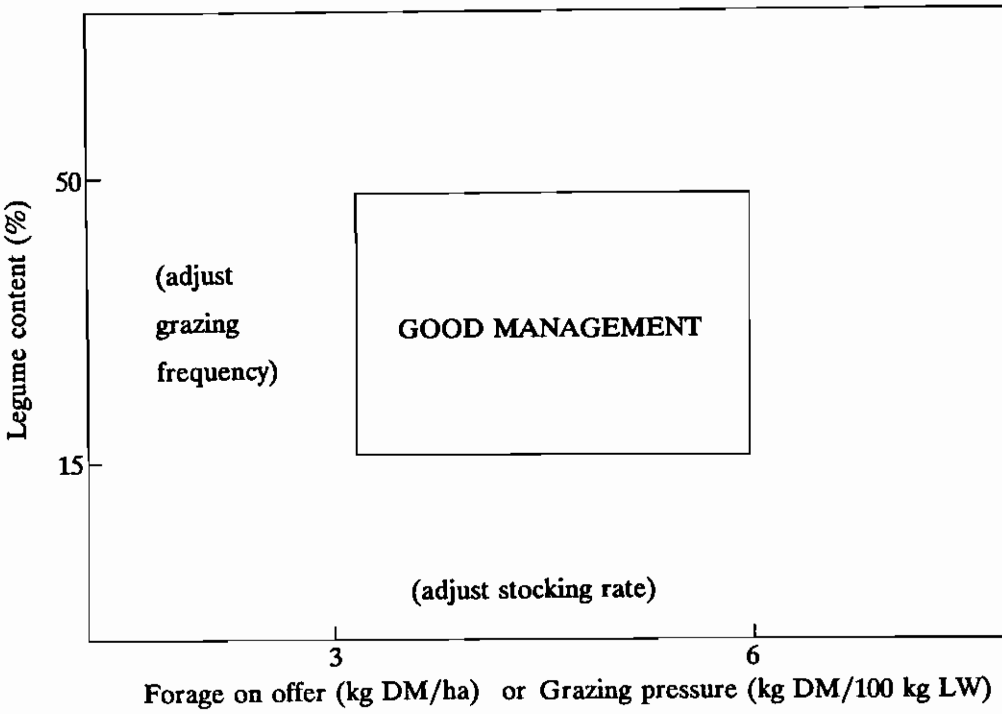


Figure 4. Flexible management of grass-legume pastures.

Table 5. Effect of stocking rate and grazing system on legume content in pastures of *Brachiaria humidicola-Desmodium ovalifolium*, after two years of grazing, Bahia, Brazil.

Stocking rate (A/ha)	Grazing system			Mean
	Continuous	7/28*	7/56*	
		(% legume)		
2	20	17	11	16
3	34	9	5	16
4	23	9	6	13
Mean	26	12	7	

* 7 days of grazing and 28 or 56 days of rest.

SOURCE: Santana, J.R.; Pereira, J. M.; Moreno, R. A. M.; and Spain, J. M. 1987. Efeito do pastejo sobre a persistência e produtividade da consorciação *Brachiaria humidicola + Desmodium ovalifolium* CIAT 350. In: Anais da XXIV Reunião Anual da Sociedade Brasileira de Zootecnia, Brasília, Brazil. p. 242. (Abstract.)

Advantages of flexible management. The flexible management methodology has several advantages for the evaluation of tropical grass-legume pastures:

1. It recognizes the dynamics, both short- and long-term, of different grass-legume associations.

2. It produces a definition of "good management" in terms of observable pasture parameters.

3. Results are more generally extrapolative in space and time, especially to commercial systems.

4. It is efficient in the use of research resources.

Summary

This chapter has dealt with the complexity of pasture research and the implications of this complexity for research methodologies for forage germplasm and pasture evaluation. In this context, the TPP has produced methodological manuals which, together with training courses held at CIAT, have contributed to improving the organization, productivity, and cost-effectiveness of pasture research in national programs. There are several instances where small national programs have promoted germplasm, selected in small-plot agronomic trials, and released commercial cultivars, without having to conduct expensive grazing experiments.

The TPP has also made progress in the adjustment of: (1) methodologies for quality characterization of tropical legumes, which will be useful for screening leguminous shrubs and trees in the new Tropical Forages Program; and (2) a reliable and efficient methodology for the evaluation of grass-legume pastures under grazing, which is being implemented at major screening sites of the TPP and by researchers in RIEPT. In addition, CIAT's Biotechnology Research Unit has developed techniques for: (1) identification and handling of genetic variability of key forage germplasm, now being implemented in CIAT's Genetic Resources Unit and by the Breeding Section in the TPP; (2) plant regeneration of key grass and legume species, leading to somaclonal lines with unique morphological traits useful in studies of mechanisms of plant adaptation to acid soils being carried out by the TPP; and (3) genetic transformation of *S. guianensis*, a successful model which opens the door for the application of advanced techniques to the enhancement of tropical forage germplasm.

In spite of the progress made by the TPP in refining methodologies, many challenges remain in forage germplasm screening and evaluation and in pasture evaluation with grazing animals.

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CHAPTER 4

GERMPLASM CASE STUDY: *BRACHIARIA* SPECIES

S. L. Lapointe and J. W. Miles*

Introduction

The purpose of the chapter on "**Regional germplasm evaluation**" (Miles and Lapointe, Chapter 2) was to give a broad overview of the multiple germplasm options being developed by the Tropical Pastures Program (TPP) for the ecosystems of tropical Latin America. The purpose of the present document is to present a more detailed examination of research being carried out at CIAT on one of the most successful tropical forages, *Brachiaria*.

There are over 200 million hectares of well-drained savannas in Brazil, Colombia, and Venezuela on which intensified grazing and crop-pasture systems could be implemented. Grasses of the genus *Brachiaria* are of large and growing importance in these areas due to their excellent adaptation to poor soils and resistance to drought. *B. decumbens* and *B. humidicola* have been widely adopted throughout Central and South America and are a key element of CIAT's objective to provide sustainable, productive, and drought-resistant forage for beef and milk production on acid, infertile soils of lowland tropical America. In addition, recent data demonstrate that *B. decumbens* can significantly increase soil fertility and crop yield in crop-pasture rotations and can be used effectively to control erosion and regenerate soil on Andean hillsides. Recent expansion of the TPP's geographic mandate has seen the introduction of selected *Brachiaria* germplasm to Africa and Southeast Asia, where materials are already being evaluated. In short, *Brachiaria* is the single most important tropical forage grass genus and one whose genetic potential, as we shall try to show in this document, is just beginning to be exploited.

History of *Brachiaria* in the New World

The first introductions of *Brachiaria* species into the New World probably occurred, intentionally or accidentally, during the 18th and 19th centuries, when *B. mutica* was

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used as bedding on ships. More recently, *B. decumbens* was introduced into Belém, Brazil, in 1952 by a FAO agronomist, and *B. brizantha* and *B. ruziziensis* were introduced around 1965. While *B. ruziziensis* has been limited by its poor adaptation to low-fertility soils, *B. decumbens* has shown excellent adaptation both to acidic, low-fertility soils and to drought. As a result, *B. decumbens* has been widely planted throughout Latin America. However, it soon became evident that *B. decumbens* was severely limited in its productivity by its susceptibility to species of a family of xylem-feeding insects known as spittlebugs. The immature stages of spittlebug feed at the base of the plant and on roots and surround themselves with a spittle mass that provides protection. Spittlebug feeding causes chlorosis and, in severe attacks, a complete necrosis or burning of the foliar parts of the plant. Another species, *B. humidicola*, was found to be tolerant to spittlebug attack. That is, *B. humidicola* supports normal nymphal development, but does not show damage symptoms except at high levels of infestation. In many areas, *B. humidicola* has largely replaced the susceptible *B. decumbens*. However, recent outbreaks of spittlebug on the tolerant *B. humidicola* have demonstrated the need to identify true antibiotic resistance to avoid the population increases that often accompany tolerance. High spittlebug populations have, in several cases, overwhelmed the tolerance of *B. humidicola*, resulting in severe damage.

Yet another introduction, *B. brizantha* cv. Marandú, is now enjoying wide adoption in many areas based precisely on its antibiotic resistance to spittlebug. However, cv. Marandú is more demanding in terms of soil fertility and is not as productive or persistent on poorer soils as is *B. decumbens*.

Importance of *Brachiaria*

Both weight gain per head and production per hectare are significantly improved in cattle grazing *Brachiaria* pastures compared with native savanna (Table 1). Other advantages of *Brachiaria* include low soil fertility requirements, good seed germination, rapid soil coverage that minimizes erosion, and good nutritional quality in the case of *B. decumbens* when compared with *B. humidicola* and *B. dictyoneura*, particularly when *B. decumbens* is associated with a legume to provide additional nitrogen.

The problem

Although the commercial cultivars developed from introduced, wild germplasm are adapted in different degrees to the soils and climates of Latin America, there are major limitations to all current cultivars, the principal of these being susceptibility to spittlebug.

B. ruziziensis. This species is adapted only to better soils, and is extremely susceptible to spittlebug damage.

Table 1. Animal production on pastures of native savanna compared with *Brachiaria* pastures.

Pasture	Production kg/animal/year	 kg/ha/year
Savanna	75	20
B. humidicola	90	180
B. decumbens	120	240
B. decumbens + kudzu	160	320

B. decumbens. This species is well adapted to acidic, low-fertility soils; is also highly susceptible to spittlebug; has good nutritional quality compared with *B. humidicola* and *B. dictyoneura* (although there is much room for further improvement); and has good animal performance provided there is a source of nitrogen. It is easy to establish and provides rapid soil cover for erosion control and to start grazing: pastures of *B. decumbens* can be grazed six months after establishment, others such as *B. dictyoneura* may take a year.

B. humidicola. Although this species is tolerant to spittlebug, it is not truly resistant and can suffer severe damage during spittlebug outbreaks. It is a poor-quality grass and a poor seed producer at low latitudes. (Seed is produced in southern Brazil.) It is highly resistant to leaf-cutter ants.

B. brizantha. Although this species is spittlebug resistant, it demands higher soil fertility and is susceptible to a bacterial root rot in poorly drained areas. It is resistant to leaf-cutter ants.

B. dictyoneura. This species is spittlebug tolerant (not resistant), of low to medium quality, and although it is a good seed producer, seed dormancy can be a problem. It associates well with legumes due to semi-erect growth habit. It is susceptible to damage by leaf-cutter ants at establishment.

The solution

Limitations facing some species could be overcome through the following: collection in Africa of *Brachiaria* germplasm; germplasm introduction and evaluation at major screening sites and through the RIEPT; identification of desired characteristics through specific screening of the collection; and plant breeding.

Collection and exchange of germplasm

Given the wide adoption and demonstrated value of *Brachiaria*, and the existence of specific biotic and abiotic limitations to its productivity, a major collection effort was initiated in 1984/85 by CIAT in Africa in collaboration with ILCA and several African national programs. Seven hundred ninety-two accessions were collected from six countries, including accessions of at least 23 known species (Table 2). The collections were established vegetatively at ILCA headquarters in Ethiopia and at national program facilities in Kenya, Zimbabwe, and Burundi. Meristem culture was carried out in 1985 by personnel from CIAT's Biotechnology Research Unit on-site in Ethiopia, Kenya, and Zimbabwe. Accessions were transferred in test tubes to CIAT, where the first field collections were established during 1986.

Germplasm introduction to major screening sites

The collection has been distributed to regional evaluation sites and promising materials are currently being evaluated through national programs and the RIEPT. Space limitations preclude going into detail regarding regional evaluation of the *Brachiaria* collection. However, the field evaluation for *Brachiaria* germplasm introduction carried out at the Carimagua experiment station will be described. Here, emphasis was placed on identification of well-adapted *Brachiaria* accessions resistant to spittlebug. It was surmised that field trials for spittlebug resistance would be more rapid and reliable if established in old fields of a spittlebug-susceptible grass such as *B. decumbens* and managed to maintain conditions that favor spittlebug. Twice-replicated plots of 265 accessions of *Brachiaria* spp. were established in June 1987 in an old field of *B. decumbens* known to be infested with spittlebug. Strips of the original *B. decumbens* were maintained around all plots to favor uniform spittlebug infestation of the collection. In addition, leaf litter at the soil surface was allowed to accumulate. In this way, proliferation of superficial roots under litter was increased and conditions of relative humidity and shade that favor spittlebug survival were created.

Although maintenance of a large collection in association with an aggressive grass such as *B. decumbens* is difficult and time-consuming, it is worth the effort when the primary objective of the collection is to identify resistance to spittlebug. Spittlebug populations in the field trial greatly exceeded those in adjacent pastures of *B. decumbens*—200 versus 10 nymphs/m^2, respectively, at the peak of infestation in June 1988. High spittlebug populations resulted in severe damage to a majority of accessions both in 1988 and again two years later in 1990. The susceptible control, *B. decumbens* CIAT 606, was completely blighted. Selection of promising accessions was made in July 1988, more than one year before the anticipated termination of the trial. Five of these accessions are currently undergoing evaluation in a small-plot grazing trial at Carimagua.

Plant breeding

Until 1990, the primary emphasis in *Brachiaria* had been on germplasm introduction, that is, release of accessions collected from the wild without genetic improvement through breeding. Indeed, prior to 1990, *Brachiaria* had never been sexually recombined in a directed breeding program because the majority of *Brachiaria* accessions, including most of the commercial varieties, are polyploid apomicts. In brief, apomixis is a reproductive mechanism whereby plants produce seed without sexual recombination, resulting in progeny that is genetically uniform and identical to the mother plant. The embryo arises by mitosis from maternal tissue. Genetic recombination, the basis of plant breeding, does not occur.

There are two important implications of apomictic reproduction for genetic improvement of *Brachiaria*. If apomixis is obligate, the combination of attributes from distinct parentals through conventional hybridization is impossible. This poses a formidable obstacle to genetic improvement, with very limited options for generating novel genetic variation. However, if some mechanism for generating the desired novel genotypes could be found, these apomictic recombinants would breed true, even if highly heterozygous. Thus, the new character combination could be propagated indefinitely, by seed, without genetic mixture or degeneration.

While *B. decumbens* and *B. brizantha* are both apomictic, a closely related species, *B. ruziziensis*, is sexual. However, direct crosses between the sexual *B. ruziziensis* and *B. decumbens* or *B. brizantha* are very difficult due to different ploidy levels. *B. ruziziensis* is a diploid while *B. decumbens* and *B. brizantha* are essentially tetraploid species. While crosses have been achieved in Australia, the resulting hybrids are infertile triploids.

To break this barrier, researchers in Belgium produced a tetraploid line of *B. ruziziensis* by treating the natural sexual diploid with colchicine (Figure 1). The resulting induced tetraploid retained completely the sexual reproductive mode of the natural diploid *B. ruziziensis*. A small number of hybrids were obtained in Belgium by pollinating the induced tetraploid, sexual *B. ruziziensis* with the functional pollen of the natural tetraploid apomicts. However, the true value of the compatible, sexual tetraploid wasn't realized fully until this material was brought to tropical America in 1985 by Dr. Cacilda do Valle, of EMBRAPA's National Beef Cattle Research Center in Mato Grosso do Sul, Brazil. Dr. do Valle brought this line to CIAT when she came here as a CIAT Fellow with the objective of applying her embryo sac analysis methods to the determination of reproductive mode in the large new collection of *Brachiaria* spp. germplasm then available only at CIAT.

It was confirmed at CIAT that interspecific hybridization by hand pollination was relatively easy, but more importantly, it was shown that hybrids could easily and reliably be made by open pollination in the field. Open-pollinated progenies were analyzed by electrophoresis for the presence of paternal bands absent in the *B. ruziziensis* mother. The presence of these paternal bands (Figure 2) in 90% of the open-pollinated progenies resulting from field hybridization is strong evidence of the hybrid origin of these progenies and suggests a high degree of self-incompatibility in the *B. ruziziensis* mother.

However, making the first interspecific hybrids on a large, field scale was not sufficient. The success of any *Brachiaria* breeding project will depend upon

Table 2. Germplasm collection of *Brachiaria* spp. in Africa (1984-1985).

Species	Country						Total
	Kenya	Ethiopia	Zimbabwe	Burundi	Rwanda	Tanzania	
	(no. of accessions)						
B. arrecta	—	—	4	—	—	—	4
B. bovonei	—	—	5	—	4	2	11
B. brizantha	58	124	77	40	11	41	351
B. decumbens	17	—	1	7	22	—	47
B. dictyoneura	4	9	—	—	—	3	16
B. humidicola	2	18	30	20	4	27	101
B. jubata	31	26	3	7	6	2	75
B. lachnantha	—	6	—	—	—	—	6
B. nigropedata	—	—	41	—	—	—	41
B. platynota	1	—	—	2	17	—	20
B. ruziziensis	2	—	—	19	4	2	27
B. serrata	—	8	12	—	—	3	23
B. subulifolia	—	—	10	—	—	—	10
Other species[1]	9	25	20	5	1	—	60
Total	124	216	203	100	69	80	792

1. *B. comata, B. deflexa, B. eruciformis, B. leucacrantha, B. longiflora, B. mutica, B. obtusiflora, B. scalaris, B. semiundulata, Brachiaria* sp.

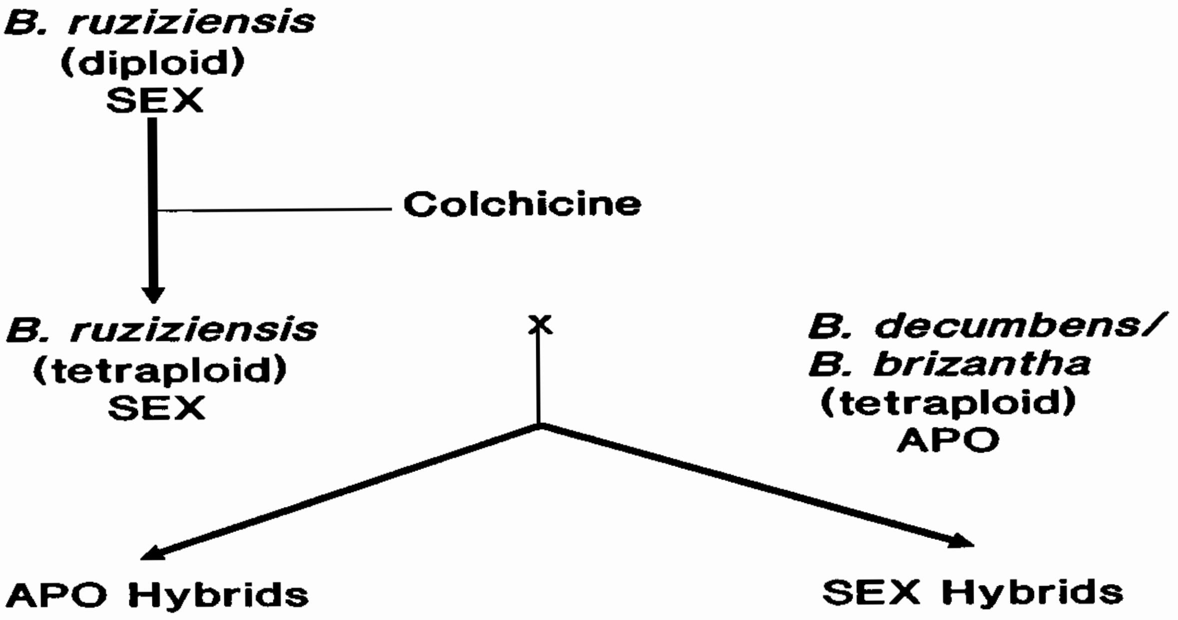

Figure 1. Hybridization scheme employed in *Brachiaria* spp.

maintaining both sexuality (to achieve genetic recombination by hybridization) as well as apomixis (to fix genetically superior recombinants in true-breeding cultivars). So we still needed to know something about the inheritance of apomixis in hybrid populations and we needed simple, rapid methods to assess reproductive mode so as to be able to manipulate apomixis in large populations.

Analysis of the structure of embryo sacs is reliable and can be done as soon as flowering occurs. However, embryo sac analysis requires trained technicians and expensive laboratory equipment—elements not always available where *Brachiaria* breeding programs might be established. Therefore, an experiment was conducted to determine the reliability of a simple field progeny test to assess reproductive mode. Open-pollinated seed harvested from a sexual mother plant should produce a heterogeneous progeny owing to cross pollination of the sexual mother. An apomictic mother, on the other hand, should produce a genetically uniform progeny, identical to itself. Therefore, assessment of the relative uniformity or heterogeneity of open-pollinated progenies should permit determination of the reproductive mode of the mother plant. Open-pollinated progenies of our first small field trial of interspecific hybrids were planted at CIAT in 1990. Based upon visual assessment of the relative uniformity of these progenies, mother hybrids were classed as either apomictic or sexual. Reproductive mode of the same maternal hybrids was assessed by embryo sac analysis. In over 85% of the cases, the results of the two methods agree,

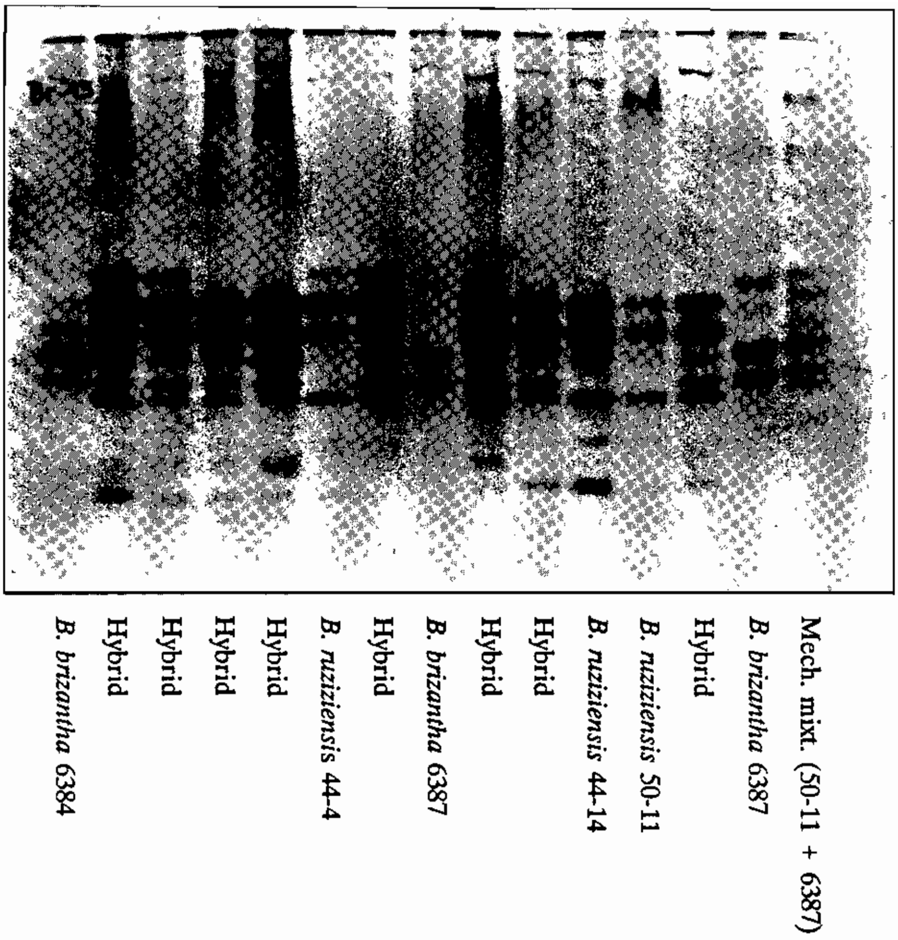

Figure 2. Alpha-beta esterase banding pattern of 15 *Brachiaria* genotypes, including parentals and interspecific hybrids.

confirming the reliability of the progeny test (Table 3). The only significant discrepancies were ten facultative apomicts which we had classified as sexuals based on the progeny test. It is worth noting that the proportions of sexuals and apomicts in this hybrid population based on embryo sac analysis (56/107 sexuals:51/107 apomicts) are not inconsistent with the single-gene model proposed by Belgian researchers based upon their much smaller sample of hybrids. More detailed studies of the inheritance of apomixis, including examination of progenies resulting from selfing or backcrossing, are being conducted by our colleague, Cacilda do Valle, with support from CIAT.

At CIAT, we now have the capacity to conduct embryo sac analysis, but we continue to develop applied breeding schemes based upon a progeny test. These breeding schemes could readily be transferred to national programs.

Thus, the stage is set for massive generation of hybrids and efficient manipulation of apomixis in segregating hybrid populations either by embryo sac analysis, where facilities permit, or by the simple but effective progeny test.

Genetic Map of *Brachiaria*

In collaboration with CIAT's Biotechnology Research Unit, a project is under way to develop molecular markers as a breeding tool by mapping the *Brachiaria* genome. The main objective is to develop genetic markers to aid in the selection of desired characters. A map is seen to be a working tool for detailed genetic analysis that complements but does not replace more traditional breeding techniques. In conjunction with traditional genetic analysis to characterize mechanisms of inheritance of key characters, the genetic map can be used to simplify the process of selection. Once we have an understanding of the genetic mechanism of apomixis (or any other attribute), markers can be used as a rapid screen that will eliminate the need for either costly embryo sac analysis or time-consuming field testing.

We are currently exploring the use of RAPD (Random Amplified Polymorphic DNA) markers, and are considering the use of RFLPs. RAPD is a simpler and faster technique than RFLP. Due to the complexity of polyploid inheritance, we shall begin mapping at the diploid level using a small number of diploid *B. decumbens* and *B. brizantha* accessions identified by Cacilda do Valle. However, it would probably be much more productive to deal directly with commercial polyploid genotypes if a method such as anther culture could be developed to derive dihaploids from tetraploid genotypes.

Breeding Objectives

Pest resistance

Spittlebug. A mass-rearing method and associated techniques for egg production and manipulation were developed for spittlebug and a colony has been maintained

Table 3. Comparison of mode of reproduction of first generation, interspecific *Brachiaria* hybrids as determined by progeny test or by embryo sac (ES) analysis.

No. of hybrids	Mode of reproduction by: Progeny test	ES analysis	% sexual embryo sacs (apomictic hybrids)
54 hybrids	sexual	sexual	
37 hybrids	apomictic	apomictic	10-73
4 hybrids	unclassified	apomictic	7-83
2 hybrids	unclassified	sexual	
10 hybrids	sexual	facultative apomicts	
541-03			10
544-04			50
549-02			17
554-02			63
554-03			77
683-01			52
687-01			70
693-02			47
694-17			43
702-03			30

at CIAT headquarters continuously since 1986. In addition to providing continuous production of eggs, nymphs, and adults for screening and experimental purposes at headquarters, this technique has been used at EMBRAPA's National Beef Cattle Research Center in Mato Grosso do Sul, Brazil, and a colony is being initiated in Costa Rica (DIECA) for studies of entomopathogens as biological control agents.

Based on success with the rearing method, a glasshouse screening technique was developed which has identified high levels of antibiotic resistance in several species of *Brachiaria*, most notably accessions of *B. jubata* and *B. brizantha* (Figure 3). Of 500 accessions screened, 27 accessions have been identified as having equal or greater levels of antibiotic resistance to spittlebugs than the resistant commercial cultivar, *B. brizantha* cv. Marandú. Nineteen of these accessions are already being used in the breeding project as sources of antibiotic resistance.

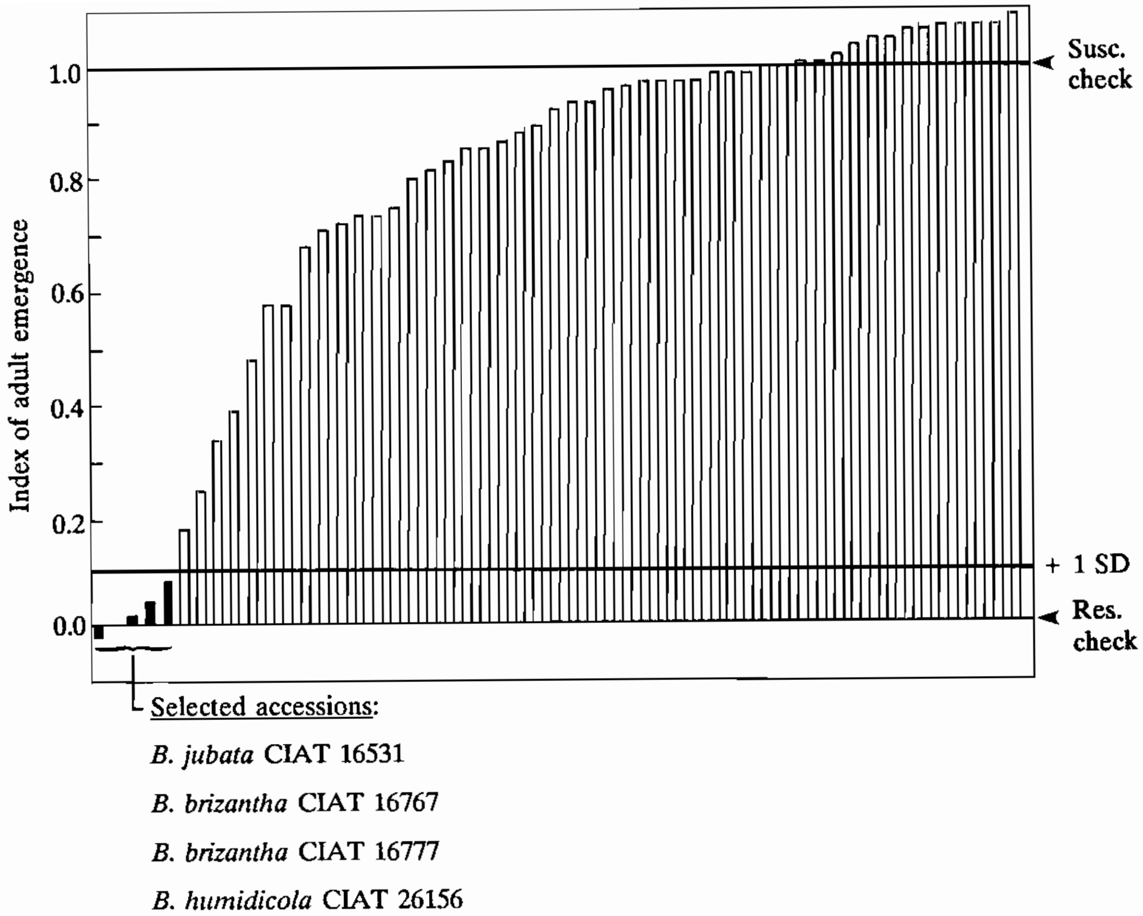

Figure 3. Glasshouse screening of 52 accessions of *Brachiaria* spp. for resistance to spittlebug.

In particular, two accessions of *B. jubata* have been found to be highly antibiotic. Resistance is associated with molt disruption, resulting in malformed pharate adults. Typically, late instar larvae fed on *B. jubata* CIAT 16531 or *B. jubata* CIAT 16203 die during molt to adult, after apolysis but before ecdysis can be completed.

Although the bioassay system used to identify resistance sources was adequate when screening a limited collection, it was recognized that if sexual recombination of the normally apomictic accessions of *Brachiaria* were possible, additional bioassay techniques for identifying resistance, elucidating mechanisms of resistance, and more rapid screening of progeny would be needed.

A unique bioassay has been developed to test plant fractions and other chemicals for their activity when ingested by spittlebug nymphs. *Brachiaria* plants are grown in nutrient solutions, infested with spittlebug larvae or eggs, and the component to be tested is administered via the nutrient solution. Uptake of ecdysone by the root xylem and its effect on larvae have been demonstrated using this system. When 50 ppm ecdysone was placed in the nutrient solution, molting occurred within 24 hours. In addition, malformed adults were produced with symptoms similar to those observed from nymphs reared on *B. jubata* CIAT 16531 and 16203.

Based on the similarity of symptoms, we are pursuing the possibility that some plant compound similar to ecdysone (a phytoecdysteroid) is responsible for resistance in *B. jubata*. However, we are simultaneously studying the nutritional requirements of spittlebugs in order to determine whether the presence or absence of key nutritional factors in the plant could play a role in resistance.

In addition to pursuing a bioassay-directed search for resistance factors, efforts are under way to develop a mass field infestation technique using spittlebug eggs for rapid evaluation of large segregating populations.

Leaf-cutter ants. Leaf-cutter ants, in addition to spittlebugs, are a major pest of forage grasses and crops in the savanna ecosystem. However, we have identified excellent sources of resistance in the species *B. humidicola* and *B. brizantha* to *Acromyrmex landolti*, the most prominent leaf-cutter of the savannas of Colombia and Venezuela (Figure 4). This resistance will be selected for in order to maintain this valuable trait in new cultivars resulting from sexual crosses.

Edaphic adaptation

Field tests for acid-soil tolerance are expensive in space, time, and labor. A rapid test suitable for detecting acid-soil-sensitive germplasm is being developed to screen progeny of sexual crosses of *Brachiaria* before field testing. The test will measure root length density (root length per unit soil volume), a trait of physiological significance. This method is proposed as a rapid bioassay for evaluation of adaptation to acid soils of *Brachiaria* progeny.

Nutritional quality

Preliminary results suggest wide variation among *Brachiaria* spp. accessions for in vitro dry matter digestibility (IVDMD). Values obtained from samples of first fully expanded leaves range from 46% to 70% digestibility. A more detailed survey conducted by Dr. C. do Valle as part of her Ph.D. thesis project found highly significant differences in a number of forage quality attributes, both among as well as within *Brachiaria* species. Given the range in IVDMD values within both *B. brizantha* and *B. decumbens*, it ought to be possible to improve the quality of bred cultivars.

Summary

Generation of hybrids and manipulation of apomixis in segregating, hybrid *Brachiaria* populations have been demonstrated and a large-scale breeding program is under way at CIAT. This project aims to produce true-breeding apomictic cultivars containing combinations of attributes not found in natural *Brachiaria* germplasm. Our prime

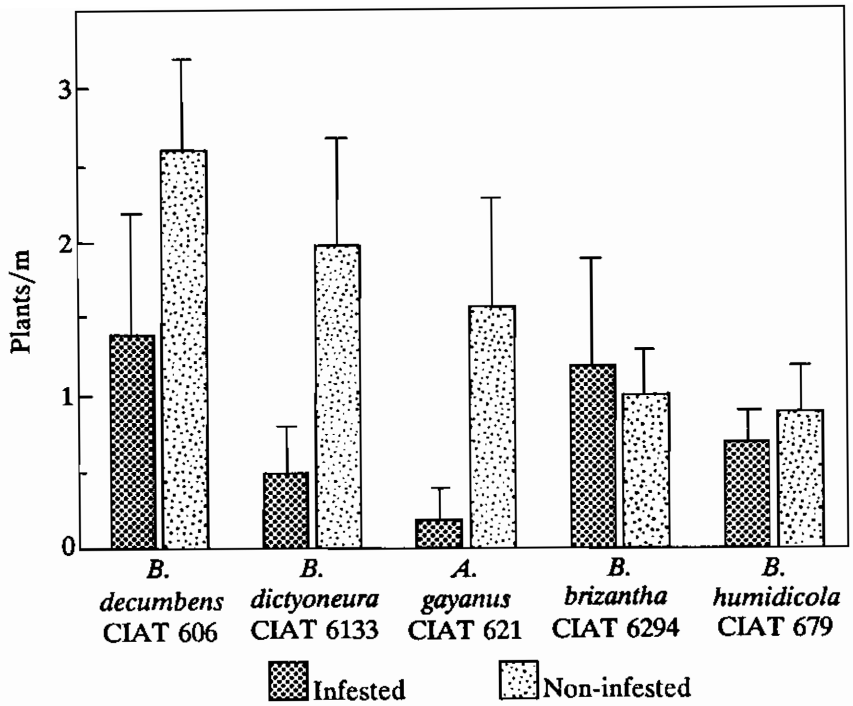

Figure 4. Effect of the leaf-cutter *Acromyrmex landolti* on establishment of five commercial cultivars of forage grass at Carimagua.

objective is to combine in heterotic but true-breeding apomictic cultivars the excellent spittlebug resistance found in natural *B. brizantha* accessions with the adaptation to acid, infertile soils of the spittlebug-susceptible *B. decumbens*. Given that we have access to ample genetic variation for forage yield and quality as well as seed yield and quality, substantial improvement in these attributes should also be possible with time.

We have attempted to give an overall view of the history of *Brachiaria* and to examine recent research on the genus at CIAT—and to show a little of what is in store in the near future. CIAT's collection of *Brachiaria* germplasm from Africa has provided a large amount of extremely valuable genetic variability. The Tropical Pastures Program has defined clear breeding priorities, has developed screening methods, and has identified sources of valuable characters such as spittlebug resistance, leaf-cutter ant resistance, and edaphic adaptation. It is particularly exciting to be witnessing the first sexual crosses and selection for useful characteristics of such a widely adapted grass that has so many applications across a range of ecosystems. In addition to the straightforward application of entomological and traditional breeding methods, we hope to take full advantage of the unique possibilities of apomixis and evolving molecular techniques in order to exploit more fully the potential of *Brachiaria* for meat and milk production, soil conservation, and fertility maintenance in agropastoral systems.

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CHAPTER 5

GERMPLASM CASE STUDY: *ARACHIS PINTOI*

P. J. Argel and E. A. Pizarro*

Introduction

Arachis pintoi is a promising pasture legume introduced by CIAT's Tropical Pastures Program (TPP) and evaluated since 1979. This legume resulted from the search for acid-soil-tolerant legumes with greater tolerance of stress and grazing, better persistence, and compatibility with aggressive grasses such as *Brachiaria* and *Cynodon*, for which no commercial legume cultivars are available. *A. pintoi* also has other positive agronomic attributes that make it a viable alternative as a ground cover crop for permanent plantations and for soil conservation.

A. pintoi is indigenous to Brazil, with distribution "apparently" restricted to the valleys of the Jequitinhonha, São Francisco, and Tocantins rivers. The TPP's more advanced accession of *A. pintoi*, CIAT 17434 (cv. Amarillo in Australia), was collected by G. C. Pinto in 1954 in the valley of the Jequitinhonha River, near the Atlantic coast between the river mouth and the city of Belmonte (15°32' S, 39°6' W; 50 m.a.s.l.), growing in low-fertility reddish sand to loamy sand with high aluminum saturation.

This chapter will focus on the legume's persistence under grazing, its nutritional quality, and animal performance. It will also examine the legume's alternative use as a ground cover, and mention limitations related to seed harvesting and slow establishment.

Morphological Description

Arachis pintoi is a perennial, prostrate legume with a stoloniferous growth habit. Leaves are quadrifoliated (two pairs of leaflets) and flowers are yellow. This legume produces a dense mat of stolons with short internodes; the stolons are held down by abundant roots and fruiting pegs (gynophores). It is a geocarpic plant with fruits mostly a single pod with a single seed forming at the end of the gynophore (Cook et al., 1990). The pods have a thin, hard pericarp and the seed varies in size and weight.

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* Agronomists, Tropical Pastures Program, CIAT, posted in San José, Costa Rica, and Brasília, Brazil, respectively. The authors would like to thank J. E. Ferguson, B. Grof, and C. E. Lascano for their contributions to this work.

Range of Adaptation

A. pintoi has a wide range of adaptation (Valls et al., 1985) but grows better in tropical conditions located between 0 and 1800 m.a.s.l. and with a total annual rainfall of 2000-3500 mm well distributed throughout the year, since growth is favored by constant availability of moisture. It can survive long dry periods (more than four months) and even frost in subtropical regions. However, severe drought stress produces defoliation and reduces the leaf/stem ratio. Prolonged drought kills leaves and some stolons but plants generally recover quickly with the onset of the rainy season (Dwyer et al., 1989).

A. pintoi grows well in areas with a temporarily high water table (CIAT, 1991). It grows on a wide range of soils with textures varying from heavy clay to sand. It seems to grow better in sandy loams if moisture is always available. This plant adapts well to poor acid soils with high aluminum saturation (70% or more) and performs better in soils with more than 3% organic matter content (Asakawa and Ramírez, 1989). The range of DM yields of *A. pintoi* across ecosystems responds to differences in soil and climatic conditions (Table 1). In Guápiles (Costa Rica), a site favored by high humidity throughout the year and moderate soil fertility, *A. pintoi* yields more than in other sites of Latin America.

Agronomic Attributes

Growth habit

The prostrate and strongly stoloniferous growth habit of *A. pintoi* favors the production of a dense mat of rooted stolons, with growing points well protected from predation by animals, yet it elevates its leaves on long petioles when associated with stoloniferous grasses such as *Brachiaria* spp. or star grass (*Cynodon* spp.). This allows it to compete with its companion grass, and the leaves are accessible to grazing animals (CIAT, 1991). Table 2 shows that complete ground cover is obtained three months after planting in Guápiles; however, significant differences ($P<0.05$) in number of stolons are observed among accessions.

Seed production

A. pintoi has a day-neutral photoperiod response. This allows the plant to flower several times during the year. Flowering commences three to four weeks after emergence, but initially few fertile pegs develop. Flushes of flowering occur during the rainy season, in response to cutting or to improved soil moisture following a dry period (Cook et al., 1990).

Seeds set throughout the season. Since the pods are buried in the ground, recovery of seed depends in part on the final distribution of mature seed pods within the soil profile. Experiences in Colombia and elsewhere have detected that above 90% of the seeds are concentrated within 0-10 cm (Table 3). For this reason,

Table 1. Dry matter yields of *A. pintoi* CIAT 17434 in different localities and ecosystems of Latin America.

Localities	Ecosystem	DM yields (t/ha) in rainy season
Carimagua, Colombia	Savanna	1.6
Brasília, Brazil	Cerrado	2.3
Misahualli, Ecuador	Humid tropics	2.4
Guápiles, Costa Rica	Humid tropics	4.1

SOURCE: CIAT, 1991.

Table 2. Ground cover and stolon development of *A. pintoi* accessions established by vegetative material in Guápiles, Costa Rica.

Months after planting	CIAT no.	Ground cover (%)	Stolons (no./m^2)
1	17434	28 a*	47 b
	18744	41 a	73 ab
	18748	34 a	71 ab
	18751	40 a	79 a
3	17434	98 a	355 b
	18744	100 a	555 a
	18748	100 a	404 b
	18751	100 a	564 a

* $P<0.05$, Duncan's Multiple Range Test.

SOURCE: CIAT, 1990.

Table 3. Distribution of seed yield within soil profile of *Arachis pintoi* at three locations in Colombia.

Farm	Province	Seed yield: Total 0-20 cm: Mean (kg/ha)	Total 0-20 cm: CV (%)	Profile distribution (cm): 0-5	0-10	0-15	0-20
				(% of total)			
Naranjal	Chinchiná	979	57	92	99	100	100
Romelia	Chinchiná	6133	23	81	98	99	100
Munda	Miranda	1966	55	72	92	97	100

SOURCE: CIAT, 1991.

harvesting methods should be directed towards the recovery of pods located within the first 10 cm of the soil profile (CIAT, 1991).

At about a year after planting, a very high proportion of pods were detached from the plants. Up to 97% of total seed yield corresponded to detached pods (Table 4), and their unit weight and tetrazolium viability were significantly higher ($P < 0.05$) than those of attached seeds. This is probably because a high proportion of attached pods were immature.

A. pintoi is a prolific seeder, but the potential expression of seed yield seems to be related to location (associated with soil type), crop age, and the availability of moisture throughout the growing season. A wide range of seed yield has been reported for *A. pintoi* CIAT 17434. Table 5 shows a range of seed yields in pods for different localities in Latin America at about one year after planting. The higher value of 5 tons/ha corresponds to the coffee zone at Chinchiná (Colombia) and is associated with high soil fertility, constant availability of moisture, and perhaps milder temperatures. Actual recovery of seed is favored by lighter or more friable soil textures (CIAT, 1991).

Nutritional quality

A. pintoi has a high nutritive value in terms of crude protein (CP) content, in vitro dry matter digestibility (IVDMD), and minerals such as calcium (Ca). CP values of leaves have averaged 13.2% and 21.8% in Carimagua during the dry and wet season, respectively, and values of 9.3% and 13.5% have been measured for stems during the same periods (Table 6).

This legume also maintains a high IVDMD (over 60%) for both leaves and stems independent from the season of the year. The IVDMD of *A. pintoi* stems is much

Table 4. Seed yield and quality of detached and attached seed pods of *Arachis pintoi* at Chinchiná, Colombia.[a]

Descriptor	Units	Detached seed	Attached seed
Seed yield[b]	%	97 a*	3 b
Seed size			
Unit weight of pod	g/100	20.6 a	18.6 b
Unit weight of seed	g/100	16.1 a	13.2 b
Seed quality			
Tetrazolium viability	%	91.0 a	75.0 b

* Means with different letters are statistically different at $P<0.05$.

a. All data represent average values from three accessions (CIAT 17434, 18744, and 18748).

b. Seed in pod at 14 months field age.

SOURCE: CIAT, 1991.

higher than that reported for *Stylosanthes capitata* (50%) and *Pueraria phaseoloides* (46%) (Lascano and Thomas, 1988).

A. pintoi has proved to be very well accepted by grazing animals if they are previously exposed to the legume. Figure 1 shows that the proportion of legume in the diet selected by fistulated steers followed the same trend as legume availability in the pasture. A high proportion of *A. pintoi* was selected during the wet season (up to 71%), but during the dry season the proportion of legume selected was less because of a lower proportion of the legume in the pasture.

In grass-legume pastures, animals usually select more legume during the dry season when the quality of the companion grass declines; however, this is not the case with *A. pintoi-Brachiaria* pastures, since legume selection has been observed to be highest in the wet season, provided the animals were previously exposed to the legume (Carulla et al., 1991).

The high selection of *A. pintoi* by grazing animals throughout the year is attributed to the legume's high quality and palatability, and to the type of sward canopy structure formed. For instance, *A. pintoi-Brachiaria* pastures form an intimate

Table 5. Potential and recovered seed yield in pods of *A. pintoi* CIAT 17434 harvested manually in different localities of Latin America.

Country/location	Crop age (mo.)[a]	Seed yield (kg/ha)	
		Potential[b]	Recovered[c]
Colombia			
Pto. López (Llanos)	14	1200	790
Chinchiná (coffee zone)	14	7180	5210
Miranda (Cauca Valley)	14	1966	1560
Bolivia			
Santa Cruz	10	—	500
Brazil			
Planaltina (Cerrado)	16	—	1240
Costa Rica			
Guápiles (Atlantic zone)	10	1040	—
San Isidro (south zone)	16	1378	—
Peru			
Pucallpa (Amazon)	—	53	—

a. Mo. = months after establishment.
b. Estimated in small areas (1-5 m^2).
c. Achieved in areas above 100 m^2.

SOURCE: CIAT, 1991.

Table 6. Crude protein content and in vitro dry matter digestibility of *A. pintoi* CIAT 17434 during the dry and wet season in Carimagua, Colombia.

Season	CP (%)		IVDMD (%)	
	Leaf	Stem	Leaf	Stem
Dry	13.2	9.3	66.9	63.5
Wet	21.8	13.5	60.4	62.7
Mean	17.9	10.1	63.1	63.6
CV (%)	17.8	18.7	4.1	5.7

SOURCE: Carulla, 1990.

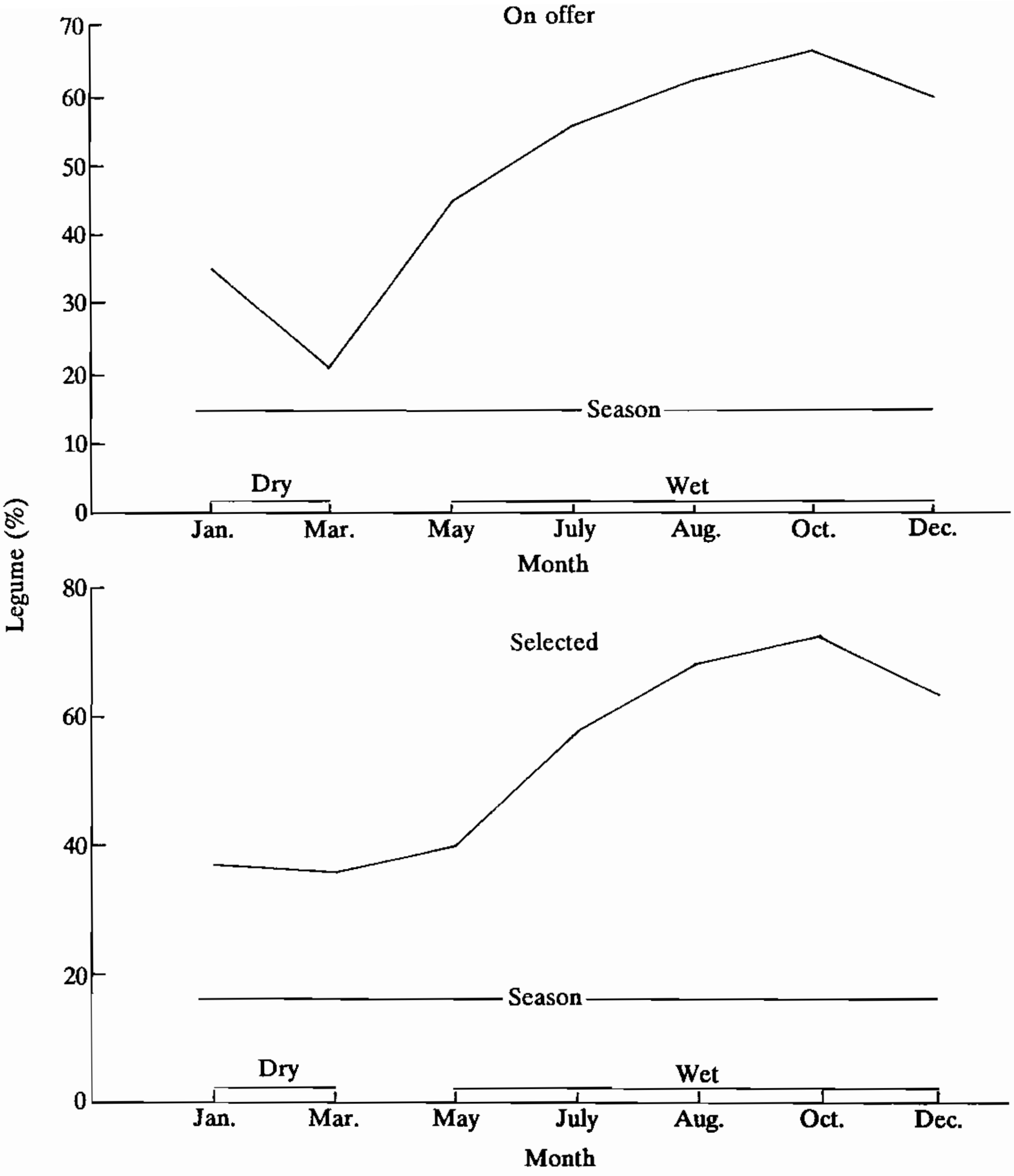

Figure 1. Proportion of *A. pintoi* (17434) in the forage on offer and selected by esophageal-fistulated steers in grass-legume associations in different months of the year in Carimagua, Colombia (a, b, c, d, e, P = 0.05). (Adapted from Lascano and Thomas, 1988.)

mixture that may limit the ability of grazing animals to make active selection against the legume (Lascano and Thomas, 1988; CIAT, 1990). As a consequence, animal performance in *A. pintoi*-based pastures should be higher than that on a pure grass pasture.

Disease and pest resistance

A. pintoi is resistant to peanut rust (*Puccinia arachidis*) and leaf spot (*Mycosphaerella* spp.), and seems to be resistant to some of the root-knot nematodes (*Meloidogyne* spp.). Dark stem lesions caused by *Colletotrichum* have been recorded, but these have not affected plant vigor. In Colombia, a potyvirus closely related to peanut mottled virus (PMoV) has been isolated in *A. pintoi* CIAT 17434 by CIAT's Virology Research Unit (Morales et al., 1991). This virus induces mottling and ring spots in infected plants. Current studies are investigating the effect of this virus on forage quality, DM yield, and seed production of *A. pintoi.*

Pasture Attributes

Persistence under grazing

Long-term survival of a pasture component depends on both the longevity of the original plants and the ability to regenerate either vegetatively or from soil seed reserves. *A. pintoi* is well recognized for its persistence under grazing. Several factors contribute to this characteristic:

1. Large volumes of buried seeds that produce vigorous seedling at the onset of rains.
2. Stoloniferous, prostrate growth habit with growing points protected from grazing.
3. Tolerance to trampling and defoliation.

Table 7 illustrates observations carried out in Carimagua (Colombia) on soil seed reserves and seedling numbers of *A. pintoi* in a two-year-old pasture (Rocha et al., 1985). At the onset of rains in May 1984, a large number of seedlings were observed in both *A. pintoi-Brachiaria humidicola* CIAT 679 and *A. pintoi-B. dictyoneura* CIAT 6133 pastures (128 and 145 seedlings/m^2, respectively).

Grazing experiments conducted in Carimagua and elsewhere report excellent persistence of *A. pintoi* under grazing (Lascano and Thomas, 1988; CIAT, 1990 and 1991). Table 8 shows an adequate proportion of this legume after five consecutive years under grazing. It can be seen that independent from the amount of the legume initially planted, it presently accounts for about 50% of total DM biomass in *B. decumbens* pastures. Although less is observed in *B. humidicola*, it is still in adequate proportions.

Similarly, *A. pintoi* has persisted for over four years under grazing in association with the very aggressive star grass (*Cynodon nlemfuensis*) in conditions of Turrialba,

Table 7. Soil seed reserves and number of seedlings of *A. pintoi* CIAT 17434 in monoculture and associated with two grasses in Carimagua, Colombia.

Pasture	1983 seeds		1984 seedlings (no./m²)
	no./m²	g	
A. pintoi (ungrazed)	6535 ± 286	611 ± 29	—
A. pintoi + *B. humidicola*	618 ± 209	57 ± 20	128 ± 17
A. pintoi + *B. dictyoneura*	670 ± 176	48 ± n.a.	145 ± 16

SOURCES: Grof, 1985; Rocha et al., 1985.

Table 8. Legume proportion in *A. pintoi* CIAT 17434/*Brachiaria* spp. pastures after five years under grazing in Carimagua, Colombia.

Pasture	Percentage of legume	
	Wet	Dry
Row planting		
B. decumbens + 20% *A. pintoi* initial	50	16
B. humidicola + 20% *A. pintoi* initial	29	12
Strip planting		
B. decumbens + 50% *A. pintoi* initial	57	27
B. humidicola + 50% *A. pintoi* initial	50	23

SOURCE: Rincón and Argüelles, 1991.

Costa Rica (premontane tropical forest). Table 9 shows that the legume presently contributes 44% of the total DM biomass; the initial contribution of the legume was only 10% (Hurtado et al., 1988). In addition, the associated pasture had significantly ($P<0.05$) less weed and native grass invasion than the star grass in monoculture (van Heurck, 1990).

Animal performance

In an ongoing experiment in Carimagua, we are measuring animal performance in pastures of *B. humidicola* CIAT 679, in pure stand and in association with *A. pintoi*, under three stocking rates in a flexible alternate grazing trial (CIAT, 1990). Animal liveweight gains in grass-legume pastures have been similar during the dry season. In the rainy season of the first two years, liveweight gains were not improved in the legume-based pastures (Figure 2). However, during the third and fourth year of grazing, liveweight gains during the wet season have been 46% higher in the associated pastures compared with pure stand regardless of the stocking rate. The response to legume in the third and fourth year is related to increase in legume content in the pasture. As Figure 3 shows, the proportion of *Arachis* was initially around 5% in the three stocking rates. However, in the third and subsequent years, the legume content increased to about 15%, particularly in the high stocking rate. This shows that *A. pintoi* in association with an aggressive grass has a slow start, but is able to compete and increase its contribution in the pasture with time.

The potential liveweight gains that can be obtained in *A. pintoi*-based pastures have been measured in Carimagua. The liveweight gains per animal recorded in a *B. dictyoneura*-*A. pintoi*-based pasture have been 180 kg/year. Because the pasture has a high carrying capacity—up to 3 animals/ha year-round—production per hectare has been over 500 kg of beef per year, which is a record figure for Carimagua (Figure 4).

Dual production systems of beef and milk are very important in many tropical areas of Latin America. Therefore, it has been of interest to determine the potential contribution of *A. pintoi* to milk production. An experiment conducted in Turrialba, Costa Rica (Table 10), shows that this legume in association with star grass (*C. nlemfuensis*) increased milk production by about 1 liter/day/cow (14% increase) compared with the grass in monoculture. This indicates that *A. pintoi*-based pastures are an alternative to expensive supplements to improve cattle nutrition and production in the tropics.

Alternative Use as Ground Cover/Soil Conservation

A. pintoi is a plant that tolerates shade. Observations carried out in Palmira (Colombia) have shown that full sun plants have about three quarters of the specific leaf area (leaf area per unit leaf mass) of shaded plants (Table 11). Also, shaded plants have higher above-ground biomass. This partly explains why this legume is able

Table 9. Persistence and contribution of *A. pintoi* CIAT 17434 associated with star grass (*C. nlemfuensis*) after four years of grazing in Turrialba, Costa Rica.

Pasture	Grass	Legume	Weeds	Native grasses
	(%)			
Star grass	51 a*	0	10 a	39 a
Star grass + *Arachis*	44 a	44	4 b	8 b

* $P<0.05$.

SOURCE: van Heurck, 1990.

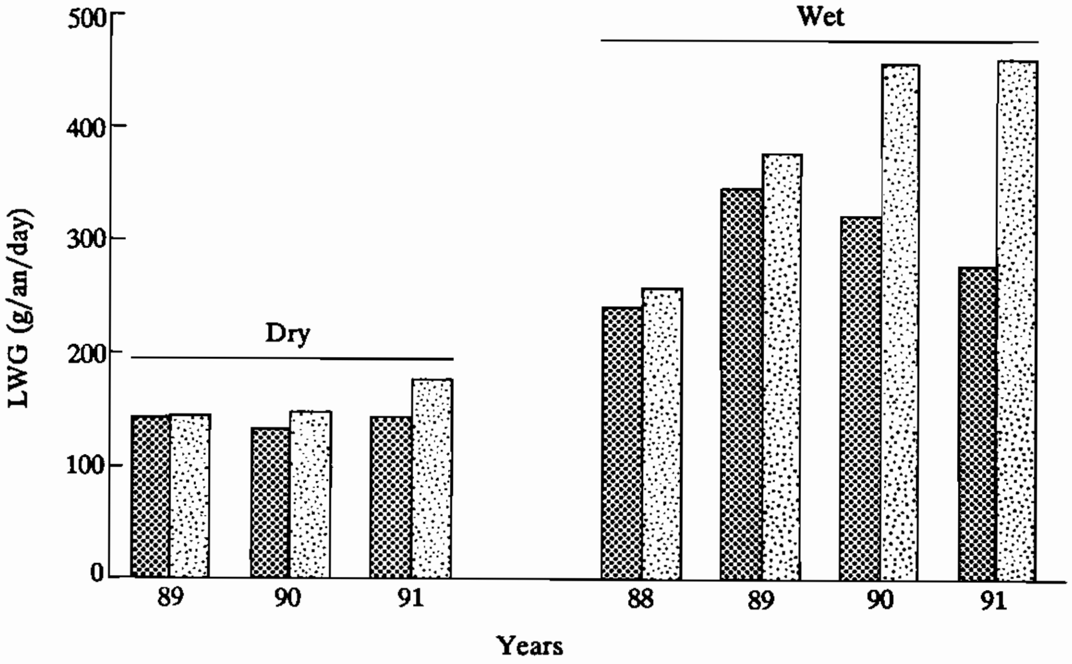

Figure 2. Animal liveweight gains in *A. pintoi* (17434)-*B. humidicola* pastures in Carimagua, Colombia. (Means of stocking rates of 2, 3, and 4 an/ha, a, b, different means, P = 0.05; CIAT, 1991.)

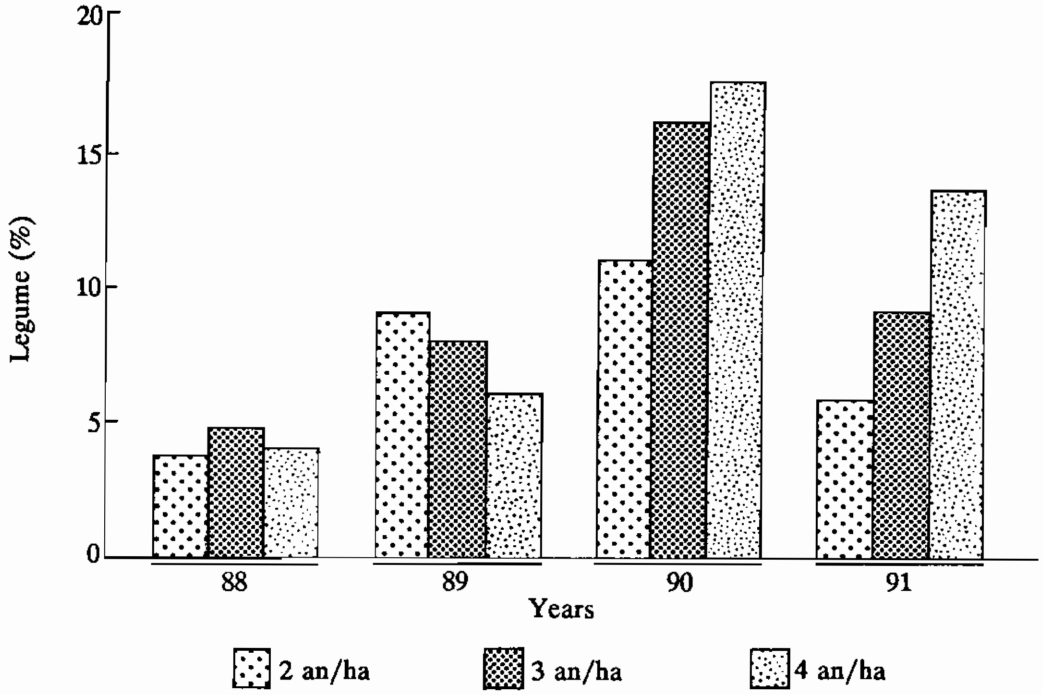

Figure 3. Percentages of legume in *B. humidicola*-*A. pintoi* CIAT 17434 pastures over several years in Carimagua, Colombia (rainy season only). (Adapted from CIAT, 1991.)

Table 10. Daily milk production of dual-purpose cows in different pastures in Turrialba, Costa Rica.

Pasture	Milk (kg/cow/day)
A. pintoi CIAT 17434 + star grass	8.8 a*
Star grass	7.7 b
S.E.	0.2

* a, b, different means, P<0.0001.

SOURCE: van Heurck, 1990.

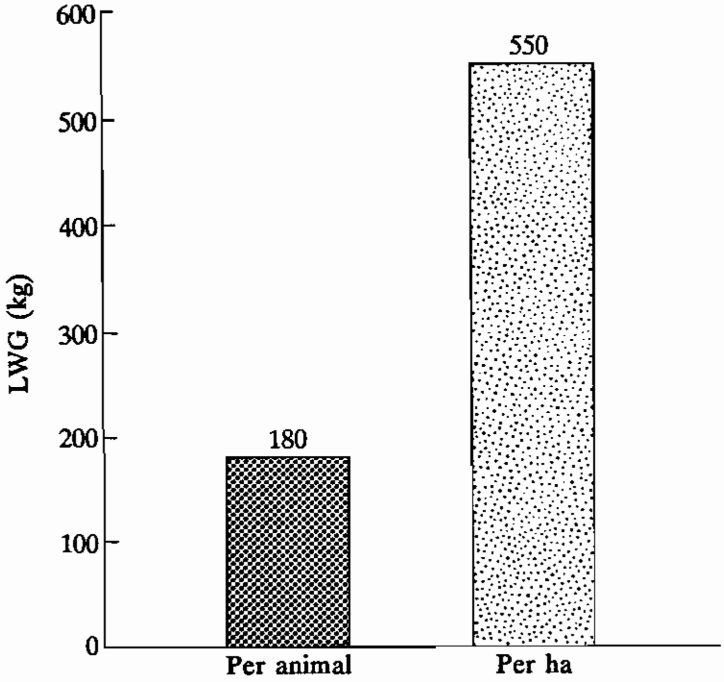

Figure 4. Liveweight gains in *A. pintoi-Brachiaria* spp. pastures in Carimagua, Colombia. (Adapted from CIAT, 1991.)

Table 11. The effects of different levels of shade on the growth of *Arachis pintoi* CIAT 17434 in pots at Palmira, Colombia, May-November 1990.

Level of shade	Number of leaves	Specific leaf area (cm^2/g)	Above-ground biomass (g/pot)
Full sun	457	150	9.77
70% full sun	401	204	11.24
50% full sun	423	216	12.56
30% full sun	442	214	12.98
S.E.	13.1 ns	6.4***	0.32**

*** $P<0.001$.
** $P<0.01$.
ns $P>0.05$.

SOURCE: CIAT, 1991.

to compete and grow in association with grasses that apparently compete with it for light (CIAT, 1991).

Ground covers are a cost-effective method of reducing the loss of valuable topsoil and the resultant decline of soil structure and productivity of plantation orchards. In addition, cover crops reduce weed invasion and give a nitrogen input to the plantation. Two major factors contribute to the suitability of *A. pintoi* as a cover crop and soil conservation plant: its ability to grow in shaded areas and the dense mat of rooted stolons that enables the plant to protect the soil from high-intensity rainfall.

There are only a few studies that report on nutrient competition of *A. pintoi* as a cover crop during the establishment of a permanent plantation. For instance, in Turrialba, Costa Rica, it was found that this legume negatively affected the growth of pejibaye (*Bactris gasipaes*) during the first nine months of plantation growth, mainly because of competition for nitrogen, as illustrated in Table 12 (Domínguez and de la Cruz, 1990). Perhaps in plantations already established or with a well-developed deep root system the competition of *A. pintoi* is negligible.

Limitations

Seed harvesting

Because of the sward-forming growth habit and asynchronous seed set of *A. pintoi*, conventional peanut cultural and harvesting practices are unsuitable. In addition, *A. pintoi* differs from the commercial peanut (*A. hypogaea*) in that seeds are not concentrated at the plant crown nor are they so firmly attached to the plant in either time or space because of its perennial growth habit and asynchronous seed set. Thus, seed harvesting of this plant is obviously different from that of other forage species (CIAT, 1991).

Rotary hoeing and sieving of the soil is the practice used to harvest underground seed. Hoeing has the dual effect of loosening the soil and cutting most of the pegs still attached to the pods (Dwyer et al., 1989). Mechanical field separators have been constructed at CIAT based on prototypes developed in Australia. These are being used in current harvests of small production areas of the TPP. In this process, a considerable amount of soil needs to be removed.

Slow establishment

A. pintoi is regarded as a slow plant to establish. However, the rate of ground cover seems to be related to availability of moisture and soil fertility. Figure 6 shows that there were differences in ground cover at 12 weeks after planting in different sites of Colombia's savannas (CIAT, 1986). At Villavicencio, under better soils and high environmental humidity, ground cover was considerably higher compared with other sites with poorer soils and less humidity.

Table 12. Nutrient concentration in leaves of pejibaye (*Bactris gasipaes*) at 9 months after planting with and without *A. pintoi* CIAT 17434 as cover crop.

Treatment	Nutrient (%)			
	N	P	K	S
Pejibaye + *A. pintoi*	2.55 b*	0.18 a	1.55 b	0.14 a
Pejibaye	4.35 a	0.16 a	0.80 a	0.15 a

* $P<0.05$.

SOURCE: Domínguez and de la Cruz, 1990.

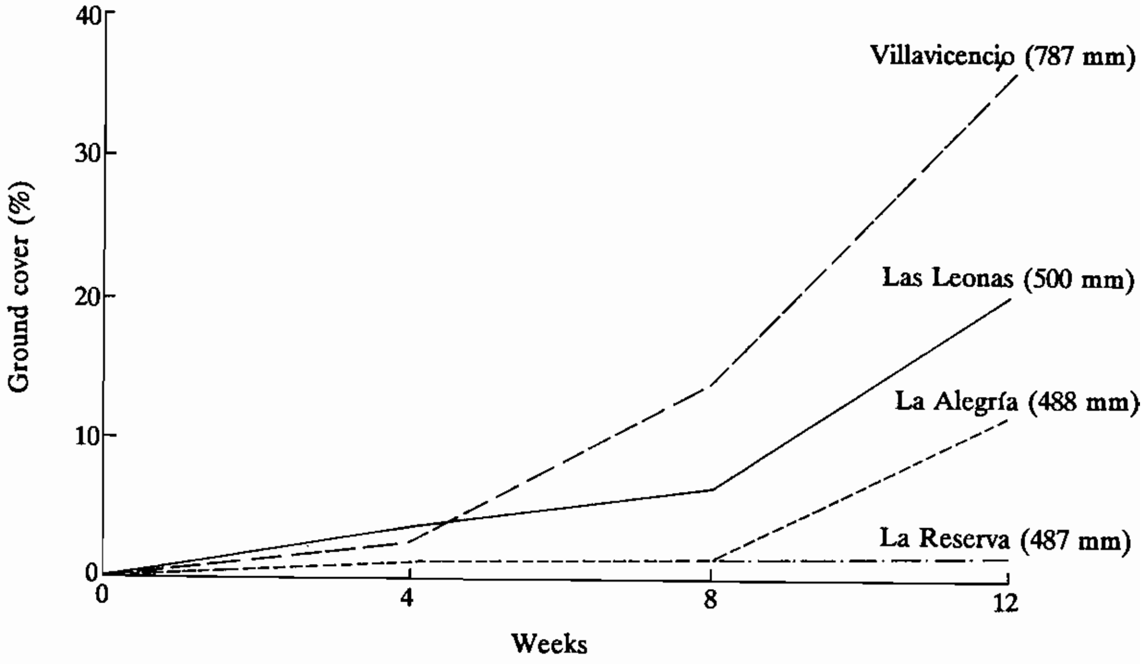

Figure 5. Ground cover of *A. pintoi* CIAT 17434 during establishment at four sites in Colombia. Total rainfall at 12 weeks is in parentheses. (Adapted from CIAT, 1988.)

Future Priorities

Although *A. pintoi* is a highly promising species, CIAT's TPP presently has only eight accessions, which represent a narrow genetic base for a species that may have ample variability based on the natural distribution of the genus *Arachis* in South America. It is therefore necessary to broaden the genetic base by plant collection and search for plants more tolerant to drought and quicker to establish.

Conclusions

Arachis pintoi is a species that has agronomic characteristics that make it suitable as a legume for grazing and as a ground cover plant. Its positive agronomic attributes include adaptation to poor acid soils; resistance and tolerance to pests and diseases; prostrate, stoloniferous growth habit; and being a prolific seeder.

A. pintoi also has several positive grazing attributes. It is a high-quality legume; it is well consumed by animals during the dry and wet season; it has good animal performance; it is highly compatible with stoloniferous grasses; and it tolerates heavy grazing and heavy defoliation. For soil conservation and ground cover potential, *A. pintoi* has a dense mat of rooted stolons and it tolerates shade.

A. pintoi has two limitations: slow establishment and buried seed that is difficult to harvest. In addition, we have a very narrow genetic base of *A. pintoi*. This calls for plant exploration in the center of diversity.

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CHAPTER 6

INTEGRATING THE NATIVE SAVANNA RESOURCE WITH IMPROVED PASTURES

M. J. Fisher, C. E. Lascano, R. R. Vera, and G. Rippstein*

Introduction

Location

We shall consider the use of the native savannas of South America in the well-drained savannas of both Brazil (Cerrados) and Colombia and Venezuela (Llanos), with a combined area of some 200 million ha. In both of these subdivisions, the strongly seasonal rainfall causes a seasonal variation in both the quality and quantity of the forage resource.

Infrastructure, and its influence on property options

Infrastructure, meaning roads, closeness to market, and so on, varies tremendously on a national basis (Figure 1). It is very well developed in Venezuela, not quite so well developed but generally adequate in Brazil, and virtually non-existent in Colombia, with scarcely any paved roads east of the Andean piedmont.

Where infrastructure is limited, the cost of land is low (US$40-50/ha in the Colombian Llanos, for example), there is very little management input, and graziers attempt to maximize production per head in their breeding operations, which is the predominant system. As the infrastructure improves, the cost of land increases to US$100-200/ha, and there is a rather larger management input, particularly when the operation develops sufficiently to include fattening in addition to a cow-calf herd. The areas close to markets with good infrastructure have high-priced land of US$500-1000/ha, and attempt to maximize production per unit of land. In these areas, savanna pastures are unimportant, and crops and intensive animal systems are the norm. We shall consider only the first two cases in this article.

The point to note is that the level of infrastructure development largely determines property development. It also determines the research emphasis on grassland management and the potential adoption of improved pasture technology.

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* Pasture ecophysiologist, animal scientist, animal scientist, and grassland ecologist, respectively, Tropical Pastures Program, CIAT. The authors would like to thank J. M. Spain for his contributions to this work.

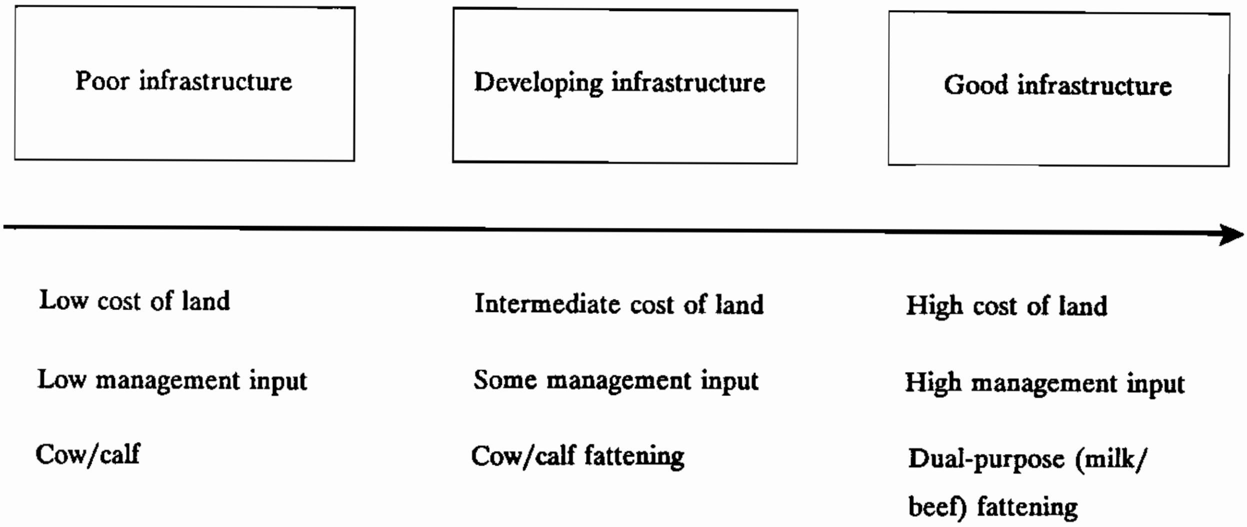

Figure 1. Latin American savanna grasslands.

The Savanna Resource

Genetic diversity of savanna communities

The savanna communities are characterized by wide species diversity. Not only do they vary widely in their composition among the various land units within one ecosystem, but they vary more widely among ecosystems. For example, at Carimagua, with an area of 22,000 ha, over 150 species have been identified in the savanna communities. It is possible to influence species composition profoundly by management practice, such as grazing intensity and time and frequency of burning.

With high annual rainfall the Panicoid grasses dominate (Table 1), principally species of *Axonopus* and *Leptocorphium* (Johnson and Tothill, 1985). However, in the better drained lands, the Andropogonoid grasses dominate, with species of *Andropogon* and *Trachypogon* together with *Leersia* and sedges. Herbaceous legumes tend to be sparse and to make little or no contribution to animal performance in unimproved savanna. In the Brazilian savannas, a number of *Paspalum* species occur, which offer the potential to respond to higher fertility.

Table 1. Dominant species in savanna vegetation.

Site characteristics	Suborder	Genera
High rainfall	Panicoidae	*Axonopus* *Leptocorphium*
Better drained	Andropogonae	*Andropogon* *Trachypogon*
		Leersia
		Various sedge species

SOURCE: Johnson and Tothill, 1985.

Savanna productivity

The main characteristic of the savanna communities is their low nutritional quality for grazing animals. This is entirely reasonable, at least from the plants' point of view, because the soils are uniformly low in N, P, K, and Ca, plant nutrients essential for production of high-quality forage. The plants have therefore developed strategies to conserve their scarce resources, generally by rapidly becoming lignified. The main point about lignin is that it is not digestible.

When savanna grasses are divided into prostrate and erect types, and the erect ones are further divided into high and low crude protein content (Table 2), the digestibilities also separate out. The prostrate grasses, such as the *Axonopus* spp., have reasonable digestibility and adequate protein. However, they have low drought resistance, and are of little use during the dry season. The tall grasses endure quite well in the dry season, but even at the start of the wet season, when quality is at its highest for the year, the high crude protein group has marginal digestibility, while the low crude protein group is well below animal requirements for digestibility, protein, calcium, and phosphorus.

Traditional management of savanna

The traditional management consists of burning twice a year: the upland areas at the start of the rains, and the lower areas, which are too wet to graze during the rainy

Table 2. Savanna grass species grouped by habit and nutritive quality at the start of the wet season (after Hoyos and Lascano, 1988).

Pasture type	IVDMD (%)	Crude protein (%)	Calcium (%)	Phosphorus (%)
Prostrate	43.0 a	8.1 a	0.24 a	0.15 a
Erect, high CP	35.0 b	7.8 a	0.24 a	0.15 a
Erect, low CP	23.6 c	4.5 b	0.09 b	0.07 b
Standard error	2.0 ***	0.29 ***	0.01 ***	— ***

Figures in the same column followed by the same letter do not differ significantly.

*** $P<0.001$.

season, at the end of the rains. Grazing is continuous, but the cattle concentrate on the recently-burned areas. Mineral supplementation is sporadic and variable.

Animal production is very low, with liveweight gains of 40 or less to 70 kg/head per year. Breeding rates are also low (50%), particularly in lactating animals, and abortions and mortality losses are high. This poor performance is largely due to poor nutrition.

Data from Altagracia farm, neighboring Carimagua, in consecutive years for steers grazing native savanna emphasize the point (Table 3). Over the seven months of the rainy season, animals weighing 230-240 kg at the start of the season gained only 150-210 g/day or 35-50 kg/head.

Research Objectives

Define limitations

The research objectives of the Tropical Pastures Program (TPP) in the savannas are based on the recognition that savannas are an important resource that we need to understand. We then tried to define their nutritional limitations and to identify low-cost alternative management practices to overcome them. The nutritional limitations were found to be mineral deficiency, principally phosphorus, and deficiency of digestible energy in the diet. The management strategies to overcome these

Table 3. Liveweight gains of steers grazing savanna in the rainy season in the Colombian Llanos (Altagracia).

	Year		
	1983	1984	1985
Days of grazing	219	228	223
Number of steers	16	15	15
Initial liveweight (kg)	242	231	233
Liveweight gain (kg/day ± S.E.)	0.174 ±0.075	0.212 ±0.043	0.154 ±0.025
Total liveweight gain (kg/head)	38	48	34

SOURCE: R. Vera, unpublished data.

limitations were to determine responses to mineral supplements, and to seek to raise the digestible energy by managed burning, by grazing management, by providing fodder banks, and by oversowing the savanna with legumes.

Identify management options

We shall now describe how we have defined the nutritional limitations of savanna vegetation and how they are responsible for low animal productivity, and how we have tested management options to overcome them in terms of animal production, while not degrading the resource. We shall then discuss the integration of this savanna resource with improved pastures, which may be used to increase the productivity of animal production systems, either by complementing or supplementing the savannas, but not by replacing them completely. We shall conclude by considering some implications improved pastures have for the savanna resource.

Limitations

Energy versus protein

In northern Australia, Norman (1966) showed that savanna grasses were protein deficient, especially during the dry season (Figure 2). When cattle grazing native pasture were supplied with protein supplement, their liveweight gain was proportional to the digestible crude protein of the supplement. In contrast, cattle grazing savanna pasture at Carimagua showed no clear relation between protein content and animal liveweight gain (Figure 3A). More specifically, even when crude protein was in excess

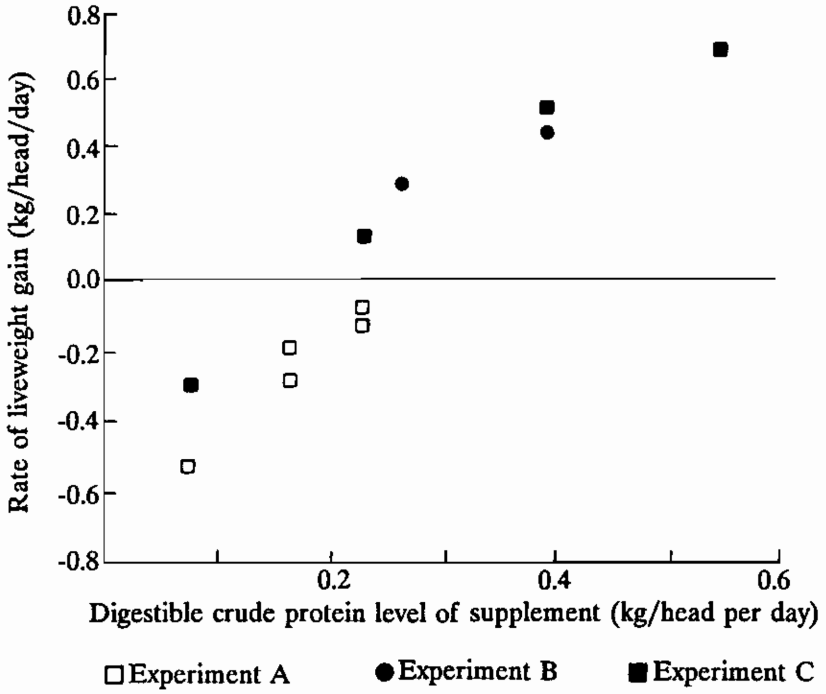

Figure 2. Relation between liveweight changes on native pasture during the dry season and digestible crude protein in the supplement (from Norman, 1966).

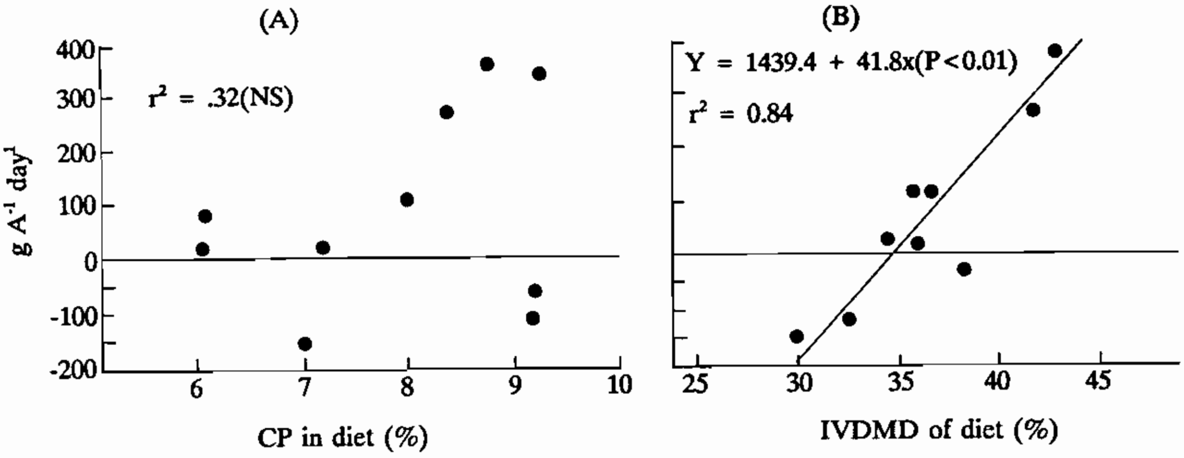

Figure 3. Relationship of liveweight gain with crude protein (A) and digestibility (B) of the diet selected by cattle grazing savanna. (From Alvarez and Lascano, 1987.)

of 9%, the animals still lost weight, which is compelling evidence that protein content of the South American savannas does not control liveweight. On the other hand, there was a clear relation between in vitro dry matter digestibility and liveweight gain (Figure 3B), and the regression also indicates that the critical digestibility to meet the animals' energy needs is about 35%, somewhat lower than the commonly accepted 40% (Alvarez and Lascano, 1987).

Mean digestibility of neotropical savanna grasses is rarely more than 40% (Figure 4), so that animals grazing them are unable to satisfy their energy needs. In contrast, mean crude protein content during the rainy season is 8%-9%, and 6% during the dry season (Figure 4) (Alvarez and Lascano, 1987). In northern Australia, savanna grasses have higher digestibility but lower protein contents, so that there the animals' energy needs are met, and they respond to supplementary protein.

Minerals

Because the mineral contents of savanna grasses are so low, mineral deficiencies in grazing livestock, particularly of phosphorus, are widespread. The effects depend on the class of the animals involved, and are demonstrated by the performance of cattle supplemented with phosphorus, contrasted with those without a supplement (Table 4) (Vera, 1990). Supplementation with a salt lick containing 6% phosphorus had spectacular results in terms of the first conception of maiden heifers, mainly through reduced abortions and reduced calf mortality during the first month after birth. Mature cows did not respond to the same extent (Table 4). There is little doubt that improved reproduction is associated with increased liveweights, most probably due to enhanced voluntary intake, but P deficiency is unequivocally related to low breeding performance.

The improved weight gains of young animals with P supplementation were demonstrated in an experiment in which heifers were supplemented with different concentrations of P in the mineral lick when grazing savanna at the very conservative stocking rate of 10 ha per animal, compared with heifers grazing an *Andropogon gayanus-Centrosema acutifolium-Stylosanthes capitata* pasture stocked at 1.5 head/ha (Figure 5). The savanna heifers had ample opportunity to select a diet within the savanna community that was adequate in terms of protein and probably energy, that is, their diet had higher digestibility, which was likely to have been responsible for the interaction between pasture type and phosphorus level (Vera, 1990).

Management Options

Burning

Farmers use burning to make young green growth accessible. Burning destroys the lignified, mature material and exposes the tender, young growth to the grazing

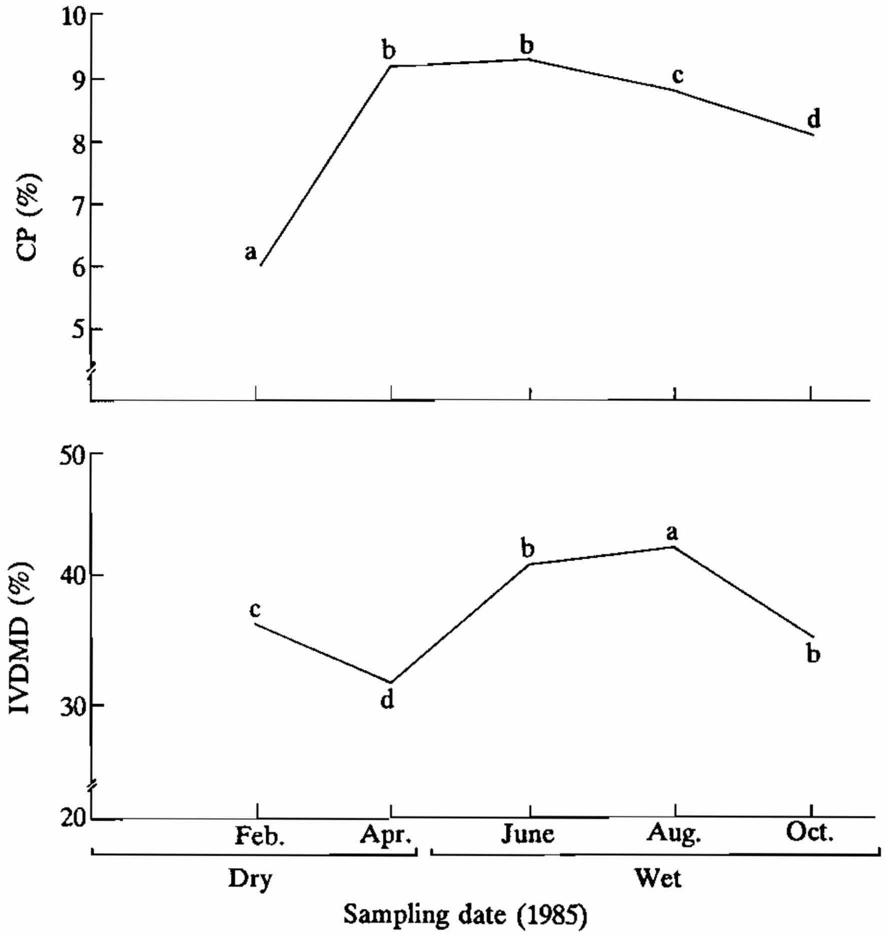

Figure 4. Diet quality of savanna. (From Alvarez and Lascano, 1987.)

Table 4. The effect of mineral supplementation on the reproductive performance of heifers and cows grazing native savanna in Colombia (from Vera, 1990).

Mineral supplement	First-calf heifers		Adult cows
	Abortions (%)	Calving (%)	Calving (%)
Salt	24	52	52
Salt with 8% P	3	91	55

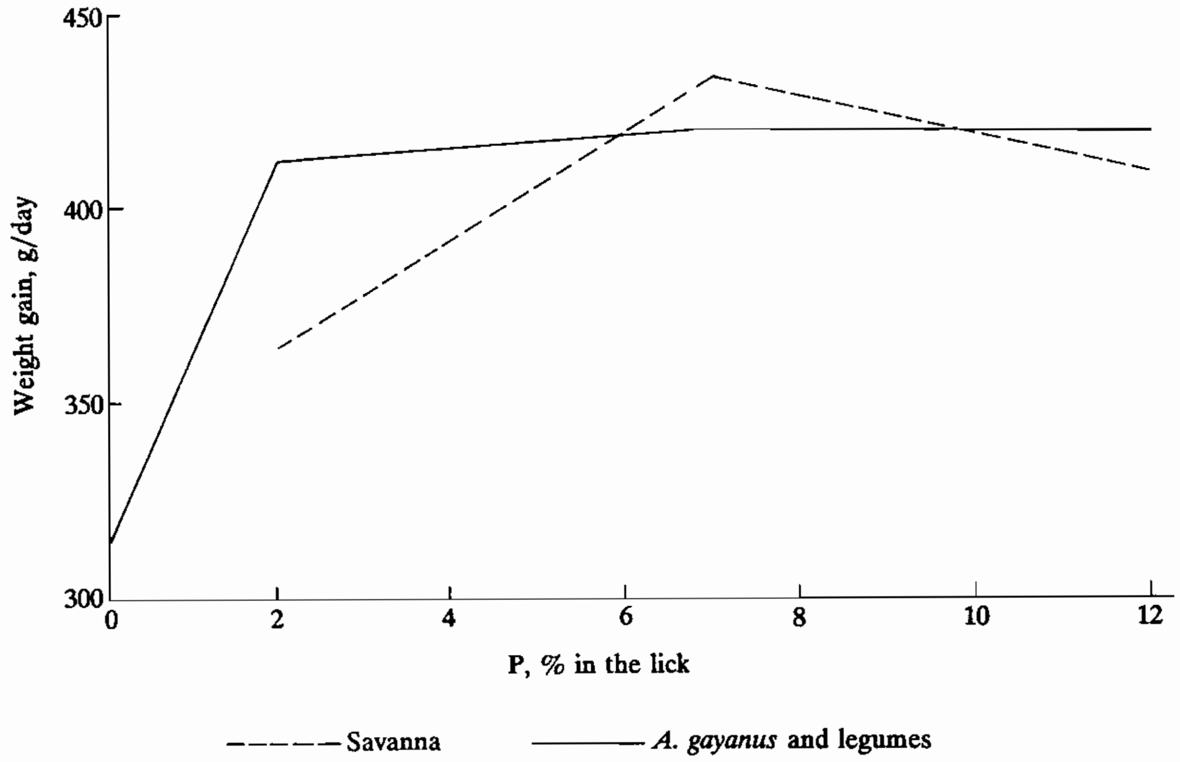

Figure 5. Response to phosphorus in heifers.

animals. Certainly, the protein content of the young regrowth is higher, up to 9%, but it is not protein that is limiting. Unfortunately, even when savanna grasses are young and green, their digestibility is still less than 40%.

Moreover, after burning, the quantity of forage is limited (Figure 6), as illustrated in the dry-matter yields of savanna burned at three different times during the year. One month after the burn, dry-matter yields were less than 200 kg/ha, so that the animals grazing these burned areas were frequently unable to satisfy their appetite (Alvarez and Lascano, 1987). Not only were they hungry, but because of the low digestibility of the forage they could not make use of what they did eat. Nevertheless, cattle preferentially graze areas that are recently burned. In the same pasture, burned at the end of the rains, at the end of the dry season, and in the middle of the rainy season, cattle spent more than 50% of the effective grazing time on recently burned areas (Figure 7).

The low dry-matter yield of recently burned pastures is further complicated by the rapid regrowth of the native grasses, which results in rapid decline of forage quality, particularly for protein and minerals. The P levels in leaf of native grasses can be as low as 0.05% and rarely exceed 0.15%, which is below the requirements of growing animals.

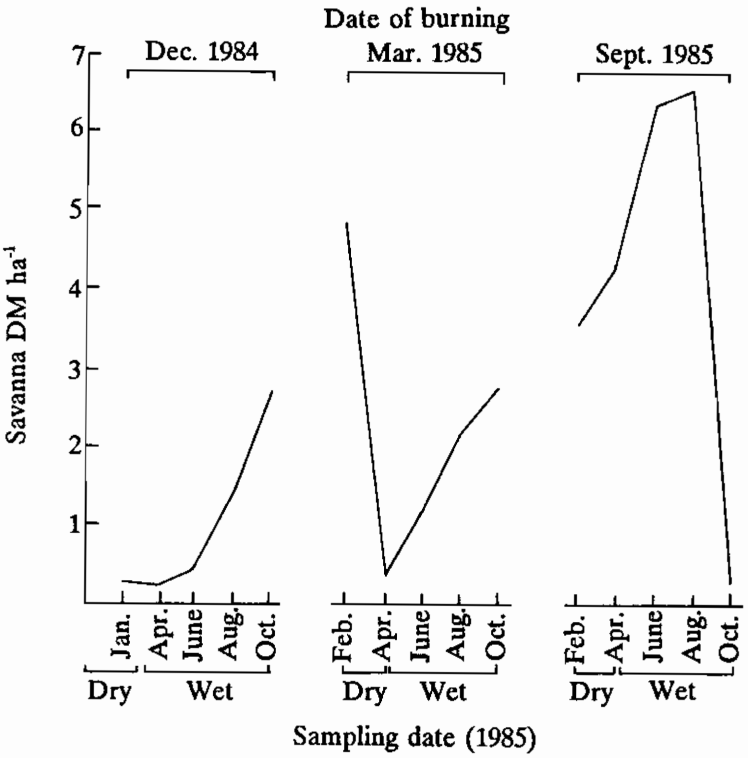

Figure 6. Forage availability in savanna. (From Alvarez and Lascano, 1987.)

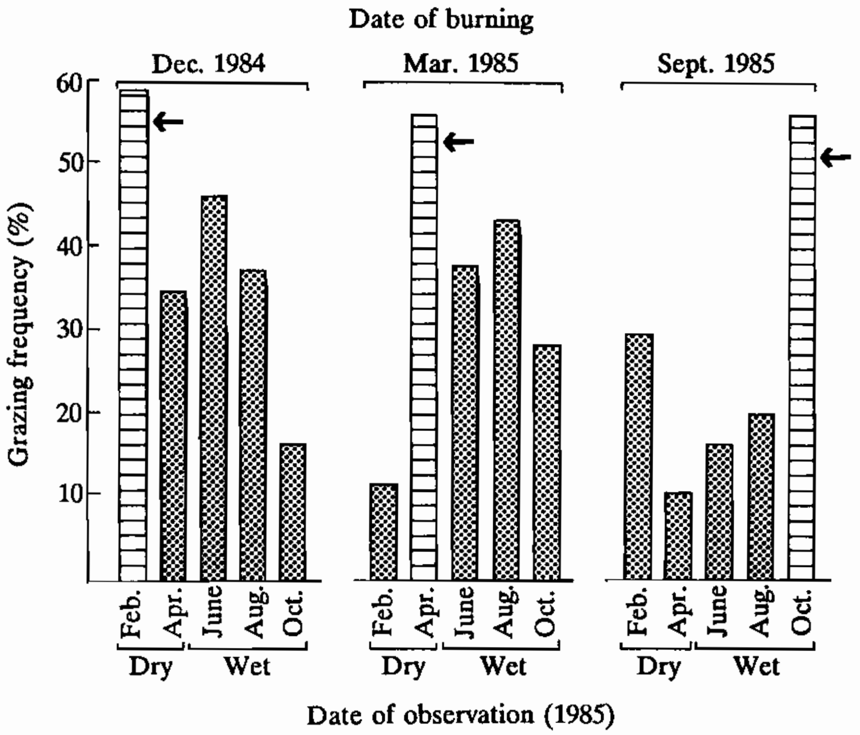

Figure 7. Effect of time of burning native savanna on grazing frequency. Arrows indicate the recently burned plots. (From Alvarez and Lascano, 1987.)

Burning does give a response in animal liveweight gains, especially if the stocking rate is not so high that the animals are limited by the low availability of forage. Thomas et al. (1990) showed that when the stocking rate is no more than 3 ha/animal unit, liveweight gains are about 90 kg/head compared with 30 to 40 kg/head in unburned savanna (Table 5).

The botanical composition of an old burning experiment was determined after the treatments had been applied for 10 years at Carimagua (Table 6). The experiment was burned at one of three times, in April at the start of the rains, in August in the middle of the rainy season, and in December at the end of the rains. The burning treatments were each grazed at either 2 or 4 ha/animal. Botanical composition was greatly influenced by the time of burning (note the large decrease in the presence of *Axonopus purpusii* when burned at the start or end of the rains, and the almost total elimination of *Gymnopogon foliosus* with burning in August and December). Burning and stocking rate interact strongly with *Trachypogon vestitus*, which is favored by light grazing and burning either at the start or end of the rains (G. Rippstein, unpublished data).

Grazing management

Rotational grazing. Continuous grazing of burned savanna was compared by Paladines and Leal (1979) with rotational grazing at Carimagua with the idea of controlling the rate of savanna regrowth, and hence its rate of decline of quality (Figure 8). At all the stocking rates used (2 to 5 animals/ha), rotational grazing was obviously inferior to continuous grazing.

Fertilizer application to savanna. It is a valid question to ask whether savanna grasses would respond to fertilizer as much as introduced species. There is also likely to be transfer of nutrients from fodder banks, which we shall examine in the next section, to the savanna in integrated grazing systems, so the question is more than academic.

A range of fertilizers were applied to savanna grasses growing on both a clay and a sandy soil at Carimagua (Table 7). **Growth rates** of the savanna grasses did not respond to nitrogen in the absence of other nutrients. On the sandy soil, there were responses to nitrogen only when P and K were applied, while on the heavier soil there were responses to nitrogen only when Ca was applied as well. Although growth rates were over twice those of the controls, they were still less than 20% of the growth rates of grasses such as *Andropogon gayanus* or the *Brachiaria* species. Digestibilities of the savanna grasses were never better than those of the unfertilized savanna (G. Rippstein, unpublished data).

Protein contents followed the same pattern as growth rate (Table 8). That is, **protein content** did not respond to nitrogen in the absence of other nutrients. On the sandy soil, there were responses in protein content to nitrogen only when P and K

Table 5. Effects of burning native savanna vegetation on the liveweight gains of steers at three stocking rates on the Colombian Llanos (from Thomas et al., 1990).

Stocking rate	Liveweight gains			
	Without burning		With burning	
	kg/animal	kg/ha	kg/animal	kg/ha
0.20 AU/ha	28	6	92	18
0.33 AU/ha	38	13	94	33
0.50 AU/ha	2	1	74	37

Table 6. Relative presence of some native savanna grasses after 10 years of burning at different times of the year, grazed at two stocking rates.

Species	Low stocking rate (0.25 AU/ha)			High stocking rate (0.5 AU/ha)		
	Burning in:			Burning in:		
	April	Aug.	Dec.	April	Aug.	Dec.
Axonopus purpusii	0.0	45.1	6.2	0.6	62.0	10.4
Andropogon leucostachyus	2.6	5.3	11.9	1.3	3.5	7.1
Gymnopogon foliosus	34.8	0.3	0.0	48.7	0.0	0.0
Panicum versicolor	3.0	3.4	11.8	11.7	6.1	5.8
Trachypogon vestitus	38.0	19.5	51.5	12.1	3.3	3.7

SOURCE: G. Rippstein, unpublished data.

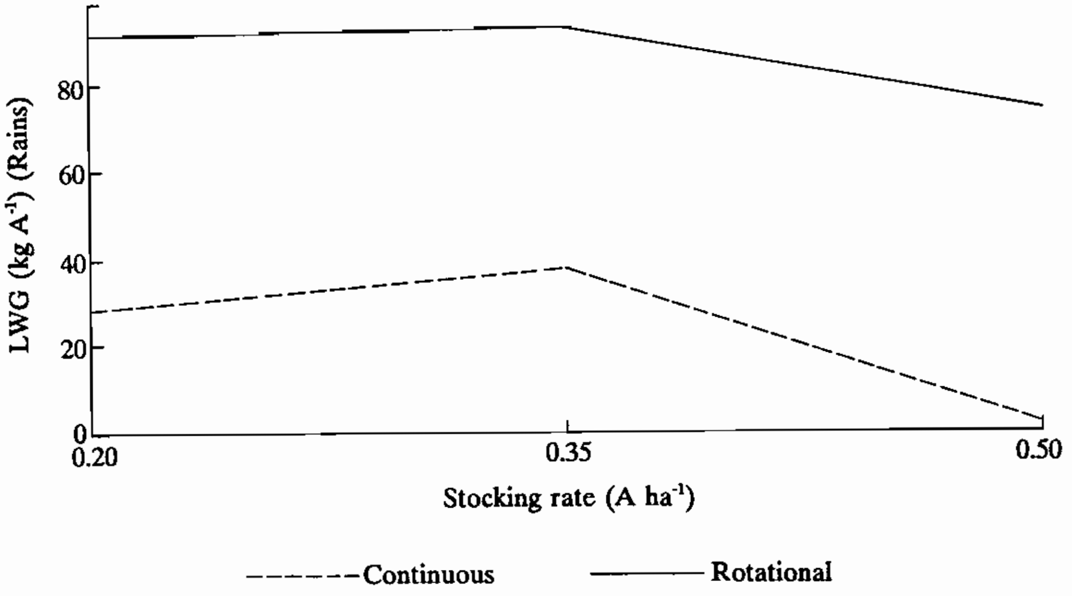

Figure 8. Liveweight gain in savanna with different grazing systems. (From Paladines and Leal, 1979.)

Table 7. Response of growth rate and in vitro digestibility in savanna on a sandy and a clay soil to fertilizer treatments.

Treatment	Sandy soil		Clay soil	
	Growth rate (kg/ha/day)	IVDMD (%)	Growth rate (kg/ha/day)	IVDMD (%)
Control	4.5 a	35.1	4.5 a	42.6
N*	6.0 a	28.7	5.7 a	41.0
PK	6.0 a	36.5	5.6 a	41.1
NPK	9.3 b	32.9	6.9 a	37.6
NPKCa	10.6 b	33.2	11.2 b	44.9

* N = 100 kg/ha, P = 44 kg/ha, K = 55 kg/ha, Ca = 100 kg/ha.

Numbers followed by the same letter in each column did not differ significantly ($P>0.05$).

SOURCE: G. Rippstein, unpublished data.

Table 8. Response of phosphorus and protein contents in savanna on a sandy and a clay soil to fertilizer treatments.

Treatment	Sandy soil		Clay soil	
	P (%)	Protein (%)	P (%)	Protein (%)
Control	0.10	8.4	0.09	7.9
N*	0.08	8.4	0.09	8.4
PK	0.18	8.8	0.09	6.1
NPK	0.19	9.8	0.13	7.9
NPKCa	0.21	10.1	0.15	10.5

* N = 100 kg/ha, P = 44 kg/ha, K = 55 kg/ha, Ca = 100 kg/ha.

SOURCE: G. Rippstein, unpublished data.

were applied, while on the heavier soil there were protein responses to nitrogen only when Ca was applied as well. It seems likely that protein content of the savanna grasses controls their growth rate. Phosphorus concentrations in the tissue increased markedly on the sandy soil when P was applied, but on the clay soil only when N and K were applied as well (G. Rippstein, unpublished data).

It seems unlikely that we can expect much improvement in the growth or quality of savanna, either if fertilizer were applied directly, or with nutrient transfer from areas of improved pastures that receive fertilizer.

Fodder banks

Fodder banks refer to protein and energy banks. A protein bank is a legume pasture with little or no grass, and an energy bank is a legume-grass association.

Lascano and Plazas (1990) complemented cattle grazing native savanna with either an energy bank that consisted of 2000 m^2/animal of an *Andropogon gayanus* (grass) pasture with a legume component (*S. capitata*), or a protein bank of 2000 m^2/animal of a kudzu (legume) pasture (Figure 9). The animals were given unrestricted access to the banks throughout the year.

The animals clearly responded more to the energy bank than to the protein bank, with liveweight gains of 157 kg/animal over a one-year period, which were significantly better than the 113 kg/animal with the protein bank. The other point to

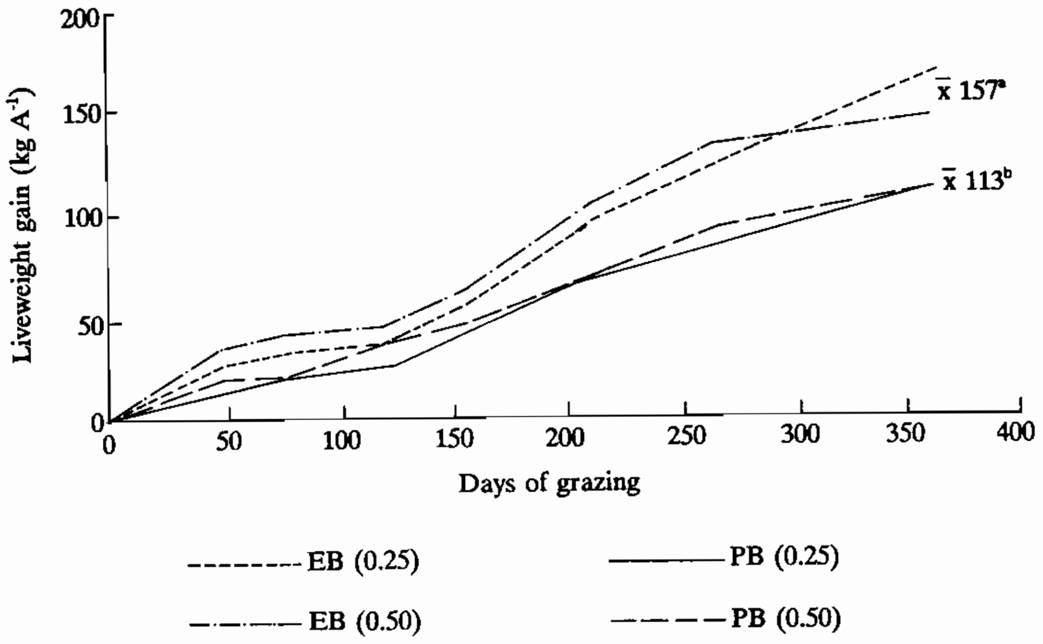

Figure 9. Effect on liveweight gain of complementing savanna with a protein bank (PB) or an energy bank (EB) at 2000 m^2/head (Carimagua). Figures in parentheses are the stocking rates on savanna.

note is that there were no marked seasonal trends in the liveweight gains of the cattle with access to the protein bank, although in the energy bank liveweight gains declined during the dry season, when digestibility of the sown grass fell.

The higher liveweight gain of animals with access to the energy bank as compared with the protein bank at both the high and low stocking rates was associated with higher digestibility of the diet selected in both seasons of the year (Table 9). Cattle selected a diet with 47% IVDMD in the energy bank/savanna, while in the protein bank/savanna the diet selected was only 41% digestible. Protein in the forage selected by the cattle was not a limiting factor either in the savanna, where it averaged 10.5%, or in the energy bank, where it averaged 10% across both seasons of the year.

The animals grazed almost four times as much in the energy bank as compared with the protein bank (Table 10). Grazing frequency in the energy bank was around 50% and only 15% in the protein bank.

In spite of the high grazing frequencies in the energy bank, it was not overgrazed. Average dry matter on offer throughout the year was above 2000 kg/ha with the high stocking rate and over 3000 kg/ha with the low stocking rate (Figure 10).

Table 9. Quality of the diet selected in savanna and fodder banks.

Season	Savanna		Protein bank[a]		Energy bank[b]	
	CP (%)	IVDMD (%)	CP (%)	IVDMD (%)	CP (%)	IVDMD (%)
Dry	11.3	36.6	16.1	41.0	9.8	45.7
Wet	10.0	41.2	14.9	40.6	10.2	47.7

a. *Pueraria phaseoloides* (2000 m^2 A^{-1}).
b. *Andropogon gayanus/Stylosanthes capitata* (2000 m^2 A^{-1}).

SOURCE: Lascano and Plazas, 1990.

Table 10. Grazing frequency in protein (PB) and energy (EB) banks as complement of savanna.

Season	Stocking rate (A ha^{-1})	PB[a] (%)	EB[b] (%)
Dry	0.25	14	42
	0.50	16	63
Wet	0.25	12	57
	0.50	18	55

a. *Pueraria phaseoloides* (2000 m^2 A^{-1}).
b. *Andropogon gayanus/Stylosanthes capitata* (2000 m^2 A^{-1}).

SOURCE: Lascano and Plazas, 1990.

The burning sequence on the savanna (three times a year), combined with the mineral licks and watering points being placed outside the banks, encouraged the animals to move out of the bank and to graze the native grasses.

Cattle supplemented with the energy bank (small areas of grass pasture) gained sufficient liveweight to support a fattening system, with a projected turnoff age of 3 years (Paladines and Leal, 1979).

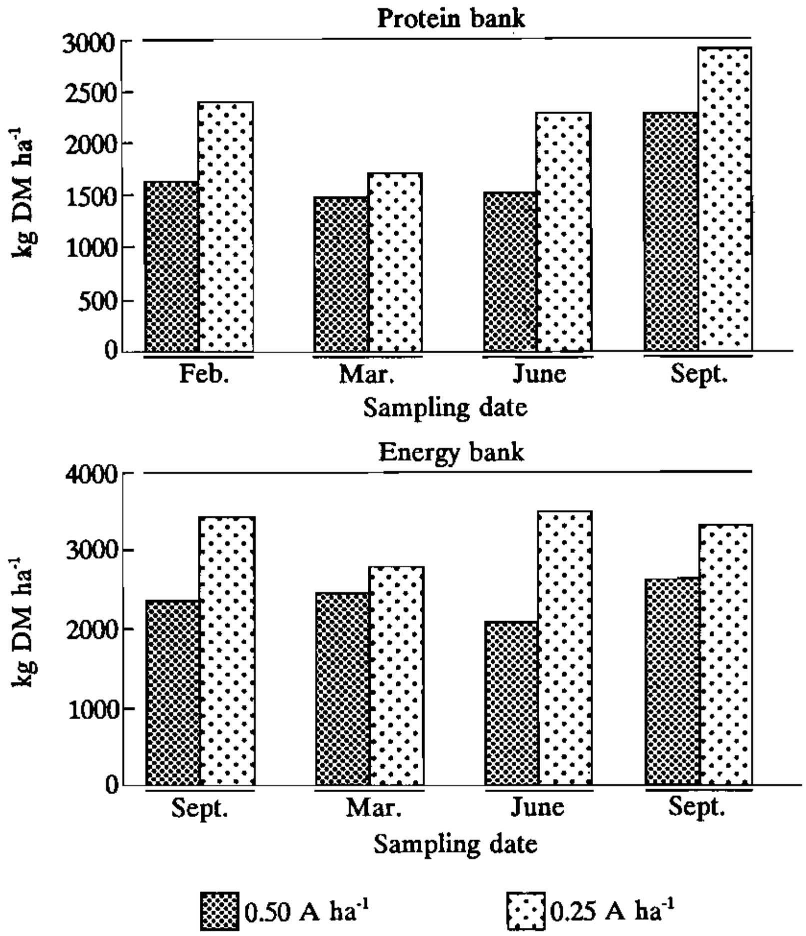

Figure 10. Forage-on-offer fodder banks complementing native savanna. (From Lascano and Plazas, 1990.)

A commercial property on the Colombian Llanos sowed 5% of its area to *Andropogon gayanus* and *Stylosanthes capitata* (Table 11). The performance of the herd was measured over six years, 1979-1984. Carrying capacity doubled and cow weights increased by 40%. Conception rates were variable but were some 50%-60% higher, and weaning weights of the calves increased by over 30% (Vera and Seré, 1990). This is a spectacular increase when one considers the small proportion of the area actually sown to pasture, and that these were on-farm results for a herd of more than 300 cows. It provided the basis for the confidence with which the TPP undertook involvement in extension activities in the area in association with the national program (see Ferguson, Chapter 7). With regard to the analysis of data on herd performance, we must pay tribute to CIAT's Data Services Unit, which has developed innovative statistical techniques to deal with the complexities of these data.

Small areas (1800 m^2 per animal) of a sown grass-legume mixture were used to supplement a breeding herd year-round, by allowing animals free access to them

Table 11. Use of small areas of improved pastures on a commercial farm.[a]

Parameter	Year					
	1979	1980	1981	1982	1983	1984
No. of cows	330	328	390	427	446	485
Stocking rate (AU ha^{-1})	0.08	0.13	0.15	0.16	0.19	0.19
Cow weights (kg)	233	292	303	301	332	328
Conception (%)	50	64	62	76	53	60
Weaning weight (kg)	109	119	118	142	148	143

a. 5.5% of farm area with improved pastures (*Andropogon gayanus/Stylosanthes capitata*).

(Vera, 1990). The breeding performance was better, as measured by increased weaning rates, improved conception in lactating cows, and a shorter time to reconception (Table 12). It was also possible to use a much cheaper mineral supplement containing only half the amount of P that the savanna herd needed.

Oversowing savanna with legumes

Savanna can be oversown with pasture legumes, with the idea that cattle would complement their diet by grazing both the savanna and the legume more or less simultaneously, in contrast to a fodder bank, which is physically separate from the savanna. It was thought that this might stimulate intake, and that the legume might make a contribution to quality of the savanna grasses. Of course, as was already mentioned, we have recently shown that nitrogen responses in savanna grasses are unlikely unless other nutrients such as P, K, and Ca are also applied.

Hoyos (1987) oversowed *Stylosanthes capitata* in a savanna to give 1500 m^2 of sown area per head, and grazed at 1 and 1 1/3 animals/ha, compared with an unsupplemented savanna grazed at 1/3 animals/ha (Table 13). There was little difference among the animal liveweight gains, so that production per hectare was three or four times better than in the unsupplemented savanna. The data for the *Stylosanthes capitata* on offer during the course of grazing show that the animals grazed it to an extreme extent, so much so that at the end of the first growing season the legume had been virtually eliminated (Figure 11). At this stage, the animals started to lose weight heavily, as could be expected, since by that stage they were really grazing unimproved savanna at a very high stocking rate.

Table 12. Comparison of the reproductive performance of breeding herds grazing savanna, either continuously supplemented with small areas of improved pastures or unsupplemented. Mating was continuous.

	Control	Supplemented
P in lick (%)	8	4
Weaning rate (%)	51 a	61 b
Reconception in lactating cows (%)	15 a	35 b
Calving-reconception interval (days)	290 b	255 a
Calf mortality (%)	12	12

Numbers followed by the same letter in each column did not differ significantly ($P<0.05$).

SOURCE: Vera, 1990.

Table 13. Liveweight gain of steers grazing savanna alone and oversown with legumes (*S. capitata*) during the rainy season (206 days).

Stocking rate	Savanna[a]		Savanna + legume[b]	
	g $A^{-1} day^{-1}$	kg ha^{-1}	g $A^{-1} day^{-1}$	kg ha^{-1}
0.33	380	26		
1.00			400	82
1.33			386	106

a. Traditional burning.

b. 1500 m^2 A^{-1} (original area planted with legume).

SOURCE: Hoyos, 1987.

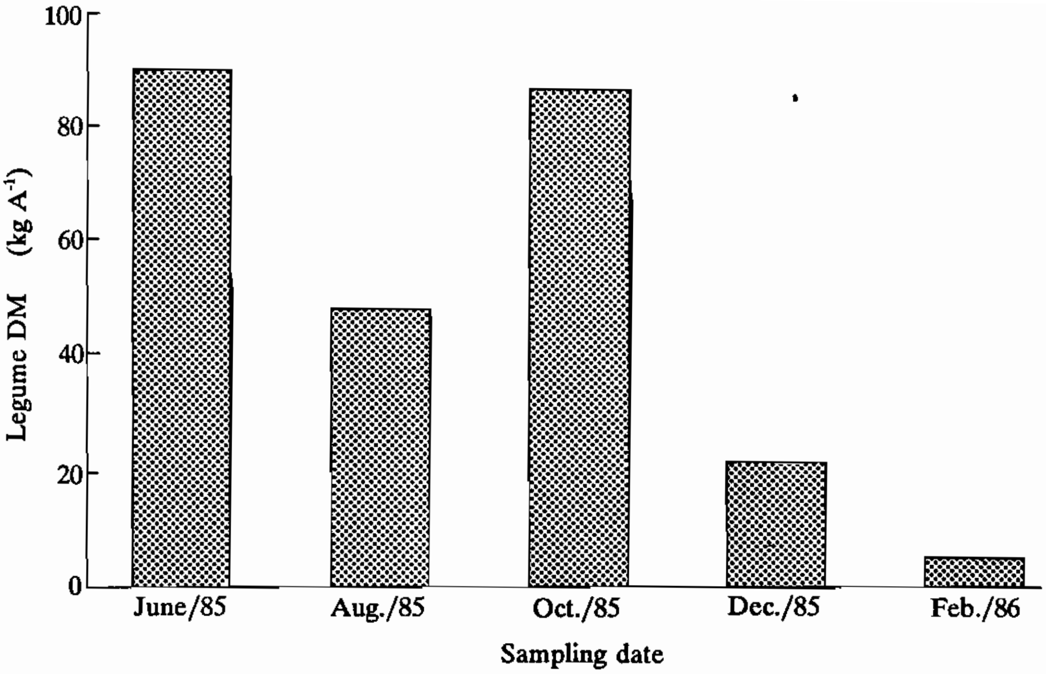

Figure 11. Legume (*S. capitata*) oversown in savanna. (From Hoyos, 1987.)

Subsequently, *Centrosema acutifolium* oversown in a native savanna was evaluated under different stocking rates (CIAT, 1989). Figure 12 shows the liveweight gains in each of the stocking rates over three years. The numbers above the bars are the selection index for the legume, that is, the proportion of legume in the diet compared with the proportion of legume in the diet on offer. A number greater than one indicates that the cattle selected the legume in preference to the grass.

Liveweight gain responded to the presence of the legume in all stocking rates in the first year, and was satisfactory, but by the third year it was down to less than 200 g/head/day in both the heavy and medium stocking rates. For selection indices, in all cases the animals preferentially grazed the legume, which we interpret as substituting the legume for the savanna in their diets.

Figure 13 shows data for the forage on offer, with the numbers above the bars indicating the percentage of legume in the forage. With the heavy and medium stocking rates, the amount of the native grasses in these pastures declined considerably over the three years, especially in the heavy stocking rate, showing that the native grasses do not tolerate heavy grazing pressures.

We conclude that oversowing legumes, at least with *Stylosanthes capitata* or *Centrosema acutifolium*, is not a viable option because the animals substitute the legume for the savanna species. In doing so, they subject the legumes to

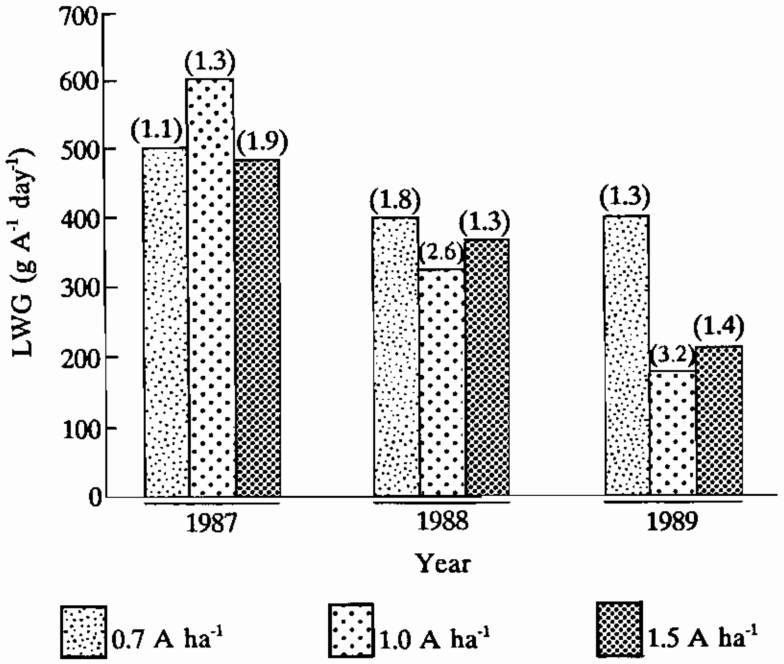

Figure 12. Liveweight gain in savanna oversown with legumes grazed at different stocking rates. Numbers in parentheses are legume selection index. (From CIAT, 1989.)

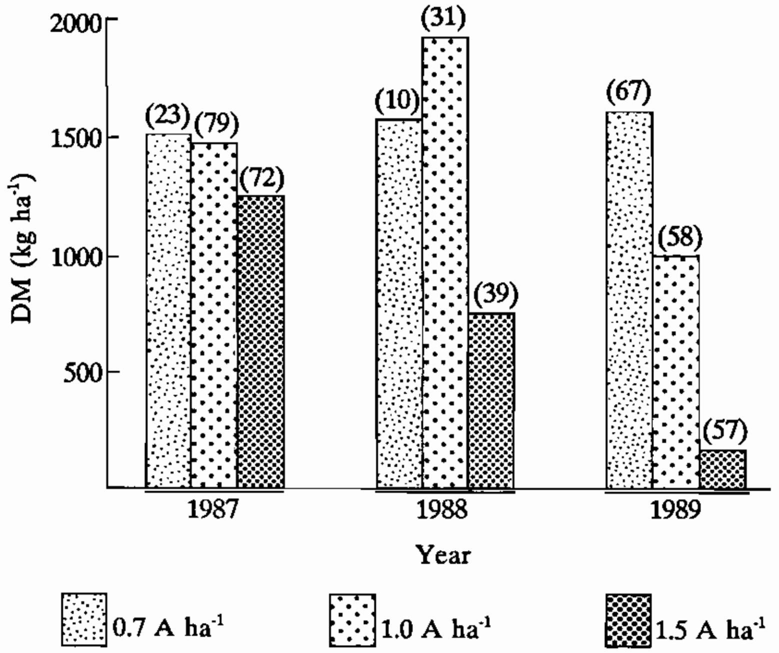

Figure 13. Forage on offer in savanna oversown with legumes and grazed at different stocking rates. Numbers in parentheses are percent legume. (From CIAT, 1989.)

disproportionate pressure, and the savanna cannot withstand the heavy grazing pressures implied by the system.

In a modeling exercise based in part on the Texas model, Thornton (1989) looked at the effect of various options on herd performance (Table 14). If savannas are not complemented with sown pasture, the only management possible is to use strategic burning, and supplementation with phosphorus. This produces improved reproductive performance, particularly of maiden heifers, and improvements in the growth rates of both heifers and store steers. However, liveweight gains are still less than 100 kg/head/year, which is not sufficient for a viable fattening operation, which requires at least 150 kg/head/year. Areas of sown pasture, in this case a grass-based pasture, can result in substantially improved performance, and can improve the internal rate of return. Even then, using the best management techniques, such as controlled mating, the savanna can only be regarded as a resource for the production of store cattle for fattening elsewhere. This is not necessarily a limitation for low-input production because the land is cheap, particularly in Colombia, and can provide internal rates of return as high as 21.1% (Table 14).

Conclusions and Implications

Let us summarize the results of the TPP's work with managing savanna, and of complementing it with sown legume-grass pastures. Firstly, the dominant issue is that the savanna will remain a major pasture resource in the region for the foreseeable future. We have learned what the constraints are, and how to overcome them for low-input systems, that is, we have learned how to manage the savanna resource for modest and sustainable increases in production, and how to supplement it for greater increases in production.

Where there is little infrastructure development, there are few options to increase animal production (Figure 14). Here the rancher is limited to mineral supplementation and some form of rotational burning. External inputs and management requirements are low, but the system is sustainable in the longer term, although the outputs in terms of animal production are very low. As a result, the internal rate of return is also low, but positive.

Where infrastructure is developing, the rancher has other alternatives to increase animal production with the use of small areas of legume-grass pastures (Figure 15). Higher inputs are needed, such as fertilizer and mineral supplementation, and herd management.

Continued development of the savanna will put increasing pressure on the remaining savanna area, particularly within any one ranch. The implications of this stress in terms of the savanna's stability with respect to plant communities and soils are vital to the long-term maintenance of the savanna resource.

Table 14. Performance of alternative cow-calf systems (from Thornton, 1989).

System	Control	With 20% pasture	20% pasture, culling, and strategic management
Relative carrying capacity	100	131	191
Conception (%)	47	83	89
Weaning weight (kg)	133	148	142
Adult mortality (%)	11	8	6
Sales (kg/AU/yr)	34	81	69
Internal rate of return (%)	3.0	13.3	21.1

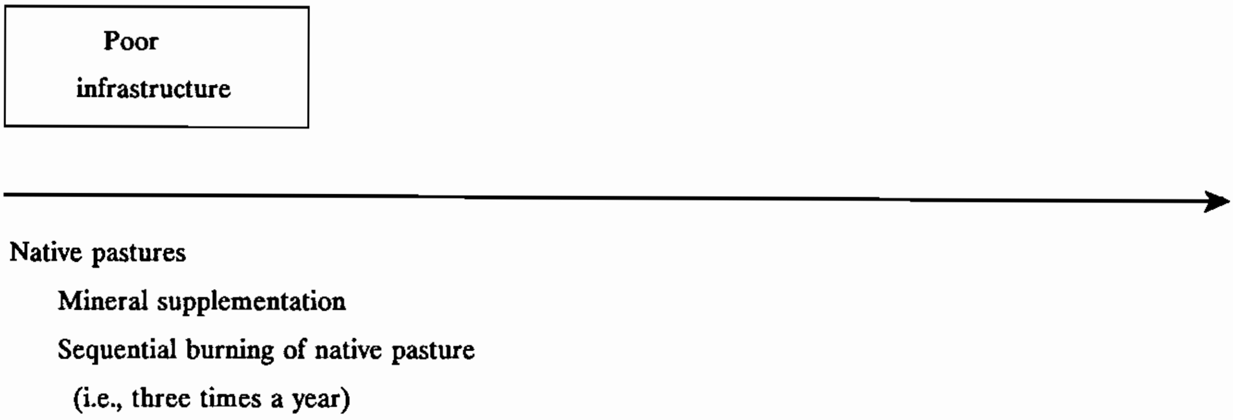

Figure 14. Options for increasing animal production in Latin American savannas with poor infrastructure.

Developing
infrastructure

Native pasture (base)
- Mineral supplementation
- Sequential burning
- Use of small areas of improved pastures (grasses/legumes)
  - Strategic management
  - Fertilizer

Figure 15. Options for increasing animal production in Latin American savannas with developing infrastructure.

The TPP has therefore initiated continuing studies of the savanna to determine the stability of this resource under more pressure, for example:

> The effects of rotational burning on the botanical composition of savanna in formal experiments.
>
> The use of satellite imagery to inventory the savanna resource on a continuous basis, and to document savanna communities, land classes, pasture condition, and changes in botanical composition on a broader basis than is possible by ground survey.

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CHAPTER 7

EXPERIENCES AT THE INTERFACE OF RESEARCH AND DEVELOPMENT WITH TROPICAL PASTURES

J. E. Ferguson*

Introduction

The 1986 External Panel Review of the Tropical Pastures Program (TPP) recommended that the Program increase its contact with the farming community (especially mixed farmers). The idea was to expose producers to the new grass-legume technology, attractive on the basis of on-station data, and also to better understand the limitations to adoption.

The Program welcomed this "green light" for involvement in an area perceived to be on the absolute margin of CIAT's actions and more within the traditionally conceived responsibility of NARIs. Beginning in 1987-88, and despite many real limitations, the TPP entered into several pilot projects designed to place the most promising associations in the on-farm context in a range of ecosystems.

Stated another way, we ventured to the "interface." The latter term refers to a complex and dynamic project environment outside of the comforts of the parent institution, CIAT. It involves collaborative work with a blend of new regional institutional partners to focus on on-farm performance of novel materials with pioneer adopting producers lacking previous experience.

This paper attempts to present a progress report on three such initiatives, each an independent and different case, and each an ongoing and evolving project.

The Interface and Project Environment

The role of CIAT's TPP

The TPP's general objectives in collaborative projects with national institutions included:

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1. On-farm evaluation of promising forage materials.
2. Developing on-farm evaluation methodologies that could also be useful to national institutions in charge of transfer and extension.
3. Providing feedback to the Program on technology options or possible targets.
4. Contributing to pilot agricultural development programs with a pastures component for acid soils.
5. Economic evaluation of technology.

Beginning in 1987, the systems subgroup of the TPP (the Livestock Production Systems, Economics, and Seed Production sections) began to participate actively in collaborative projects with a number of national partners (Table 1). Some projects began as a further evolution, or step out, from existing focal points of traditional TPP activities (e.g., project nos. 1, 3, and 10). Others evolved in and with totally new regions and partners (e.g., project nos. 5, 6, 7, and 9). To the extent possible, the TPP promoted project coordination by a national institution. In some cases or during some periods, however, this role had to be assumed by the TPP to maintain project continuity (e.g., project nos. 5 and 10).

TPP contributions were varied and dynamic. Initially, the TPP contributed project planning, materials, seeds, and technical assistance in pasture establishment and management. At later stages, its contributions included training, technical assistance in seed production, and analysis of results. Table 2 summarizes these contributions.

Materials

The germplasm materials on which the 3 pilot projects were based were either recently released cultivars or highly promising accessions, identified principally from on-station research. Only in the case of the Colombian Llanos had the TPP also conducted a first cycle of on-farm experiments. Materials included both grass and legume species (Table 3).

Summary of three pilot projects

CRECED-Altillanura, Colombia. In 1988, ICA-CRECED-Altillanura (C-A) at Puerto López, Meta, Colombia, began a technology transfer project based upon new materials for improved pastures. In support of C-A, the TPP provided significant technical assistance, for both pasture and seed activities.

Conceptually, the entire project had a large number of diverse participant groups, including technology transfer, selected graziers, researchers, the agro-livestock service sector, and seed enterprises (Table 4). The organizational framework for participation from the different groups has tended to be somewhat informal. The project has expanded from year to year (Table 5), and has involved 250 farmers and the establishment of approximately 10,000 ha of improved pastures.

Table 1. Summary of TPP on-farm, interface pilot projects, 1986-1991.[a]

No.	Country	Region	Ecosystem[b]	Other participants
1	Brazil	Sylvania	TS,WD,t	EMBRAPA-CPAC
2	Colombia	Cauca	TSE,SF	FGV, CVC, ICA
3		Llanos[c]	TS,WD,h	CRECED-Altillanura
4		Piedmont	TRF*/TS,WD,h	ICA, Tech. Univ. Berlin, others
5		Caquetá[c]	TRF	FGV, Nestlé, ICA, GTZ
6		Chinchiná	TSE,SF	CENICAFE
7		San José de Guaviare	TRF	Corp. Araracuara
8	Costa Rica	Guápiles	TRF	CATIE, MAG
9	Ecuador	NAPO	TRF	IICA, INIAP
10	Peru	Pucallpa & Tarapoto[c]	TSE,SF	IVITA, INIAA
11	Venezuela	El Tigre	TS,WD,h	FONAIAP

a. Program sections involved: Livestock Production Systems, Economics, and Seed Production.

b. TS,WD,t = tropical savanna, well drained, thermic
TS,WD,h = tropical savanna, well drained, hyperthermic
TRF = tropical rain forest
TSE,SF = tropical semi-evergeen, seasonal forest
* Transition, TRF/savanna

c. Pilot project reviewed herein.

During the planning phase of the overall project (1988), there were virtually no commercial sources for seeds of most new pasture cultivars on which pasture improvement was to be based (an exception was *Andropogon gayanus*). Therefore, the Seed Production Section (SPS) commenced seed multiplication in 1988 for certain predefined priority materials (cv. Llanero, cv. Capica, and cv. Vichada) so as to begin supplying seed to graziers participating in C-A in 1989.

Table 2. Contributions of CIAT's TPP.

Contributions	Project		
	CRECED Altillanura	IVITA Pucallpa	FGV Caquetá
By TPP in general:			
Pasture research base	XXX[a]	XXX	XXX
Materials	XXX	XXX	XXX
By TPP sections: Livestock Production Systems, Economics, and Seed Production			
Seeds	XXX	X	XX
Project coordination	—	XX	XX
Technical collaboration			
- Pasture estab./mgmt.	XX	XXX	X
- Seed production	X	X	X
Training	XXX	XXX	XXX
Analysis	XX	XX	X

a. Relative levels: X = low; XX = medium; XXX = high.

In 1989, most seeds available to C-A were used to establish improved pastures. At that time, internal seed generation by C-A activities was not an objective. In 1990, however, following a proposal by the SPS, C-A agreed to incorporate a significant seed generation component within their activities, so they would not be so dependent on CIAT's SPS for future seed supplies. This trend was consolidated in 1991, along with an expansion of participation to include the private seed sector, i.e., "second-order participation."

FGV, Nestlé, and others, Caquetá, Colombia. The Caquetá region is part of the Andean piedmont, and has a humid forest ecosystem. Colonization has occurred during the last 30 years. The major farming system is dual-purpose cattle (beef and milk), with a high degree of influence from private milk enterprises. Average size of the selected farms was 135 ± 73 ha, with stocking rates of 0.8 ± 0.3 AU/ha. Farm size ranged from 80 to 200 ha carrying 35-90 milk cows.

Table 3. Grass and legume materials included in on-farm research projects in three regions, 1986-1991.

Material		Region		
Scientific name	Common name	Colombia (Altillanura)	Colombia (Caquetá)	Peru (Pucallpa)
Grasses				
A. gayanus	Andropogon	X[a]	—	X
B. decumbens	Brachiaria	X	X	X
B. dictyoneura	cv. Llanero	X	X	X
B. humidicola	Humidicola	X	X	—
Legumes				
A. pintoi	Arachis	X	X	—
C. acutifolium	cv. Vichada	X	—	—
C. macrocarpum	Macrocarpum	—	X	X
D. ovalifolium	Ovalifolium	X	X	X
S. capitata	cv. Capica	X	—	—
S. guianensis	cv. Pucallpa	—	X	X

a. X = included; — = not included.

This project began in mid-1988 for the purpose of comparing grass-alone pastures with grass-legume associations on small farms with dual-purpose cattle to determine the potential contribution of associations to milk production. Additionally, the project sought a more thorough understanding of milk production systems in tropical lowlands. Project leaders were the FGV and Nestlé. Besides the TPP, other participants included ICA, the Technical University of Berlin (TUB), and GTZ (with partial financing).

The control grass was *B. decumbens,* while *B. dictyoneura* was the grass in the association. The association included a mixture of legumes. Pasture establishment was achieved using minimum tillage techniques because of the low availability of machinery and high risk of soil erosion in the region. A contact herbicide (paraquat) was applied, followed by planting of *B. decumbens* vegetative material and seeds of the other species. No fertilizers were applied, following the practice common in the region. Pasture establishment was initially characterized by severe weed infestation associated with relatively low initial growth rates of the perennial species. Weed

Table 4. Total participatory groups in CRECED-Altillanura pasture and seed project between 1988 and 1991.

Participant group	Name	Role/activity
Technology transfer for pastures and seeds	CRECED-Altillanura	Project leader Technical assistance and promotion
Selected early adopting graziers	(Many) (Some)	Pasture development On-farm seed production
Research on pastures and seeds	ICA and CIAT	On-farm pasture research Cultivar release Pasture and seed technology Initial seed stocks
Agro-livestock service sector	Graziers Association of Puerto López	Receive payments for seeds
	(Many)	Physical inputs, e.g., fertilizer, etc. Machinery rental
	Banco Ganadero	Financing of graziers
Seed enterprises	(Several)	Seed harvesting Seed marketing Contract seed production

control was somewhat ad hoc, involving fire and/or herbicides and manual control. Two pastures were established on each farm: a grass-only pasture and an associated pasture of equal size. This size varied from 3 to 8 ha among farms. These pastures became part of the normal rotation used by farmers. In general, each pasture was grazed for 7-10 days, with an average rest period of 30 days. Farmers kept milk yield records, with frequencies varying from every day to 2-3 times per week. From a

Table 5. Summary of pasture and seed activities by CRECED-Altillanura between 1986 and 1991.

Descriptor	Year						
	1986	1987	1988	1989	1990	1991	Total
Pastures (ha)							
Associations	275	3390	1190	625	1315	1041	7836
Grass only	80	820	555	369	1055	286	3165
Seed fields (ha)							
Grass	—	—	150	52	98	235	535
Legume	35	145	55	106	80	30	451
Graziers with technical assistance (no.)	24	50	75	58	26	72	250*

* Refers to number of different graziers.

methodological point of view, the analysis of resulting milk yield in animals subject to rotational grazing (thus confounding stage of lactation with paddocks) is very complex.

While 6 farmers were involved in formal on-farm research (OFR) to compare grass and grass-legume associations, the milk enterprise Nestlé has been active in providing technical assistance to 180 other farmers. Table 6 summarizes farmer involvement in this region.

IVITA, Pucallpa, Peru. During 1988, 9 farms owned by settlers in Pucallpa's region of influence were selected based on the presence of regularly milked dual-purpose cattle. The collaborating farmers intended to establish or reestablish sown pastures in existing paddocks dominated by either degraded native pastures ("torourco") or secondary forest growth. Farmers were provided with free seed and technical advice while they provided the remaining inputs.

In every case, 2 pastures were established following minimum (manual) tillage or were associated with an annual crop such as maize. No fertilizers were applied. The 2 pastures were the grass-alone control and the grass-legume association. On one

Table 6. Summary of farmer involvement in FGV, Nestlé, and other CIAT projects, Caquetá, Colombia, 1988-1991.

Descriptor	Formal OFR[a]	Farmer evaluation[b]	Total
Farmers involved (no.)	6	180	186[c]
Sown pastures (ha)	—	12	12
Seed fields (no.)	5	46	51

a. Refers to formal on-farm comparision of grass-alone versus grass + legume association.

b. Refers to additional farmer evaluation of grass + legume associations.

c. In addition, the FGV has established 1200 ha.

farm, the grass was *A. gayanus*, while on the rest a mixture of *B. decumbens* and *B. dictyoneura* was used. A cocktail of legume species was used for the associated pastures, including *S. guianensis* cv. Pucallpa, *C. acutifolium* CIAT 5277, *C. macrocarpum* CIAT 5713, and *C. pubescens* CIAT 438 and 442. In the *Brachiaria*-based pastures, *D. ovalifolium* CIAT 350 was also added. Both pastures became part of the rotation of paddocks used by the farmers. Farmers made pasture management decisions, with limited but decreasing input from researchers. As a consequence, and consistent with common regional practices, some farmers have subjected both the control and test pastures to regular burning, intended mostly to control weeds and secondary bush regrowth.

Because of logistical problems and other difficulties, only 7 of the 9 original farms have been regularly monitored. Soil chemical and physical characteristics are also being evaluated. Forage availability and botanical composition are recorded at 3-month intervals. Animal performance is also monitored at regular intervals.

In addition to the 7 farms involved in the formal OFR to compare grass and grass-legume associations, IVITA has provided technical assistance to establish associations on 10 other farms (Table 7).

Outcomes and Feedback

On-farm species performance

Establishment. The TPP first assessed establishment on each farm based upon plant populations per unit area at 3-6 months after planting. Secondly, average species performance was assessed per project based upon the probability of successful

Table 7. Summary of farmer involvement in the IVITA-CIAT project, Pucallpa, Peru, 1987-1991.

Descriptor	Formal OFR[a]	Farmer evaluation[b]	Total
Farmers (no.)	7	10	17
Established pasture associations (ha)	13	10	23

a. Refers to formal on-farm comparison of grass alone versus grass + legume association.

b. Refers to additional farmer evaluations of grass + legume associations.

establishment under average farm conditions. Table 8 summarizes results and shows that all species attained at least a medium rating (i.e., approximately 50%). *S. guianensis* attained a high rating in 2 ecosystems, while *A. pintoi* also had a medium rating in 2 ecosystems.

The overall conclusion is that farmers can establish all materials with an acceptable probability.

Persistence. Persistence is regarded as the continuity of a degree of minimum presence (> 5-10%) in a pasture over time. This assessment was made after only 2-3 years of exposure to farm conditions. Assessment was first made at each farm, and then an average species rating was made for each ecosystem (Table 8).

Species such as *A. pintoi* and *D. ovalifolium* showed long-term persistence, *S. guianensis* and *C. macrocarpum* had medium-term persistence, and *C. acutifolium* exhibited short-term persistence.

Legumes and animal production. We assessed the contribution of the legume component to animal productivity in 2 of the 3 ecosystems.

In the Colombian Llanos, estimates of liveweight gain indicate that grass-alone pastures provide from 125 to 282 kg/ha/year, while grass-legume associations provide from 178 to 454, thus indicating an advantage for associations of from 32 to 61% (Table 9) in terms of beef. In the forest margin region of Pucallpa, but with cows of very low potential, the advantage was approximately 10-15% (Table 10) in terms of milk production.

Overview of adoption status

As the materials under on-farm evaluation are products of recent research and there are high expectations for these materials, it is only natural, especially in the

Table 8. Summary of on-farm establishment and persistence of legume species in 3 regional pilot projects.

Material	Establishment feasibility[a]			Persistence term[b]		
	Llanos	Pucallpa	Caquetá	Llanos	Pucallpa	Caquetá
A. pintoi	M	—	M	L	—	L
C. acutifolium	H	—	—	S	—	—
C. macrocarpum	—	M	H	M	M	S
D. ovalifolium	—	M	H	L	L	L
S. capitata	H	—	—	L	—	—
S. guianensis	—	H	H	M	M	M

a. H = High (> 75%), M = Medium, L = Low (< 25%).
b. L = Long (> 3 years), M = medium, S = short (< 2 years).

Table 9. Influence of legumes on animal productivity (beef) on-farm in the Colombian Llanos.

Legume	Liveweight gain (kg/ha/year)		
	Grass alone	Association (grass + legume)	Advantage (%)
S. capitata	125	178	42
C. acutifolium	282	454	61
D. ovalifolium	199	264	32

Table 10. Influence of legume on animal productivity (milk) on-farm in Pucallpa region of Peru.

Pasture	Milk production[a]	Average gain[a]	
type	(kg/cow/day)	(kg/cow/day)	Advantage (%)
Grass only	2.77	—	—
Association (grass + legume)	3.05	0.28	13

a. Average of 7 farms.

context of a CIAT review, to be expected to define their status for adoption, diffusion, and impact. While expectations are valid, it is not easy to provide a simple answer. In that context, a degree of "poetic license" is assumed so as to provide a "quick and dirty," but clear, response. A qualitative rating scale for adoption was defined (Table 11) and applied to each material within each project. Results are presented in Table 12.

In relative terms, adoption is further advanced with the **grasses** as a group. *B. humidicola* has a rating of 4 in the Colombian Llanos. *B. dictyoneura* is already at 3 in all 3 project regions, even with its very recent appearance on the scene. *A. gayanus*, with a rating of 2, has not been widely adopted in the Llanos. Farmers obviously prefer *Brachiaria* spp. and will readily adopt new materials of this genus.

With the **legumes** as a group, adoption is incipient. Both *S. capitata* in the Llanos and *D. ovalifolium* in Caquetá were rated at 3. While still too early to draw conclusions, the following trends are noteworthy:

a disappointing rating of 1 for *C. acutifolium* in the Llanos;
a promising rating of 2 for a very recent *A. pintoi* in Caquetá;
an acceptable rating of 2 (almost a 3!) for *S. guianensis* at Pucallpa, considering the extremely negative socioeconomic environment.

Non-pasture scientists, with little exposure to pasture research and with an inherent bias toward their traditional crops, may view these results with pessimism. On the other hand, I would claim that significant progress has been made in the face of a high intensity of constraints, as only pioneers encounter and comprehend.

Limitations to adoption are many and varied. In the context of feedback to the TPP, it is worthwhile to both identity and record the following:

Table 11. Description of a qualitative rating scale for adoption.

Rating	Description or stage	Farmer involvement (%)	Farm areas
0	Zero	0	0
1	Trace	5	Small
2	Minor	10	↓
			Medium
3	Incipient exponential	> 20	↓
4	Advanced exponential	> 50	Large

Table 12. Summary of adoption status of materials in 3 regions with OFR projects.

Material	Adoption status overview[a]		
	Llanos	Caquetá	Pucallpa
A. gayanus	2	—	1
B. dictyoneura	3	3	3
B. humidicola	4	3	1
S. capitata	3	—	—
C. acutifolium	1	—	—
C. macrocarpum	—	2	2
S. guianensis	—	2	2
D. ovalifolium	1	3	2
A. pintoi	1	2	0

a. Qualitative scale: 0 = zero, 1 = trace, 2 = minor, 3 = incipient exponential, 4 = advanced exponential. (See also Table 11.)

1. In general, with such novel and perennial forage materials, the overall adoption process is inherently complex and slow.
2. With legumes, consumer (farmer) awareness of relevance and benefits is low. Stated another way, farmer perception is low, and benefits have low transparency.
3. Low commercial availability of seed of new materials.
4. Limited availability of technical assistance.
5. Capital and credit requirements.
6. A limited number of options (i.e., materials).
7. "Matching the material and the ecological niche." This capacity takes time and experience to develop.

Seed supply

Both the evaluation and then adoption of new materials depend to some degree on the availability and price of seed to consumers. At any time, a seed consumer has various possible procurement options. In the broadest sense, these include: donation, purchase, exchange (or barter), or production. The latter is used to embrace the following alternatives: self-production, sharefarming, or contract production, which vary mainly in the contributions of the possible participants to the production effort.

In the context of new materials for OFR, seed availability is implicitly restricted. Therefore, the range of procurement options is **not** complete and, in most cases, a production effort is required. These 3 projects offer 3 cases of seed supply development, both from the viewpoint of composite seed (i.e., the sum of all the different materials) and each particular material.

Three somewhat arbitrary, consecutive, overlapping phases of seed supply development are recognized: (1) an initial "start-up," (2) first-order participation, and (3) second-order participation.

Phase One, initial "start-up. In the context of these OFR projects with new materials, the planners had to come to terms with numerous concerns. These included the ways and means to define and balance diverse issues and procure inputs. Issues were farmer number and selection, materials and their placement, minimum paddock sizes, land preparation, fertilizers, seeds, and others.

For seed procurement, when and where possible, seeds with commercial availability were purchased, either directly by the selected farmers or by the OFR project. Seeds were also procured in other ways.

The C-A project procured seed from both ICA and CIAT's TPP-SPS. In the latter case, C-A demand was anticipated and production began in 1988 with the objective of supplying seed to C-A. From 1988 to 1991, the SPS generated seeds by a combination of self-multiplication, sharefarming, and contract production with seed enterprises, using a special rotating fund set up for this purpose. Seeds were to be delivered to the

Graziers Association of Puerto López, which received payment from the selected farmers and returned funds to the CIAT Rotating Fund.

The FGV-Nestlé project procured seeds from the TPP and used vegetative propagation extensively.

The IVITA-CIAT project procured *S. guianensis* seeds locally (e.g., timely harvested in 1987 by Mr. Pedro Cabrera), and both IVITA and CIAT's TPP-SPS also provided them.

Phase Two, first-order participation. First-order participants are those directly involved in the OFR project and who also participate in seed production activities.

In the case of C-A, it was not until 1990 that seed production was accepted as a priority. C-A assigned 30% of available seed stocks of *S. capitata* and *B. dictyoneura* to on-farm seed production by a selected subgroup of participating graziers (multipliers). The TPP-SPS offered technical assistance to C-A, which in turn provided direct technical assistance to the multipliers. In addition, the SPS provided a seed-harvesting capacity (two combines and a reel beater) plus seed-conditioning equipment to the C-A multipliers. With *B. dictyoneura*, in 1990-91, a total of 333 ha among 11 multipliers was harvested to produce 3.7 tons of graded seed. At the same time, with *S. capitata*, a total of 199 ha, involving 11 multipliers, resulted in the production of 8 tons of graded seed.

In Caquetá, with the FGV-Nestlé project, on-farm seed production was promoted, but consisted essentially of vegetative propagation with manpower available from participating farmers.

In Pucallpa, with the CIAT-IVITA project, seed production was not part of the OFR project but was developed by a parallel, multi-institutional seed project conducted by INIAA-IVITA-CIAT. Herein, two seed project nuclei were established and consolidated at Tarapoto and Pucallpa with minimum resources. Each nucleus provided technical assistance to selected farmers to support their participation in sharefarming and contract seed production. A rotating fund was established at Pucallpa, allowing the project to purchase and sell seeds. Over a 5-year period (1986-91), a composite total of 8.5 tons of seeds were generated with similar net contributions from both regional nuclei. From a total of 24 novices, a core of 4 experienced multipliers was identified.

The seed project distributed seeds principally to research projects conducting on-station and on-farm pasture evaluation (especially grass-legume associations), thus giving them a strong impetus. An external consultant (from CIAT's TPP) helped conduct an annual training and review workshop. The program was highly participatory and involved reports, definition of constraints, training modules, field visits, and planning. Additionally, national and international study tours were conducted for relevant activities. Participants were encouraged to improve their communication and analytical skills, establish links with both relevant researchers and private industry, and adjust to the dynamics of expanding seed supply. Table 13 summarizes the dynamics of participation, production, and distribution of composite seeds.

Phase Three, second-order participation. This refers to participation by parties beyond those originally involved in the OFR project.

In the case of the C-A project, C-A facilitated second-order participation via the concentration of *S. capitata* and *B. dictyoneura* seed areas in and around Puerto Gaitán and Puerto López, respectively, in 1990-91. The first participants were a seed enterprise that rented a beater harvester, and a renter of combines for harvesting *S. capitata*. Later, an established seed enterprise offered seed-conditioning facilities and a marketing outlet on a contract basis. Thus, the first linkages have been established with the private sector. With *B. dictyoneura* and *S. capitata*, strong demand forces are now driving an expanding availability of seeds (Figure 1).

In the case of the FGV-Nestlé project in Caquetá, no second-order participation has yet evolved.

In the case of the seed project in Pucallpa, combine rental has occurred and one farmer has undertaken open-market production of *S. guianensis* (in addition to his contract production for the seed project).

In summary, the evolution of both participation and seed supply expansion depends on:

1. The level of priority given to seed multiplication within research institutions and then within OFR projects.
2. The promise or potential shown by the materials on-farm as seen by the participating farmers.
3. The basic seed production characteristics (prolificacy and synchrony of flowering, efficiency of both seed set and seed recovery, seed quality, etc.) of **each** particular species.
4. Level of real demand for seed of **each** material from farmers.
5. The influence of market forces on both production and distribution of seeds. To the maximum extent possible, farmers participating in OFR should purchase seeds at full cost, with the funds rotated to promote further production.

Participation trends and spinoffs

CRECED-Altillanura Project. During the period 1988-91, C-A not only consolidated itself internally, both operationally and in human resources, but gained national recognition within ICA as one of the most effective CRECEDs.

Table 13. Summary of the dynamics of seed activities in participation, production, and distribution between 1987 and 1991 in Peru.

Descriptor	Year				
	1987	1988	1989	1990	1991
Project nuclei (man-years)					
Tarapoto	2.75	2.75	1.50	1.25	1.00
Pucallpa	2.25	2.75	2.50	2.75	2.50
Multipliers (no.)					
Novice	1	12	11	24	15
Experienced	0	0	4	4	4
Contract production					
Contracts delivered (no.)	0	0	0	1	8
Seed volume (kg*)	0	0	0	75	505
Total production (kg*)					
Tarapoto	2151	652	513	1425	678
Pucallpa	185	700	837	758	507
Total	2336	1352	1350	2183	1185
Seed distribution					
Volume (kg*)	1400	1200	1100	2200	900
Sales income (US$)	0	0	0	5131	9100

* Refers to net amounts of composite seeds (i.e., of all grass and legume materials) received by the Project.

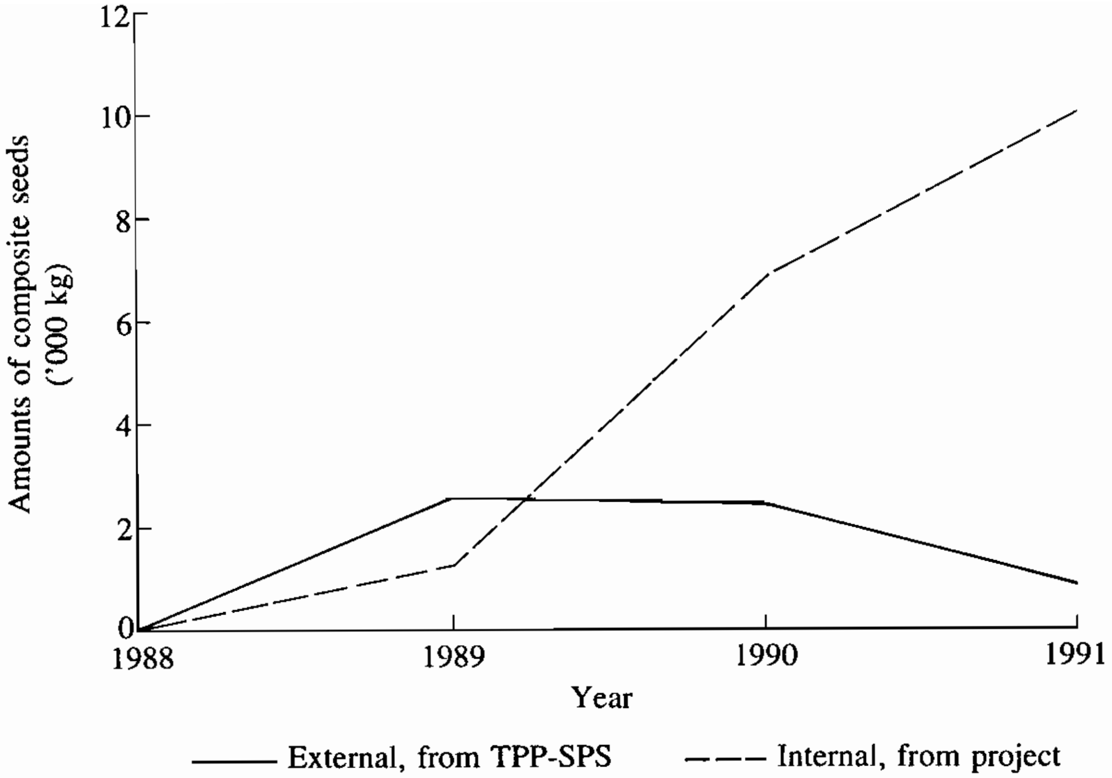

Figure 1. Dynamics of seed supply, both external and internal, for CRECED-Altillanura Project between 1988 and 1991.

The degree of farmer participation has continued to exceed the capacity of C-A to provide seeds and technical assistance. C-A has also been quick to incorporate additional new technology, such as rice-pasture establishment. A new generation of producers is entering the region, and they look to C-A for guidance as well as adding synergy to the overall development process.

The Banco Ganadero (Graziers Bank) has been a willing financier of training workshops organized by C-A to increase the skills and numbers of transfer agents in pasture establishment and management.

Drawing on the experiences of C-A, ICA personnel at CNIA-Carimagua applied for and obtained funds from the Colombian government to implement a new extension initiative for Vichada Department. This project, called Plan Vichada, has a budget of US$150,000, and includes the appointment of three new technical assistants, acquisition of vehicles, seed multiplication, production of publications, and the provision of technical assistance to farmers in the vicinity of Carimagua.

Also during the period, ICA's Pasture Program was eliminated in a structural reorganization. But it was then revived, in part because of the evolving recognition of the benefits of pasture research and technology transfer projects.

FGV, Nestlé, and others, Caquetá. The FGV, on its own property, has advanced a large-scale pasture development initiative. It has planted over 1000 ha of improved pasture, mainly *Brachiaria* spp. in association with *D. ovalifolium* or *A. pintoi*, using vegetative material. Nestlé has expanded technical assistance to farmers in the region by promoting legume associations. It has purchased seeds from the TPP to sell to its farmers. The TPP has presented a proposal to the German government seeking funding to continue on-farm research.

Peru. The 2 complementary but independent projects (pastures and seeds) have evolved during a period of marked reductions in funding to national research institutions, combined with serious social conflicts and economic recession in the region. Only the dedication of the local participants and external funding support (from CIAT and IDRC) have kept the project viable. IVITA has achieved additional support from IDRC to continue. CIAT has decided to withdraw from Peru but will transfer its facilities to FUNDEAGRO, which is expanding activities in the region and will continue with the seed project.

Despite the deep recession and negative economic environment, farmers continue to expand their pasture areas for livestock. The *S. guianensis* associations are attractive to those few farmers with funds to invest and also for use as a ground cover under perennial tree crops.

TPP-CIAT. As the projects evolved, the TPP tended to reduce direct involvement in field activities. It also tended to contribute more to training workshops and courses, develop linkages with other national actors and possible donors, as well as promote more analysis of project experiences. Independently, but concurrently with the projects, the TPP has shared experiences from these projects with RIEPT members. In 1990, a workshop was held with the Advisory Committee on the theme of on-farm pasture research. This type of activity will be continued. Changes under way within CIAT, foreseen in the Strategic Plan, indicate a reduced role for the new Tropical Forages Program in this type of project. This increases the need to identify more national participants, especially NGOs.

Conclusions

1. The TPP has been extremely proactive (even "hyperactive") in exposing new materials to on-farm evaluation within multi-institutional project settings, often with a pathfinding or pioneer character. Even though most projects are not yet mature or finalized, the outcomes and feedback have been overwhelmingly positive and rewarding. Further and more profound analyses remain pending. This progress report only touches the surface (offering mostly "vignettes").

2. Without the support and direct participation of the TPP, these initiatives and benefits would not have been realized. While many of the TPP's contributions have focused on field work necessary to get projects off the ground, the TPP has

also provided critical technical leadership and project continuity. The time is opportune for both analysis of progress and a change in the TPP's participation.

3. These on-farm project experiences have led to an increased demand for farmer participation and a wider range of participating institutions. In future projects, the lead institution should be national, farmer-oriented, regional-based, and have adequate mobility and a clear focus. NGOs (such as graziers associations—FGV—and FUNDEAGRO) must assume a greater role.

4. In the altillanura of Colombia, within large-farm cow-calf production systems, the benefits to animal production (beef) of a legume component in associations have been demonstrated.

5. In the humid tropics, the benefits to milk production of legumes in associations within small-farmer dual-purpose systems have been shown, but were not as marked and took longer to record than expected. The experimental and analytical difficulties are such that comparisons may be best conducted on-station.

6. Farmers have rapidly adopted new materials (different species) of the genus *Brachiaria*. Adoption in the Colombian Llanos of *Andropogon gayanus* has been less than expected.

7. In the context of final utilization, however, the use of legume "cocktails" has been shown to be very positive in achieving more rapid contributions and longer persistence of the legume component in associations.

8. The adoption of several legume materials is incipient. While their benefits are apparent to researchers, farmers perceive these benefits (versus requirements) slowly. Consequently, such new materials require focus and promotion as new products or novel crops (and not as "new cultivars").

9. The limitations to increased rates of adoption for the legume materials cover policies, institutions, and research. While frustratingly slow up to now, the tendency is favorable for those farmers who have had a chance to explore the utility of these materials. Integrated, multi-institutional projects are essential to generate initial exposure to a critical mass of pioneer adopters.

10. Farmers participating in such integrated, on-farm projects should purchase seeds at full cost, both to initiate market forces and to provide funds for rotation to furthur seed production.

11. While research institutions can assign priority and resources ("supply push") to seed multiplication and generate seeds for research and basic seed, an expanding supply of commercial seed is essentially demand-driven. Only as an increasing

number of farmers seek the benefits of a particular material will higher levels of demand for seed attract broader (second-order) investment in seed production and marketing.

12. In the context of an expanding seed supply, each legume species is a particular case. The tendency to generalize about the utility of "legumes" presents a paradox in the context of their seed supply. This can make it difficult for one legume to acquire a specific identity that creates an effective demand level.

13. The future Tropical Forages Program should continue with the following activities: (a) continue analyzing and monitoring these integrated on-farm projects; (b) support RIEPT to concurrently expand on-farm pasture research and seed-supply development; (c) direct the movement and use of new materials to the new agroecosystem programs; and (d) continue searching for and developing new materials, both legumes and grasses, for the many niches in farmers' fields.

Acknowledgments

Sincere thanks are extended to my fellow "teammates," present and past, Raúl Vera, Carlos Seré, Pepe Toledo, and Bill Loker, for their tremendous initiatives and contributions during a grand era of inspired hard work and accomplishment.

The annual reports from sections in TPP annual reports from 1986 to 1991 have been the source of much information used in this progress report.

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CHAPTER 8

THE ROLE OF PASTURES IN PRODUCTION SYSTEMS

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Introduction

Pastures are utilized to produce beef and milk, products which are staples in Latin American diets and represent about 25% of the food budget of this region's people. Future projections indicate decreasing self-sufficiency levels in tropical Latin America, i.e., net importation of beef and milk (CIAT, 1990).

Pastures have other beneficial properties such as increasing soil organic matter (OM) and recuperation of degraded lands. These latter two aspects have been recognized for centuries and were well expressed by Joulie in 1882, who wrote that "it is preferable to alternate the cultivation of roots and cereals with that of grass leys so as to repair by the second the loss of N which the first cause to the soil." He also wrote, "by this means cultivation can be kept up indefinitely without purchased N."

As CIAT moves into research on natural resource management, the soil-enhancing properties of pastures will receive increasing attention in tropical Latin America.

The ability of pastures to accumulate OM and recuperate land is unique because, unlike crops, the offtake of nutrients is relatively small and this, together with the perennial nature of pastures and complete ground cover, results in a stabilizing effect on the soil. As crops expand onto better soils, often benefiting from the reserves accumulated under pastures, they tend to force pastures onto more marginal soils of lower productivity and higher acidity. A key factor in this pattern of land use is the development of acid-tolerant germplasm which enables pasture species to establish a foothold in these difficult environments.

Major objectives of the TPP in the last two years have been to document the soundness of the use of grass-legume pastures and to develop sustainable pasture-based production systems which enhance the capacity of improved pastures to maintain or improve soil properties. All of these objectives utilize the ability of the legume to

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provide an input of N and to improve the quality of forage on offer. The latter is a major limitation on animal production in the tropics.

In this article, we will emphasize the role of the legume in pasture-based production systems, show the production benefits associated with selected sown grass and grass-legume pastures, and point out the potential of pastures to recuperate degraded lands.

Why Do We Need Legumes, How Much of Them Do We Need, and What Are the Problems That Need to Be Overcome?

Legumes perform the following functions:

provide an input of N via biological fixation;

improve the nutritive value of forage (protein and minerals);

improve nutrient cycling via increased quality of litter and greater amounts of nutrients passing through animals;

stimulate soil biological activity via quality of litter and exudates; and
can aid in weed and pest control (e.g., control of ticks by stylos).

How much legume is needed?

Amounts vary depending on the target, i.e., maximum animal liveweight gain (LWG), herbage production, or N input? Little is known about the requirements of legume N to sustain the whole soil-plant-animal system. A modeling/simulation approach has been undertaken to answer these questions using the N cycle as a conceptual framework. In this approach, the production system is considered from the viewpoint of the ecosystem and not just from a production (animal LWG or forage production) viewpoint.

The N cycle in Figure 1 is simplified (after Thomas, 1992) to show only the major pools and processes. There are three pathways for recycling: excreta, litter, and internal remobilization.

The cycle is driven using the following assumptions:

1. A known amount of plant biomass is the starting point and a steady-state production level is assumed on an annual basis, i.e., every year x tons of DM or N are produced. A time period of 1-5 years is used.
2. Animals retain only 10% of the ingested N; the remainder is excreted. Animal liveweight gain contains 2%-2.5% N.

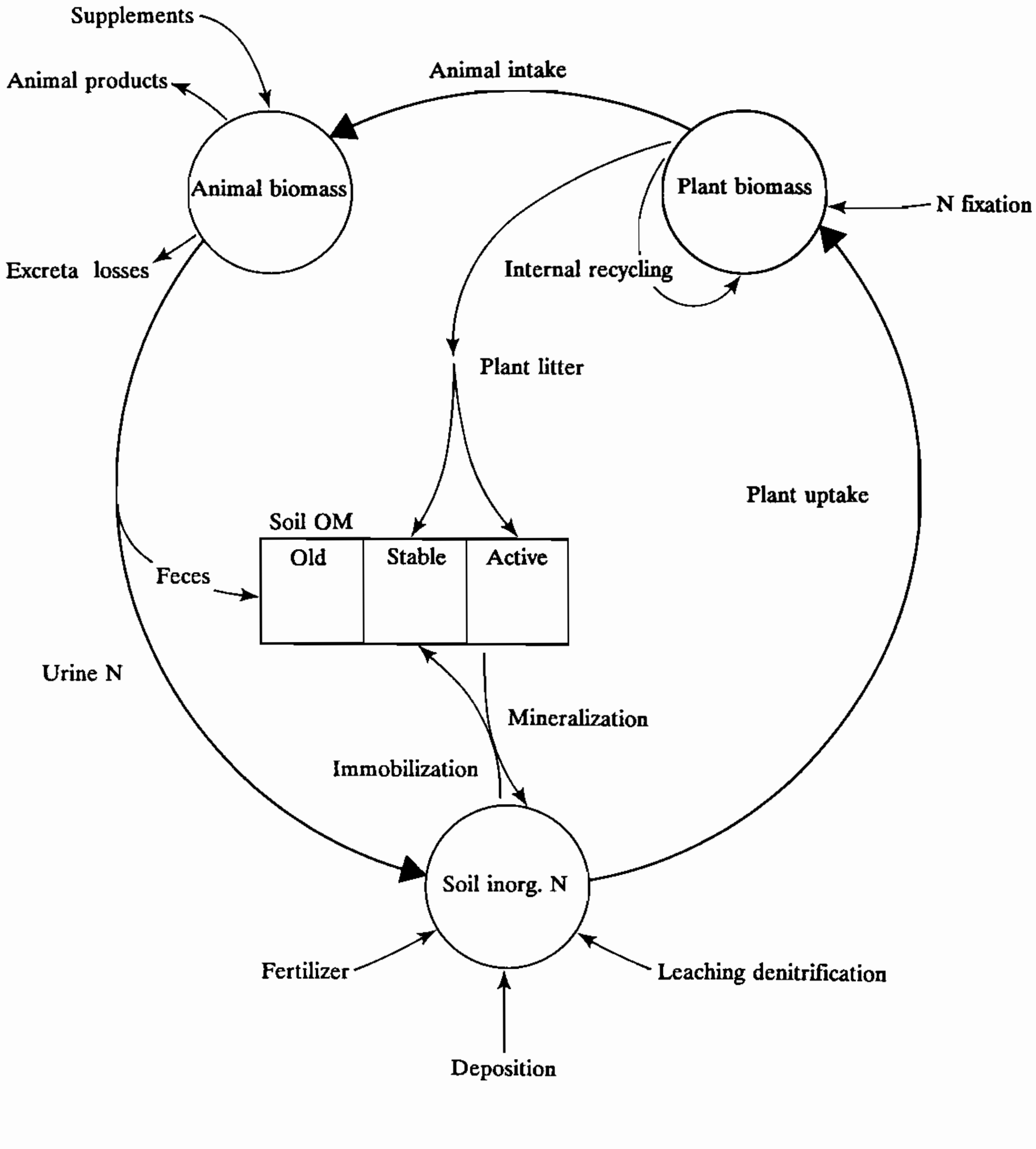


Figure 1. N cycle of grazed pasture.

3. Of the excreta N, only 30% is recovered by plants over 1-5 years. The remainder is lost via volatilization, leaching, and denitrification.

4. A maximum of 40% of the litter N is recovered by plant uptake over 1-5 years. The remainder enters stable or recalcitrant soil OM pools, which are generally unavailable for further plant uptake during this 5-year period.

5. Fifty percent of the herbage N is internally recycled (remobilized) from senescing leaves and stems to growing tissues.

6. With the exception of excreta, N losses are small and are balanced by inputs from the atmosphere when no N fertilizer is added.

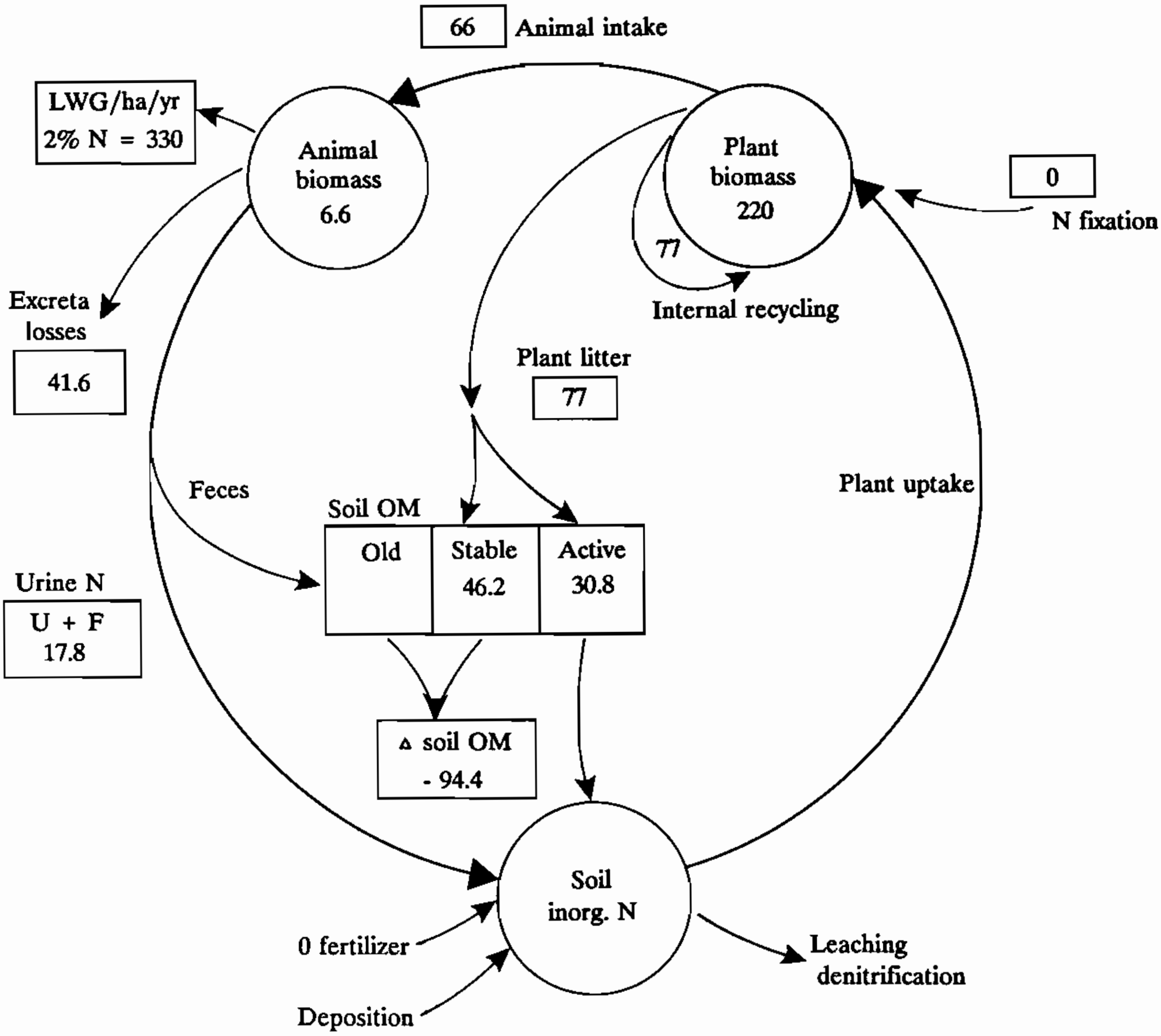
7. Forage legumes fix up to 90% of their requirements; the remainder is taken up from soil pools.

Applying these assumptions to a grass-only pasture which produces 22 t DM/ha/yr containing 1% N (220 kg N) and which is 30% utilized (i.e., 30% of herbage is eaten), we can estimate that 66 kg N are ingested by the animal (0.3 x 220) and converted into 330 kg LWG/ha/yr if 2% N in animal LWG is assumed (Figure 2). The animals excrete 59 kg N (66 x 0.9), of which only 30% (or 18 kg N) is taken up by plants. The other N pools available for recycling are internally remobilized ([220 - 66] x 0.5 = 77), along with N originating from the decomposition of plant litter (77 x 0.4 = 31). This gives a total amount available for recycling of ~126 kg N (18 + 31 + 77). The amount of N required to balance the cycle is then 220 - 126 = 94 kg N. In the absence of inputs, this N must come from the soil OM via net mineralization.

The effect of introducing a legume can be illustrated in a similar cycle producing 15.6 t grass + 6.4 t legume = 22 t DM/ha/yr (Figure 3). This corresponds to a *B. dictyoneura/A. pintoi* pasture at Carimagua. Here the legume contains 2.5% N compared with 1% N in the grass, thus giving 160 kg legume N + 156 kg grass N = 316 kg N in total. The input of fixed N is assumed to be 90% of legume N (160 x 0.9 = 144 kg N). Assuming a greater palatability, we set the percentage utilization at 40% and run the simulations as before. This gives a total amount of N available for recycling of 313 kg (36 kg from excreta + 38 kg from litter + 95 kg from remobilization + 144 kg from fixation). The amount thus needed to balance the cycle is only 316 - 313 = 3 kg N. Therefore, this is virtually a negligible drain on available soil OM pools, and animal production has been increased by 53% compared with the grass-only pasture.

We can run simulations with different amounts of steady-state biomass production and animal utilization to obtain an amount of N required to balance the losses and set this amount equal to that required from fixation. If we express this on a percentage of biomass N basis, we obtain a range of N requirements varying from 38%

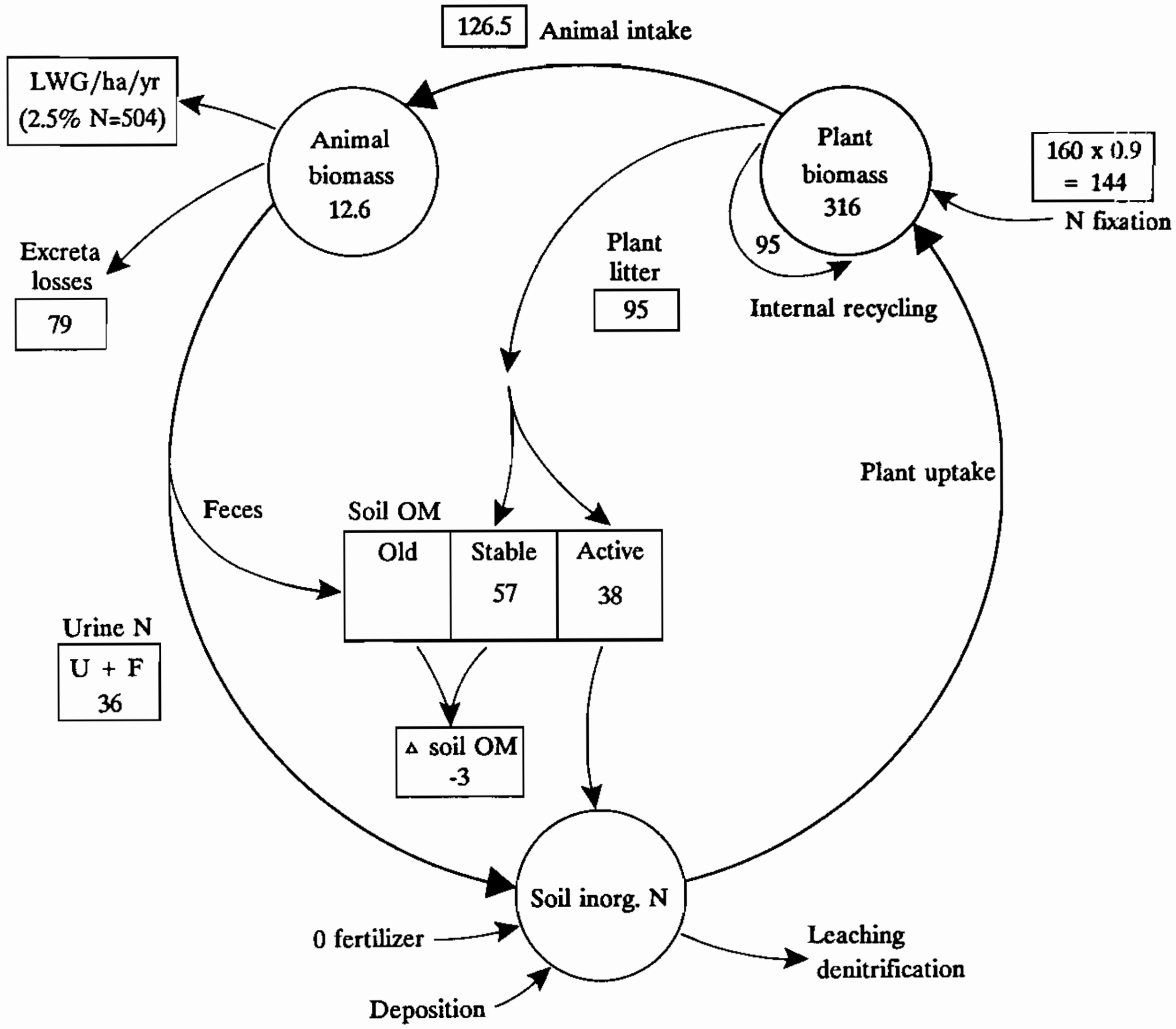
t DM/ha/yr = 22
kg N/ha/yr = 220
Utilization = 30%



U + F = 17.8
Litter = 30.8
Remob. = 77
Sum = 125.6
Δ soil = 220 - 125.6

Figure 2. N cycle of a grass-only pasture.

t DM/ha/yr 15.6 + 6.4 = 22
kg N/ha/yr 156 + 160 = 316
Utilization = 40%



U + F = 36
Litter = 38
Remob. = 95
N_2 fixed = 144
Sum = 313
▵ soil = 316 - 313

Figure 3. N cycle of a grass-legume pasture.

to 67% of the biomass over a utilization range of 10%-70% (Figure 4). After correcting for 90% biological nitrogen fixation (BNF) by the legume and a differential N concentration in grass and legume (1% vs. 2.5%), we obtain the ranges shown in Table 1.

These estimates will vary depending on the percentage recovery of N by each recycling process. This can be examined in a "sensitivity analysis," which is illustrated for variations in the recovery of N from each recycling process in Figure 5. Root data are not included here but first estimates indicate that the requirement for N will vary by ± 14% depending on root turnover.

We can use these simulations to ask how much N needs to be fixed to sustain the system and do our forage legumes have such a potential? Taking a range of pasture DM production of 3-22 tons of DM/ha/yr, we obtain a range of N_2 fixation of 15-158 kg N/ha/yr. This is within the range measured in our forage legumes (Cadisch et al., 1989.)

Problems with legumes

Legumes have four problems:

persistence,

anti-quality factors,

rhizobium requirements,

and farmer acceptance.

Persistence. There are examples of lack of persistence and legume dominance with tropical species. Obtaining the target legume content is a delicate balancing act. If the legume improves the N nutrition of the grass, then the grass may gain a competitive advantage and reduce the legume population. If the legume is more palatable than the grass or is in some other way selectively grazed by the animal, it could be grazed out of the pasture. The factors involved in grass-legume compatibility are numerous and include growth habit, palatability, anti-quality factors, response to nutrient limitations, and competition for light and space.

Anti-quality factors. Many legumes have high levels of tannins and other polyphenols, which result in low digestibilities in ruminants (see Lascano and Spain, Chapter 3).

Rhizobium requirements. These are highly variable depending on the legume species, with some requiring specific strains and others capable of forming efficient symbioses with a number of strains. The TPP now has a large data base and a sufficient amount of training material to facilitate the transfer of rhizobium inoculant technology to national programs.

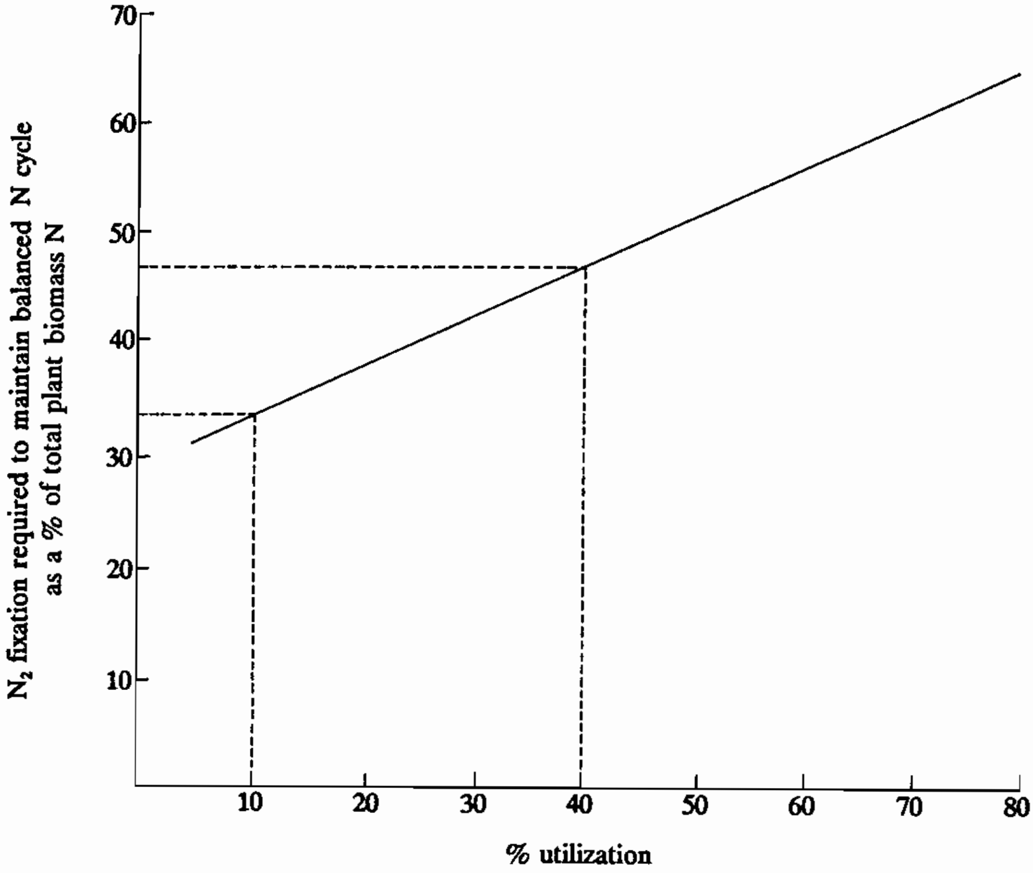


Figure 4. Fixation of N_2 required to balance the N cycle as a function of pasture utilization.

Table 1. Amounts of legume required to balance the N cycle without involving a net change in soil organic N reserves.

Grazing	Pasture utilization (%)	Legume N required as % of herbage N	Legume required as % of herbage DM
Extensive	10-40	38-53	20-31
Intensive	50-70	56-67	35-45

a. Assumes % N in legume = 2.5%, in grass = 1% N, and 90% of legume N is derived from fixation.

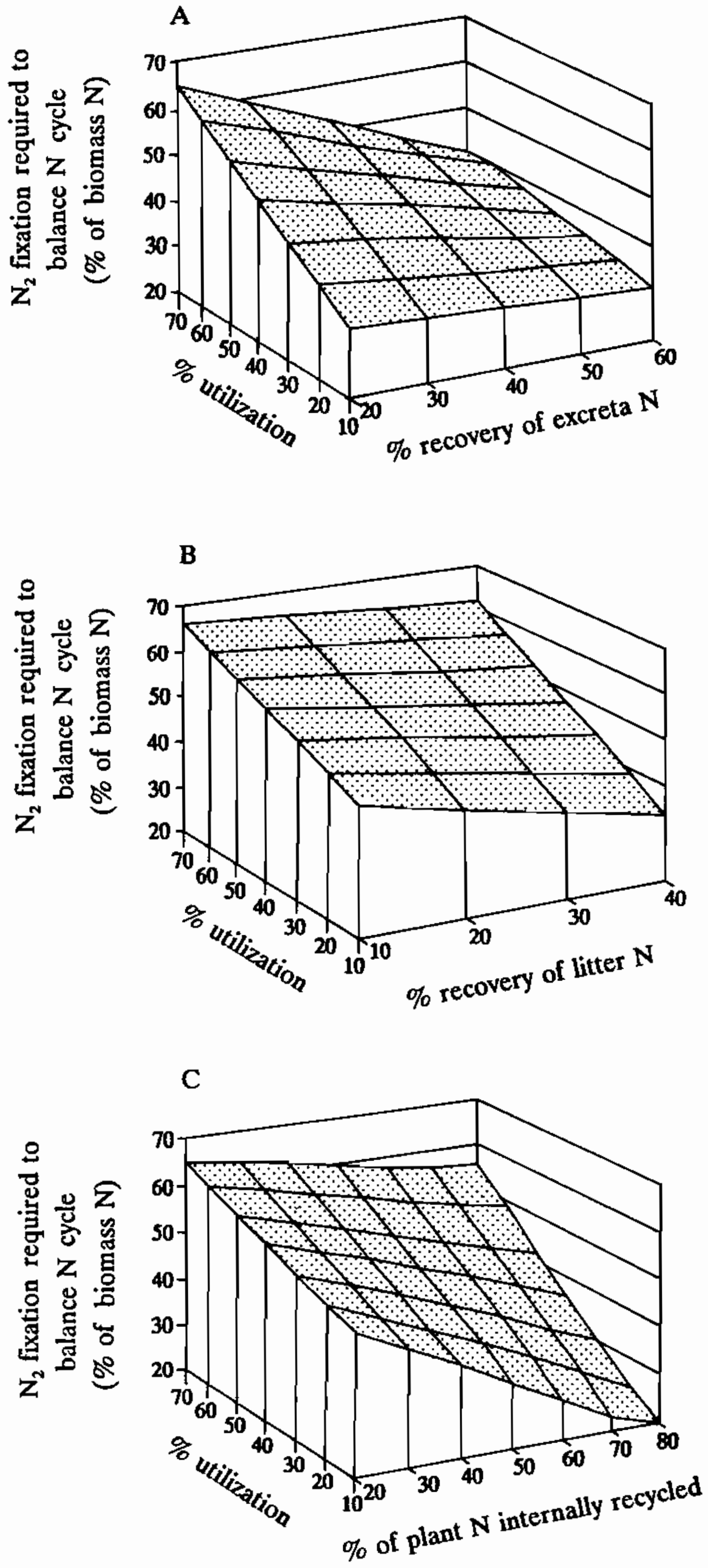


Figure 5. The effect of variable % recoveries of N from (A) excreta, (B) plant litter, and (C) remobilization on the required N input from fixation as a function of pasture utilization.

Farmer acceptance. This remains an area of concern, particularly the lack of adoption of grass-legume pastures. Initially, the TPP concentrated on the collection of legume species with their appropriate rhizobium species. These components are now available but studies on the evaluation of the components under grazing is slow and difficult (see Lascano and Spain, Chapter 3). The likely rapid adoption of a pioneer rice-pasture system which will speed up the establishment of grass-legume pastures (as a result of higher inputs) points towards an optimistic future! (see Ferguson, Chapter 7).

Production Benefits of Sown Pastures

Animal LWG

In the Colombian Llanos, grass-legume pastures have more than doubled animal LWG per head and shown a 10-fold increase in productivity per hectare compared with a managed native savanna (Figure 6). The grass-legume pasture increased LWG by 50% and LWG/ha increased by 20%-30% compared with the pure grass pasture. Similar results have been obtained from other environments such as the humid tropics on degraded forest lands (Table 2).

Milk production

At Quilichao, increases in milk production on the order of 20% have been obtained in grass-legume pastures compared with pure grass pastures (Figure 7). In addition, the effect of the legume was greater than the effect of fish meal as a protein supplement, indicating both a qualitative and quantitative effect of the legume (Figure 8).

Reproduction

Compared with results on the native savanna, dates of first calving of cows grazing an *A. gayanus/S. capitata* pasture were 30% earlier and calving intervals 22% less (Figure 9), thus demonstrating the value of improved pastures for animal reproduction.

Long-term contribution

The contribution of legumes to long-term pasture productivity and stability has been documented in the Colombian Llanos. The grass-legume pasture resulted in greater animal LWGs than those of pure grass pastures in the dry season. During the rainy season, higher productivity of the grass-legume pasture developed after the first 4 years and persisted thereafter (*B. decumbens*/kudzu 10-year-old pasture) (Figure 10). Similar results were seen with *A. pintoi* in association with *B. humidicola* (Figure 11).

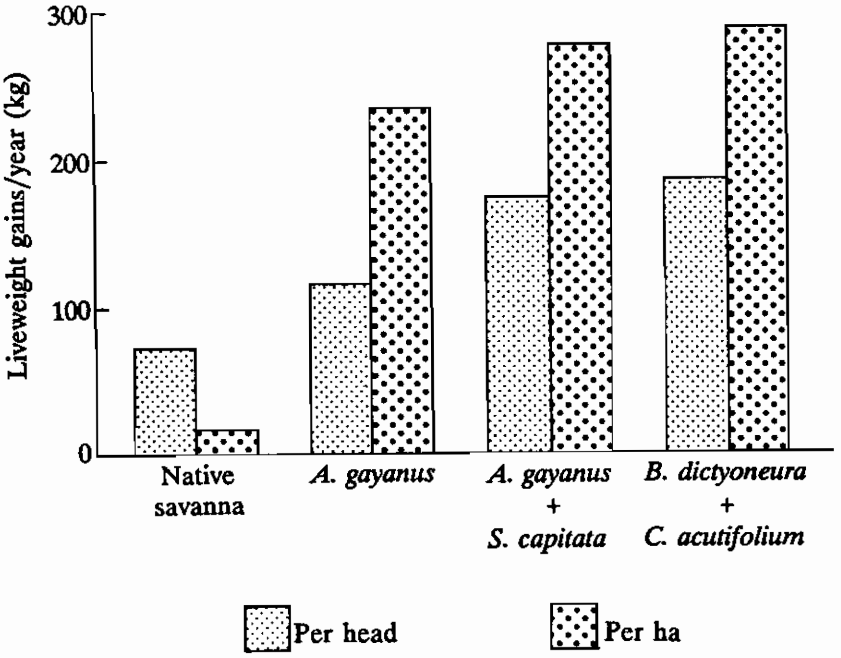


Figure 6. Potential productivity of native savanna and improved pastures in Carimagua, Colombian Llanos.

Table 2. Animal liveweight gains from pastures after degraded rainforest lands.

Pasture	No. of years	Liveweight gains kg/ha/yr
Native grassland		
Homolepis aturensis	1	110
Paspalum notatum	1	204
Improved grass		
B. humidicola	2	351
A. gayanus	2	340
Improved grass-legume		
B. dictyoneura + *D. ovalifolium*	4	803
A. gayanus + *C. macrocarpum*	5	660

SOURCE: Toledo et al., 1991.

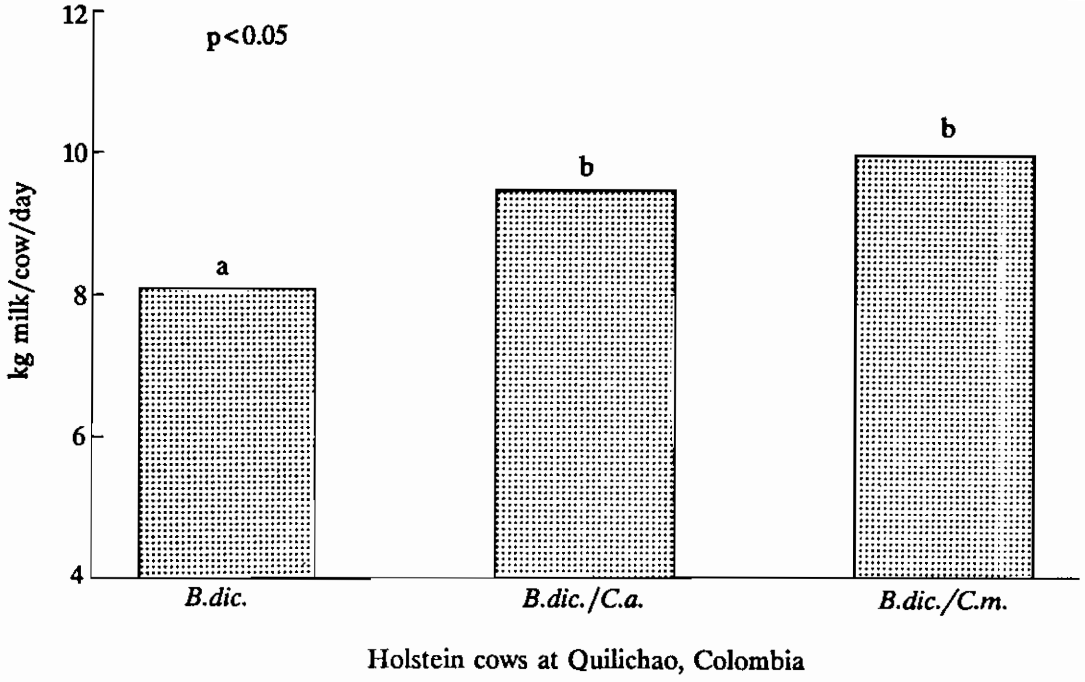


Figure 7. Effect of the legume on milk production. (*B.dic.* = *Brachiaria dictyoneura*, *C.a.* = *Centrosema acutifolium*, *C.m.* = *Centrosema macrocarpum*.)

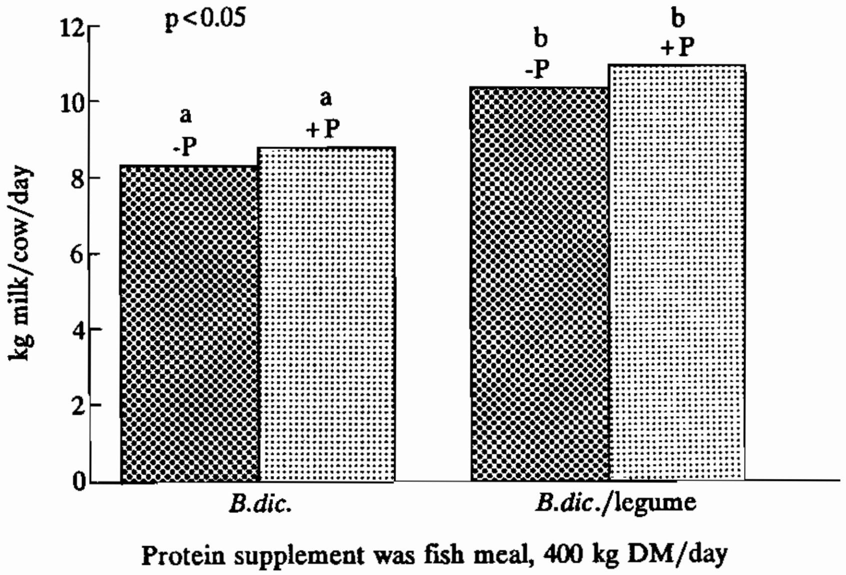


Figure 8. Effect of bypass protein supplement with/without legume on milk yields. (*B.dic.* = *Brachiaria dictyoneura*, - P = without protein supplement, + P = with protein supplement.)

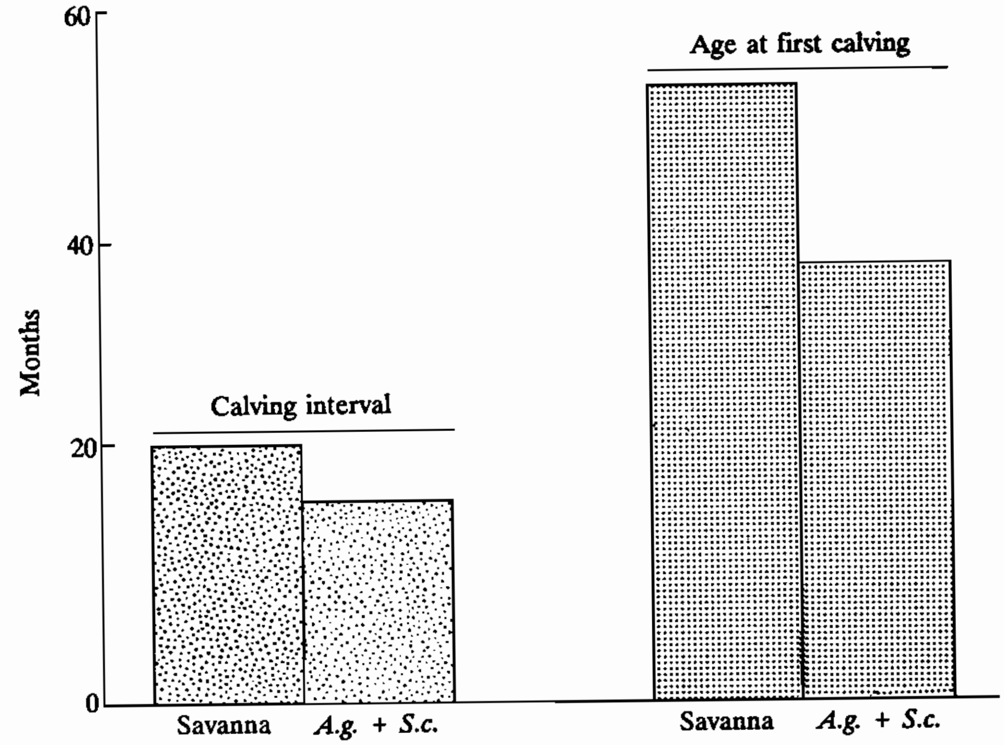


Figure 9. Reproductive performance of cows. (*A.g.* = *Andropogon gayanus*, *S.c.* = *Stylosanthes capitata*.)

Pastures and Rice

The establishment of pastures with selected germplasm requires a very modest amount of inputs but is a relatively slow process. Recently, in a joint project with the Rice Program, it has been demonstrated that pasture establishment can be greatly accelerated by simultaneously sowing a pioneer rice crop, using the newly developed acid-tolerant rice germplasm.

Since 1988, the TPP and Rice Program have collaborated in studies on agropastoralism, work which was stimulated by the successful development of acid-tolerant rice lines which almost match the acid tolerance available in the forage germplasm developed by the TPP. This success story has been highlighted in the last two CIAT TPP annual reports and therefore only a few salient points will be discussed.

> It is now possible to establish improved pastures in a shorter time with rice as a result of increased inputs of fertilizer. The latter still results in improved soil nutrient status after both rice and pasture establishment (Table 3).

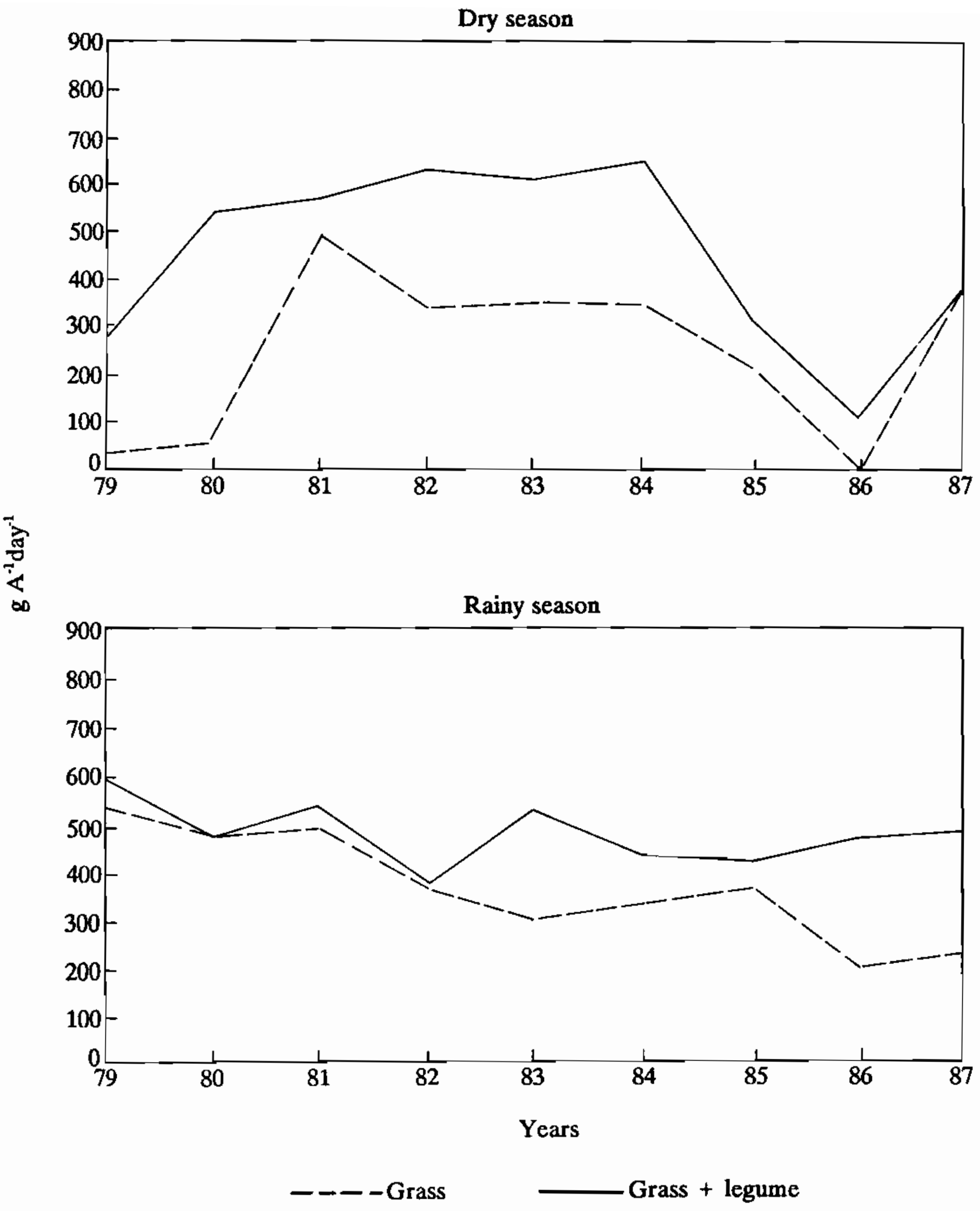


Figure 10. Liveweight gains in *B. decumbens* alone and in association with *P. phaseoloides*, Carimagua, Colombia.

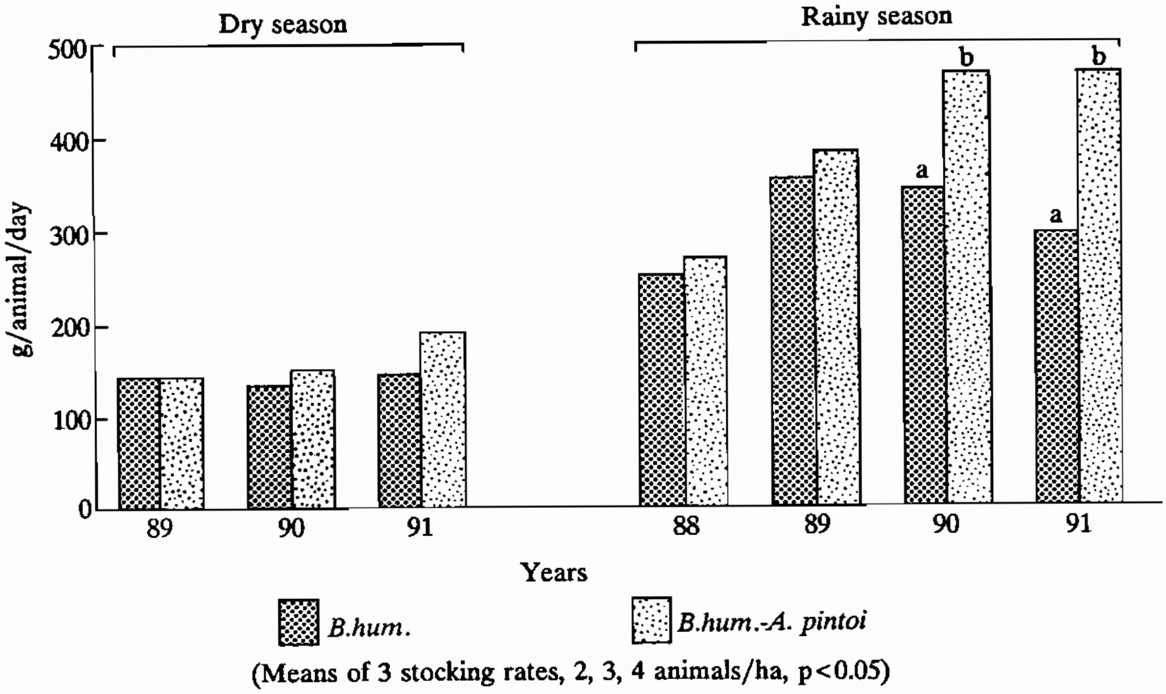


Figure 11. Liveweight gains from a *Brachiaria humidicola* and a *B. humidicola-Arachis pintoi* pasture.

Table 3. Chemical composition of soil, five months after cropping, compared with the undisturbed savanna, Matazul Farm, Puerto López, Colombia.

Analysis	Savanna	Rice-pasture	% increment
pH	4.4	4.6	9
% OM	4.6	4.4	-9
P (ppm)	2.5	9.9	296
Al (meq/100 g)	3.8	2.7	-29
Ca (meq/100 g)	0.25	0.57	128
Mg (meq/100 g)	0.09	0.16	78
K (meq/100 g)	0.09	0.16	78
Al saturation (%)	89.8	75.2	-14.8

Note: Samples were taken on 15 Dec/89 at a depth of 5 cm, mean of 9 samples; fertilization (kg/ha) = 80 N, 50 P, 300 dolomitic lime.

We have obtained very high animal LWGs on the pastures established with a rice crop, 1 and 2 years after harvest of the crop (Tables 4 and 5).

Rice yields can be considerably increased if rice is sown after a pasture which has had a legume, and this effect has continued after two successive rice crops (Table 6).

These results were obtained with a 10-year-old pasture. Do we need to wait that long to obtain benefits from a legume? Decomposition of litter generally follows an exponential function, as illustrated with an example from Australia (Figure 12). Using data on pasture productivity and legume contents obtained from the *B. decumbens* and *B. decumbens*/kudzu pasture at Carimagua and estimates of shoot-to-root ratios from other pastures, we can estimate the contribution of kudzu to soil N pools by applying an exponential function similar to the example from Australia. This estimation suggests that between 80% and 90% of the potential benefit from kudzu in terms of N would have been obtained between 3 and 5 years. Thus we need not wait 10 years to obtain economically important benefits from a legume-based pasture.

Studies on rice-pasture associations have demonstrated that forage germplasm adapted to low-fertility soils responds positively to higher fertility levels. These studies also open up new options for the use of grass-legume species. For example, a pasture-crop ley system can be envisaged wherein the lack of legume persistence of one legume (e.g., *C. acutifolium*) would not be a limitation as the pasture can be reestablished economically with another crop-pasture association after 3-5 years. This would be important if a particular legume had many beneficial attributes apart from persistence under grazing, such as a high rate of N fixation or high litter quality.

Recuperation of Degraded Lands

Land degradation is occurring in all three of CIAT's targeted ecosystems mainly as a result of inappropriate cropping and pastoralism.

Savannas

Pastures can be improved/recuperated by introducing improved species using techniques such as those developed in the Cerrrados, or more recently by introducing a rice-pasture mix (see CIAT TPP annual report, 1990). In the Cerrados, pastures have been renovated with pioneer crops such as maize, sorghum, and rice (Figure 13).

Forest margins of the humid tropics

At Pucallpa, a number of techniques have been tried to recuperate the native torourco pasture of low productivity, including rest and burn, mob stocking instead of mechanical disturbance (disking), and herbicide treatment. Data confirm the value of

Table 4. Animal productivity from a pasture established with a rice crop compared with a traditional method of pasture establishment.[a]

Animal production parameters	Traditional establishment *B. dec.*[b]	With a rice crop + *B. dec.*	With a rice crop + *B. dec.* + *S.c.* + *C.a.*
Days of grazing (Dec. 90 - Aug. 91)	167	231	231
Stocking rate (animals/ha)	1.27	1.43	1.38
Liveweight gain (g/animal/day)	144	521	564

a. Rice sown in May 1990 with 80 kg N, 50 kg P, 200 kg K, 300 kg dolomitic lime per ha.
b. *B.dec.* = *Brachiaria decumbens*, *S.c.* = *Stylosanthes capitata*, *C.a.* = *Centrosema acutifolium*.

Table 5. Animal liveweight gains from a pasture established with a rice crop at Matazul, Puerto López, Colombia.[a]

Pasture	Animal liveweight gains (g/animal/day)
A. gayanus + *S. capitata*	705
B. dictyoneura + *C. acutifolium*	629

a. Pasture established with rice in May 1988, rotationally grazed from May 1990 - Sept. 1991, total no. of grazing days = 482.

Table 6. Yields of successive rice crops sown after a 10-year-old grass and grass-legume pasture.[a]

Year	*B. decumbens*	*B. decumbens* + kudzu
	(t/ha)	
1989	1.36 ± 0.17	3.07 ± 0.26
1990	1.40 ± 0.21	2.22 ± 0.21

a. Each rice crop received 0 N + 25 kg P/ha.

± S.E.

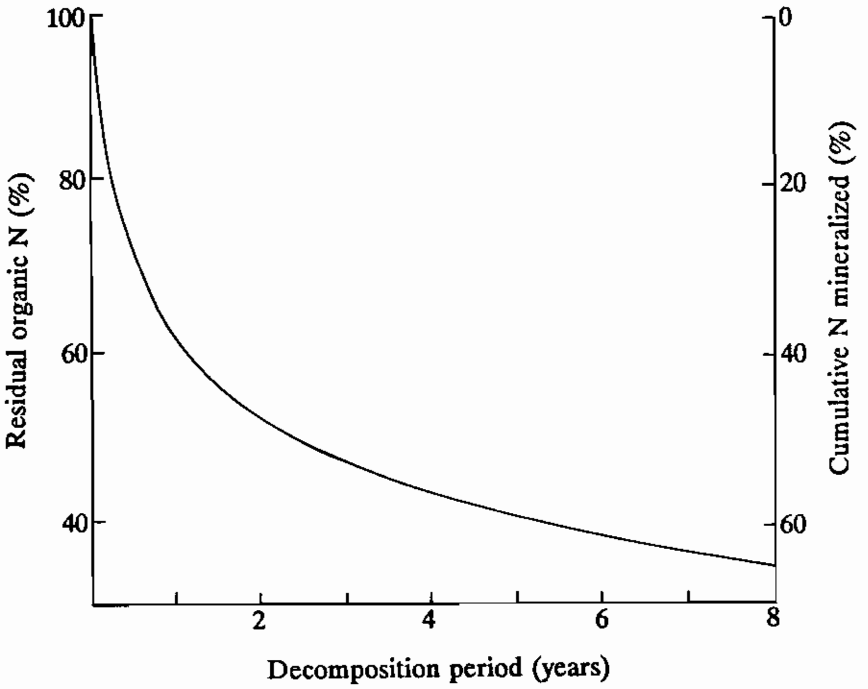
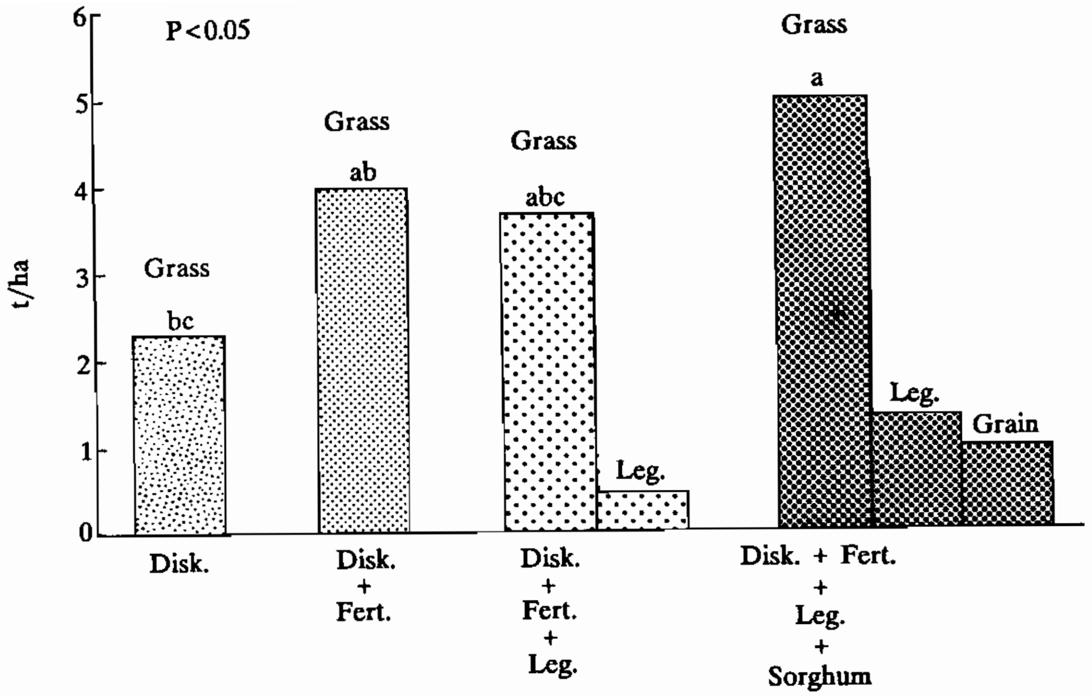


Figure 12. The decline with time in organic N of soil-incorporated annual legume residues. (Redrawn from Ladd and Amato, 1985.)



(Legumes are *Calopogonium mucunoides, Stylosanthes capitata, S. guianensis*, and *Centrosema brasilianum*; fertilization is NPK 75-76-78 kg/ha, lime to 35% saturation)

Figure 13. Renovation of a degraded *Brachiaria decumbens* pasture, Cerrados, Brazil.

rest/burn and mob stocking as a treatment comparable to the other methods which have greater environmental risk (erosion and herbicide) (Figure 14). Crops such as maize, cowpea, and rice have been tried as pioneer crops. CIAT rice lines have produced respectable yields of over 4 t/ha. The other crops have not shown as much promise to date (Table 7).

Hillsides

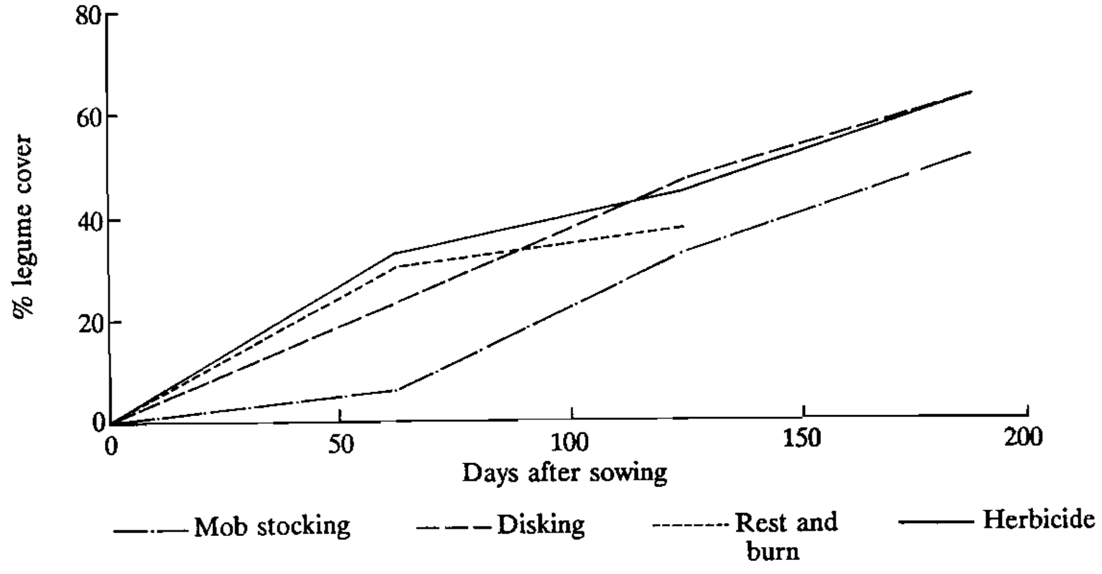
Hillsides vary greatly, with soils of low and high fertility, but most have erosion problems. Pasture germplasm is being tested at a number of locations. At Mondomo, Cauca, erosion problems are associated with cropping and overgrazing. Land is normally left to fallow naturally for 6-8 years before being brought back into production. Pasture has been established in similar areas and a complete ground cover has been achieved together with some animal production (Table 8).

Pasture productivity is low as a result of very poor soils (eroded to subsoil in some localities) and cool night temperatures. On the same farm, the farmer has planted coffee on his better areas and has included *A. pintoi* as a ground cover. This has been so successful that he now sells vegetative material of *Arachis* to his neighbors.

Table 7. Grain yield of rice grown at Pucallpa, Peru.

Lines	Yield (t/ha)
P5589-11043M	4.64 a
CT6947-71421M	4.47 ab
CT7723-2M23M	4.36 ab
CT7079-561111	4.34 ab
CT6947-71117	4.22 abc
CT7244-921521	4.12 abcd
Col 1/m312A	4.01 bcd
CT6196-3310415	3.99 bcd
CT6196-331113	3.73 cd
CT6946-91221M	3.58 d
Porvenir 86	2.34 e
Chanca Banco	2.33 e

Note: Means of two seeding rates, 30 and 45 kg/ha, and two fertilizer treatments of 50 N, 25 P, 50 K, 15 S, 250 lime (kg/ha) and two times these amounts. P<0.05, Duncan's Multiple Range Test.



(Data from humid tropics, Pucallpa, Peru)

Figure 14. Effect of different establishment methods on % cover of *S. guianensis*.

Table 8. Forage production on a hillside farm, Las Lajas, Mondomo, Colombia.[a]

Pasture species	Forage (kg fresh wt/ha)[b]	
	+ fertilizer	- fertilizer
B. decumbens	7,422	3,609
Legumes (*A.p.* + *D.o.*)[d]	469	273
Weeds	1,742	3,133
B. dictyoneura	13,063	5,320
Legumes (*A.p.* + *D.o.*)	305	258
Weeds	1,906	1,367

a. Slope 25%-50%; pH 4.3; OM 2.8%; 80% Al saturation; previous land use was cassava.

b. Production over 16 weeks during rainy season.

c. Fertilizer = 20 kg P/ha as rock phosphate.

d. *A.p.* = *Arachis pintoi*, *D.o.* = *Desmodium ovalifolium*.

In the coffee zone itself, much of the land with poorer soil is under pasture with no fertilization, and there are erosion problems within the coffee plantations and with overgrazed pastures. Forage germplasm has been introduced in collaboration with CENICAFE to reduce erosion and to test the ability of legumes to fix N in coffee plantations in order to reduce the use of N fertilizer (currently 250 kg N/ha).

Results show the potential of pasture germplasm to reduce erosion and of forage legumes to provide a ground cover rapidly and to fix N (Figures 15 and 16).

Conclusions

The following conclusions can be drawn:

pastures can be established on poor/degraded soils as a result of adapted germplasm;

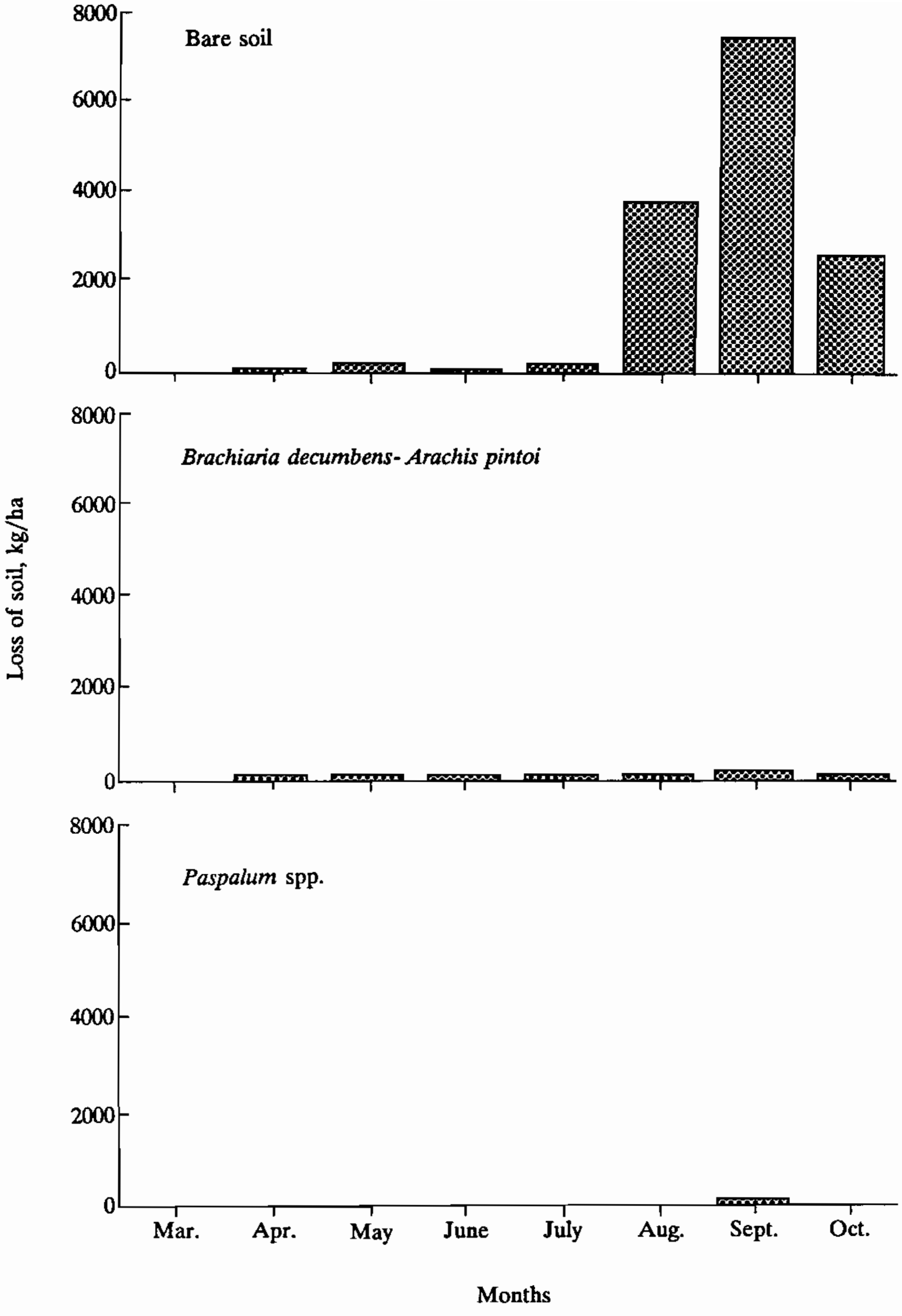
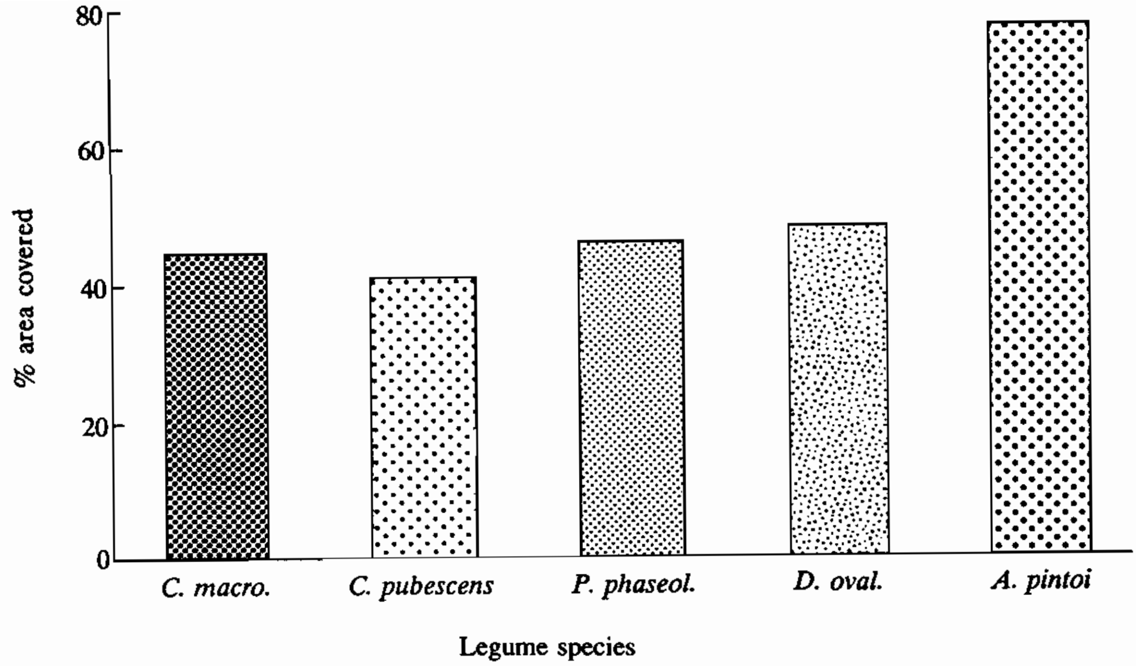


Figure 15. Monthly soil erosion from bare soil, grass-legume, and native pasture at Romelia, Colombia, during 1989. Mean of two replicates.



(Pure stands of legumes were used)

Figure 16. Percentage soil cover with forage legumes at Romelia, Colombia, after 12 weeks growth.

selected, adapted pasture species markedly increase animal production, especially with a legume;

adapted germplasm responds well to increased inputs of fertilizer;
target legume contents have been identified for sustaining the N requirements of the pasture complex;

pasture can recuperate degraded lands with/without crops; and
improved soil conditions under pastures can be utilized by subsequent croppings.

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CHAPTER 9

SOIL-PLANT FACTORS AND PROCESSES AFFECTING PRODUCTIVITY IN LEY FARMING

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Introduction

In this work, we will try to summarize the multidisciplinary efforts of the Tropical Pastures Program (TPP) towards a mechanistic understanding of the soil-plant factors and processes affecting productivity in ley farming. We would like to deal with this subject in sections. We will start with a brief introduction, followed by our research efforts to understand the adaptation attributes of forage germplasm, recycling of nutrients, and soil conditions. Then we will use the research data collected on these three aspects to explain the benefits from soil enhancement in pastures. That will be followed by a brief description of our approach to integrate a number of processes related to soil-plant-animal interactions in pastures under grazing. Finally, we will present a few conclusions.

Productivity in nutrient-poor acid soils is influenced by at least three major soil-plant factors in addition to management as described in three other articles in this book (Lascano and Spain, Chapter 3; Fisher et al., Chapter 6; Thomas et al., Chapter 8). These factors include: adaptation attributes of forage germplasm; extent of nutrient recycling; and soil conditions. Each major factor is controlled by a number of key processes. The TPP has begun to identify and elucidate some of these processes in order to: select and characterize germplasm; optimize soil enhancement; and define guidelines for management of a number of the most promising forage grasses and legumes. For the sake of clarity, we will focus in this article on only a few species.

The TPP has developed a research strategy to generate improved forage plants and pasture technology for sustained productivity (Toledo and Nores, 1986). An improved understanding of the above three major soil-plant factors affecting productivity of the most promising species is essential for the development of improved forage plants and pasture technology. The strategy is based on the logic that well-adapted forage species should be able to extract nutrients from infertile

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soils and recycle those nutrients within the system effectively and improve soil conditions. Integration of improved germplasm with sound management technologies is essential for the development of viable production systems in different agroecosystems.

Adaptation Attributes

Plants have evolved adaptive mechanisms by which they respond to nutrient-poor acid soil and improve their chances of survival or production of offspring (Foy, 1988; Taylor, 1988; Wright, 1989; Marschner, 1991). Plant adaptation is used to define processes conferred by genetic attributes that serve to "fit" the plant to ambient conditions of light, temperature, and mineral and water availability. In our target environment of nutrient-poor acid soils, plant adaptation responses involve changes in: (1) partitioning of biomass between shoots and roots; (2) root growth and distribution; (3) nutrient acquisition; (4) nutrient transport; and (5) nutrient use efficiency. All these processes are affected by the availability of nutrients and water. Improved understanding of the factors that control these processes will assist our efforts to improve productivity and persistence of forage species.

The size and activity of shoots show a functional equilibrium with root activity (van Noordwijk and de Willigen, 1987). The shoots fix carbon and the roots take up water and nutrients from the soil. Although these functions are separate, both parts of the plant interact to make plant growth possible (Chapin, 1991). Adequate nutrient supply favors shoot growth relative to root growth (Marschner, 1986). Conversely, nutrient stress results in a shift of carbon allocation to roots, leading to decreased shoot growth (Terry and Rao, 1991).

The ability of forage plants to remove nutrients from soil is important both for the use of "natural" nutrients and for the efficiency with which fertilizers are used. As pasture production increases, the demand for nutrients, both total amount and the intensity of supply required, increases. The link between nutrient demand and plant biomass can be modified by changes in the partitioning of assimilates to various parts of the plant, i.e., an increase in relative biomass of shoot will usually increase nutrient demand, while an increase in root will normally reduce relative demand.

Adaptation to low fertility

Under glasshouse conditions at CIAT-Palmira, we have investigated the effect of soil type and fertility on biomass production, dry-matter partitioning between shoots and roots, and nutrient uptake and use efficiency in a number of most promising forage grasses and legumes adapted to acid soils (Rao et al., 1991). The grasses include: *Brachiaria dictyoneura*, *B. brizantha*, *B. humidicola*, *B. decumbens*, *Andropogon gayanus*, *Panicum maximum*, and *Hyparrhenia rufa*. The legumes include: *Arachis pintoi*, *Stylosanthes capitata* CIAT 10280, *S. capitata* CIAT 1315, *S. guianensis*, *S.*

macrocephala, *Centrosema acutifolium*, *C. brasilianum*, *C. pubescens*, *C. macrocarpum*, *Desmodium ovalifolium*, *Pueraria phaseoloides*, and *Macroptilium gracile*. Results from only a few species will be presented for the sake of clarity. The two soil types used were sandy loam (Alegría) and clay loam (Pista). These soils were collected from an Oxisol at Carimagua (0-20 cm soil profile). These two soils provided contrasting physical and chemical properties (Table 1). Sandy loam soil had 65% sand compared with 18% in clay loam soil. Although both soils are characterized by high acidity and high Al saturation, the sandy loam soil had lower levels of soil organic matter and total nitrogen (Table 1). The low soil fertility treatment was similar to the recommended level of fertility for pasture establishment (kg ha^{-1}: 20 P, 20 K, 48.2 Ca, 14.2 Mg, and 10 S) in which nitrogen and micronutrients were not applied. The high soil fertility treatment was similar to the fertility recommended for crop-pasture rotations (kg ha^{-1}: 40 N, 50 P, 100 K, 103.4 Ca, 28.5 Mg, 20 S, and micronutrients).

A glasshouse study was conducted to evaluate the differences in adaptation to acid soils among three grass + legume associations. The results from a *Brachiaria dictyoneura* + *Arachis pintoi* association are presented. Large plastic containers were used, with 40 kg of soil per container. The two soil types and fertility levels were as described before. Each container was inoculated with mycorrhizae and *Rhizobium*. Grass and legume species were planted in alternate rows with equal distance between the rows.

The differences in biomass production and dry-matter partitioning are shown in Figure 1. There was a clear effect of low fertility on the partitioning of dry matter between shoots and roots in both soils. The proportion of dry matter partitioned in roots under low fertility was higher than that of shoots. In other words, root growth under low fertility increased at the expense of shoot growth. An increase in fertility increased shoot growth more than root growth.

The proportion of legume root biomass in the total root biomass of the associations was determined using the carbon isotope ratio technique. Because of the presence of the C_4 pathway in the grass and the C_3 pathway in the legume, it was possible to quantify the legume root proportion using the differences in ^{13}C to ^{12}C ratio of an association and that of the pure grass or legume (Svejcar and Boutton, 1985). Under low-fertility conditions, the proportion of legume root biomass in an association was 19% in sandy loam soil and 20% in clay loam soil (Table 2). This indicated that the grass could explore more soil volume for nutrients and water than the legume.

Soil type and fertility status affected not only root biomass production but also root length density (Figure 2). Root length density (the length of roots per unit soil volume) was two times higher in the sandy loam soil than in the clay loam soil at both fertility levels. Despite similar root biomass in both soils, this difference in root length density indicates greater fine root production in the sandy loam soil.

Table 1. Physical and chemical properties of two soil types at Carimagua, Colombia.

Characteristics	Soil type Sandy loam	 Clay loam
Physical		
Clay (%)	17	37
Sand (%)	65	18
Chemical		
Al saturation (%)	77	89
pH	5.1	5.0
Organic matter (%)	0.9	3.4
Total N (ppm)	336	1008
Available P (ppm)	2.0	2.1

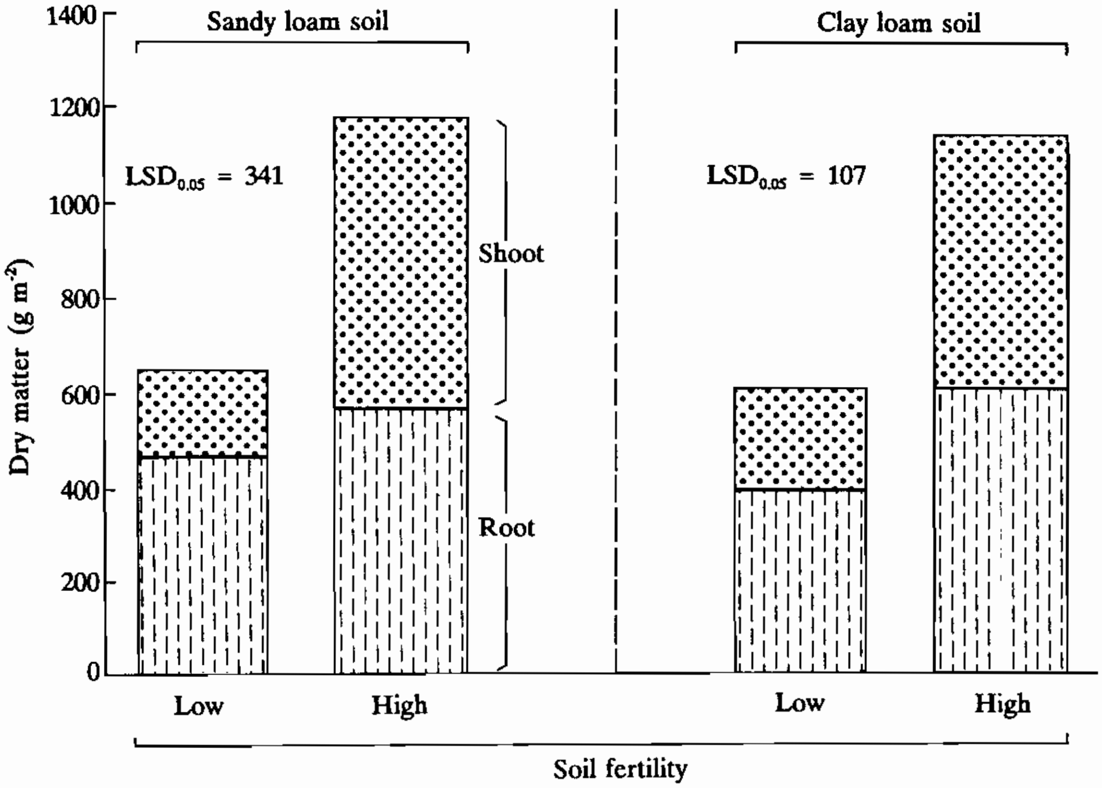

Figure 1. Changes in dry matter partitioning between shoots and roots of a grass + legume association (*B. dictyoneura* + *A. pintoi*) as affected by soil type and fertility status. LSD values at 0.05 probability level are shown for comparison.

Table 2. Proportion of legume shoot and root dry matter in a grass + legume association of *B. dictyoneura* + *A. pintoi*.

Soil and fertility	Proportion of dry matter Shoot	 Root
	(%)	
Sandy loam		
Low fertility	59	19
High fertility	25	8
Clay loam		
Low fertility	57	20
High fertility	42	16

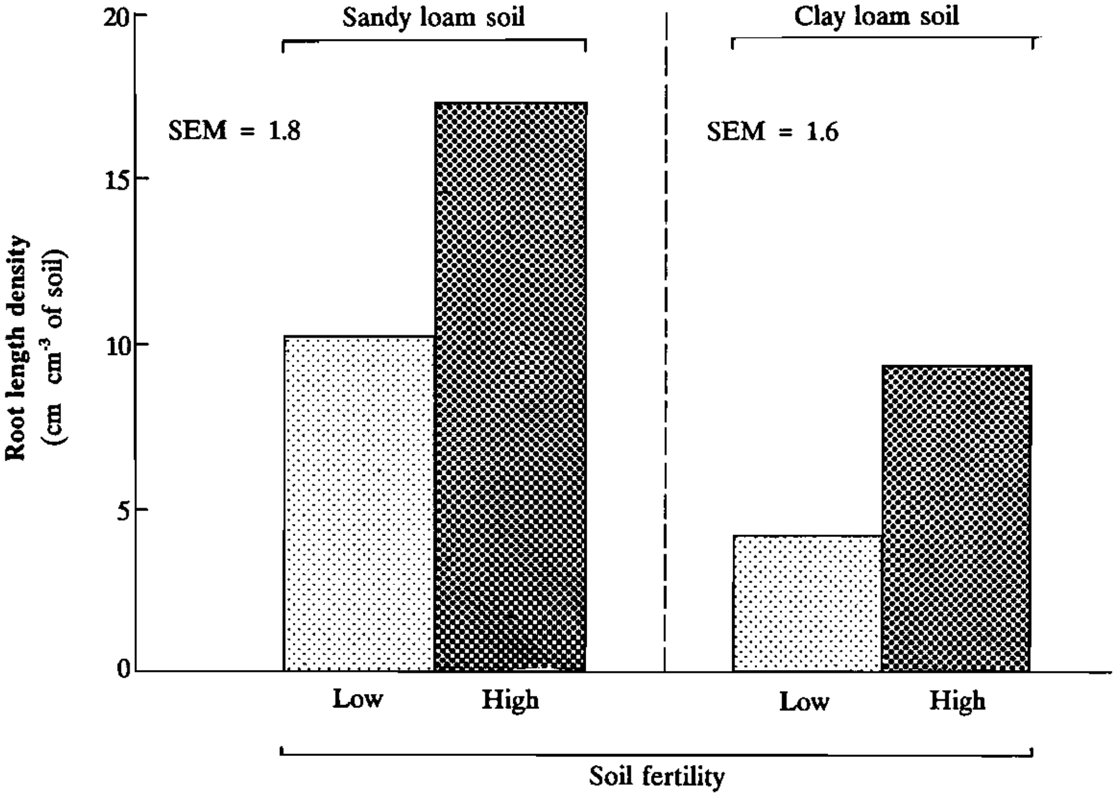

Figure 2. Changes in root length density of a grass + legume association (*B. dictyoneura* + *A. pintoi*) as affected by soil type and fertility status. Each value represents the average rooting density over a 0-15 cm depth of soil profile. Standard error mean values are shown for comparison.

Maintaining photosynthetic activity is essential for guaranteeing the productivity of a grass + legume association in nutrient-poor acid soils. Photosynthetic measurements on intact grass leaves indicated that because they have a C_4 photosynthetic pathway, their net photosynthetic rates were higher than those of the legume with a C_3 photosynthetic pathway (Figure 3). An important observation was that low fertility did not reduce the rate of net photosynthesis in the leaves of either the grass or legume in the association. These results indicate that grass-legume associations adapt to low-fertility acid soils by maintaining their photosynthetic activity per unit leaf area and allocating a higher proportion of fixed carbon to root growth and production.

Responses to change in phosphorus supply

Phosphorus deficiency in forage species is a function of both the supply of phosphorus to the plant and the plant's demand for phosphorus. Phosphorus availability in the soil limits productivity in acid, infertile soils (Sánchez and Salinas, 1981; Salinas and Saif, 1990; Salinas et al., 1990). Therefore, another glasshouse study was conducted to determine how the supply of P in the soil affects biomass production, dry-matter partitioning, and uptake and utilization of P by three different legumes when grown alone (monoculture) or in combination with a grass (association). The trial was conducted in two soil types as described before, but results from a clay loam soil are presented for the sake of clarity. The mineral nutrients added to the soil were the same as for high fertility in the previous experiment except for the element P. The four rates of P used were 0, 10, 20, and 50 kg ha^{-1} supplied as triple-superphosphate. All containers received mycorrhizae and legumes received inoculation with effective *Rhizobium* strains. The results from *B. dictyoneura* and *A. pintoi* as monocultures as well as associations are presented.

The response to P of the shoot biomass per unit soil surface area is shown in Figure 4. In the monoculture, the response to P was greater with the grass than the legume at all P rates except when there was no P supply to the soil. Furthermore, the grass responded to increased P supply enormously when compared with the legume. The legume responded only up to 20 kg ha^{-1}. The differences in shoot biomass production became larger as the supply of P increased in the soil.

The response of root biomass production to increased P supply is shown in Figure 5. Root biomass production in the grass and the association increased with the increase in P supply, while the increase was very small with legume alone. The legume root proportion in the association was determined by the carbon isotope ratio technique. Because of the presence of a C_4 photosynthetic pathway in the grass and a C_3 pathway in the legume, it was possible to quantify legume root proportion in an association. An increase in P supply in soil increased grass root biomass, while the increase was small in legume roots (Figure 6). This dramatic difference in root production between the grass and the legume helps the grass to be very aggressive and dominate the legume in order to explore the soil volume for the uptake of nutrients

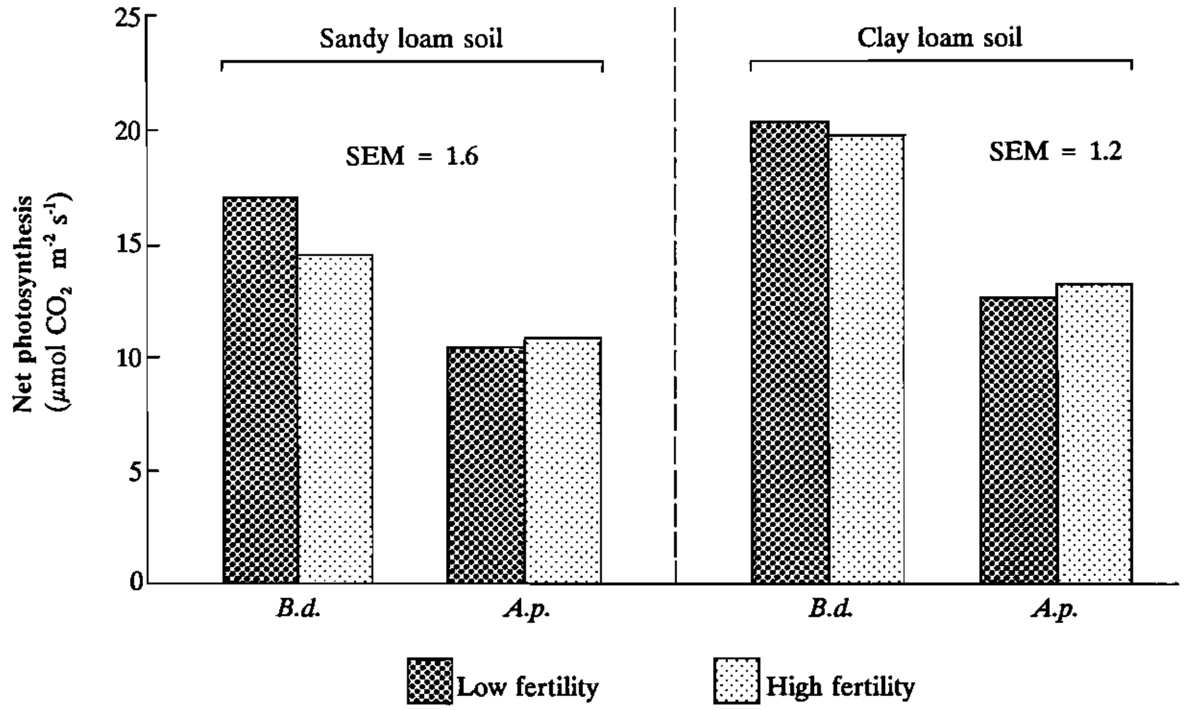

Figure 3. Changes in net photosynthesis of leaves of a grass + legume association (*B. dictyoneura* + *A. pintoi*) as affected by soil type and fertility status.

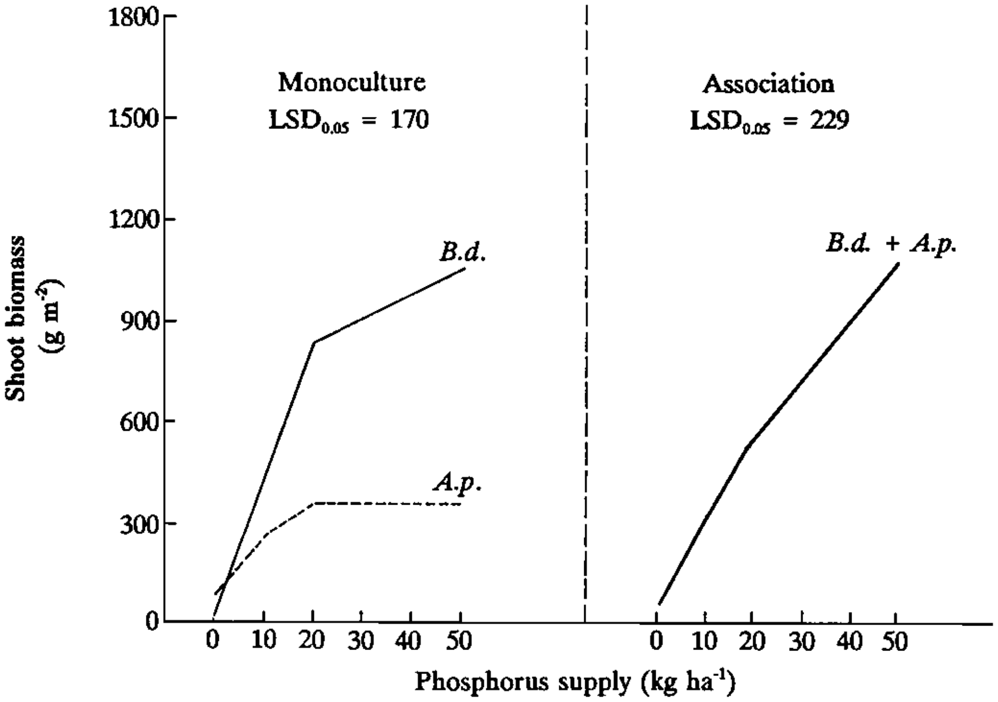

Figure 4. Changes in shoot biomass production per unit soil surface area for a grass (*B. dictyoneura*) or a legume (*A. pintoi*) when grown as a monoculture or as an association (*B. dictyoneura* + *A. pintoi*), as affected by phosphorus supply in a clay loam soil.

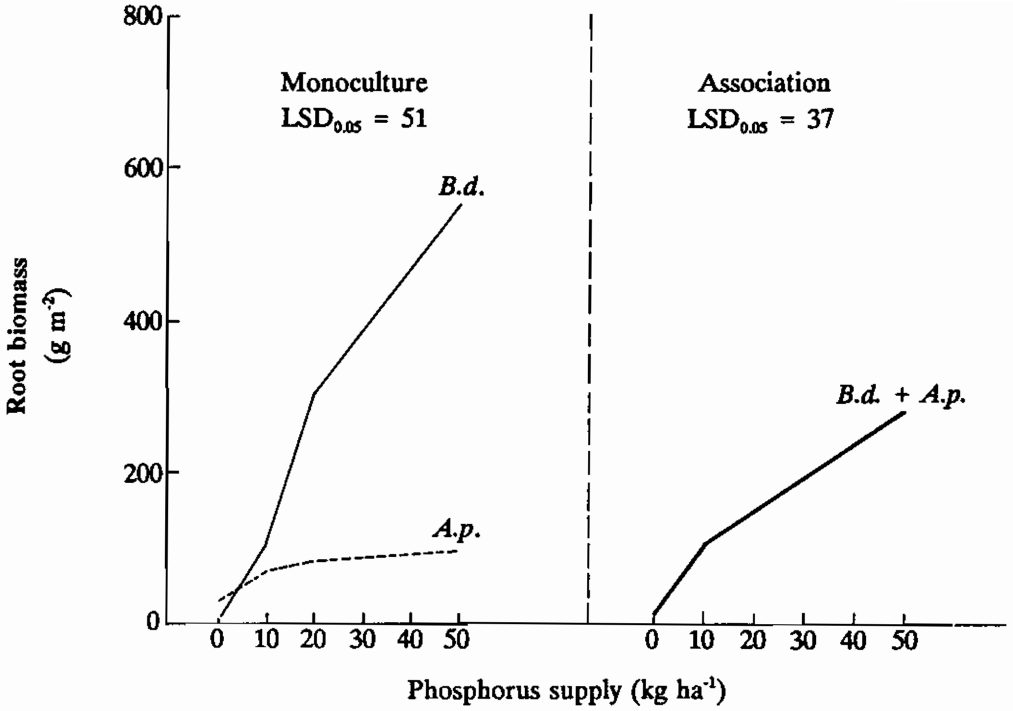

Figure 5. Changes in root biomass production per unit soil surface area for a grass (*B. dictyoneura*) or a legume (*A. pintoi*) when grown as a monoculture or as an association (*B. dictyoneura* + *A. pintoi*), as affected by phosphorus supply in a clay loam soil.

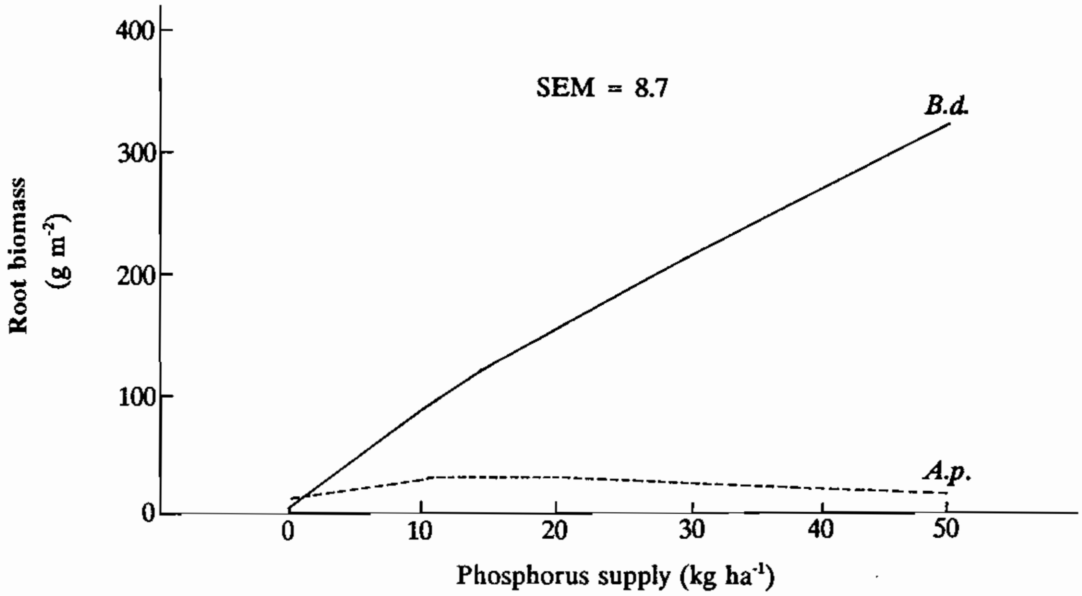

Figure 6. Root biomass production of a grass (*B. dictyoneura*) and a legume (*A. pintoi*) in an association as affected by phosphorus supply in a clay loam soil. The relative proportion of root biomass was estimated based on stable carbon isotope analysis.

and water. This competitive ability of the grass in root growth together with the presence of a C_4 photosynthetic pathway helps the grass to produce markedly higher shoot biomass (forage yield) than the legume (Toledo and Fisher, 1990).

Total P uptake (per unit soil surface area) of the legume with its smaller root biomass was better than for the grass at all levels of P supply (Figure 7). At 50 kg ha^{-1} of P, the total P uptake of the association was significantly higher than that of the grass-alone treatment. The increase in total P uptake of the legume was achieved through higher P uptake efficiency (P uptake in shoot biomass per unit root weight), which was several times higher than that of the grass (Figure 8). The P uptake efficiency of the legume increased with the increase in P supply, while for the grass it either remained the same or even decreased. This is simply because the grass responded to increased P supply by increasing the root biomass so that P uptake efficiency per unit root weight remained the same.

Vesicular-arbuscular mycorrhizae are important for phosphorus supply to forage grasses and legumes in tropical Oxisols (Salinas et al., 1985). The superior P uptake efficiency in the legume could be due to more efficient mycorrhizae and/or increased root phosphatase activity in addition to other factors such as superior uptake kinetics, longer roots, and longer root hairs. We tested mycorrhizal root infection in both species and found that there was a higher infection level in grass than in legume (Figure 9). The percentage of root length mycorrhizal decreased with the increase in P supply to both species. However, the activity of root acid phosphatase was several times higher in the legume at higher levels of P supply in monoculture as well as in association (Figure 10). When there was no external supply of P, the root acid phosphatase activity of the grass was even higher than that of the legume. These results indicate that the mechanisms of P acquisition between the grass and the legume are different.

Phosphorus use efficiency (g of forage produced for g of P uptake in shoots) of the grass was several times higher than that of the legume (Figure 11). The highest P use efficiency of the grass was observed at the recommended level of pasture fertility, i.e., 20 kg ha^{-1} of P supply. In addition to P use efficiency, N use efficiency of the grass was also higher than that of the legume, especially at higher levels of P supply (Figure 12).

It is generally believed that larger root systems with greater surface area, typical of tropical grasses, may be better for acquiring P per unit soil surface area than the smaller ones that are typical of tropical legumes. Larger root systems are often associated with plants that are better competitors, such as tropical grasses, and that trait may competitively exclude companion species such as legumes. However, legumes with smaller root systems may have evolved a greater capacity to rapidly take up P than grasses with larger root systems. The higher uptake of P in the legume *A. pintoi* than in the grass *B. dictyoneura* per unit soil surface area may be attributed to the ability of the legume root system to modify the chemistry of the rhizosphere by

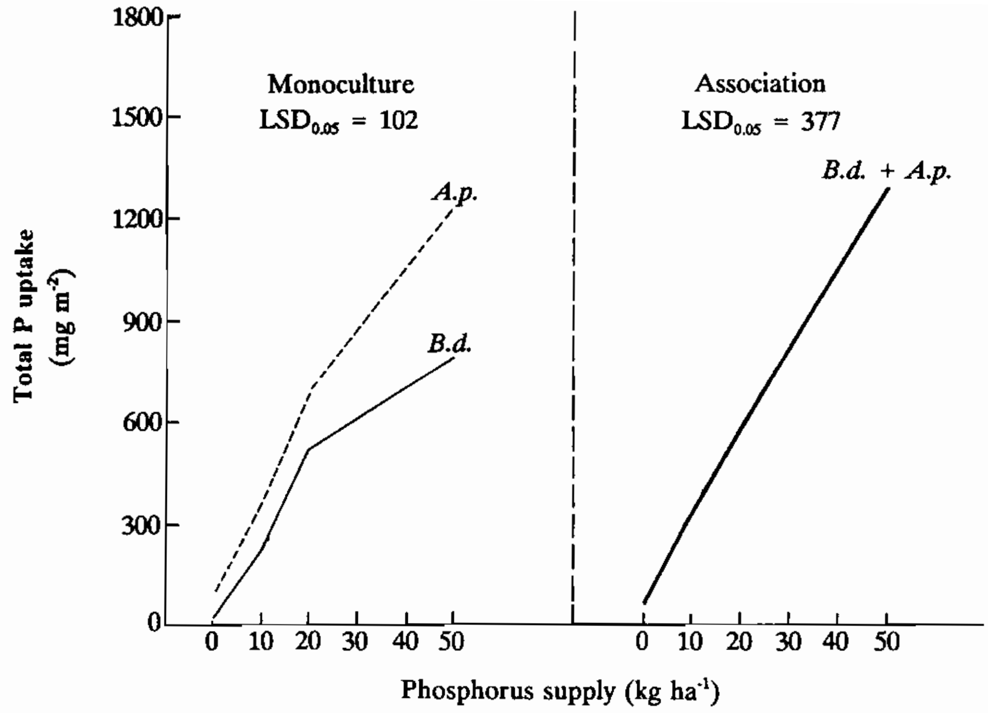

Figure 7. Changes in total P uptake per unit soil surface area for a grass (*B. dictyoneura*) and a legume (*A. pintoi*) when grown as a monoculture or as an association (*B. dictyoneura* + *A. pintoi*), as affected by phosphorus supply in a clay loam soil.

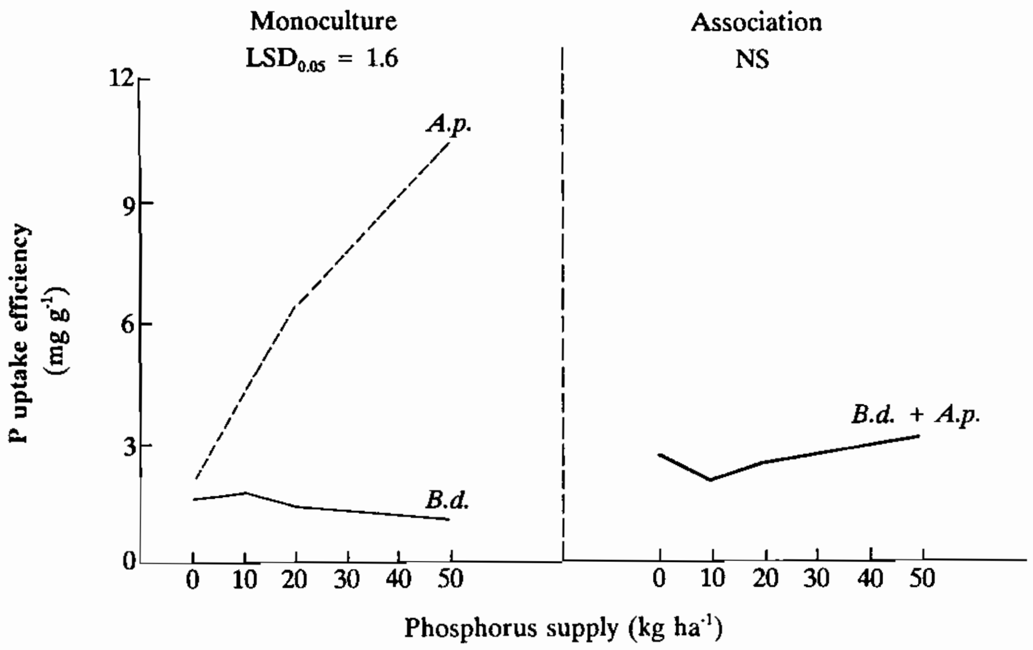

Figure 8. Changes in P uptake efficiency for a grass (*B. dictyoneura*) or a legume (*A. pintoi*) when grown as a monoculture (*B. dictyoneura*) or as an association (*B. dictyoneura* + *A. pintoi*), as affected by phosphorus supply in a clay loam soil. NS = not significant.

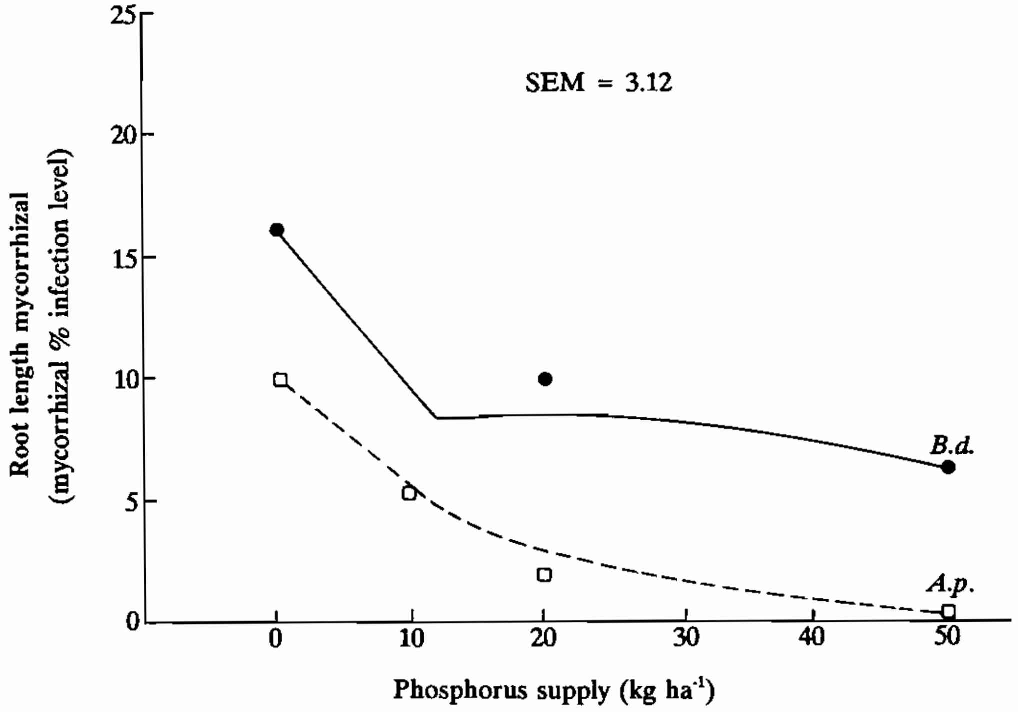

Figure 9. Changes in root length mycorrhizal (% infection) for a grass (*B. dictyoneura)* or a legume (*A. pintoi*) in a monoculture, as affected by phosphorus supply in a clay loam soil.

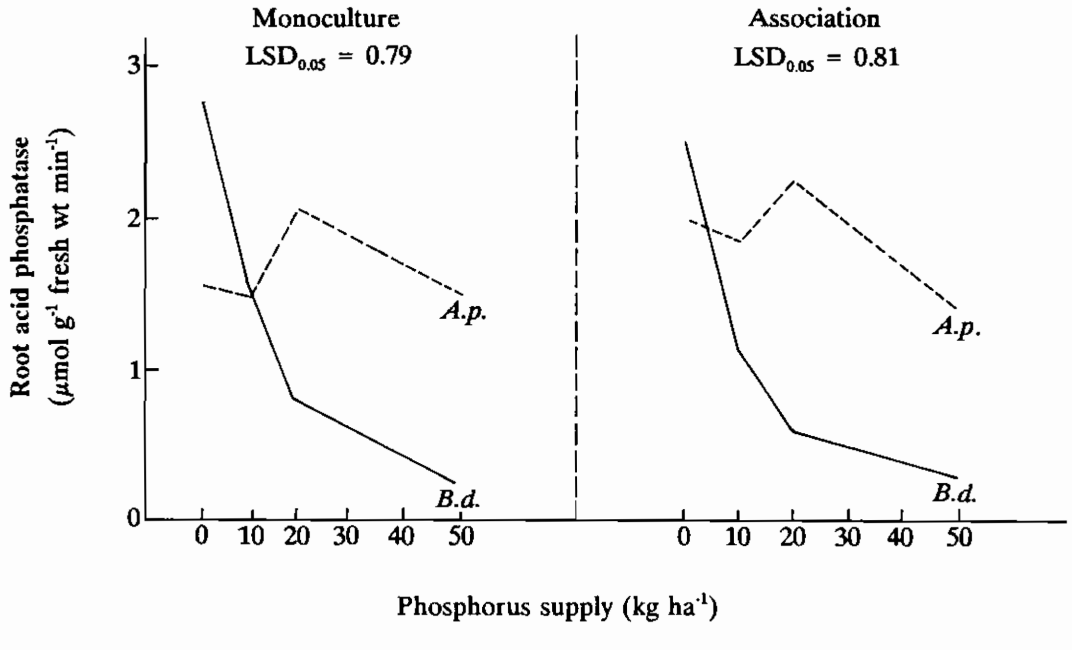

Figure 10. Changes in acid phosphatase activity in root extracts for a grass (*B. dictyoneura*) or a legume (*A. pintoi*) when grown as a monoculture or as an association, as affected by phosphorus supply in a clay loam soil.

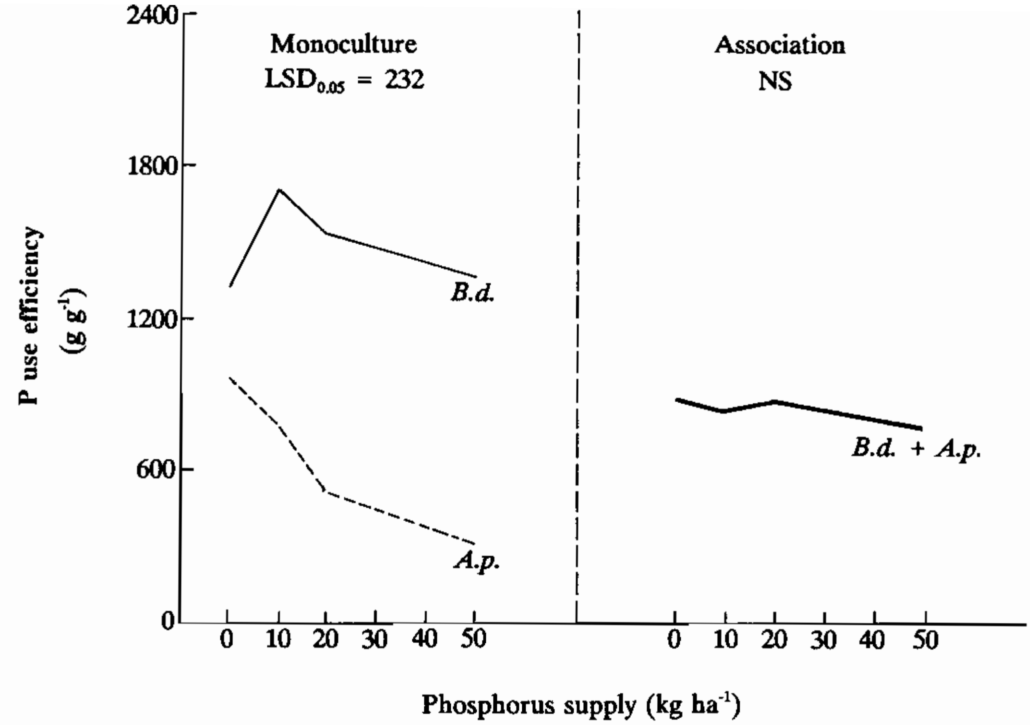

Figure 11. Changes in P use efficiency for a grass (*B. dictyoneura*) or a legume (*A. pintoi*) when grown as a monoculture or as an association (*B. dictyoneura* + *A. pintoi*), as affected by phosphorus supply in a clay loam soil. NS = not significant.

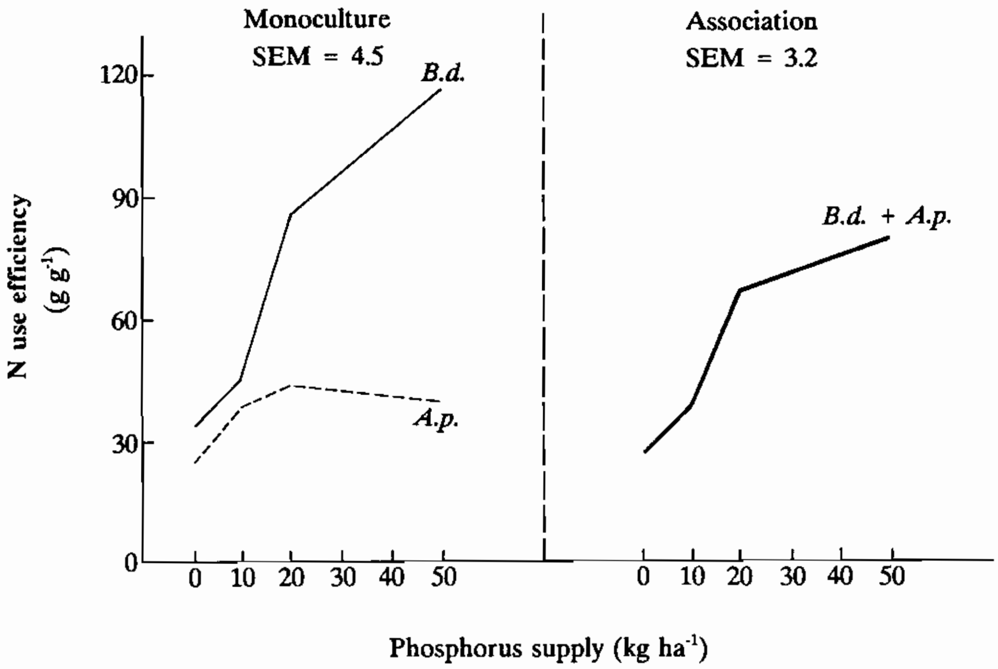

Figure 12. Changes in N use efficiency for a grass (*B. dictyoneura*) or a legume (*A. pintoi*) when grown as a monoculture or as an association (*B. dictyoneura* + *A. pintoi*), as affected by phosphorus supply in a clay loam soil.

exuding organic acids, Al- and Fe- chelators, reducing agents, or enzymes such as phosphatases.

Response to water deficits in soil

Seasonal drought is a dominant feature of the savanna environment, so that adapted forage species must be able to tolerate considerable soil water deficits (Cochrane et al., 1985; Baruch and Fisher, 1991). Research conducted in the TPP before this review period indicated that a number of most promising forage grasses, including *Brachiaria* spp., *Andropogon gayanus*, and *Panicum maximum*, are tolerant of seasonal droughts (CIAT, 1978). Recently, the ability of a range of forage legume species to tolerate water stress was evaluated (Table 3). The data presented are for the minimum water potential measured, and the number of weeks to achieve it. Water potential is a measure of physiological water deficit in plant tissue (Hsiao, 1973). Well-watered plants have leaf water potentials around 0 to -5 bars. Most crop plants tolerate water deficits up to -20 bars in leaves. When we compare tropical forage legumes to most field crops, they seem to tolerate much lower water potentials. Both *S. capitata* and *D. ovalifolium* were outstandingly tolerant of water stress. In contrast, *C. brasilianum* maintained its water potential relatively high (less negative value). A time-dependent decrease in leaf water potentials for *A. pintoi* and *C. brasilianum* is shown in Figure 13. Tolerance of soil water deficits in *A. pintoi* was better than in *C. brasilianum*. These two species may have contrasting physiological mechanisms to tolerate (*A. pintoi*) or avoid (*C. brasilianum*) water deficits in soil. These data indicate a broad range of adaptation to water stress in the forage species tested.

Recycling of Nutrients

In grazed pastures, nutrients cycle from the soil to pasture plants and then back to the soil, either through the death of plant tissue or via the excreta of grazing animals as shown in Figure 14. Nutrient gains to the cycle occur from rainfall and the addition of fertilizers. Nutrient losses from the cycle occur via removal in animal products, leaching, and volatilization as nutrients move through different pathways (Wilkinson and Lowrey, 1973).

The soil compartment includes plant and animal residues, available soil nutrients, and unavailable soil nutrients. The plant compartment includes the whole plant (tops + live roots). The available plant nutrient compartment involves those nutrients in solution in soil water as well as elements from the soil's labile pool of nutrients. The unavailable soil-plant nutrient compartment lumps together all sources of unavailable plant nutrients. Nutrients may be released from this compartment by processes of weathering, by mineralization of organic forms of the nutrient, or by solubilization, and may be rendered unavailable by the processes of immobilization and chemical fixation. The fertilizer compartment is shown with mineral flow to the soil's available plant nutrients.

Table 3. Water stress tolerance of forage legumes.

Legume species	Minimum water potential (bars)	Time to reach minimum water potential (weeks)
Stylosanthes capitata	- 65.9	21.5
Desmodium ovalifolium	- 65.7	14.8
Arachis pintoi	- 61.9	13.3
Centrosema acutifolium	- 60.8	13.2
Centrosema brasilianum	- 28.9	16.8
Standard error of means	5.4***	1.0***

*** $P < 0.001$.

Animals retain only a small proportion, about 20%, of the nutrients that they ingest, and the rest are returned to the soil through excreta. The expected "buildup" in soil fertility in a grass-legume pasture under grazing could result from a more rapid cycling and greater proportion of nutrients in a plant-available form.

For purposes of illustration, a pasture ecosystem from Carimagua is used as a basis for demonstrating the extent of nutrient recycling in pastures. The pastures consist of several most promising forage species, but for the sake of clarity one grass and one legume species are selected.

Biomass production

The above- and below-ground biomass pools for a grass alone (*B. dictyoneura*) and a grass + legume (*B. dictyoneura* + *C. acutifolium*) pasture were quantified eleven months after planting and just before grazing on a sandy loam soil. There was a visual difference between the pastures. The grass-alone pasture was apparently nitrogen-deficient. These pastures received recommended fertility for establishment, which did not include nitrogen. Although the grass-alone pasture looked chlorotic, it had almost an equal amount of above-ground biomass (Table 4). However, the below-ground biomass production in the grass-alone pasture was 44% higher than in the association. These data indicate that, in the absence of the legume, the grass explores a greater volume of soil in search of the limiting nutrient nitrogen.

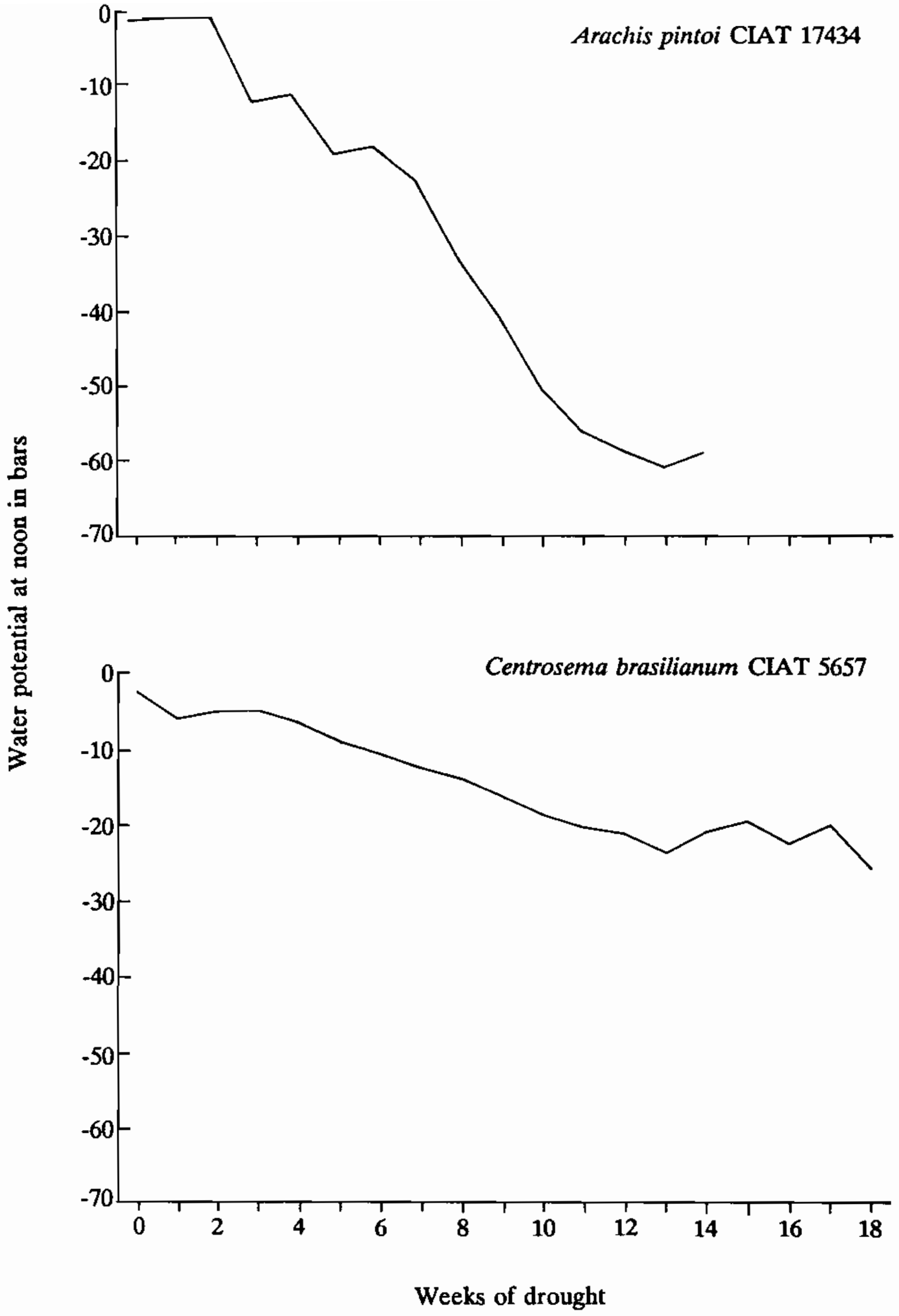

Figure 13. Changes in leaf water potential during drought.

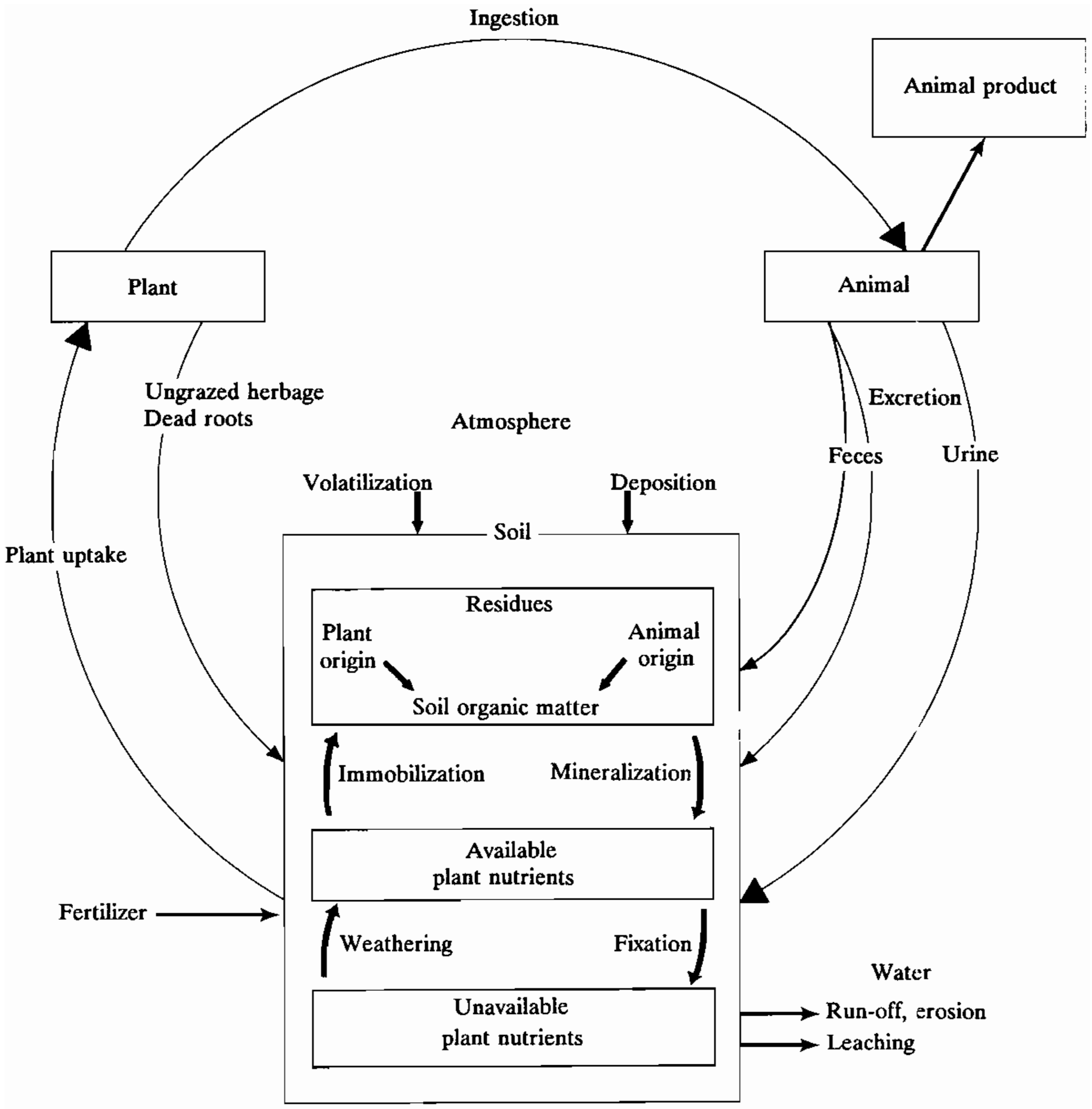

Figure 14. Simplified cycle of nutrients in grazed pasture. (After Wilkinson and Lowrey, 1973.)

Table 4. Distribution of above- and below-ground biomass (g m^{-2}) in 11-month-old pastures in a sandy loam soil prior to grazing.

Dry matter	Grass alone (*B. dictyoneura*)	Association (*B. dictyoneura* + *C. acutifolium*)	
Above-ground			
Standing live	213	173	79
Dead	149	109	39
Below-ground			
Roots	418 ± 156	291 ± 101	
Total	780	691	

± S.E.

Root distribution across the soil profile for the same pastures is shown in Figure 15. There was more root biomass in the top 20 cm of soil profile in the grass-alone pasture than in the association. The legume root proportion in the association was estimated using a $^{13}C/^{12}C$ ratio and found to be less than 20% across the soil profile. Also, the greater distribution of roots in the topsoil layers is important for nutrient conservation because the distance between the site where nutrients are released by plant residues and organic matter and the site where they are absorbed by the plant is very short. Therefore, nutrients are not leached before being used by the plant. It is important to note that a considerable amount of root biomass was distributed in the deeper layers of the soil profile.

Plant residues

The above-ground litter decomposition over time as a percentage of organic matter remaining for *B. dictyoneura* and *A. pintoi* was determined using litter-bag techniques (Figure 16). It is clear that decomposition was faster for the legume than for the grass. The half-life of grass litter was 116 days compared with only 50 days for legume litter. The extent of release of N from the legume litter was also markedly higher than that of the grass (Figure 17). The legume litter released almost four times more nitrogen than the grass. The legume litter also released P and K (Figure 18). The pattern of release of P was similar to that of N, but 80% of K was released very rapidly within two weeks.

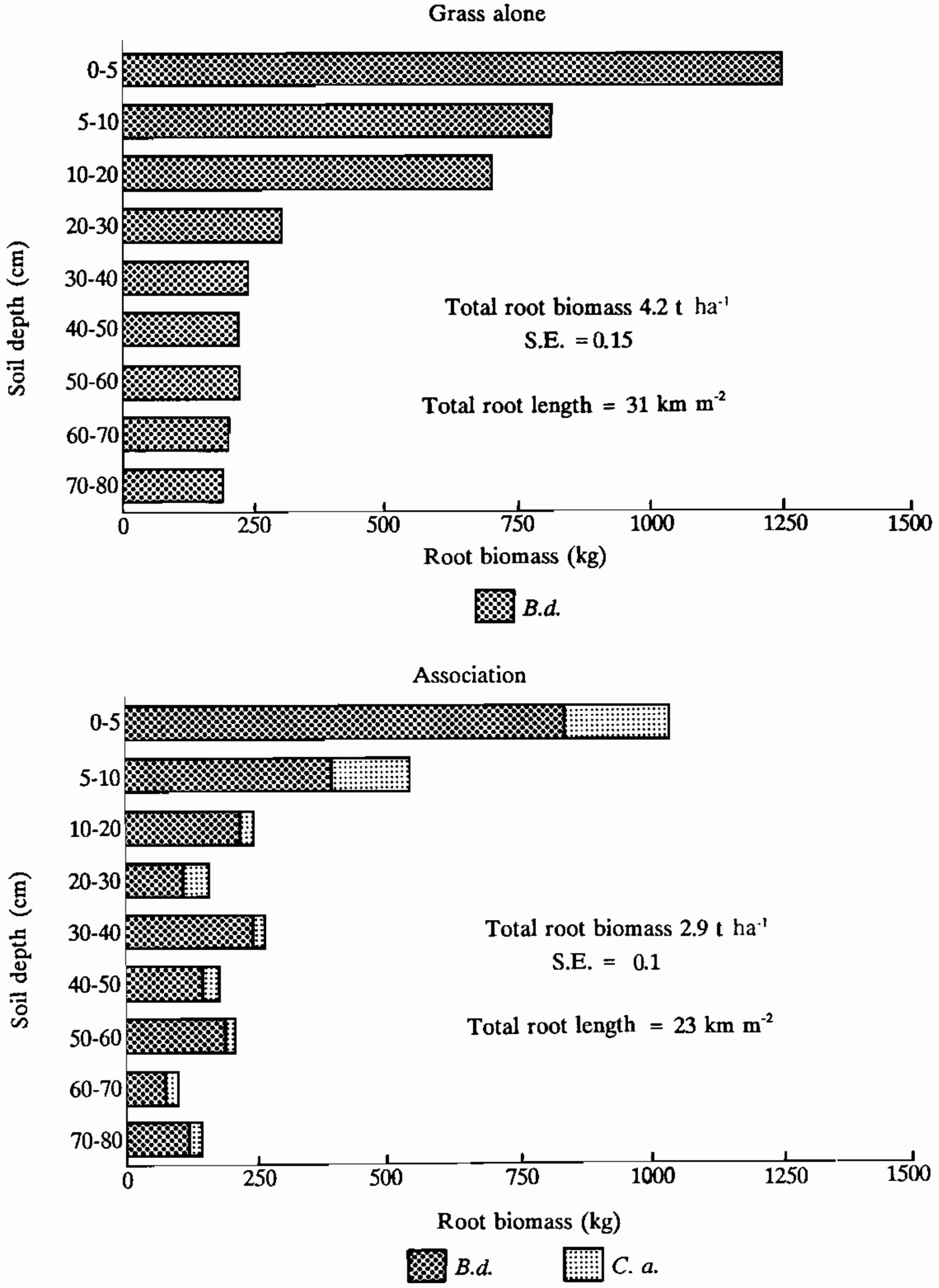

Figure 15. Root biomass distribution in a grass alone (*B. dictyoneura*) or grass + legume (*B. dictyoneura* + *C. acutifolium*) pasture at 11 months after establishment. The legume root biomass in an association was determined by stable isotope analysis.

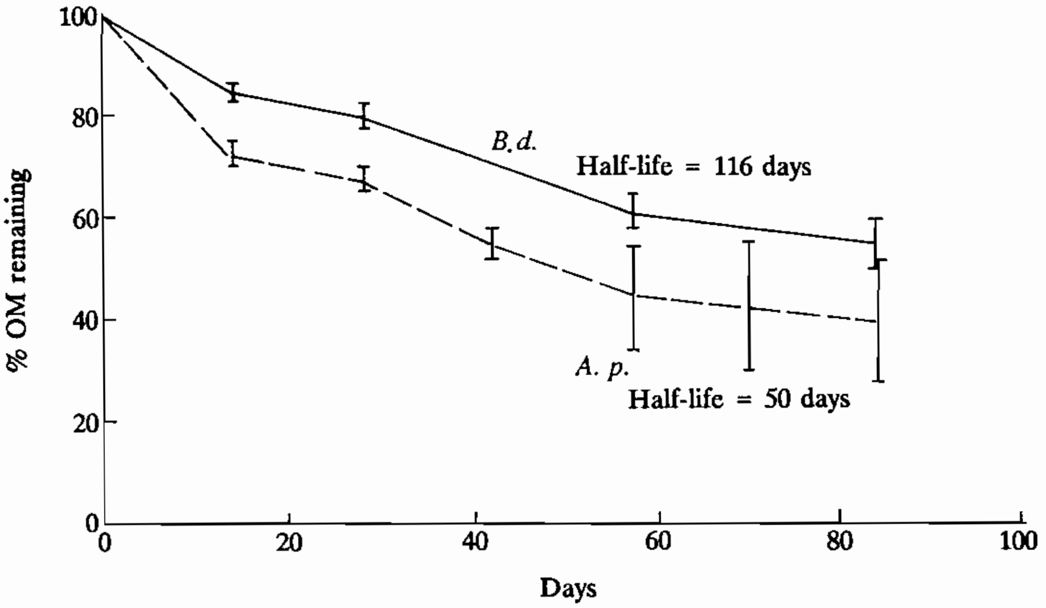

Figure 16. Decomposition of a grass (*B. dictyoneura*) or a legume (*A. pintoi*) litter over time as determined by % of organic matter remaining in the litter bag. Values are mean ± S.E. for 5 replications.

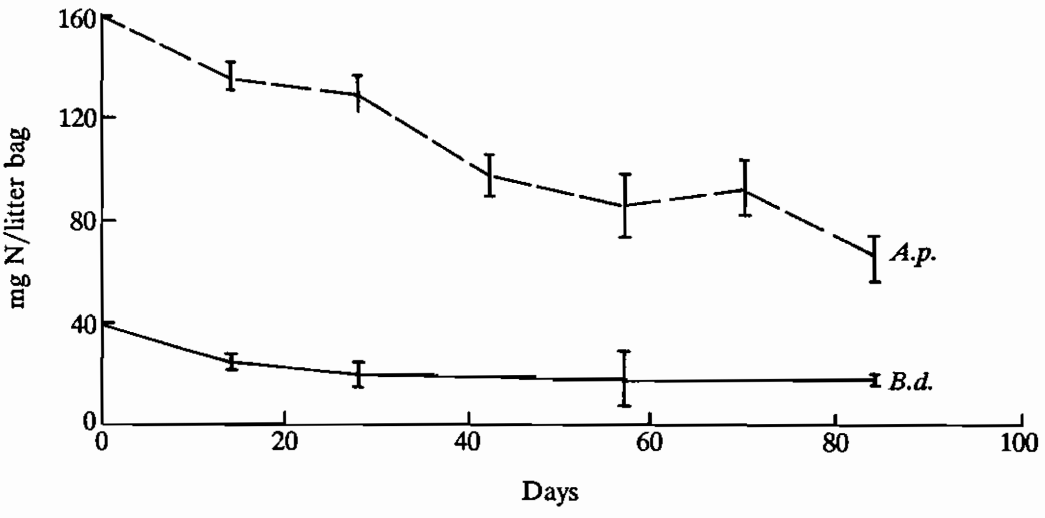

Figure 17. Release of N from litter bag for a grass (*B. dictyoneura*) or a legume (*A. pintoi*) over time. Values are mean ± S.E. for 5 replications.

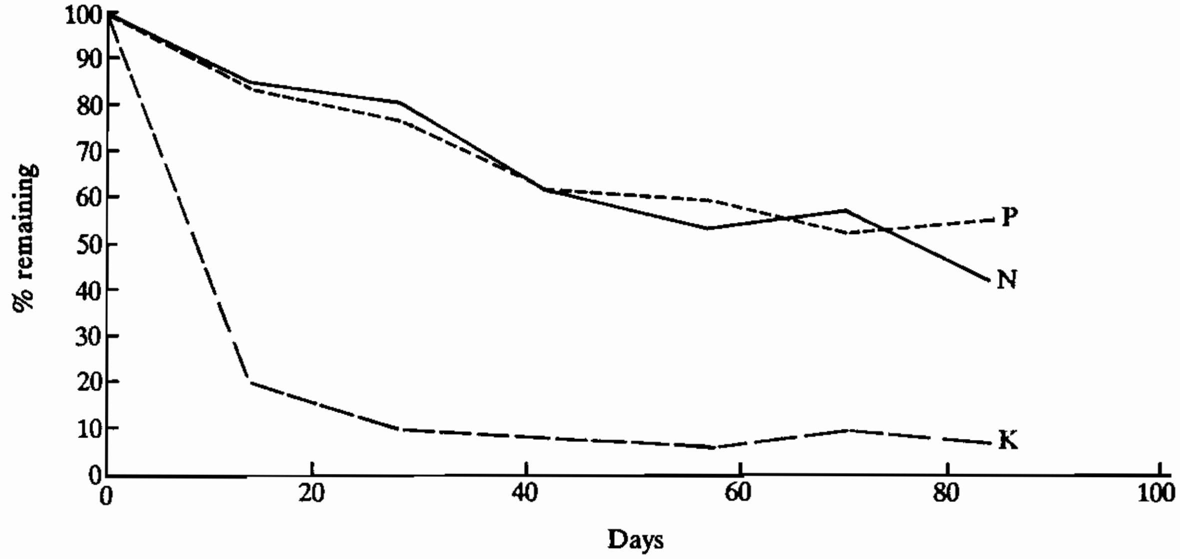

Figure 18. Release of N, P, and K from a legume (*A. pintoi*) litter over time as determined by % of nutrient remaining in the litter bag.

Animal residues

Compared with the nutrient composition of above-ground litter, the animal dung pats had a higher concentration of several key nutrients (Table 5). The levels of N, K, and S are high in the urine. Since the animal in the system is mobile, cycling of nutrients from animal residues will be a function of that mobility, whereas cycling of mineral nutrients from plant residues is not complicated by mobility factors. The mapping of feces distribution in a grass + legume pasture at two stocking rates indicated that dung pats tended to be randomly distributed across the paddock and the number of dung pats increased with the increase in stocking rate.

Organic matter quality and turnover

Plant and animal residues contribute to the overall soil organic matter quality and turnover. This was assessed in long-term pastures (12 years old) of grass alone (*B. decumbens*), grass + legume (*B. decumbens* + *Pueraria phaseoloides*), and legume alone (*P. phaseoloides*) using principles of isotopic dilution. In collaboration with scientists from CSIRO (J. Skjemstad and R. LeFeuvre), Australia, we have used the technique of ^{13}C natural abundance in soil organic matter (Skjemstad et al., 1990; Vitorello et al., 1989) in order to identify carbon sources in soil and to determine the changes that occur in soil organic matter when a native savanna vegetation (C_4) is substituted by grass (C_4) or grass + legume (C_3) pastures.

Table 5. Nutrient composition of above-ground litter and dung pats of animals.

Source	Nutrient composition				
	N	P	K (% of dry wt)	Ca	Mg
Grass litter (*B.d.*)	0.50	0.04	0.09	0.27	0.06
Legume litter (*A.p.*)	1.79	0.07	0.40	1.92	0.12
Dung pats	1.40	0.61	0.56	1.41	0.50

The differences in vertical distribution of total carbon and δ ^{13}C values for each pasture at different soil depths are shown in Figure 19. The total carbon content in grass-alone and grass + legume pastures was very similar at different soil depths (Figure 19A). However, when δ ^{13}C values of the two pastures were compared, there were marked differences between the two pastures. Using these δ ^{13}C values, the percent carbon derived from the legume was calculated at 2-cm intervals for the top 10 cm of the soil profile. These values are shown in parentheses for the grass + legume pasture. Based on these calculations, the contribution of the legume carbon was estimated to be up to 29% of the total carbon of the association at 0-2 cm soil depth, and its contribution decreased gradually through the soil profile (7% at 8-10 cm depth) (Figure 19B).

Soil Conditions

Well-adapted, well-managed, legume-based tropical pasture systems have low levels of soil nutrient extraction because most of the output is high-quality energy and protein that is primarily made of freely available C, N, H, and O and small amounts of P, K, Ca, and Mg from soil. As shown before, such pastures also maintain high above-ground production (Thomas et al., Chapter 8) coupled with profuse and vigorous root systems for minimizing leaching of nutrients and soil erosion while improving soil structure and fertility status.

Fertility

Changes in soil organic matter content and total nitrogen status at different soil depths for long-term pastures of grass alone, grass + legume, and legume alone are shown in Figure 20. Although the soil organic matter content of the topsoil for grass-alone and grass + legume pastures was similar (Figure 20A), and because of the contribution of the legume residues which had higher nitrogen status, the total

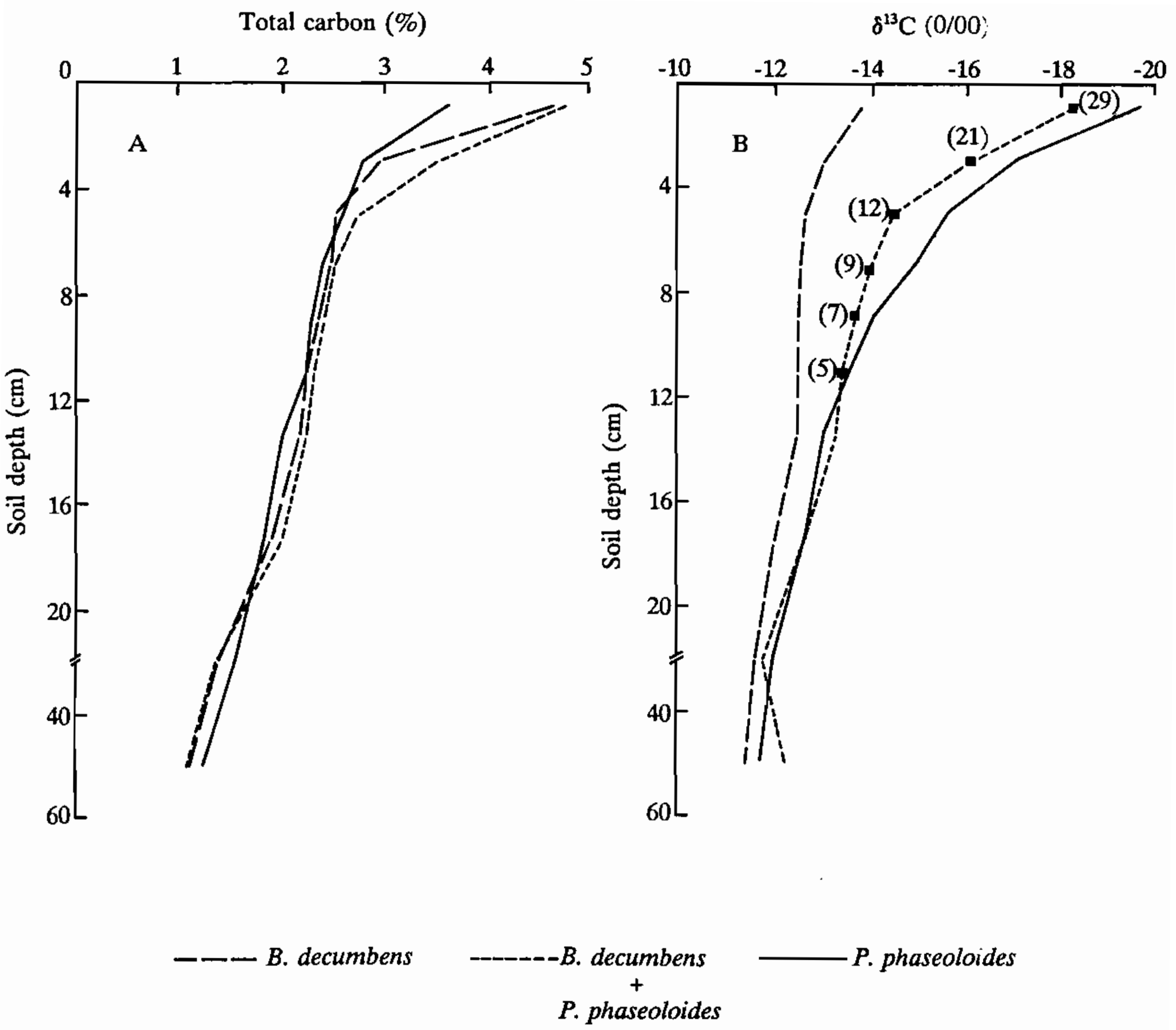

Figure 19. Distribution of total carbon content and ^{13}C natural abundance in relation to soil depth in different pastures. Values in parentheses represent % of carbon derived from legume in a grass + legume association.

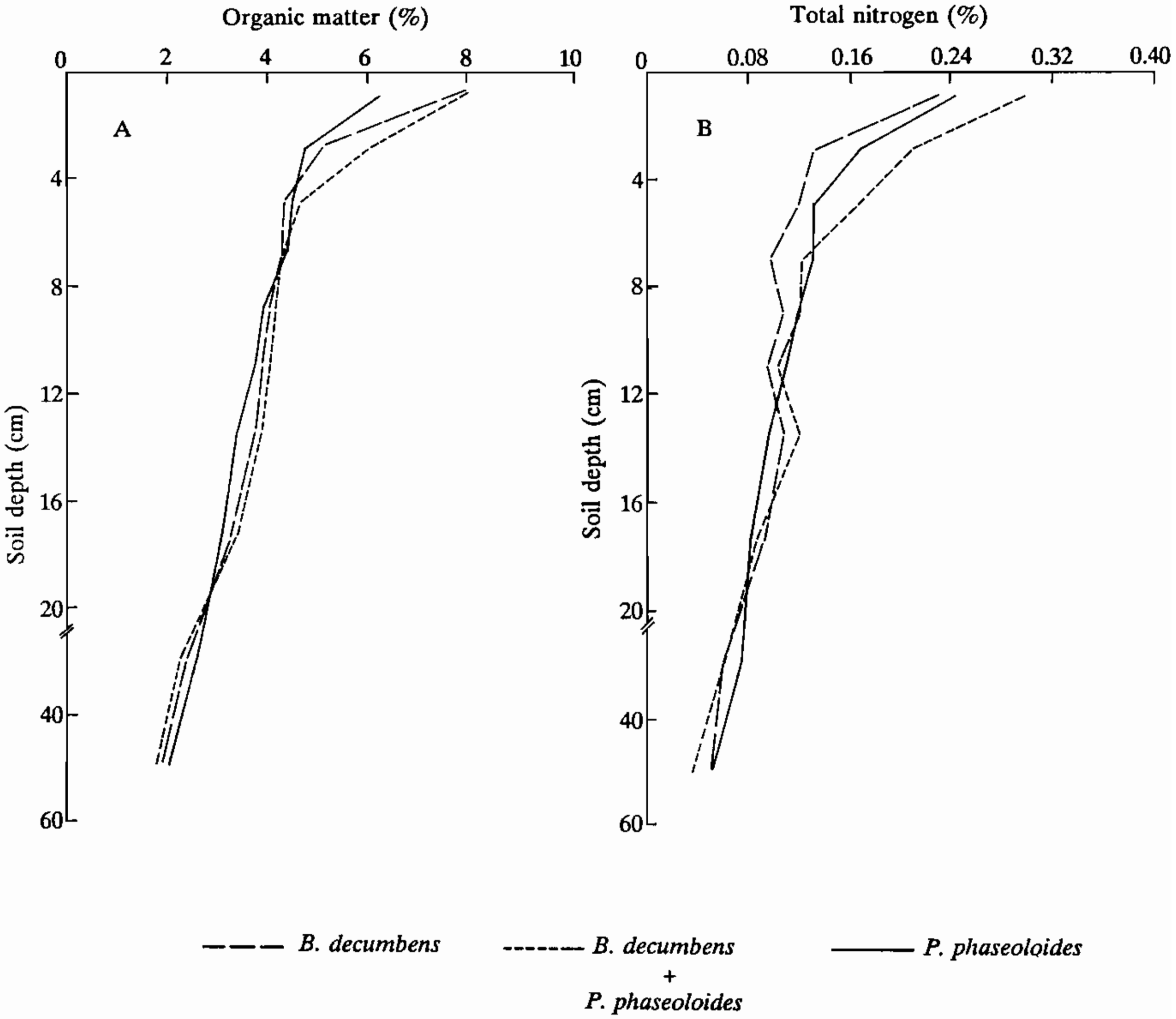

Figure 20. Distribution of soil organic matter and total nitrogen in relation to soil depth in different pastures.

nitrogen content of the 0-10 cm depth of the profile was higher in the grass + legume pasture (Figure 20B). The potential N mineralization rates (as assessed by two different methods) of soil from grass + legume pastures were substantially higher than that of the grass-alone pastures (Table 6).

Soil organic P level as a percent of total P was estimated in native savanna, improved grass, and grass + legume pastures (Figure 21). Legume-based pasture had twice as much organic P as the native savanna. In the case of exchangeable levels of K, Ca, and Mg, the legume-based pastures within two years pumped more Ca and Mg from deeper layers of soil profile while K availability was not much affected (Figure 22).

Structure

In order to estimate soil structural changes in different pastures, we have determined soil aggregate size and water infiltration rates. Compared with native savanna pastures, legume-based leys improve soil structure by increasing soil aggregates and water infiltration (Table 7).

Biological activity

Compared with native savanna, the biological activity of the improved pastures, in terms of the population of nitrifying bacteria (TPP annual report, 1985) and mycorrhizal spores and percent of mycorrhizal root infection (Dodd et al., 1990), was markedly higher (Table 8). The activity of earthworms increased threefold in the improved pastures. This increased biological activity is beneficial to soil properties such as mineralization, humification, texture, porosity, water infiltration, and retention. Soil characteristics are both a determinant and the consequence of earthworm activities, since these macro-organisms greatly influence the functioning of the soil system. They build and maintain the soil structure and take an active part in energy and nutrient cycling through the selective activation of both mineralization and humification processes (Lavelle, 1988).

Benefits from Soil Enhancement

The contribution of legume residues to soil organic matter quality and turnover together with improved soil fertility, soil structure, and biological activity were associated with a 1.7 t ha^{-1} yield increase in a rice crop following 10-year-old grass + legume plots that did not require any N fertilizer when compared with rice following a grass-alone pasture of the same age (Figure 23). These yield differences indicate that the technique of ^{13}C natural abundance in soil organic matter may prove to be a valuable aid in predicting the likely beneficial effects of a forage legume for subsequent production of pastures and/or field crops. For our partners in national programs, determination of total nitrogen in the top 10 cm of soil profile at 2-cm

Table 6. Potential N mineralization rates of soil under *B. decumbens* or *B. decumbens* + kudzu pasture measured by two methods.

Method	*B. decumbens*	*B. decumbens* + kudzu
	(μg N g^{-1} soil day^{-1})	
Incubation in pots in glasshouse for 4 weeks	0.519 ± 0.085	0.913 ± 0.116
Anaerobic incubation at 40 °C for 7 days	3.86 ± 1.33	6.84 ± 1.69

Mean ± S.E. of 15 samples.

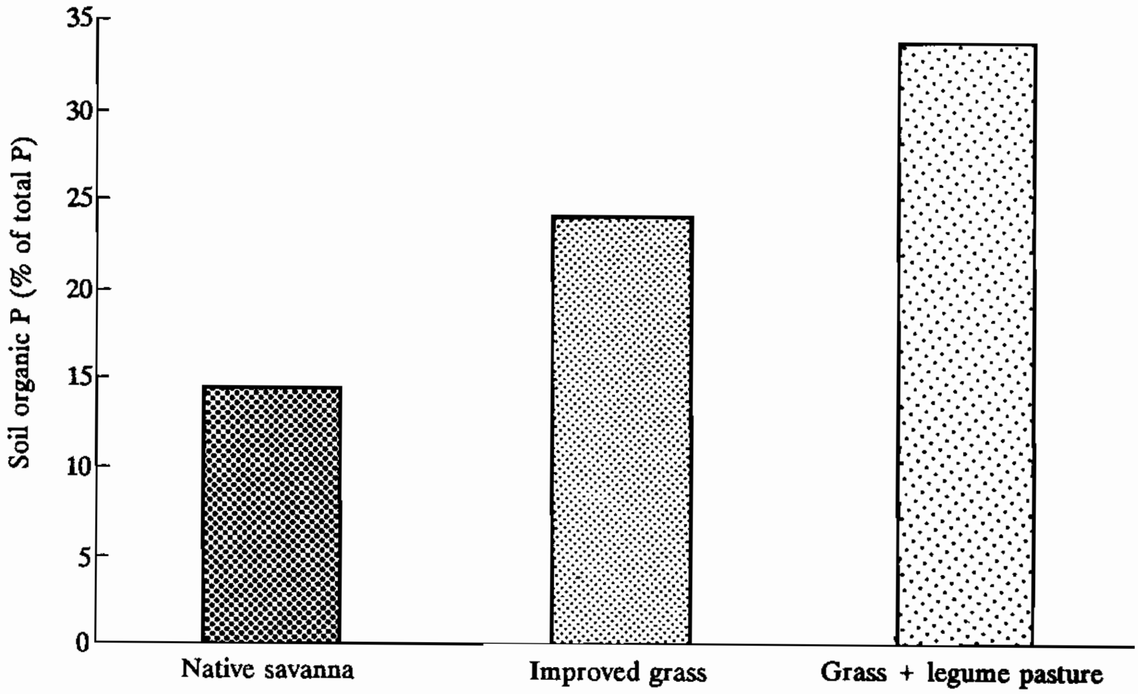

Figure 21. Proportion of soil organic P as % of total P in different pastures.

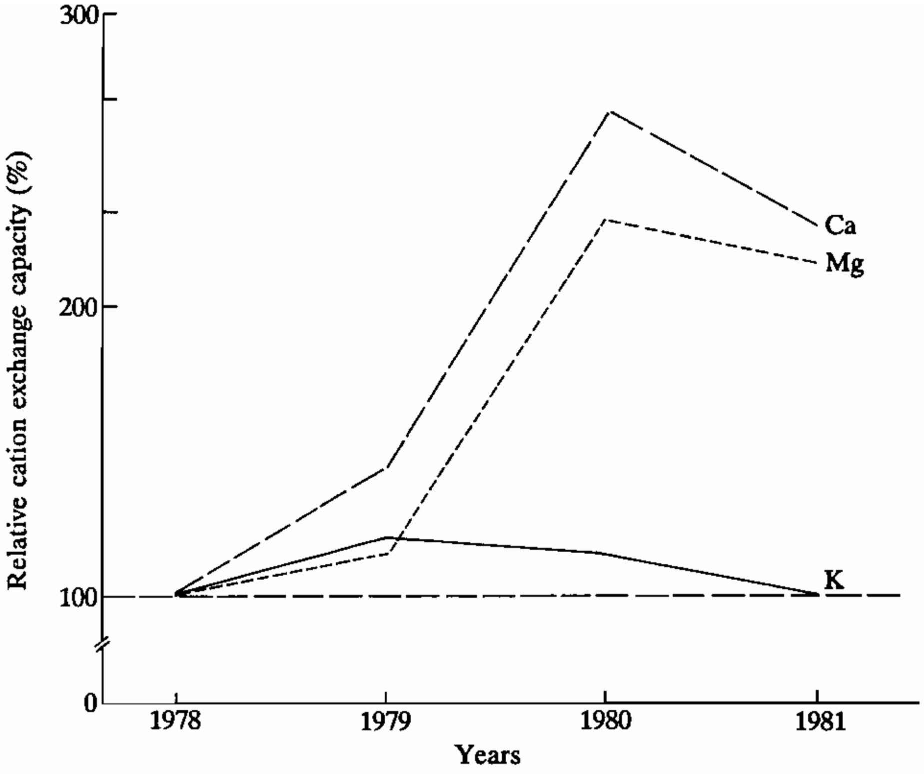

Figure 22. Relative increases of Ca, Mg, and K in a grass + legume (*A. gayanus* + *P. phaseoloides*) pasture.

Table 7. Soil physical properties in different pastures in a medium-texture Oxisol of Carimagua, Colombia.

Pastures	% of soil aggregates > 0.5 mm	Water sorptivity (cm/sec$^{1/2}$)
Native savanna	9.6 a	0.20 a
Improved grass	25.5 b	0.40 b
Grass-legume pasture	31.9 b	0.39 b

Means in a column not followed by the same letter differ.

(T test, P = 0.05).

Table 8. Comparison of soil biological activity in different pastures.

Soil biological characteristic	Savanna	Improved grass	Grass + legume
Nitrifying bacteria (number/g soil)	3.9×10^6	2.7×10^8	—
VA mycorrhizal fungi spore population (spores/100 g soil)	50	190	275
Root infection with VA mycorrhizae (%)	31	54	58
Earthworm activity (casts/m^2)	0.9	2.1	3.1

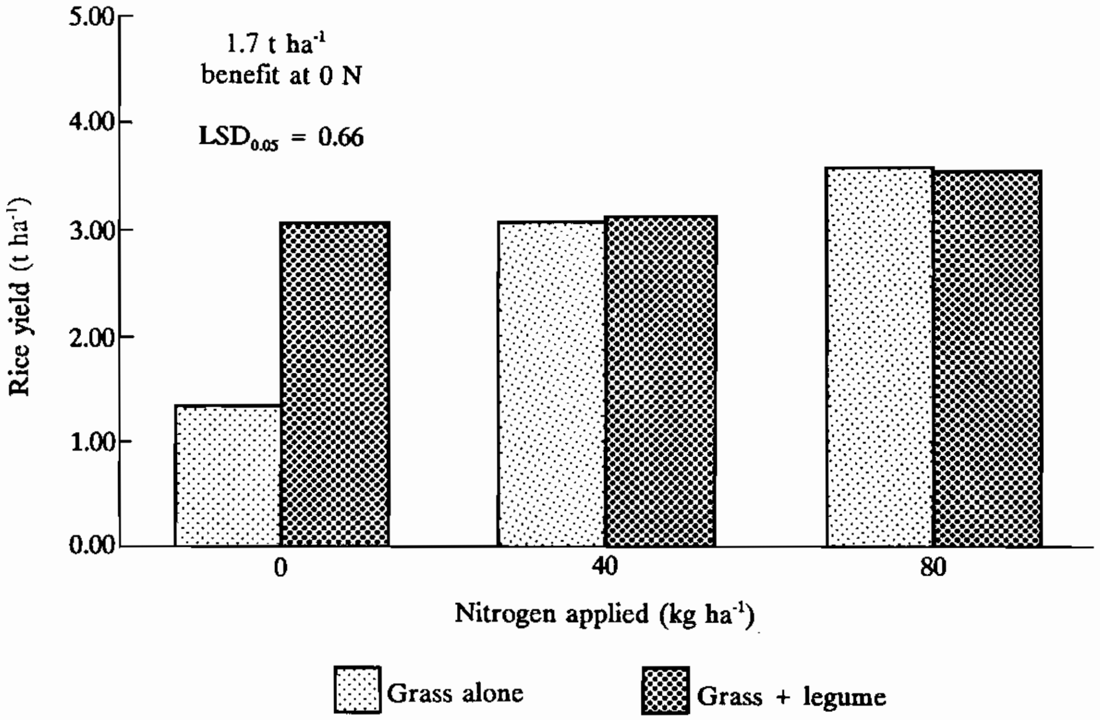

Figure 23. Grain yield response of rice crop to N application following 10-year-old grass-alone (*B. decumbens*) or grass + legume (*B. decumbens* + *P. phaseoloides*) pasture.

intervals and rate of potential N mineralization could serve as simple research methods to evaluate the contribution of forage legumes to soil enhancement.

Integration of Processes

Pastures under grazing are more complex than annual cropping systems. As shown before, the limiting processes and regulatory mechanisms are numerous and varied, and they all have to be studied simultaneously and continuously over a long period of time in order for the system to be understood in its totality. However, weaknesses exist in our ability to effect a detailed integration of the various processes and their relations. Therefore, the holistic analysis offered by a "Modeling Approach" can enable us to predict the net results from different interacting processes.

Modeling is only a tool to put things together holistically and aim at a cause-effect assessment of a complex system. A model can provide the functional framework to organize and identify key processes (within the soil-plant-animal factors) and to focus experiments to better understand how pastures respond to strategic inputs and management. A good model will provide a reduced description encapsulating the essence of the processes involved. The modeling approach will make us become increasingly aware of the need to think quantitatively and to view our results within the context of the whole soil-plant-animal system. In collaboration with Prof. John Thornley of the United Kingdom and Prof. W. Parton of the United States, we are in the process of modeling legume-based tropical pastures under grazing. We are also interacting with the Tropical Soil Biology and Fertility (TSBF) program.

* * *

As Aldo Leopold (1949) said, "For every atom lost to the sea, the prairie pulls another out of the decaying rocks. The only certain truth is its creatures must suck hard, live fast, die often, lest its losses exceed its gains."

Conclusions

Adaptation attributes

Improved grasses and legumes adapt to nutrient-poor acid soils by maintaining their photosynthetic activity per unit leaf area and allocating fixed carbon to root growth and production at the expense of shoot growth and production.

The greater root and shoot production in grasses is associated with more efficient use of nitrogen and phosphorus. The higher phosphorus uptake efficiency in legumes is associated with greater activity of the enzyme acid phosphatase in roots.

Recycling of nutrients

Compared with grass litter, legume litter has more nutrients (N, Ca, K) and they are released faster, thereby contributing to the superior soil organic matter quality of legume-based pastures.

^{13}C natural abundance in soil organic matter, total nitrogen status of topsoil profile, and potential rate of nitrogen mineralization in the soil are useful indicators of soil enhancement in legume-based pastures.

Soil conditions

Soil improvement in legume-based pastures is due to increased soil fertility from nutrient recycling through plant and animal residues, improved soil structure, and greater soil biological activity.

Summary

Integration of improved germplasm with sound management technologies is essential for the development of viable production systems in different agroecosystems in lowland tropics. An interdisciplinary research team was assembled at CIAT for improved understanding of soil-plant-animal factors and processes in order to design better systems of ley farming. In addition to management, productivity in legume-based leys, in nutrient-poor acid soils, is affected by adaptation attributes of forage germplasm, recycling of nutrients, and soil conditions. Tropical forage species adapt to acid soils by maintaining their photosynthetic activity per unit leaf area and allocating a significant proportion of fixed carbon to root growth and production. Soil enhancement in legume-based leys is due to increased soil fertility from biological nitrogen fixation and nutrient recycling through plant and animal residues, improved soil structure, and greater soil biological activity. Carbon-13 natural abundance in soil organic matter, total nitrogen status of the soil surface horizon, and the potential rate of nitrogen mineralization in the soil are useful indicators of soil enhancement in legume-based leys.

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CONCLUSIONS

R. R. Vera*

The documents in this volume have provided a sample of the Tropical Pasture Program's achievements over the past few years. Many other achievements, including the very significant contributions made by CIAT's research support units, such as the Biotechnology Research Unit, the Virology Research Unit, the Genetic Resources Unit, and the Data Services Unit, were only mentioned briefly in the verbal presentations of this Annual Program Review. Nevertheless, their contributions are recorded in detail in the Program's full written annual report.

The TPP has continued to make significant advances in identifying grasses and legumes adapted to acid soils (Miles and Lapointe, Chapter 2). These newer species include *Centrosema acutifolium*, *C. rotundifolium*, *Arachis pintoi*, *Desmodium velutinum*, *Flemingia macrophylla*, *Cratylia argentea*, *Brachiaria* spp., *Panicum maximum*, and *Paspalum* spp.

I wish to emphasize a recurrent theme that has been implicitly and explicitly addressed throughout several of the articles in this volume. I refer to the fact that the TPP deals with a wide variety of crops--perennial forage crops, but crops nonetheless. Each of these has its own characteristics, and its own particular problems and advantages. Furthermore, as has already been mentioned, most of these species have no previous history as cultivated crops.

Thus, the TPP is generating a wide set of alternative species for an equally diverse set of niches, whether they be at the ecosystem level or at the level of the farming system. Some of the species listed, such as *Flemingia*, *Desmodium velutinum*, *Panicum*, etc., represent what one could consider as the third generation of species in the TPP's brief history.

For the first time, these species include some woody legumes with excellent agronomic adaptation to extreme edaphic conditions. I emphasize the term **agronomic adaptation** to make clear that with many of these species there is still a long way to go in terms of characterization of their nutritional value, utilization, and definition of their potential roles.

Similarly, I feel that there have been significant advances in a variety of techniques and methodologies.

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At the most basic level, the TPP is one of the first in the CGIAR system to have available a genetically transformed plant using new biotech methods. I refer to *Stylosanthes guianensis*, made resistant to the herbicide BASTA.

At a more applied level, and thanks to the efforts of the Virology Research Unit, we can now count on laboratory techniques to detect a number of previously unknown and undetected viruses in some key grass and legume species.

Over the period under review, laboratory techniques have been developed and/or adapted to artificially rear spittlebugs, bioassays have been developed to screen for a number of traits, and techniques to evaluate specific antinutritional factors were made available (Lapointe and Miles, Chapter 4; Lascano and Spain, Chapter 3).

At the other end of the spectrum, that is, at the statistical level, a number of techniques have been tested and adapted by the Data Services Unit to deal with intractable variables in long-term animal production experiments.

Exciting recent developments include those related to various mechanisms and processes operating in, and around, grazed pastures (Thomas et al., Chapter 8; Rao et al., Chapter 9). The TPP has moved toward a better understanding of soil-plant-animal interactions in grazed pastures by studying:

population dynamics and implications for management;

the role of roots, litter, and above-ground biomass in nutrient use and cycling;

contributions to soil organic matter;

interactions in prototype ley-farming systems;

the mechanisms of plant adaptation to acid soils; and

responses to higher input levels.

To some extent, the TPP has thus begun to confirm what was anticipated in terms of the contribution of well-managed, adapted, grass-legume pastures to soil enhancement.

As early as 1983, the TPP tried to quantify the contribution of grass-legume pastures to a subsequent rice crop. In this particular case, the exercise failed because the rice varieties available at that time were not adapted to savanna conditions. Nevertheless, this illustrates that the TPP was already well aware of the need, and also of opportunities, to interact with agricultural crops such as rice and others. Maybe at that time we were only dreaming.

This improved understanding that I was referring to is particularly important in view of the abundant but very poorly documented literature produced recently regarding the proclaimed evils of pastures in the tropics. We believe that pastures, like all other crops, have advantages and disadvantages, and that it is up to MAN to put them to the best possible use.

In the context of developing a better understanding, the data that the TPP is beginning to produce clearly point out some of the tradeoffs that forage plants make in adapting to poor soils and low external inputs.

Despite the operation of those mechanisms of adaptation that imply that a significant portion of the photosynthesized carbon is translocated to the underground biomass, we need to remember that these pasture species are still able to generate highly increased levels of animal production (Table 1).

This table shows some of the gains in potential animal production that have been made over the years, as new species continued to be identified and assembled into highly productive pastures. One should mention that the levels of production observed for these *Arachis pintoi*-based pastures are reaching record highs.

At a different level, still other tradeoffs have to be made, at least with some species. I refer specifically to the potential difficulties in controlling some forage species such as *Brachiaria humidicola* and *Arachis pintoi*, initially selected for resilience, persistence, and perenniality, if they are to be followed by annual crops.

From this point of view, the existence of a wide range of species selected by the TPP, and which have different mechanisms of persistence, is an added advantage, possibly not appreciated until relatively recently.

Chapters of M. J. Fisher et al., R. J. Thomas et al., and J. E. Ferguson should have shown that progress has also been made in researching some of the many alternative uses of grass-legume pastures in diverse farming systems.

It can be anticipated that as these farming systems intensify thanks to the introduction of crops and high-carrying-capacity sown pastures, the pressure on the remaining native resources, particularly the savannas, will also increase. This issue is currently being investigated, and it is expected that the new Savannas Program will continue those studies.

Valuable feedback has been produced as a consequence of studies on alternative uses of grasses and legumes, which led to the identification of some species, and uses of those species, that would otherwise have passed unnoticed.

In the same vein, I think that the TPP reacted positively and expeditiously to the perceived institutional and technical constraints that limit the development of seed

Table 1. Weight gains averaged over 4 or more years, Carimagua, Colombia.

Pastures	Yearly weight gain (kg)	
	per head	per hectare
Savanna	60	12
A. gayanus-S. capitata	160	300
B. dictyoneura-A. pintoi	190	600

supplies. We certainly do not claim to have solved the problem, but we do believe that significant progress has been achieved in a number of pilot initiatives.

The value of those pilot initiatives was recently recognized by RIEPT's Advisory Committee, when it agreed to give them top priority for further development. Even more recently, in December 1991 as a matter of fact, FAO agreed to explore the feasibility of a regional forage seed project in Central America centered around a selected number of species identified by RIEPT and based on what has been learned in those initial projects.

Although we have not directly addressed the issue of our collaboration with national institutions, there should be little doubt that the TPP has had a tremendous qualitative and quantitative impact on tropical pasture research in Latin America.

The size and activism that permeate RIEPT demonstrate that influence and they are reflected in Table 2, which shows both the quantitative and qualitative growth of RIEPT.

RIEPT activities have created a massive amount of information, which has been systematized in a large centralized database located in CIAT's mainframe computer. Given that nowadays all national research institutes have access to microcomputers, in 1991 that large database was subdivided into smaller fractions according to ecosystems, and is presently being distributed to our collaborators on microcomputer diskettes.

Nevertheless, there are areas of concern for the future. On the one hand, we see an expanding group of institutions actively interested in our germplasm; increasingly, these institutions are closer to development activities than to research. This is a positive development if the TPP is to make a significant impact, but it brings its own specific set of institutional and policy-related problems.

Table 2. Evolution of RIEPT between 1986 and 1991.

Factor	Year		Increase (%)
	1986	1991	
Countries	16	22	38
Institutions	58	95	64
Participants	155	403	160
Agronomic trials	138	274	99
Grazing trials	40	84	110
Support trials	16	75	369
Establishment and recuperation trials	4	33	725

On the other hand, many of our more traditional partners, the NARIs, are becoming operationally weaker. In this setting, the issue of devolution of some of CIAT's research responsibilities will have to be revisited in the near future.

In a more positive tone, the TPP has begun to face some new challenges: a global rather than regional mandate; tropical mid-altitude regions in addition to lowlands; and multipurpose forage trees and shrubs. Let us look briefly at just one of these initiatives.

Regarding the global mandate, the TPP anticipated some of the likely implications, and began a modest networking effort in the humid and subhumid zones of West and Central Africa during 1989 thanks to the support of the IEMVT.

The map of West Africa in Figure 1 depicts the locations of ongoing agronomic experiments in the region, which are being evaluated with a standardized methodology.

Likewise, a network was created in 1989 for Southeast Asia, but it has not yet become operational. Nevertheless, thanks to limited Australian funds, that became possible in January 1992, when we set up a major screening site in the Philippines. B. Grof is our man on the scene.

Over the next few months, CIAT and the TPP will change substantially. The latter will become more closely focused on germplasm development and will have an enlarged geographic, ecological, and germplasm mandate. To reflect these changes, it will be known as the Tropical Forages Program. CIAT will also begin to address issues of natural resource management in selected tropical ecologies of the continent. We believe that previous work undertaken by the TPP and reviewed in this document provides a strong foundation to meet these new challenges.

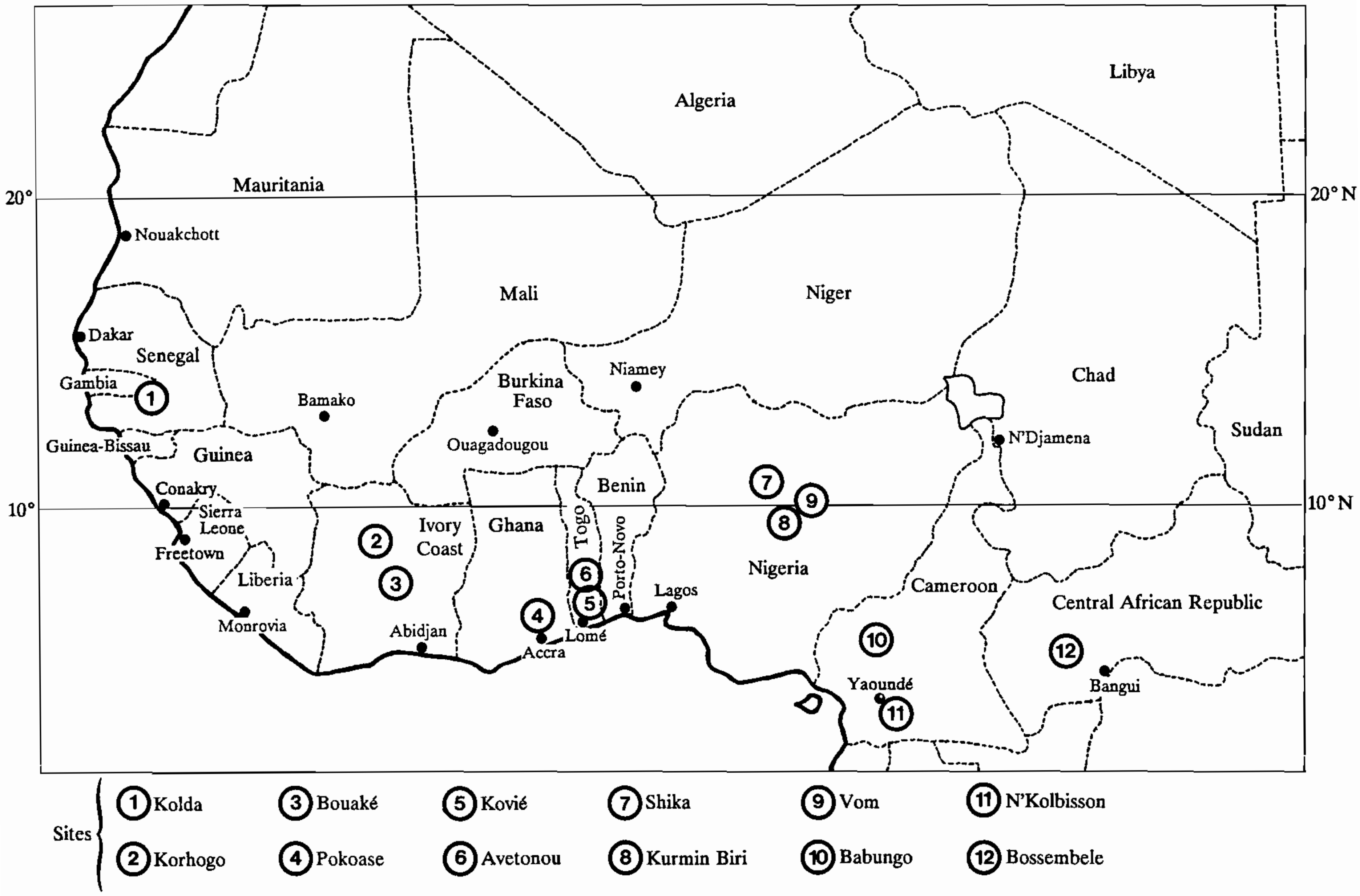

Figure 1. Location of regrowth trials in Western Africa.

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ACRONYMS

Acronym	Institution	Country
ACIAR	Australian Centre for International Agricultural Research	Australia
ALPA	Asociación Latinoamericana de Producción Animal	
ANAGAN	Asociación Nacional de Ganaderos de Panamá	Panama
APPA	Asociación Peruana de Producción Animal	Peru
ASA	American Society of Agronomy	USA
ASCOLFI	Asociación Colombiana de Fitopatología y Ciencias Afines	Colombia
BID	Banco Interamericano de Desarrollo	USA
CARDI	Caribbean Agricultural Research and Development Institute	
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza	Costa Rica
CENICAFE	Centro Nacional de Investigaciones de Café	Colombia
CGIAR	Consultative Group on International Agricultural Research	USA
CIAT	Centro Internacional de Agricultura Tropical	Colombia
CICADEP	Centro Internacional de Capacitación en Desarrollo Pecuario	
CIEEGT	Centro de Investigación, Enseñanza y Extensión en Ganadería Tropical	Mexico
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo	Mexico

CIP	Centro Internacional de la Papa	Peru
CIPAV	Convenio Interinstitucional para la Producción Agropecuaria en el Valle del Río Cauca	Colombia
CNI	Centro Nacional de Investigaciones	Colombia
CPAC	Centro de Pesquisa Agropecuária dos Cerrados	Brazil
CPATU	Centro de Pesquisa Agropecuaria do Trópico Umido	Brazil
CRECED	Centros Regionales de Educación, Capacitación, Extensión y Difusión de Tecnología	Colombia
CSIRO	Commonwealth Scientific Industrial and Research Organisation	Australia
CVC	Corporación Regional Autónoma del Valle del Cauca	Colombia
DANE	Departamento Administrativo Nacional de Estadística	Colombia
DANIDA	Danish International Development Agency	Denmark
DRI	Programa de Desarrollo Rural Integrado	Colombia
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária	Brazil
EMPASC	Empresa de Pesquisa Agropecuária de Santa Catarina	Brazil
FAO	Food and Agriculture Organization of the United Nations	Italy
FEALQ	Fundação de Estudos Agrarios Luiz de Queiroz	Brazil

FEDEARROZ	Federación Nacional de Arroceros de Colombia	Colombia
FGV	Fondo Ganadero del Valle	Colombia
FONAIAP	Fondo Nacional de Investigaciones Agropecuarias	Venezuela
GTZ	German Agency for Technical Cooperation	Germany
IBGE	Fundação do Instituto Brasileiro de Geografia e Estatística	Brazil
IBPGR	International Board for Plant Genetic Resources	Italy
IBSRAM	International Board of Soil Resources and Management	Thailand
ICA	Instituto Colombiano Agropecuario	Colombia
ICA	Instituto de Ciencia Animal	Cuba
IDRC	International Development Research Centre	Canada
IEMVT	Institut d'Elevage et de Médecine Vétérinaire des Pays Tropicaux	France
IFPRI	International Food Policy Research Institute	USA
IICA	Instituto Interamericano de Cooperación para la Agricultura	Costa Rica
IITA	International Institute of Tropical Agriculture	Nigeria
ILCA	International Livestock Centre for Africa	Ethiopia
INCORA	Instituto Colombiano de Reforma Agraria	Colombia
INIAA	Instituto Nacional de Investigación Agraria y Agroindustrial	Peru
INIAP	Instituto Nacional de Investigaciones Agropecuarias	Ecuador

INRA	Institute National de Recherche Agronomique	France
INTSORMIL	International Sorghum and Millet Program	USA
IRRI	International Rice Research Institute	Philippines
ISNAR	International Service for National Agricultural Research	Netherlands
IVITA	Instituto Veterinario de Investigaciones Tropicales y de Altura	Peru
MAG	Ministerio de Agricultura y de Ganadería	Costa Rica
NARIs	National Agricultural Research Institutions	
NFTA	Nitrogen Fixing Tree Association	USA
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios	
PNR	Plan Nacional de Rehabilitación	Colombia
PROCISUR	Programa Cooperativo de Investigación Agrícola del Cono Sur	Uruguay
REDAPT	Red de Adopción de Tecnología para Pequeños Productores en América Latina	
REFCOSUR	Red de Evaluación de Forrajeras del Cono Sur	
RIEPT	Red Internacional de Evaluación de Pastos Tropicales	
RISPAL	Red de Investigaciones en Sistemas de Producción Animal	Costa Rica
RISTROP	Red Internacional de Suelos Tropicales	
RLAC	Regional Office for Latin America and the Caribbean (FAO)	Chile

SEAFRAD	Southeast Asian Forages Research and Development Network	
SEAP	South-East Asia Project	
SENA	Servicio Nacional de Aprendizaje	Colombia
SOCOLEN	Sociedad Colombiana de Entomología	Colombia
TARC	Tropical Agricultural Research Center	Japan
UNAM	Universidad Nacional Autónoma de México	Mexico
USDA	United States Department of Agriculture	USA
WAFNET	West Africa Forage Network	
WECAFNET	West and Central African Forages Sub-Network	

ABBREVIATIONS

Abbreviation	**Description**
BNF	biological nitrogen fixation
BRU	Biotechnology Research Unit, CIAT
CP	crude protein
DM	dry matter
EB	energy bank
ES	embryo sac
IVDMD	in vitro dry matter digestibility
LW	liveweight
LWG	liveweight gain
OFR	on-farm research

OM	organic matter
PB	protein bank
RAPD	random amplified polymorphic DNA
RFLP	restriction fragment length polymorphism
RTA, RTB, RTC, RTD	regional trials A, B, C, D
TPP	Tropical Pastures Program, CIAT