POTENTIAL FOR PASTURE PRODUCTION IN ACID TROPICAL SOILS

A Proceeding of the Seminar Organized by

CARDI/EDF Held in UWI Campus, St. Augustine,

Trinidad onJune 23-24, 1986.

Caribbean Agricultural Research and Development Institute

UWI Campus, St. Augustine, Trinidad, W.I.

"DEVELOPMENT OF FORAGE SPECIES FOR THE ACID INFERTILE SOILS OF TROPICAL SOUTH AMERICA"

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INTRODUCTION

The tropics of Latin America contain an estimated 190 million head of cattle, about 20 per cent of the world total. Both beef and milk are considered staple foods in the region but during the last decades, with few exceptions, supplies have lagged behind demand growth (ANON, 1981). As a result, prices have increased in real terms with serious implications for low-income urban consumers, who spend a significant proportion of family income on beef and dairy products. Such trends can be counteracted if appropriate pasture-based livestock production technology is developed for the vast, underutilized land areas in the region. COCHRANE *et al.* (1985) have estimated that the lowland tropics of South America, east of the Andes, cover 820 million hectares. Some 200 million hectares are covered by savannas and the remainder are under forests. These areas have an extremely high potential for cattle production, with little or no opportunity costs.

THE ENVIRONMENT

The majority of soils are classified as Oxisols and Ultisols and are distributed over 66 per cent of the region (COCHRANE *et al.* 1985). Substantial areas are found in Bolivia, Brazil, Colombia, French Guiana, Guyana, Peru, Suriname and Venezuela (COCHRANE 1979). These soils are acid and infertile in their undisturbed state. Topography and physical properties are generally favourable, but the converse is true for chemical properties. According to COCHRANE *et al.* (1985) about 75 per cent of the soils have a pH < 5.3, indicating potentially toxic levels of exchangeable aluminium. Toxicities of manganese and iron are also present in some soils. Phosphorus deficiency is widespread, with levels of available-phosphorus ranging from 1 to 7 ppm (Bray II). Other limiting nutrients include nitrogen, potassium, sulphur, calcium, magnesium and zinc.

COCHRANE *et al.* (1985), have classified the land resources of these areas in terms of climate, landscape and soils. The distribution of native vegetation has been accounted for by a quantitative method based on total wet-season potential evapotratranspiration (COCHRANE and JONES 1981). Five major agroecological zones of interest to livestock production have been classified (Table 1). This is serving as the basis for the research strategy of the Tropical Pastures Programme at the Centro Internacional de Agricultura Tropical (CIAT) based in Colombia.

POTENTIAL FOR PASTURE IMPROVEMENT

Cattle in the region depend almost exclusively on native pasture to meet their nutrient requirements. However, the dry-matter production of native pasture is low and the nutritive value of the grasses falls to sub-optimal levels where the dry season is pronounced. Not surprisingly, animal performance under these conditions is very low (Table 2).

The potential for increasing production through improved technology is considerable. Average stocking rates currently at 0.12 animals per ha in the savannas could be increased more than ten-fold (ANON, 1981), with a commensurate increase in beef production per ha. Calving rates could be doubled and liveweight gains per animal at lease quadrupled. Weaning age, slaughter age and age at first parturition could be reduced by up to 50 per cent, and slaughter rate doubled. Milk production per lactation could be correspondingly doubled, as most milk and dairy products consumed in the region come from small and medium-sized beef herds.

CIAT has adopted a low-cost, low-input approach to pasture improvement. Forage species are being selected which show adaptation to soil acidity and which require relatively small amounts of fertilizer for maximum growth. The legume is expected to supply nitrogen in the system and improve the nutritive value of feed in the dry season. In an attempt to further reduce fertilizer costs, alternative sources of nutrients from natural rocks are being sought. For example, Latin America has large deposits of rockphosphates, some 20 major ones, that can be exploited. The natural acidity of the Oxisol-Ultisol associations interacts with rock-phosphate to make the phosphorus available to plants. The unit cost of phosphorus in rock-phosphate is appreciably cheaper than that of triple or simple superphosphate. The residual value of rock-phosphate is also likely to be equal or greater than that of more soluble sources. Furthermore, since continuous dissolution of rock-phosphate occurs in acid soils, the release of phosphorus over time is more in unison with the requirements of a perennial crop such as pastures. The feldspars, also abundant in Latin America, could do the same for potassium. Other examples are serpentine, gypsum and elemental sulphur. Simple, low-cost establishment methods such as strip-planting are being considered for savanna improvement and suitable equipment developed. An example of this is a tractor-pulled fertilizer spreader and seed-drill mounted on the rear bar of a chisel-plough. This lightly ploughs the land, applies fertilizer and sows seed in one pass.

SELECTION OF ADAPTED SPECIES

The first prerequisite for successful pasture improvement is the availability of cultivars well adapted to the ecosystem. Forage cultivars are developed through a step-wise evaluation process as shown in Table 3. In the intermediate phase grazing is preferable to cutting since the effects of treading, excretion and selective defoliation can be examined. The large-scale grazing trial provides a final assessment in terms of marketable products, and results can be subjected to economic analysis. A wide range of experimental techniques are used in pasture evaluation and various options have been described by SHAW and BRYAN (1976). JONES *et al.* (1980, TOLEDO and SCHULTZE-KRAFT (1962, PALADINES and LASCANO (1983) and THOMAS and ANDRADE (1984).

The multiplication of seed is vital to any pasture evaluation programme. Promising accessions can only pass through the testing process if adequate supplies of seed are available. The size of the experimental area increases with each stage of evaluation. The lack of seed can cause considerable delays in the advancement of new germplasm. At CIAT, seed multiplication plays a major role in the development of new cultivars.

EXISTING CULTIVARS

A number of forage cultivars are commercially available in countries such as Brazil, most of them developed for Australian conditions (THOMAS *et al.* 1983). In tropical America the use of Australian commercial cultivars in low-input systems has often resulted in failure for two major reasons. First, cultivars of species such as *Centrosema pubscens, Neonotonia wightii, Macroptilium atropurpureum, Leucaena leucocephala, Panicum maximum* and *Cenchrus ciliaris* were released for soil conditions very different from those prevailing in the Oxisol-Ultisol associations. In general, in tropical Australia, the range of soil pH and supply of exchangeable bases is higher than in tropical South America, whilst phosphorus fixation rates are lower and aluminium toxicity is unimportant (SANCHEZ and ISBELL 1979). Second, although cultivars of species of *Stylosanthes* are adapted to acid, infertile soils, they are susceptible in many areas to the endemci, fungal disease, anthracnose caused by *Colletotrichum gloeosporioides*. The older commercial cultivars were selected before this disease also became a problem in Australia.

PLANT INTRODUCTION AND BREEDING

In the search for adapted species emphasis has been given to the exploitation of natural variation. Hence, plant collection and exchange with other institutions have played a dominant role in germplasm development. Presently, CIAT has 16,091 forage accessions in the germplasm bank, with legumes representing 85 per cent of the collection (CIAT 1986). Legumes have been collected mainly in tropical America, but, latterly, collection trips have been conducted in south-east Asia. Grasses have come predominantly from Africa. Significant numbers of accessions especially from the genera *Stylosanthes, Desmodium, Centrosema, Brachiaria* and *Panicum* are now available at CIAT. In addition, 3,000 strains of *Rhizobium* have been collected for legume inoculation (CIAT 1986).

However, as a natural evolution of the selection process plant breeding studies have been initiated with some species. Intraspecific and interspecific crosses have been made to incorporate missing, desirable characteristics into collected germplasm. At CIAT, *Leucaena leucocephala* (HUTTON 1984), *Centrosema pubescens* (HUTTON 1985), *Stylosanthes guianensis* (CIAT 1986) and *Andropogon gayanus* (CIAT 1986) have been subjected to genetic improvement by plant breeding. The relative emphasis on plant breeding is likely to increase at CIAT in the future.

DESIRABLE PLANT CHARACTERS

The important characteristics sought in pasture plants are those affecting growth, survival and feed value. A single accession cannot be expected to contain all of the required characteristics. The use of grass-legume mixtures and more than one type of pasture can compensate for individual plant deficiencies.

PLANT GROWTH

Selected plants should possess a capacity to grow and produce reasonable yields of dry matter. There is no absolute limit for this but, distribution, in time is as important as the amount produced. Therefore, accessions must be adapted to existing climatic, edaphic and biotic factors such as diseases and pests.

Experience in tropical South America has shown that species such as *Andropogon gayanus*, *Brachiaria decumbens*, *Stylosanthes guianensis* and *Centrosema macrocarpum* show wide climatic adaptation in terms of dry-matter production. Other species such as *Desmodium ovalifolium*, *Arachis pintoi* and *Brachiaria humidicola* are less vigorous in climates with a prolonged dry season. Plants collected in acid soils with a high aluminium saturation are well adapted to these edaphic conditions. Large amounts of lime to neutralize aluminium are unnecessary and may actually decrease dry-matter yield in adapted species (GROF *et al.* 1979). This is illustrated in Table 4. In these plants relatively low inputs of nutrients are required for establishment and growth. Edaphically adapted accessions are found in a wide range of genera, including *Andropogon*, *Brachiaria*, *Paspalum*, *Aeschynomene*, *Centrosema*, *Desmodium*, *Stylosanthes* and *Zornia*. On the other hand species such as *Cenchrus ciliaris*, *Setaria anceps*, *Neonotonia wightii* and *Macroptilium atropurpureum* are not productive on the acid, infertile soils unless large inputs of lime and fertilizer are applied. Some species have shown a capacity to respond to improved fertility even though selected for tolerance to low fertility conditions. For example, accessions of *Stylosanthes guianensis* var. *pauciflora* and *Centrosema macrocarpum* have demonstrated marked responses to phosphorus application (CIAT 1984), as shown in Figure 1. This flexibility is of significance in areas such as the central savannas of Brazil, where pastures follow annual crops and residual soil fertility may be relatively high for pasture establishment.

Diseases and pests are major limitations to cultivar development in tropical South America. A wide range of fungal, bacterial and virus diseases attack legumes, whilst nematodes, stem-borer and bud-worm are the main pests (CIAT 1983). However, the effects of disease organisms can vary between different locations. For example, in forest ecosystems commercial cultivars of *Stylosanthes guianensis*, the so-called "common" types, have persisted in the presence of pathogenic isolates of the anthracnose fungus with only slight levels of disease. Yet, in savanna ecosystems, the same cultivars are devastated by anthracnose. Yield reductions of 64 per cent have been recorded (CIAT 1982), and eventually plant death occurs. Recent studies at CIAT suggest that the progress of anthracnose in forest regions may be inhibited by the considerable populations of antagonistic bacteria on the leaf surfaces throughout the year and by the phenomenon of latent-infection (ANON, 1984). The fungus invades the host, establishes a host-parasite relationship, but the mycelium remains latent and plants appear unaffected. This gives the plant a form of resistance. It would appear that under narrow diurnal temperature fluctuations, as occur in forest regions, latent-infections are less likely to develop into active ones than in savanna ecosystems where such fluctuations are much greater. The significance of this is that new cultivars can be developed for these areas from vigorous "common" types of *Stylosanthes guianensis*. This has already happened in Peru where accession CIAT 184 was recently released as cv. Pucallpa (ANON, 1986). The differential response to anthracnose of *Stylosanthes capitata* in Brazil and Colombia is a further example of this type of variation (LENNE *et al.* 1984). Although grasses are susceptible to diseases these are less important than in the legumes. Spittlebugs of the genera *Aenoslania, Deois* and *Sulia* are the major pests attacking grasses. COSENZA (1982) has demonstrated in Brazil that cultivars of *Andropogon gayanus* var. *bisquamulatus* and *Brachiaria brizantha* are very resistant to spittlebugs of the species *Deois flavopicta*, whereas other species of *Brachiaria* are highly susceptible (Table 5.). Leaf-cutting ants, although not specifically a pasture pest, can cause serious damage to legumes and grasses at establishment. There is no doubt that in pasture plants genetical resistance is the most practical and economical control method and, as a component of integrated pest management, has considerable potential in controlling pests (LENNE *et al.* 1980).

SURVIVAL

Selected plants must have the capacity to persist in pastures. This is generally more problematical in the legumes than in the grasses. Persistence is influenced by such factors as tolerance to defoliation, a capacity to regenerate and resistance to pests and diseases.

The level of tolerance to defoliation may differ between accessions because of factors such as the position and number of new growing points and storage reserves. Species with twining stems such as *Galactia striata* and *Centrosema macrocarpum* or accessions of species such as *Stylosanthes guianensis* with erect shoots branching from the main stem are very vulnerable to defoliation. Some new accessions of *Centrosema macrocarppum* and hybrids with *Centrosema pubescens* have shown an enhanced capacity for stolons to root at the nodes which should reduce their susceptibility to defoliation. Low growing types of *Stylosanthes guianensis* var. *pauciflora* are also available where defoliation does not remove growing points. In *Arachis pintoi* well-developed stolons may reach a length of one metre, frequently rooting at the nodes. These have growing points well protected from defoliation and treading damage (da ROCHA *et al.* 1985).

The capacity of accessions to produce sufficient quantities of seed is also important. The cycle of seed formation, soil seed reserves and seedling recruitment is an important pathway for persistence in grazing systems. Seed production problems at certain latitudes have been encountered in *Stylosanthes guianensis* var. *pauciflora*, *Centrosema macrocarpum*, *Galatia striata*, *Desmodium ovalifolium* and *Pueraria phaseoloides*. However, significant soil seed reserves are built up in pastures containing species such as *Arachis pintoi*, *Centrosema brasilianum*, *Stylosanthes capitata* and *Stylosanthes macrocephala*. Preliminary results from breeding programmes involving *Stylosanthes guianensis* and *Centrosema macrocarpum* indicate increased seed production potential in the crosses.

The relationship between the incidence of pests and diseases and the failure to persist is obvious and needs no further comment.

FEED VALUE

Animal production is a direct function of the intake of digestible nutrients. Therefore, selected accessions should be acceptable to the animal and provide forage of satisfactory feed value free from toxic compounds.

In a mixed pasture,grasses are expected to supply the bulk of the energy for the grazing animal, whilst legumes should provide sufficient protein to meet animal requirements for maintenance and production. Grasses and legumes differ in mineral composition with the latter generally higher in nitrogen, phosphorus, potassium, calcium and magnesium, but lower in sodium. There are also intraspecific and interspecific differences within both grasses and legumes. No selection pressure has yet been put on increased mineral composition in the CIAT germplasm because of the overriding need to select environmentally-adapted plants. However, numerous analyses of mineral composition have been conducted at CIAT and could serve as a base for future selection and breeding for this characteristic.

Animal acceptability, as a limitation to intake, tends to be more of a problem in legumes than in improved grasses. Extreme acceptability problems have been encountered in Brazil with *Zornia brasiliensis* (THOMAS and ANDRADE 1969). Grazing steers refused to consume the plants even in the dry season when there was an abundance of green leaves. Accessions have a strong odour and alkaloids have been detected in the species (CIAT 1984). Acceptability problems have also been noted in *Calopogonium caeruleum*, *Calopogonium mucunoides*, *Dioclea guianensis*, *Desmodium ovalifolium*, *Desmodium strigillosum*, *Desmodium velutinum* and *Centrosema arenarium*. In Colombia, some problems have been observed in accessions of *Stylosanthes guianensis* var. *pauciflora* and *Stylosanthes viscosa*. In Brazil, the former is well consumed by cattle. In *Desmodium ovalifolium*,low animal acceptaibility is associated with a high tannin content. SALINAS and LASCANO (1983) found that feed value and intake could be increased in *Desmodium ovalifolium* by fertilizer application. Small amounts of magnesium and sulphur added to a fertilizer mixture of phosphorus, calcium and potassium increased protein and mineral contents and reduced tannin levels. The important element was subsequently found to be sulphur and a maintenance fertilization of 20 to 30kg per ha was sufficient to ensure continued high productivity, feed value and animal acceptance. On the other hand, accessions of *Stylosanthes capitata*, *Stylosanthes macrocephala*, *Centrosema brasilianum* and

Centrosema sp.n. have an inherently high feed value. *Stylosanthes capitata* and *Stylosanthes macrocephala* also produce large amounts of inflorescences of high nutritive value (CIAT 1981). *Brachiaria humidicola* is one improved grass where there appears to be some problem. Feed value is lower than in *Brachiaria brizantha* or *Brachiaria dictyoneura*. HOYOS and LASCANO (1985), using oesophageal-fistulated steers, reported a low digestibility and volunatry intake in *Brachiaria humidicola*. At low stocking rates, where abundant forage was available, intake was limited by low crude protein values.

SOME IMPORTANT LEGUMES

The evaluation studies conducted over the years at CIAT have resulted in the identification of a number of new species with forage potential. Cultivars have already been named in *Stylosanthes capitata, Stylosanthes guianensis* and *Stylosanthes macrocephala*, whilst accessions of *Arachis pintoi, Centrosema brasilianum, Centrosema macrocarpum, Centrosema* sp.n. and *Desmodium ovalifolium* are in advanced stages of testing. Relatively new collections of *Pueraria phaseoloides, Stylosanthes scabra, Stylosanthes viscosa* and *Zornia glabra* may also yield promising material in the future.

SPECIES OF STYLOSANTHES

Three species, *Stylosanthes guianensis, Stylosanthes capitata* and *Stylosanthes macrocephala*, have considerable potential for use in pasture improvement in tropical South America. As mentioned previously, in forest ecosystems, "common" types of *Stylosanthes guianensis* may be sown. However, in savanna ecosystems, where anthracnose is a major problem, a new morphologically-district group, referred to as "tardio" (Spanish or Portuguese for late) has been identified. The species, taxonomically classified as var. *pauciflora*, is predominantly late-flowering and accessions show better resistance to anthracnose than "common" types.

All three species have a rather narrow range of distribution in South America. *Stylosanthes macrocephala* is native to central and eastern Brazil, and both *Stylosanthes guianensis* var. *pauciflora* and *Stylosanthes capitata* occur in the tropical savannas of Brazil and eastern Venezuela. Accessions show good tolerance of soil acidity, high aluminium saturation and low soil phosphorus levels (GROF *et al.* 1979, THOMAS and ANDRADE 1983, SCHULTZE-KRAFT *et al.* 1984). Considerable intraspecific variation exists in morphology, dry-matter yield and chemical composition. THOMAS *et al.* (1986) found that accessions of *Stylosanthes guianensis* var. *pauciflora* collected in Brazil were more productive than those collected in Venezuela (Table 6). Anthracnose resistance and digestibility were also superior in the Brazilian accessions. On the basis of better disease resistance, the authors suggest that future collection of "tardio" types should be restricted to Brazil.

Selected accessions of the species have persisted well with *Andropogon gayanus* and *Brachiaria decumbens* in small plots under intermittent grazing regimes (THOMAS 1984, THOMAS and ANDRADE 1984, THOMAS and ANDRADE 1986). The performance under grazing of a number of accessions of *Stylosanthes macrocephala* is shown in

Figure 2. High seed yields are obtainable in *Stylosanthes capitata* and *Stylosanthes macrocephala* under satisfactory environmental conditions (FERGUSON *et al.* 1983, ANDRADE *et al.* 1983a).

In Brazil, *Stylosanthes guianensis* var. *pauciflora* CIAT 1281 (formerly CIAT 1582) was released as cv. Pioneiro. In Colombia, a blend of five accessions (CIAT 1314, 1318, 1342, 1693, 1728) of *Stylosanthes capitata* was released in 1983 as cv. Capica.

SPECIES OF CENTROSEMA

Centrosema pubescens is the only species that has so far attained economic significance as a forage plant. However, commercial cultivars have had no impact in the Oxisol-Ultisol associations because of a lack of adaptation to edaphic conditions. The genus *Centrosema* comprises about 35 recognised species according to CLEMENTS and WILLIAMS (1980), and accessions of many of the species have been evaluated at CIAT. Three species are particularly promising as forage legumes for the acid, infertile soils. These are *Centrosema brasilianum*, *Centrosema macrocarpum* and the undescribed *Centrosema* sp., which is closely related to *Centrosema pubescens*.

Most of the germplasm of *Centrosema brasilianum* comes from north-east Brazil and Venezuela. Two important attributes of the species are drought tolerance and high seed production, which allow excellent regeneration under grazing. *Centrosema brasiliamum* probably has more potential for savanna ecosystems with a pronounced dry season, as it performs poorly in forest regions due to severe attacks of foliar blight caused by *Rhizoctonia solani*. Accession CIAT 5234 is already under grazing in Brazil and Colombia.

Accessions of *Centrosema macrocarpum* have originated from Belize, Colombia, Brazil, Mexico and Venezuela. The species is extremely vigorous and productive, with a high resistance to diseases. At certain latitudes, under savanna conditions, problems have been encountered in flowering and seed production. Consequently, non stoloniferous types fail to persist under grazing. SCHULTZE-KRAFT and KELLER-GREIN (1985) believe the species to have more potential at latitudes near the equator in the forest ecosystems. Under these conditions the species has outyielded others of the genus (Table 7). In the savannas, it is likely that hybrids with *Centrosema pubescens* will have more potential (HUTTON 1985).

Centrosema sp.n. has a narrow natural distribution in central Brazil and the Orinoco region between latitutes 4ºN and 6º (SCHULTZE-KRAFT and KELLER-GREIN 1985). One free-seeding accession, CIAT 5277, is highly promising and is in an advanced stage of evaluation under grazing and in on-farm trials in the savannas of Colombia.

DESMODIUM OVALIFOLIUM

This species has been used widely in plantation agriculture in south-east Asia, and seed of one accession, CIAT 350, is commercially available from Singapore. The species grows well in forest regions and savanna ecosystems with a dry season of no more than three to four months. It is extremely tolerant of both aluminium and manganese toxicities and phosphorus stress (CIAT 1981, CIAT 1982). The outstanding attribute of the legume is its persistence under grazing with aggressive grasses such as *Brachiaria decumbens* *Brachiaria dictyoneura* and *Brachiaria humidicola*. The species is also compatible with *Brachiaria brizantha* (GROF 1982). In certain locations pure seed yields of up to 220kg per ha have been obtained (FERGUSON *et al.* 1983).

The major limitations are pests and diseases. Accession CIAT 350 is badly attacked in the Colombian savannas by false-rust caused by the fungus,*Synchytrium desmodii*,and by a new stem-gall nematode *Pterotylenchus cecidogenus* (LENNE 1983). More resistant accessions (CIAT 3776, 3788, 3794, 13089, 13092) have now been selected and are under grazing in Colombia.

ARACHIS PINTOI

This is a stoloniferous, perennial species from Brazil which shows considerable promise for savanna regions with a relatively short dry season. It is probable that further evaluation will also demonstrate its suitability for forest ecosystems. In the Eastern Plains of Colombia flowering is continuous, interrupted for short periods only by moisture stress or excessive rainfall. The species shows excellent compatibility with the mat-forming grasses such as *Brachiaria dictyoneura* and *Brachiaria humidicola*. Some attributes of *Arachis pintoi* grown in association with species of *Brachiaria* are summarized in Table 8.

SOME IMPORTANT GRASSES

Andropogon gayanus var. *bisquamulatus* and a number of species of *Brachiaria* are now recognised as important grasses for pasture improvement in tropical South America. In the future other species are likely to become available. A large collection of over 400 accessions of *Panicum maximum*, showing marked morphological variation, is currently under eveluation in Colombia and *Paspaum guenorum* and *Paspalum conspersum* are showing promise in Brazil. A new collection of over 900 accessions of many *Brachiaria* species has been assembled at CIAT and detailed eveluations will begin in 1987.

ANDROPOGON GAYANUS VAR. *BISQUAMULATUS*

This species is well adapted to the climatic conditions prevailing in savanna ecosystems and shows excellent tolerance of low soil pH and high aluminium saturation. *Andropogon gayanus* tolerates both drought and fire and is free of serious pests and diseases. Large amounts of dry matter (up to 29.6 t/ha) and significant quantities of seed can be produced. Pure seed yields of 350kg per ha are reported from Brazil by ANDRADE *et al.* (1983b.), but an appropriate defoliation management is required to reduce the risk of lodging (ANDRADE and THOMAS 1984). The species is compatible with a number of legumes from genera such as *Centrosema*, *Desmodium*, *Stylosanthes* and *Zornia*. In agronomic trials under cutting or grazing, legume contents of over 20 per cent have been maintained for more than three seasons.

In 1980, the accession, CIAT 621, was released in Brazil as cv. Planaltina and in Colombia as Carimagua I. During 1982 and 1983 national institutions in Panama, Peru and Venezuela released the same accession under different cultivar names. There are presently at least 170,000 ha sown in Brazil and the area is increasing. The earlier studies on the grass were reviewed by Jones (1979). A new in-depth review of *Andropogon gayanus* is due to be published as a monograph by CIAT in 1987.

SPECIES OF *BRACHIARIA*

Brachiaria decumbens has been used extensively in pasture development in tropical America. However, its great limitations are a lack of resistance to spittlebug attack and the tendency to cause photosensitization in grazing animals. Three other species, *Brachiaria brizantha, Brachiaria dictyoneura* and *Brachiaria humidicola*, with better resistance to the pest and without photosensitization problems have now been identified. All three grasses are well adapted to soils with a low pH and a high aluminium saturation. Although adapted to a range of climatic conditions, *Brachiaria humidicola* and *Brachiaria dictyoneura* are less vigorous in savanna ecosystems with a long dry season. In the Brazilian savannas, *Brachiaria humidicola* has given pure seed yields as high as 501kg per ha following the establishment year (ANDRADE *et al*. 1983b). In the Colombian savanna more seed is produced by *Brachiaria dictyoneura* than *Brachiaria humidicola*.

A commercial cultivar of *Brachiaria humidicola* is available in a number of countries and new accessions are being tested under grazing in Colombia. *Brachiaria brizantha* (CIAT 6294) was recently released in Brazil as cv. Marandu. *Brachiaria dictyoneura* is in an advanced stage of evaluation in Colombia.

ANIMAL PRODUCTION

Data from grazing trials conducted at CIAT (Table 9) and elsewhere confirm that pasture improvement can result in increased levels of animal production. However, the use of pure grass pastures will not prevent dry season weight losses in savanna econsystems. Carrying capacity and production per ha are increased but individual animal performance remains relatively low. PALADINES and LEAL (1979) have concluded that a successful fattening enterprise in the Eastern Plains of Colombia would necessitate gains of 150kg per animal per year to sent steers for slaughter weighing 450kg at three years of age. Gains of this order cannot be consistently achieved from grass alone. On the other hand, grass-legume pastures are consistently able to produce liveweight gains in excess of 150kg per animal per year. In the wet season, gains are often higher on grass-legume pastures than on pure grass pastures, but the main effect is through the prevention of weight loss in the dry season. Studies with oesophageal-fistulated steers show that legume consumption generally increases at the end of the rains and continues throughout the dry season when the nutritive value of grasses is declining. Even when legume availability is low animals continue to select these plants.

If high levels of animal production are to be regularly achieved, it is essential that the legume persists over time.

Notwithstanding inherent plant characteristics which favour persistence, this will also be influenced by maintenance fertilizer application and grazing management. Although species adapted to low fertility conditions are being selected some fertilizer input is necessary. Maintenance fertilizer applications will depend on the degree of the initial deficiency and the residual value of applied fertilizer. Once nutrients are built up above critical levels annual applications are unnecessary. Cheaper sources of nutrients from natural rocks are attractive since they have a high residual value. Trace elements also have a high residual effect and probably would not be required more often than every three to ten years. The recycling of nutrients within well-managed, grass-legume pastures can be highly efficient.

Stocking rate exerts a dominant effect on production and very heavy grazing over a long period can lead to sward deterioration and legume disappearance. Grazing trials to determine safe stocking rates for given pasture types are being conducted at CIAT. Pastures are subjected to a range of stocking rates which involve both underutilization and overutilization. The effect of grazing system is presently unclear. Continuous grazing is the least expensive method and the easiest to employ. However, there are legumes such as *Leucaena leucocephala* and *Pueraria phaseoloides* which necessitate some form of rotational or alternate grazing. One system of management being considered by CIAT is the use of pure blocks of legume ('protein banks") strategically utilized along with native pasture. In this system interspecific plant competition is minimized and limiting fertilizer resources can be applied to a small area of land. In this system shrub legumes have an advantage over herbaceous legumes which are vulnerable to weed growth as soil nitrogen levels build up over time. New shrub species such as *Flemingia macrophylla* and *Tadehagi triquetrum* may have potential in this respect.

CONCLUSIONS

Substantial progress has been made at CIAT in identifying species for the acid, infertile soils of tropical South America. Concurrently, studies have been conducted on the establishment, management, pathology and nutrient requirements of these species. Major collections of forage species and *Rhizobium* have been built up. Most of the research work has been carried out at two major centres, Carimagua in Colombia for the isohyperthermic savannas and the Centro de Pesquisa Agropecuaria dos Cerrados (CPAC) in Brazil for the the isothermic savannas. Recently, a major evaluation site for the forest ecosystems has been established at Pucallpa, Peru. Although these sites are representative of large areas within a given ecosystem, it is inevitable that some variation will occur in climatic, edaphic and biotic factors. Therefore one cannot automatically assume that germplasm selected at the major centres will be adapted across the entire ecosystem. To overcome this a regional trial network, co-ordinated by CIAT was established towards the end of the last decade to facilitate pasture evaluation outside the major screening centres.
Since 1978 the network has grown considerably in Central America, South America and the Spanish-speaking islands of the Caribbean.

There are presently 160 trials in progress, some of them under grazing (CIAT 1986). The active participation of countries of the English-speaking Caribbean in this network would be highly desirable and a most welcome development. According to COCHRANE (1979) there are large areas of acid, infertile soils in Trinidad (84 per cent) and Belize (18 per cent). CIAT germplasm and technology would be highly relevent to these countries. In addition, the flexibility shown by many species in fertilizer response and in tolerance to a range of pH suggests that they also have potential for the more fertile and less acid soils in areas such as the Caribbean. The future commitment of CIAT to begin selecting forage germplasm for moderately acid soils is reflected in the imminent placement of a senior scientist in Costa Rica to cover Central America and the Caribbean.

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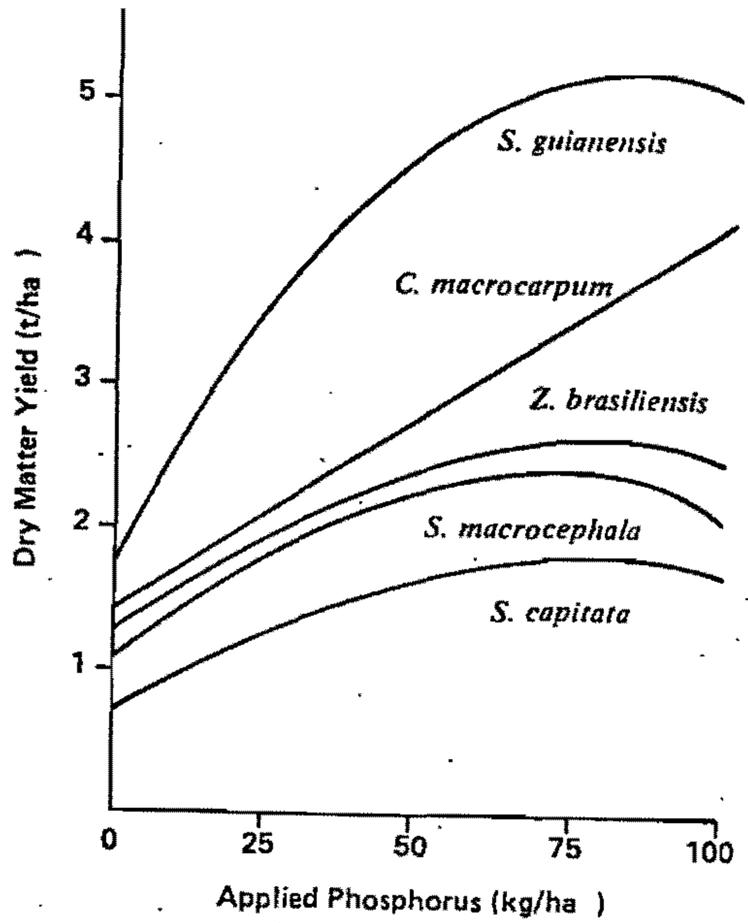

Figure 1. The response of five legumes to applications of phosphorus on an Oxisol in Brazil.

Source: Couto (1985).

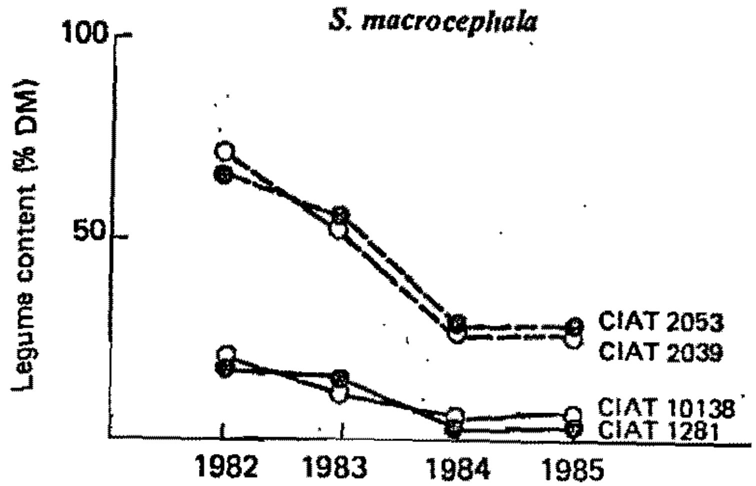

FIGURE 2. Changes in legume contents of four accessions of *Stylosanthes macrocephala* under grazing in Brazil.

Source: Thomas and Andrade (1986).

TABLE 1. AGROECOLOGICAL ZONES DETERMINED FOR THE TROPICAL PASTURES PROGRAMME OF CIAT IN THE LOWLANDS OF TROPICAL SOUTH AMERICA.

AGROECOLOGICAL ZONES	CLIMATIC PARAMETERS[1]	REPRESENTATIVE AREAS
POORLY DRAINED SAVANNA	WSPE < 900 MM, < 6 MONTHS WET SEASON, WSMT > 23.5°C.	"BENI" IN BOLIVIA; "PANTANAL" IN BRAZIL; "CASANARE" IN COLOMBIA; "APURE" IN VENEZUELA.
WELL DRAINED ISOHYPERTHERMIC SAVANNA	WSPE 900-1060 MM, 6-8 MONTHS WET SEASON, WSMT > 23.5°C.	"LLANOS" OF COLOMBIA AND VENEZUELA; SAVANNAS OF SURINAME AND GUYANA; SAVANNAS OF RORAIMA AND AMAPA IN BRAZIL.
WELL DRAINED ISOTHERMIC SAVANNA	WSPE 900-1060 MM, 6-8 MONTHS WET SEASON, WSMT < 23.5°C.	"CERRADOS" OF BRAZIL EXTENDING INTO PARAGUAY AND BOLIVIA.
SEMI-EVERGREEN SEASONAL FOREST	WSPE 1061-1300 MM, 8-9 MONTHS WET SEASON, WSMT > 23.5°C.	AMAZON AND ORINOCO BASINS IN BOLIVIA, BRAZIL, COLOMBIA, GUYANA, PERU, SURINAME AND VENEZUELA.
TROPICAL RAIN FOREST	WSPE >1300 MM, >9 MONTHS WET SEASON, WSMT >23.5°C.	UPPER AMAZON BASIN OF NORTHWEST BRAZIL, COLOMBIA, ECUADOR, NORTHEAST PERU AND VENEZUELA.

[1] WSPE = TOTAL WET-SEASON POTENTIAL EVAPOTRANSPIRATION.
WSMT = WET-SEASON MEAN MONTHLY TEMPERATURE.

SOURCE: ANON. (1981), COCHRANE *ET AL.* (1985).

TABLE 2. SOME PRODUCTION PARAMETERS FOR THE SAVANNAS OF BRAZIL.

CALVING RATE (%)	40-45
CALF MORTALITY (%)	7-8
WEANING AGE (MONTHS)	8-10
AGE AT FIRST PARTUITION (YEARS)	3.5-4.5
INTERVAL BETWEEN CALVINGS (MONTHS)	25-30
SLAUGHTER AGE (YEARS)	4.5-5.5
SLAUGHTER RATE (%)	12
CARCASS WEIGHT (KG)	192
CARCASS YIELD (%)	43-52
BEEF PRODUCTION (KG/HA)	20
MILK PRODUCTION (KG/LACTATION)	705

SOURCE: DE MIRANDA (1975), BARCELLOS ET AL. (1979).

TABLE 3. CATEGORIES OF PASTURE EVALUATION.

	CATEGORIES OF EVALUATION
I and II	Preliminary evaluation as spaced plants or in pure swards against controls. Main interest is general adaptation to climatic, edaphic and biotic factors.
	↓ (Seed Multiplication)
III	Agronomic evaluation of grass-legume mixtures in small grazed plots. Main interest is persistence.
	↓ (Seed Multiplication)
IV	Evaluation in large paddocks under grazing at different stocking rates. Main interest is animal gain. Pasture measurements can be made using computing procedure "Botanal".

TABLE 4. DRY-MATTER YIELDS OF THREE LEGUMES GROWN AT TWO pH LEVELS ON AN OXISOL IN COLOMBIA.

SPECIES AND ACCESSION	DRY-MATTER YIELD (MG/POT) pH 4.3	pH 6.0	CHANGE DUE TO LIMING (%)
Stylosanthes guianensis CIAT 64A	568	483	-15
Stylosanthes capitata CIAT 1019	290	202	-30
Centrosema species CIAT 1733	575	779	+36

SOURCE: Grof *et al.* (1979).

TABLE 5. RESISTANCE IN GRASSES TO SPITTLEBUG (*Deois flavopicta*) IN BRAZIL.

SPECIES	DEGREE OF DAMAGE*	NO. NYMPHS/PLOT
Andropogon gayanus cv. Planaltina	1	1
Hyparrhenia rufa	1	2
Panicum maximum cv. Makueni	1	6
Brachiaria brizantha cv. Marandu	1	23
Brachiaria humidicola	1	164
Panicum maximum cv. Common	2	40
Panicum maximum cv. Petrie green panic	3	63
Brachiaria decumbens cv. Basilisk	4	128
Brachiaria ruziziensis	4	150

* 1.0 = NO DAMAGE; 5.0 = LEAVES COMPLETELY DRY.

SOURCE: COSENZA (1982).

TABLE 6. MEANS FOR DRY-MATTER YIELD, CHEMICAL COMPOSITION AND REACTION TO ANTHRACNOSE OF TWO GROUPS OF "TARDIO" STYLO FROM BRAZIL AND VENEZUELA.

GROUP	DM YIELD (g/plant)	IVDDM (%)	N CONTENT (%)	ANTHRACNOSE (1.0 – 5.0)*
BRAZIL	12.5	42.75 (40.80)	1.83 (7.71)	2.0
VENEZUELA	6.5	37.17 (37.52)	1.96 (7.92)	4.5
LSD	3.4 ***	(2.07) ***	NS	0.4 ***

*1.0 = NO DAMAGE; 5.0 = PLANT DEATH.

SOURCE: THOMAS ET AL. (1986).

Table 7. Cumulative dry-matter yields under cutting of accessions of five species of *Centrosema* in Cauca, Colombia.

CIAT No.	Species	Dry-matter yield[1] (g/m²)
5065	*C. macrocarpum*	3161 a[2]
5276	*C. macrocarpum*	3001 a
5277	*Centrosema* sp.n.	2059 b
5112	*Centrosema* sp.n.	1980 b
5278	*Centrosema* sp.n.	1967 b
5161	*C. schiedeanum*	1902 bc
5247	*C. brasilianum*	1792 bcd
5189	*C. pubescens*	1775 bcd
5126	*C. pubescens*	1588 cde
5234	*C. brasilianum*	1441 de
413	*C. pubescens* (commercial)	1414 e
5118	*Centrosema* sp.n.	1079 f

1 Sums of 8 cuts.

2 Means followed by the same letters are not significantly different at <P 0.01 (multiple range test of Duncan).

Source: Schultze-Kraft and Keller-Grein (1985).

TABLE 8. SOME ATTRIBUTES OF *ARACHIS PINTOI* CIAT 17434 ASSOCIATED UNDER GRAZING WITH SPECIES OF *BRACHIARIA* IN THE EASTERN PLAINS, COLOMBIA.

DRY-MATTER YIELD (t/ha^{-1})	LEGUME CONTENT (%)	MEAN DDM CONTENT[1] (%)	P CONTENT (%)	CA CONTENT (%)	SOIL SEED RESERVES ($no./m^2$)	SEEDLING RECRUITMENT ($no./m^2$)
5.2-9.6	20-45	60.4	0.18-0.20	1.92-2.00	618-670	128-145

[1] MEAN DIGESTIBLE DRY-MATTER CONTENT.

SOURCE: CIAT (1985), DA ROCHA *ET AL.* (1985).

TABLE 9. ANIMAL PERFORMANCE ON DIFFERENT PASTURES IN THE EASTERN PLAINS OF COLOMBIA.

PASTURE TYPE	ANNUAL LIVEWEIGHT GAINS (KG) PER ANIMAL	PER HECTARE
NATIVE PASTURE	38	13
NATIVE PASTURE + BURNING	75	15
BRACHIARIA DECUMBENS	130	226
ANDROPOGON GAYANUS	113	355
ANDROPOGON GAYANUS + *S. CAPITATA* CIAT 1405	177	283
ANDROPOGON GAYANUS + *S. CAPITATA* CIAT 1019 + 1315	180	285
ANDROPOGON GAYANUS + *P. PHASEOLOIDES* CIAT 9900	173	294

SOURCE: PALADINES AND LEAL (1979), CIAT (1981), CIAT (1984).