SUSTAINABILITY OF PASTURE PRODUCTION IN THE SAVANNAS OF TROPICAL AMERICA

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ABSTRACT
"Savannas" regions are the last and more important frontier to agricultural and livestock exploitation in Tropical America. Amazon jungle is another important native region but because of its great biodiversity and fragility, it has serious constraints to common agricultural exploitation. Brazil, Venezuela and Colombia have the largest area of Savannas in Latin America. More than 80 % of that is in Brazil and in this country, the horizontal expansion in savannas is near the end. Since 1970, natural vegetation has been rapidly substituted by introduced grasses from Africa. A monoculture grassland of *Brachiaria decumbens* is dangerously covering large areas of brazilian savannas. Estimates reach up to 40 million ha. Initial impact caused by this introduction increased animal production 2 to 3 folds compared to native grassland. After that, soil, animal and pasture mismanagement led to pasture degradation, declining animal yields and to potential environment problems. Pasture degradation must be avoided and sustainability of pasture and animal production pursued. Understanding sustainability and searching for indicators to monitor it should be emphasized. Some suggestions such as diversification of grasses species in the current farming systems, increasing use of grass-legume pasture, chemical and mechanical pasture recuperation and adoption of agropastoral systems are some alternatives to reach sustainability.

This paper has the objective of discussing some soil and plant variables potentially useful as indicators of sustainability in the Savannas of Tropical America.

KEYWORDS
Brachiaria, Cerrados, green matter availability, organic matter, Panicum, P-plant, P-soil

INTRODUCTION
Savanna designation refers to vegetation associations which are formed by grasses and small trees in many different proportions ranging from pure grass stands to open woodland savannas (Sanchez,1976). The estimated area of savannas in tropical America is 27 %; it is 57% in Africa, and in the Tropics approximately 43% of the land is covered by savannas. There are 250 million ha of well-drained savannas in tropical America. In South America the countries with the large areas of savannas are: Brazil, Venezuela and Colombia. Brazil has almost 207 million ha of savannas, which represent around 25% of the total national territory. They extend from latitudes 25^o S to 6^o N.

The climate and soils of savannas are very typical. Soil moisture regime is mainly ustic, that is, soil control section is dry for more than 90 cumulative days, but less than 180 days during the year. Soil orders are predominantly Oxisols and Ultisols which are very old and weathered soils. Soil fertility is usually low and acidity is a regular constraint. Some important soil physical properties such as water holding capacity are low even in the rainy season. The occurrence of short dry periods called "veranicos" in Brazil, which can affect forage growth and favor pest attacks, is very common.

Many of these soils under savanna vegetation have recently been brought into cultivation of cash crops once they have the acidity problem corrected by application of dolomitic limestone. Fertility has been further improved by using compound fertilizers and soil conservation practices. All these operations, plus removal of natural vegetation in Brazil may cost up to US$600 per ha. Such high costs cannot be afforded by many farmers in large areas of tropical savannas. Furthermore, roads and transport are also limiting factors in many situations. An important alternative of management is the partial removal of vegetation, followed by burning, disking and directly seeding pastures for livestock production. For these reasons, in many areas of savannas ranching is the most economic form of land use.

The natural grassland vegetation of Africa is rich in species of the genera *Brachiaria*, *Panicum* and *Andropogon* which are important sources of forage for livestock. South American countries, Brazil, Colombia and Venezuela have introduced some species of these grasses from Africa and are cultivating them in their Savannas. In Brazil, livestock operations on savannas are responsible for almost 55% of the country's beef which is estimated as 5.60 million tons/year. Stocking rates were improved from 0.3 to 1.0 head per ha just by introducing superior grass species from Africa to savannas of tropical America.

Brachiaria decumbens, one of the most widespread species can tolerate high levels of soil aluminum saturation, soil acidity and low fertility. However, lack of maintenance fertilization, poor animal management and inadequate cultural practices have increased pasture degradation over time. A monoculture grassland of *Brachiaria decumbens* is dangerously covering almost 40 million ha of brazilian savannas and estimates of degraded pasture reach up more than 50 % of this area.

Sustainability of pasture and animal production are directly affected by pasture degradation. Besides, later stages of pasture degradation are responsible for many damages to the local environment. Soil compaction and decrease of water infiltration rate can cause run off and soil losses to the rivers. Pasture degradation leads to soil degradation and the evolution of this process is directly related to watershed flooding and its consequences to neighboring populations. Thus, since savannas represent the largest areas of undeveloped land resources in the world it is critical to overcome the problem of pasture degradation.

The objective of this paper is to discuss some limiting factors of pasture production and research priorities regarding indicators of sustainability in the tropical savannas of Brazil and neighboring countries.

Farming systems, production indexes and limiting factors. In Savanna regions, tropical pastures can be established and maintained under different management systems, e.g.: natural grassland, introduced grass pasture, improved grass-legume pastures and intensively fertilized grasses. In Tropical American Savannas, native grass of agronomic value is poor compared to grasses of Tanzania, Kenya or Uganda, in East Africa. Some important cultivated species in America have their center of origin in those countries (Rocha, 1991). Since the late 70's, introduction and selection of promising cultivars of species such as: *Brachiaria, Panicum* and *Andropogon* have raised the stocking rate and liveweight gain of livestock in the savannas. Introduced grass pastures account for very large areas in the savannas. In the Brazilian savannas, locally called “Cerrados”, there are 48-50 million ha of such sown grass pastures.

Farming systems may be composed by all or by a combination of the following livestock production phases: cow-calf operation, stocker and finishing.

In Brazil, mean slaughtering age ranges from 42 to 48 months at 450 kg of liveweight. As stated by Sanchez (1976), pasture is abundant in the rainy season, with better protein contents and digestibility levels. In the dry season dry matter growth decreases as does forage quality. This trend in extensive ranching operations results in a zigzag pattern of liveweight increases and decreases which increase slaughtering age.

Calving rate approaches 54%, and weaning rate is 51%. Average age at first calving is 48 months. Annual liveweight gain varies from 40-50 kg per ha, when all phases of animal production are included in the total. If only stocker and finishing are computed, liveweight gain can increase to 90-120 kg/ha. Predominant animal races belong to *Bos indicus*. Regular market prices paid to farmers are mostly done on the basis of carcass weight and can range from US$18-25/ 15kg (local unit = ‘arroba’), depending on the season of the year.

After pasture recuperation and adequate animal management, productivity can increase two fold but without maintenance it can drop to even lower rates, with time. The key factor involved is pasture degradation. As detected by the National Center for Beef Cattle Research - CNPGC - in Brazil, computed annual liveweight gain of less than 55 kg/ha/year, with stocker operations in degraded pasture. This could be enough to pay for labor and animal care, but, this type of livestock operation is not sustainable.

Climate can be a limiting factor to pasture growth in large areas of tropical savannas. In the Southern Hemisphere, many of these areas have a typical bimodal rainfall distribution of alternating rainy and dry seasons. Dry periods may range from 4 to 6 months and during this period rainfall is not enough to exceed evapotranspiration. Total annual rainfall varies from 800 to 1800 mm, 70% of this total occurring during the rainy season. Thus, besides soil acidity and low fertility, grasses should be adapted to water stress.

Soil orders and soil chemical characteristics of Brazilian Savannas are presented in Table 1 and 2, respectively. Chemical characteristics of soils from the Colombian Savannas (Llanos Orientales) are presented in Table 3. As outlined, soil acidity and low fertility, with special emphasis on available P, is a common limitation in tropical savannas. Some species such as *B.decumbens, B.brizantha* and *A.gayanus* are adapted to these conditions and are responsible for keeping livestock production profitable in the tropics (Sanchez, 1976 and Macedo, 1995).

Another important soil property which can limit forage production is availability of soil water. Independently of soil texture, Oxisols and Ultisols of tropical savannas can hold only about 9-10% H_2O on weight basis, between 0.1 to 1.0 bars (Wolf, 1975). Some clayed Oxisols have their internal soil particle arrangements in such a way that soil water permeability may be as high as in a coarse sandy soil.

Soil-plant relationship and animal performance related to sustainability. Initial exploitation of Savannas was carried out on native range. Natural vegetation was removed at a fast pace once native grasses proved unable to sustain stocking rates of at least 1 head/ha/year. First operations could be agricultural crop production or cattle ranching, depending on financial possibilities and local market needs. Cattle ranching is still utilized in many cases to cut costs and to wait for complete deterioration of the remaining vegetation.

Pioneer agriculture may be conducted with or without small applications of fertilizer, utilizing upland rice as a reliable crop. With respect to soil management the target is to use as well as possible the residual effect of the natural fertility improved by the savanna biomass incorporated in the soil. As presented, the introduced and well adapted grasses from Africa had significant effects on animal production in this framework.

Since the late ‘70s, in Brazil alone almost 50 million ha of grass only pastures were established for livestock following some of these procedures. The same has been done in Colombia and Venezuela, however, on a smaller scale. Pasture utilization has been done mostly on an extensive basis. Larger areas of savanna grassland are usually grazed continuously. Overgrazing is more often a rule than the exception, thus the natural decline is accelerated. Dry matter availability and carrying capacity therefore tend to decline with time.

Open spaces or bare soil in grass stands promote the return to the native vegetation. Examples of inadequate cultural practices are excessive mowing, burning or disking in order “to clean” the introduced sown grass pasture.

This is the current situation of “pasture degradation” which can be defined as “the process of losing vigor, productivity and the natural capacity for recovering in order to sustain production and quality required by animals and to overcome the detrimental effects of insects, diseases and weeds; it leads to a considerable degradation of natural resources caused by inadequate management” (Macedo, 1993). A schematic representation of this process is as below:

Pasture establishment

Inadequate management and cultural practices

Decrease in soil fertility

Losses of plant vigor and pasture productivity effects on carrying capacity, stocking rate

Losses in pasture quality effects on individual animal performance

Soil degradation: compaction, decrease of water holding capacity, run-off, erosion

Deterioration of natural resources: flooding, water-course contamination, etc.

Some pastures of *B. decumbens* in Brazilian and Colombian savannas have been utilized with 0.7-1.0 head/ha/year for 5-10 years, following removal of natural vegetation. The longevity of sown pastures of *B.decumbens* depends upon initial soil fertility, total biomass incorporated, soil and animal management. During initial years this grass can support higher stocking rates.

Pasture degradation symptoms vary from place to place. Lack of appropriate soil and plant variables in tropical savannas as indicators of degradation obligate farmers to use common sense which is relative and individual. The perception may come at the later stages of pasture degradation.

Decline in soil fertility is pointed out as starter of the process. It affects plant vigor and productivity in the early stages. Farmers try to overcome it by decreasing stocking rate without affecting individual animal performance. If fertilizers are not applied, the degradation process continues and forage nutritive values decline. At this stage, animal diet is affected and both quantitative and qualitative factors are responsible for decreasing individual animal performance. Frequently, at this point damages to landscape are still not visible to the average person, but the disruption of natural resources equilibrium has begun.

Evidences of this fact may be observed by deterioration of some soil physical properties in areas with introduced grasses under grazing, as compared to natural vegetation. Stocking rate effects on soil degradation can be greater depending upon morphological characteristics of the grass: whether cespitose or stoloniferous type: *P.maximum* (guinea grass) or *B.decumbens* (signal grass), respectively (Table 5, Figure 5 and 6).

Soil pasture degradation will result in stand losses and exposes bare soil in the grass sward which in turn will produce soil compaction and higher bulk density in upper soil layers. As a consequence, it decreases water infiltration rate and water holding capacity. These factors accelerate run-off and erosion. Beyond this phase, it is critical to protect natural resources and not only to recuperate the degraded pastures. Large areas of tropical savannas, especially under sandy soils are potentially at this advanced stage of degradation.

Sensible management practices, such as fertilization and stocking rate adjustments should be applied to avoid reaching advanced degradation stages. Cost of fertilization of the pastures at the early phase of loss of vigor and productivity may range from US$ 60 - 100/ha. At later stages of pasture degradation, costs may rise up to US$ 500/ha, thus justifying early diagnosis and correction.

Indicators of sustainability. Sustainability implies equilibrium in biological, economical and social interaction in a system. Advantages should be in order to increase or maintain economical food production, harmless to the environment and beneficial to society as a whole. Monitoring such a dynamic and complex system is not an easy task. Utilization of tropical savannas of sown exotic grass is a relatively new approach as compared to typical natural grassland exploitation.

Despite this fact there is a gap on research relating to soil-plant relationship and animal performance.

There are pieces of information on segmented phases of pasture and animal production but there is very little about the whole production system. One needs adequate indicators of sustainability in order to avoid pasture degradation. Some selected soil and plant variables will be discussed next as indicators of pasture sustainability through the time.

Soil indicators. Soil substrate of natural tropical savannas is originally poor in nutrients. The most important soil fertility constraints are low base saturation: Ca, Mg and K and low available P. The high content of iron and aluminum oxides play an important role in the P fixing capacity of the soil. Despite the fact that many of the tropical pasture species are tolerant to soil acidity and low P, their production is affected if stress conditions are accentuated (Spain et al., 1975; Sanchez, 1976). Soil available P (Mehlich-1) in Brazilian savannas ranges from 0.5-3.4 ppm (Adamoli, 1986). When soil-P (Mehlich-1) levels are less then 3 ppm, recommendations of P application to soils in Brazil (EMBRAPA) or in Colombia (CIAT) indicate an amount of 35-70 kg of P/ha, depending upon soil texture and grass or legume species to be planted.

As discussed earlier, the majority of introduced grasses were established in the savannas without fertilizer application. Results obtained by Soares et al. (EMBRAPA/CNPGC - unpublished data) in tropical savannas of Brazil have shown a strong effect of P application on degraded *B. decumbens* pasture on sandy soils (Quartzpsament), after five years of grazing (Table 6). These soils cover areas greater than 300,000 km^2, which is equivalent to the size of whole countries such as Italy = 301,245 km^2. Response to P, measured by grass dry matter yield, and compared to other nutrients, can be 5 to 10 folds more on typical degraded pasture (Macedo, 1995).

Relative total dry matter production of different grasses species as a function of applied P at establishment can be 90% of maximum yield when soil-P ranges from 3 to 6 ppm (Mehlich-1). Therefore, most introduced grasses were established in the border line of the critical range of soil P. After pasture establishment and during the maintenance period, plant nutrient requirements are lower and pasture production can continue for some time.

Introduced grasses have a deep root system (up to 1.8 meters) and extensive area of soil substrate is exploited by them. Subsequent pasture management determines intensity of pasture production and nutrient decline. Macedo and Euclides (1997) have observed that even decreasing stocking rates yearly, pasture and animal production went down without maintenance fertilization. In this case, total dry matter (TDM) availability was held constant by removing animals when it was necessary, but total green matter (GDM) on offer declined with time. Since GDM is directly related to animal performance, animal production was not sustainable. Fertilization applied at pasture establishment was not enough to maintain animal production over the years.

These results suggest that available soil-P should be maintained higher than 3 ppm (Mehlich-1) or 5 ppm (resin) for some clayed Oxisols of tropical savannas in order to sustain carrying capacity under continuous grazing. Once soil-P is corrected, with adequate base saturation (35-45%, depending upon grass species) and there is no micronutrient limitation, soil nitrogen will be the factor responsible for pasture production.

Soils of tropical savannas under *Brachiaria decumbens*, for example, may have higher rates of organic matter than natural vegetation. This is due to the root habit of the grasses and dry matter cycling over the years. The C:N relation instead is high (14-16:1) and N mineralization usually is not favorable because of the organic quality of carbon. The rate is affected by lignin and poly-phenolic compounds present in the carbon chains (Thomas and Asakawa, 1993). These authors working in the Llanos of Colombia pointed out that the regular rate of N mineralization would be able to supply only 2-10% of total N necessary to dry matter production. Thus, pure grass pasture have a deficit in N supply over time if some extra source is not available.

Boddey et al. (1996) studying the nitrogen cycling and sustainability of improved pastures in Brazilian savannas reported a deficit of around 58 kg of N/ha/year in a pure grass stand of *Andropogun gayanus*, whereas *A. gayanus-Stylosanthes spp*, instead, had a positive input of 45 kg N/ha/year.

Broad scale N-fertilizer application under current extensive pasture management in tropical savannas is not economically viable. Its effects last only for a short period of time and annual applications would be practically impossible. Intensive use of N in pastures for animal production would be recommended only for restricted areas, with rotational grazing, highly responsive grasses and finishing off beef cattle operations. The estimated cost of 60 kg/ N/ha/year of nitrogen fertilizer application, as urea, is US$ 60/ha/year.

The solution would be to introduce a N_2- fixing legume into the pasture. Promising cultivars of *Calopogonium mucunoides*, *Stylosanthes guianensis* and *Stylosanthes capitata* are available in Venezuela, Colombia and Brazil. Even if the useful life of introduced legumes lasts only for 3-4 years, the net balance of the whole system will still be positive for N input.

Costs of legume introduction come to US$ 25-40/ha, depending on seeding rate, species and planting system. Experiments have regularly shown additional animal liveweight gain for grass-legume pasture in the order of 25-40 kg/ha. More important than the advantage of positive cost-effectiveness in animal production, the aspect of pasture sustainability should be emphasized (Thomas et al., 1992; Boddey et al., 1996; Lascano et al., 1989).

Soil organic matter (SOM) plays an important role in tropical soils. Soils of tropical savannas are old and weathered, thus its mineral fraction has clay minerals with low surface area and low cation exchange capacity (CEC). Soil physical properties, such as soil structure, water stable aggregate and water holding capacity are also dependent on levels of organic matter. One of the key points in pasture sustainability is the management of SOM in tropical savannas, in order to take advantage of its mineralization without losing the benefits of soil properties.

Initial studies in soil physical properties in pasture under grazing in tropical savannas have shown the possibility to utilize some of these properties as indicators of sustainability. However, some of the data obtained such as soil resistance, water infiltration rate, bulk density, water aggregate stability, etc, must be evaluated over time and comparing different soil management systems. Critical values for limitation to root growth and the relationship with pasture production for the species discussed here are still not available. This theme should be the subject of future research.

Plant and animal performance indicators. Grazing animals choose their own diet in grass sward. Cattle preference is for green matter and especially for leaves. Despite some grazing habit differences among animal categories (cow, calves and adult males) they all prefer to graze green leaves in the upper parts of the plants. Of course, this will depend on amounts of dry matter on offer, plant architecture, plant structure, leaf to stem ratio, etc.

Pasture management needs to be monitored in order to sustain animal production and pasture persistence. Plant productivity declines first then plant quality in pasture under grazing. This latter is related to nutritive value and individual animal performance. Therefore, to sample plants in grass sward searching for indicators of sustainability depends on the target objective: animal diet or plant nutrition.

Sampling for animal diet (ADS) requires simulation of animal grazing behavior, thus plucking plant parts by hand has produced reliable results. However, Euclides et al. (1992), working in the savannas of Brazil, observed that this sampling method is dependent on the sampler which must be trained to avoid biased results. On the other hand, sampling for plant nutrition (BLS) in pasture under grazing requires comparisons of a specific part of plant within the same physiological stage. The first and/or second fully expanded leaf from the top of the plant and the leaf blade without the sheath, is the best sample to be used (Macedo, 1997).

There is a statistically significant linear correlation between BLS and ADS. The sample for ADS contains a large portion of BLS and depends on grass sward structure, season of the year and pasture production. For plant nutrition purposes, however, BLS is better because foliar nutrients are better correlated with soil nutrient content than ADS. Mean nutrient content (N,P,K and S) in ADS is 14 to 16% less than BLS (Macedo, M.C. 1996. unpublished data).

The interpretation of plant indicators could be misleading if reference points are not set. Sampling technique, sampling time and grass species must be specified. Animal performance and green matter on offer also need to be specified in temporal series when sustainability is to be evaluated.

EMBRAPA's National Beef Cattle Research Center - CNPGC-, has been working in Brazilian savannas since 1987, studying yield, forage quality and animal performance over time in a typical clayed Oxisol. Grass species of *Brachiaria* and cultivars of *Panicum maximum* were planted after removal of natural vegetation. Small amounts of limestone (1.0 t/ha) and fertilizer (450 kg/ha) were applied at establishment. Paddocks were grazed continuously, and Nellore steers were added or removed in order to ensure equal forage availability (1.5-2.0 t/ha of total dry matter - TDM - in the *P. maximum* cultivars and 2.0-2.5 t/ha in the *Brachiaria* species).

Grazing trials in tropical savannas are regularly carried out using fixed stoking rate as a common methodology. A different approach of fixing grazing pressure instead of stocking rate, under different treatments, can be suitable for monitoring sustainability. This method permits modeling and to extrapolate results much better to similar ecosystems. In this study, the basic approach was to fix the grazing pressure and not the stocking rate while forage yield and animal performance were a function of soil-plant and climate relationship. After that, some selected soil and plant variables were monitored during the experiment.

A significant effect of green matter on offer (GDM) was observed in the average daily gain of animals (ADG) over a three-year period (Euclides et al., 1993) (Table 4).

A general relationship, except for periods of compensatory gain, pooled over years for *Brachiaria species* (YBS) or *Panicum* cultivars (YPC) was:

$$YBS = 551 - 1908\ EXP^{-0.0036X},$$
$$YPC = 617 - 1683\ EXP^{-0.0043x};\ \text{where:}$$
YBS or YPC=ADG g/animal/day
and X= GDM kg green dry matter/ha.

At the asymptote, ADG was around 500 and 580 g/animal/day and GDM, 1000 and 900 kg/ha, for YBS and YPC, respectively.

There was a significant decline in N, P and K in the plant content over the years, but P in the plant presented the highest linear correlation with GDM. P in the plant declined with time regardless of grasses species. *P. maximum* cultivars were more sensitive than *Brachiaria* species to lower soil available-P, reflected by P in the plant content. Initial P in the plant during the rainy season, were 1.8 and 1.4 and decreased to 1.2 and 1.1 g P/kg dry matter for *Panicum* and *Brachiaria*, respectively (Macedo et al., 1993) (Figure 1).

These results indicate that below the range of 1.0-1.2 P/kg of dry matter, GDM and also ADG may be affected significantly. Some susceptible cultivars of *Panicum*, such as "Colonião", showed losses in liveweight at the end of the dry season (July-September). During that period, GDM on offer was below 600 kg/ha/day, which limited herbage selection by animals and had low nutritive value.

In summary, low soil available-P, less than 2.5 ppm in the arable layer (Mehlich-1 extractor), and levels of P-plant in leaf tissue, lower than 1.2 g P/kg of dry matter were not enough to sustain, over the years, annual animal liveweight gain above 350-450 kg/ha, depending upon grass species. These results are a consequence of lack of maintenance fertilizer application. During the course of this experiment, soil fertility, soil physical properties, plant nutrient content, green forage availability and animal performance declined over the years, thus characterizing the degradation process.

A second cycle was planned to recuperate these pastures and to run from 1991 to 1994. Paddocks were divided in two and two levels of fertilization were applied: 1.5 or 3.0 t of dolomitic limestone and 400 or 800 kg of the formula 0-16-18 + mixture of traced elements, respectively: level-1 (LF1) or level-2 (LF2). Grass species were the same as in the first cycle, *Panicum maximum* cultivars: Colonião, Tobiatã and Tanzânia and *Brachiaria decumbens* cv. Basilisk, *Brachiaria brizantha* cv. Marandú.

Pastures were grazed continuously by two Nellore tester steers and additional animals were used to maintain equal forage availability in all treatments. Total dry matter on offer (TDM) was higher than that of the first cycle. Established values were 2.5 t/ha of TDM for *Panicum* and 3.0 t/ha for *Brachiaria*. Because a high percentage of dead matter was present in these pasture species along the year, especially in *Brachiaria*, to ensure total green matter on offer above critical limits, TDM on offer was increased.

The same trend was observed as in the first cycle: in order to keep the grazing pressure, stocking rates had to be decreased over the years (Figure 4). For *P. maximum* cv. Colonião it was only possible to keep 1.7 ± 0.3 t TDM/ha.

No nitrogen fertilizer had been applied since removal of natural vegetation in 1986, but levels of fertilizer utilized after pasture renovation had a significant effect on annual liveweight gain (LWG). Averages were 565 and 365 kg of LWG /ha/year for level 2 and 1, respectively. For level 2, LWG in the first experimental year was over 650 but decreased to around 450 kg/ha/year in the third year. Level 1 started below 450 and reached less than 350 kg LWG/ha/year (Euclides et al., 1997).

Soil and plant variables used as indicators of sustainability showed different responses and green dry matter on offer again was the best indicator relating to animal performance. It decreased over time as did stocking rate (SR) and annual liveweight gain (LWG). Rate of decrease of SR and LWG was greater in LF_2. Plant nutrient contents, expressed by chemical analysis of the first fully expanded leaves throughout the second cycle (1991-1994) were above the ranges observed at the end of the first experimental cycle (1987-1991). These results were closely related to climate. Soil organic matter (SOM) played an important role in the release of N, P, and S (Macedo et al., 1997). Leaf sample was not as effective an indicator of sustainability as it was in the first experimental cycle (Figure 2).

Soil available-P, analyzed by the resin extraction method, was the best indicator among soil and plant nutrient variables. There are references in the literature regarding P-resin as a reliable method to measure soil available-P related to organic soil fractions (Sá, 1996).

A decrease of animal production was closely related to P-soil decline. Lack of nitrogen fertilization was partially compensated by SOM mineralization: 4.41% before pasture renovation to 2.93% at the end of the experimental cycle (Macedo et al., 1997) (Figure 3). This was a high price to pay. SOM is very important to improve the performance of tropical soils.

It is possible to increase animal production in tropical savannas, LWG/ha/year for example, to higher levels than those presented here. Changes in animal and pasture management and/or increasing fertilization levels can be some of the alternatives. Sustainability at higher inputs, however, should be tested considering the appropriate biological, economical, environmental, and social approaches.

The experiences discussed here are related to the largest area of commercial *Brachiaria*- based pastures in the tropical world established in the Brazilian savanna environment. Of course, extrapolations may be confined only to closely related climate-soil-plant and animal complexes but the basic principles are widely applicable to other savanna regions.

RESEARCH PRIORITIES AND CONCLUSIONS

- There is a considerable amount of isolated information on pasture establishment and management relating to various forage species, planting systems, cultural practices, fertilization and animal performances, etc., in tropical savannas;

- There is a gap in integrated research results which take into account farming systems and climate-soil-plant and animal management relationships. These are very important in modeling, testing and in proposing research priorities for specific sites;

- Livestock production in tropical savannas is accomplished in multiple ways. Farming systems are dynamic and depend on market fluctuations. Thus, sustainability levels also should be considered in order to integrate biological, environmental, economical and social variables;

- Areas of improved grass pasture increased dramatically in the last 20 years, especially in the tropical savannas of America. Natural grassland was replaced by more intensive exploitation, but inadequate soil, plant and animal management has promoted pasture and soil degradation;

- Considering the extensive areas which are already affected, research should focus on alternative farming systems where soil and plant management costs can be afforded by farmers in developing countries;

- Certain specific research related to sustainability should be promoted, such as: farming management including grass-legume mixed pastures; crop-pasture rotational systems; and agropastoral integrated systems;

- Modeling livestock production and indicators of sustainability, such as the P levels in plant and soil found for clayed Oxisols in Brazil, once experimentally obtained, should be tested over current farming systems to validate them and to propose different possible alternatives for sustainability.

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Table 1
Soil orders of Brazilian Savannas.

Brazilian Classes	Soil Taxonomy Sinonimia	Absolute area km^2	% of Savanna
Latossolos	Oxisols	935.870	46.0
	Ultisols	57.46	2.8
Podzólicos	Ultisols	307.677	15.1
	Alfisols		
Terras Roxas	Alfisols	34.231	1.7
Cambisolos	Entisols	61.943	3.0
	Inceptisols		
Litolicos	Entisols	148.134	7.3
Areias Quartzosas	Entisols	309.715	15.2
Lateritas Hidromórficas	Alfisols	122.664	6.0
	Inceptisols		
Gley	Inceptisols	40.752	2.0
Outros	Others	19.154	0.9
Total		2.037.600	100.0

Source : ADAMOLI et al. (1986)

Table 2
Chemical characteristics of the main important soil orders of Brazilian Savannas.

Soil Variables	Soil Orders		
	Latossolos (Oxisols)	Podzólicos (Ultisols)	Areias Quartzosas (Entisols)
pH H_2O	4.5-5.2	5.0	5.2
[1]C	0.5-2.4	0.9	0.5
[2]Ca^{2+}+Mg^{2+}	0.2-5.7	0.7	0.4
[2]K^+	0.02-0.4	0.1	0.1
[2]Al^{+++}	0.7-1.4	1.1	0.7
[3]P (Mehlich-1)	0.5-3.4	1.0	1.6
[2]CTC (pH 7)	3.9-13.9	5.8	3.7
[1]Base saturation	5.9-43.9	13.8	13.5
[1]Al saturation	16.4-85.9	57.0	57.4

1 = %; 2 = meq/100 cc; 3 = ppm
Source: Adapted from ADAMOLI et al. (1986)

Table 3
Soil chemical characteristics of some typical Oxisols from the Llanos Orientales of Colombia under savanna vegetation.

Soil Horizon	Depth	Clay	pH	Exch. Bases	Exch. Al	CEC	Base Sat.	Carbon	Free Fe2O3
	cm	%		- meq	100 g	soil -		%	
Oxisol H									
A1	0-8	47	4.4	0.8	3.3	16.8	5	2.7	2.5
A3	8-19	51	4.4	0.6	2.9	13.1	5	1.8	2.4
B3	66-100	56	5.4	0.4	1.1	7.5	6	0.5	2.8
Oxisol S									
A1	0-15	14	4.6	0.7	0.9	3.3	21	0.7	—-
A3	15-32	20	4.8	0.5	0.9	3.3	15	0.5	—-
B22	65-100	27	5.3	0.4	0.4	2.6	15	0.3	—-

Source : Adapted from Guerrero, 1975.

Table 4
Means of green matter on offer (GDM), phosphorus in the plant (P), Pearson correlation coefficient (1) and average daily gain (ADG) in 5 tropical pasture species after 3 years of grazing in Brazilian savannas. Dry season : May-September 1990.

Species and/or Cultivars	*Brachiaria* *brizantha*	*decumbens*	*Panicum maximum* cv. Colonião	Tobiatã	Tanzânia
GDM kg/ha	757	931	414	710	899
P g/kg	1,1	0,9	1,1	0,8	0,9
Corr.coef*.	0,85**	0,37 ns	0,77**	0,76**	0,71**
ADG g/animal/d	54	208	85	85	177

* GDM vs P ** (1%) ns =not sig.
Source : Macedo et al. (1993)

Table 5
Changes in some soil physical properties in a clayed Oxisol after 3 years of grazing, 3 different tropical pasture species, in the Brazilian savannas, compared to natural vegetation. EMBRAPA/CNPGC.

Soil Physical Properties	Depth cm	B.decumbens cv. Basilisk	P.maximum cv.Tanzânia	P.maximum cv.Tobiatã	Natural Savanna
Water Conductivity cm / h	5	2.94	2.03	2.90	8.33
	15	1.00	0.88	1.34	2.99
	25	0.67	0.76	0.93	3.05
	35	0.69	0.63	0.54	0.50
Macroporosity %	5	14	11	13	21
	15	13	12	13	19
	25	12	13	14	19
	35	11	13	13	17
Bulk Density g / cc	5	1.30	1.33	1.31	1.21
	15	1.30	1.33	1.35	1.26
	25	1.31	1.33	1.36	1.27
	35	1.31	1.31	1.33	1.28
Water Dispersible clay %	5	19.5	20.0	18.5	20.5
	15	16.5	18.0	17.5	21.0
	25	4.0	3.0	4.5	4.0
	35	4.5	6.0	3.5	3.5
Water Infiltration Rate at Field cm / h	—	15.5	15.1	14.4	42.1

Source : Adapted from Macedo, 1995.

Table 6

Dry matter yield of *Brachiaria decumbens* cv. Basilisk cultivated in a Quartzpsament (> 85 % sand) with different soil fertilization treatments, after 5 years of grazing and removal of natural savanna vegetation . No fertilizer applied at pasture establishment ; pasture grazed year-around continuously with an average of 1 head /ha. Mato Grosso do Sul, Brazil.

Soil Treatment	Dry matter Yield g / pot	Relative Yield %
Soil - degraded pasture	0.46	100
Complete	4.80	1043
Complete minus -N	4.23	920
Complete minus -P	0.44	96
Complete minus -K	4.89	1063
Complete minus -S	4.38	952
Complete minus -Ca	4.76	1035
Complete minus -Mg	5.45	1185
Complete minus -Micron.	5.22	1135

Source : Adapted from Macedo,1995.

Figure 1

Changes in P plant content in *Panicum* cultivars and *Brachiaria* species under grazing over years: 1987/88, 1988/89, 1989/90; during rainy (R) and dry (D) season in Brazilian savannas after removal of natural vegetation.

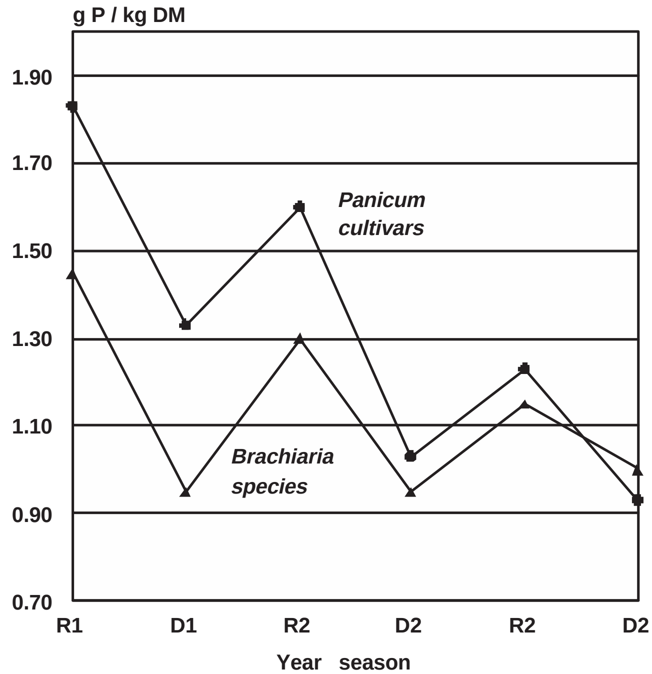

Figure 2

Changes in total dry matter (TDM), P in the leaves (P-plant), green matter on offer (GDM) and average daily gain (ADG) over 3 years on continuously grazing pasture of Brazilian savannas. Mean of 5 grasses and 2 levels of fertilization.

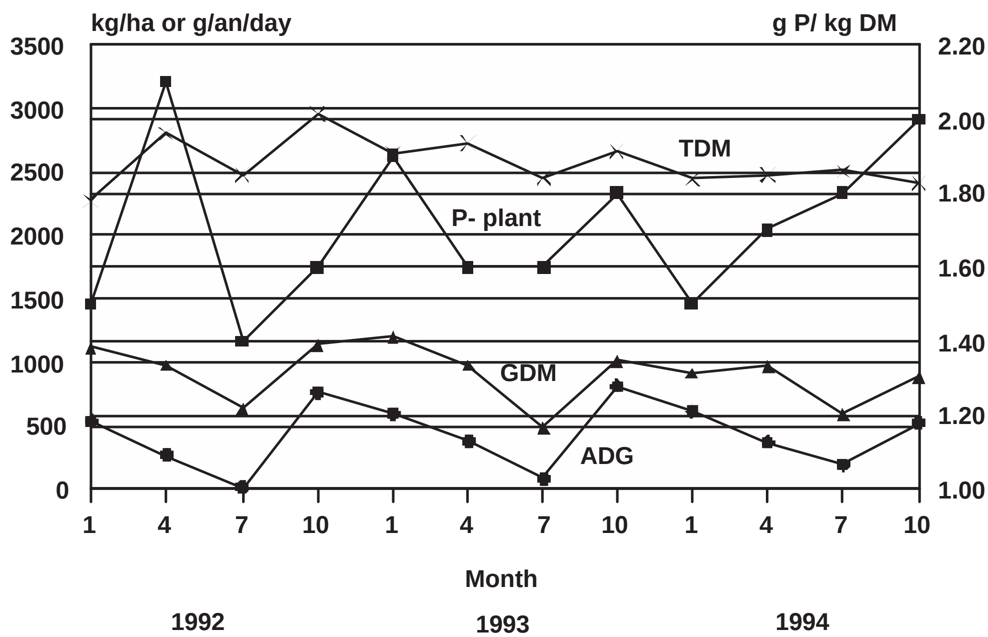

Figure 3
Changes in soil fertility in a clayed Oxisol of the Brazilian savannas under 5 different tropical pasture species after 3 years of renovation. Means of 2 levels of fertilization and 3 replications.

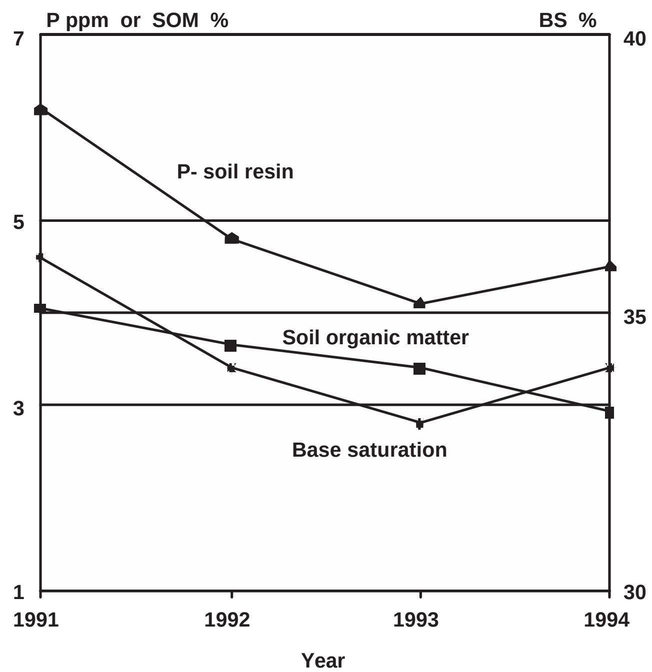

Figure 4
Changes in the green matter on offer (GDM) and stocking rates (SR-250 kg steer/ha) over time after pasture renovation in Brazilian savannas. Mean of 5 grasses and 2 levels of fertilization.

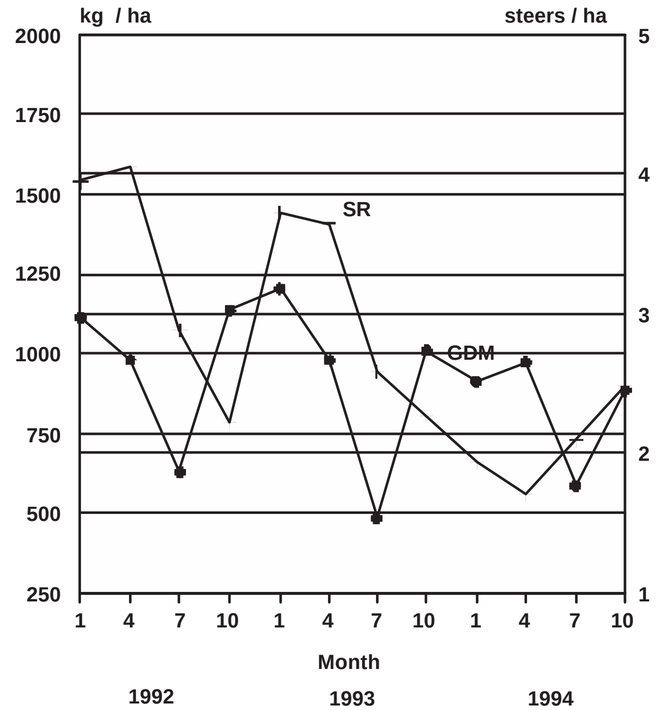

Figure 5
Soil moisture content (cm3/cm3) as function of soil moisture tension (MPa) in 3 different tropical pasture species after 3 years of grazing in an Oxisol of the Brazilian savannas compared to natural vegetation.

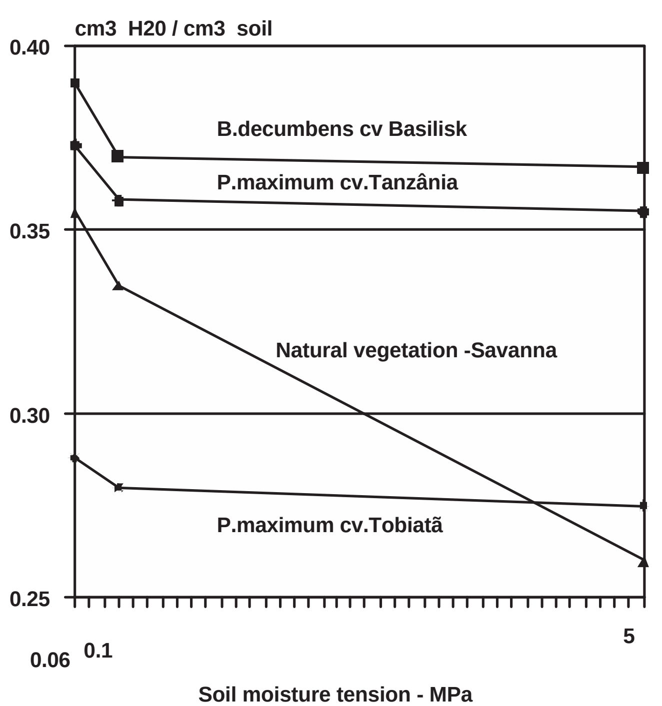

Figure 6
Soil compaction measured by resistance to a penetrometer (MPa) at soil field capacity in different depths of a clayed Oxisol after 3 years of grazing. *B. decumbens* (BD), *P. maximum* cv. Tanzânia (TZ) and *P. maximum* cv. Tobiatã (TB) compared to natural vegetation (NV) in Brazilian savannas.