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Sward dynamics, N-flows and forage utilisation in legume-based systems

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Multispecies mixtures: management implications for subtropical and tropical pasture production

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Abstract
The purpose of this review is to present some of the most recently successful grass+legume mixtures in tropical and sub-tropical regions and to discuss the reasons for low adoption of legumes. A concept in which the main constraints for the advance in using legumes is presented, as follows: i) the general agricultural conception about the role of legumes in mixtures, ii) the lack of an ecological perspective and knowledge about species strategies under disturbance. Finally, evidence of how grazing management is a central parameter in grass-legume equilibrium is discussed.

Introduction
Latin America is the centre of origin of most tropical and subtropical forage legumes, such as *Aeschynomene* spp., *Arachis* spp., *Centrosema* spp., *Desmodium* spp., *Stylosanthes* spp. Despite the huge diversity in plant forms, morphology, structure, adaptation to different levels of environmental constrains, etc., legume-based systems are far from being widely adopted. Taking Brazil as an example, from the almost 130 million hectares of cultivated pastures, legume use is estimated at only 2-3 % of the area. Despite the well known benefits of legumes in pastures, their adoption in tropical livestock systems has been less than anticipated (Shelton et al., 2005). Reasons for the poor adoption have been discussed (Valentim & Andrade, 2004), where lack of persistence (in the agricultural sense) and failure of technology transfer are always mentioned and overemphasized. Unfortunately, this subject is rarely taken in a wider ecological context. Moreover, grass-legume mixtures are obviously more complex to manage than pure grass stands, contributing to the "anti-legume complex" cited by Shelton et al. (2005).

A philosophical constrain: our grass preference
During the green revolution the availability of agricultural products was the most important demand on crop research. The use of nitrogen contributed mainly to the spectacular increase in crop production, and grassland research used the same focus. By the end of the twentieth century, increasing costs of production and pollution caused by the use of nitrogen constrained the use of pure grass stands, especially on Europe. Without these constraints, legume-based systems might not have never been discussed to the same extend.

There is a strong preference for all-grass systems among researchers, agricultural extension officers, agronomists and farmers. Fertilized grasses are synonymous with intensive, productive systems; whilst legumes are considered to belong in more extensive ones. Many "classical" reasons for legume adoption have been advocated, but the focal one is the capture and fixation of low-cost nitrogen in the system, so legumes would correct the main nutrient limitation for grass-based pastures in the tropics (low N in the soil and low protein intake). The main results expected are a positive effect on pasture growth (e.g., by N fixation - (*Stylosanthes* spp. 88 – 180 kg N/ha/year, *Arachis* spp. 26 – 99 kg N/ha/year - Valentim & Andrade, 2004) and animal nutrition (e.g., increase in 30% live weight gain –

Lascano, 2000). Interestingly, these reasons for legume adoption have been proposed to support the limitations of grasses (Jobim & Carvalho, 1995). Legumes are supposed to provide just what grasses need. This second role of legumes is evident when researchers discuss the ideal balance in grass-legume mixtures, and the craved participation of legumes (e.g., Spain et al., 1985). The desired botanical composition rarely favours legumes which have never been viewed at the same level of importance as grasses. This preference for grasses has engendered management attitudes which favour it and research focused on the potential of legumes only to palliate the limits of grass-based systems. The term grass-legume association is, *per se*, an illustration of our anthropic perception. It does not correspond to the ecological nature (mainly competition process) behind the technology.

A philosophical constraint: the evolutionary context

During the co-evolution of grasses and grazers, particularly ruminants, grasses have developed strategies to cope with grazing based mainly on tolerance mechanisms (Briske, 1996). Africa is the centre of origin of the main tropical and sub-tropical cultivated grasses and has a long grazing history. Most grasses are well adapted to grazing and have physiological and morphological mechanism to cope with, and even benefit from it. Instead, Latin America has a short grazing history and legumes appears to have evolved strategies to face predominantly non-invertebrate herbivory. Most legumes have avoidance mechanisms, and use part of their photosynthetic products to produce allelochemicals to avoid grazing. The level of grazing history, in addition to the ecosystem richness in trophic resources, defines the potential impact of grazing intensities upon plant diversity (Milchunas et al., 1988), partially explaining why the native Latin American forage species are particularly sensitive to grazing management.

This evolutionary context regarding grazing, in addition to that concerning differences in metabolic pathway between C3 legumes and C4 grasses, have as consequence the huge differences in the potential of legumes and grasses to exploit trophic resources and to cope with grazing in the tropics and subtropics.

Are grass-legume systems widely adopted?

Although there is already a large number of germplasm accessions collected and options already available to compose mixtures (Dall'Agnol & Scheffer-Basso, 2004), legumes are far from being widely adopted in mixtures with grasses in tropical and subtropical farming systems. Shelton et al. (2005) revisited the adoption of legume technology in the last 50 years and concluded that adoption of legumes has been less than anticipated. Reasons for failure were discussed by Valentim & Andrade (2004), including: i) unsuccessful experiences among farmers and researchers resulting in lack of credibility of this alternative; ii) lack of commercial cultivars adapted to different environmental conditions; iii) low availability and high cost of seeds in the market; iv) lack of knowledge among farmers regarding the proper management of grass-legume pastures; v) lack of persistence of legumes in the associations with grasses; vi) the lack of farmers participation in research and development; vii) lack of coordination on feed improvement; viii) soil fertility maintenance; ix) unfavourable policies. It can be concluded that most of the reasons for failure derive from the lack of a broader knowledge based on the ecological relationships among plants in complex natural mixtures, and its applicability on agricultural systems, apart from the management conception based on grasses as stressed earlier.

Notable adoption successes for the use of legumes have been experienced in Asia and Australia, and to a much lesser extent in Brazil (Shelton et al., 2005). The adaptation of *Stylosanthes* spp. (Stylo) in Asia is, probably, the most impressive example, reaching

750,000 ha mainly in Thailand, China and India. *Leucaena leucocephala* and *Clitoria ternatea* have success of adoption in Australia (100,000 ha each one). In Brazil, *Pueraria phaseoloides* (tropical kudzu), *Stylosanthes* spp. and *Arachis* spp. are the current most important legumes, being used in almost 700,000 ha. The recent success of these genera is responsible for the renewing interest in grass-legume mixtures in Brazil, although success stories occur in very specific niche conditions. Tropical kudzu, the best example, is estimated to be present in over 50% of the total pasture area in Acre state (Valentim & Andrade, 2004). Its success depends on being managed under continuous light stocking, lacking persistence at high grazing intensities and rotational grazing. This particular adaptation to local conditions, as well as on-farm experiments, was considered vital to tropical kudzu adoption.

In the case of Stylo, new cultivars developed by Embrapa and recent cultivars are well adapted to infertile soils and anthracnose. Stylo cv. Campo Grande, a mixture of *S. capitata* and *S. macrocephala* increased the profitability of beef production after a three years trial in 33.2% in the best grazing intensity. Forage production can reach more than 7,000 kg DM/ha, being almost 90% of the nitrogen in tissue from symbiotic origin. Figure 1 illustrates the positive (and classical) effect of legume on animal performance by the increase of nitrogen in grass herbage, as well as in live weight gain *per se*.

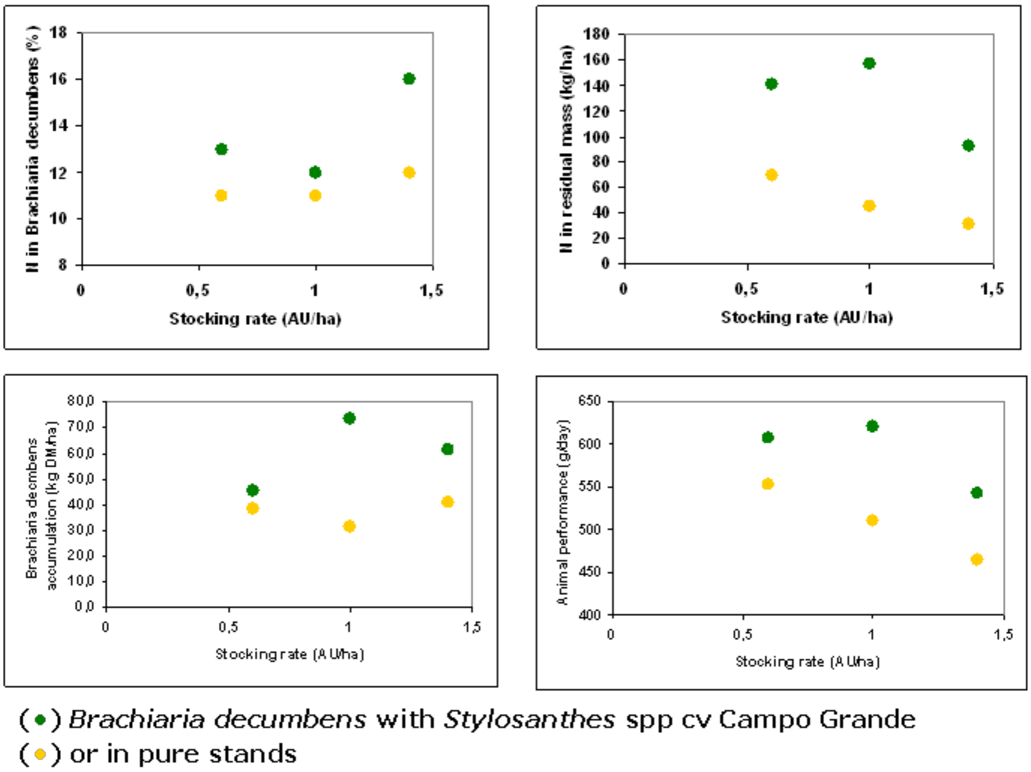

Figure 1. Pasture and animal production of a *Brachiaria decumbens* – *Stylosanthes* spp. cv Campo Grande (adapted from Embrapa, 2002).

There was an increase in grass production due to legume nitrogen fixation. The amount of nitrogen in grass when in pure stands could reach no more than 30 to 50% of that in the grass-legume system.

Arachis pintoi (forage peanut) is probably the tropical herbaceous legume with the highest number of favourable attributes related to persistence under grazing, and the more promising one. Its morphological characteristics confer a strategy to exploit the environment and resist grazing in a similar way to white clover, being called "the white clover of the tropics". When grown in mixtures with grasses, compared with pure swards, its radiation use efficiency is not affected (Fisher & Cruz, 1995). The response of forage peanut to grazing intensity is almost unique among tropical legumes, as it can be seen in Figure 2.

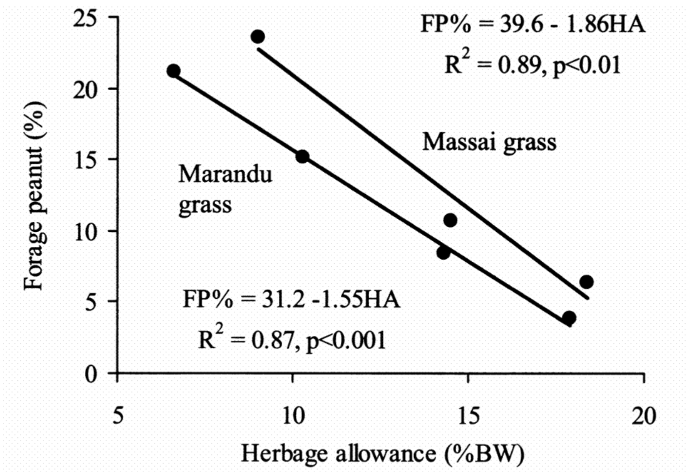

Figure 2. Botanical composition of *Brachiaria brizantha* cv. Marandu or *Panicum maximum* cv. Massai associated with *Arachis pintoi* according to different herbage allowances (Andrade et al., 2005).

Increasing grazing intensity favours forage peanut by increasing its radiation capture whilst keeping grasses at a lower leaf area index. With its growing points well protected due to its stoloniferous growth habit, forage peanut resists higher grazing intensity, which prevents tall grasses from shading excessively. The authors highlighted that increase in forage peanut was not related to selectivity, but to modifications of sward structure.

Animal selectivity regarding each component in grass-legume mixtures is also important. Depending on the level of legume preference, management strategies should aim to maintain a minimum equilibrium in the mixture. If a highly palatable legume, as forage peanut, is associated with a less palatable prostrate or tall bunch grass, light grazing intensities could provoke selective defoliation against the legume, and grasses could grow with low level of defoliation in a shading micro-environment which is detrimental to the legume. Diet selection can vary according to the sward structure and the season of the year, as illustrated by Lascano (2000 – Figure 3).

The preference for forage peanut is enhanced during the dry season, when grass is of low quality (Figure 3 – A). During dry season, if stocking rate remains the same, grazing pressure on the legume is greatly increased and can affect its persistence. Another proposed approach to face the greater growth potential of grasses is to associate a tall bunch grass with a legume of low palatability (Figure 3 – B). During the growing season, animals avoid *Centrosema acutifolium* (a stoloniferous twining legume with low palatability) in association with *Andropogon gayanus*, but alter their preference in the dry season to the point of indifference. This permits the co-existence of a grass and a legume very different in their morphological characteristics, increasing the grazing pressure on the grass component when growth conditions favour the higher growth potential of grasses. The feasibility of an association where, to persist, one component should not be grazed during half of the year could be discussed, but it illustrates the importance of managing grazing in a flexible way according to the characteristics of each grass-legume association.

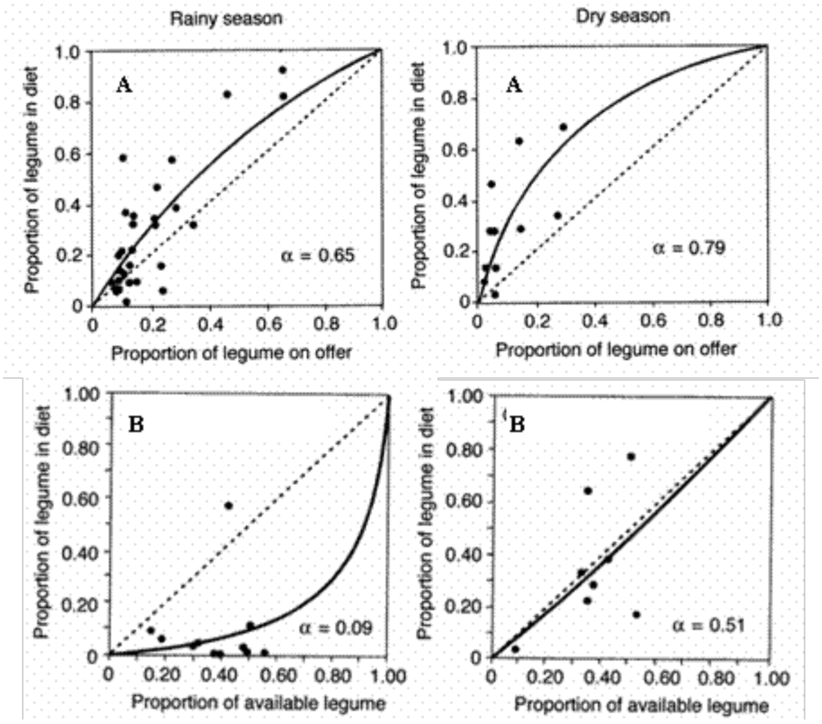

Figure 3. Relationship between legume proportion in pasture and in the diet in *Brachiaria humidicola – Arachis pintoi* pastures (A) and *Andropogon gayanus – Centrosema acutifolium* pastures (B). Adapted from Lascano (2000).

Subtropical regions: particularities for grass-legume mixtures

Natural pastures in the subtropical regions of Latin America are examples of how complex mixtures can be in the natural environment, supported by variable climatic characteristics. In natural pastures of Southern Brazil (also called "Campos"), more than 400 grasses and 150 leguminous forage species co-exist; it is possible to find more than 35 different plant species/m^2. Even for cultivated pastures, there are huge possibilities of combination of C4 grasses with temperate C3 grasses and legumes and tropical C3 legumes. Overseeding Italian ryegrass (*Lolium multiflorum*) and/or Oats (*Avena strigosa*) with clovers (*Trifolium* spp.) and birdsfoot trefoil (*Lotus corniculatus*) on natural pastures is feasible and good results can be achieved. This approach is illustrated by the classical work of Scholl et al. (1976), in which the live weight production of natural pastures was increased from about 100 kg/ha to more than 450 kg/ha when oats+ arrowleaf clover (*T. vesiculosum*) were overseeded, being equal to the effects of application of 90 kg N/ha.

Another example of complex mixtures that can be used in subtropics is that presented by Moraes et al. (1995). Pangola grass (*Digitaria decumbens*) was established in spring/summer and Italian ryegrass/white clover was overseeded in autumn. By using this type of C3+C4 combination, forage production is well distributed and animals are able to graze the pastures on a year round basis. Pangola contributes mostly in spring/summer, and ryegrass+clover mostly in winter/spring. Once pasture produces almost constantly, high levels of animal performance (0.8 kg live weight/steer/day) can be achieved throughout the year. Consequently, live weight gain per hectare reaches almost 1,200 kg/year, compared to 60 kg/year in extensive systems. Both C3 species depend on natural reseeding to persistence, therefore, grazing management must take it into account. The best grazing intensity corresponded to a daily herbage allowance around 10-12 kg DM/100 kg live weight. This type of association is also practiced with *Cynodon* spp. and works similarly.

Sward targets

Recent experimental work on pasture ecophysiology and grazing ecology in Brazil has been conceived under the conviction that control, monitoring and manipulation of sward state is an important feature of grazing management (Silva & Carvalho, 2005). Novel work is in progress for the main forage resources about how sward structure is built and how animals capture forage from these structures. As a consequence of this new knowledge and aiming to optimize pasture production (i.e., light interception) and animal intake (i.e., animal performance), some recent sward guidelines are being recommended (e.g. Table 1).

Table 1. Sward targets for *Brachiaria brizantha* cv. Marandu or *Panicum maximum* cv. Massai associated with *Arachis pintoi* in rotational grazing (Andrade, 2004).

	Sward height (cm)			
	Massai – *Arachis*		Marandu - *Arachis*	
Season	Pre-grazing	Post-grazing	Pre-grazing	Post-grazing
Rainy (Oct-May)	65 - 70	35 – 40	45 – 50	25 – 30
Dry (Jun-Sept)	50 – 55	30 - 35	30 – 35	20 - 25

As discussed earlier, tropical and subtropical mixtures have additional constrains to grass-legume balance compared to temperate counterparts, due to the differential nature of their metabolic pathways. Consequently, grazing control is more complex, but must be even more flexible and adjusted to maintain the desirable grazing pressure in each component.

Legume-based systems: final comments

Europe is focusing on grass-legume associations based on their environmental benefits (Rochon et al., 2004) while in Latin America profitability is still the driving force for adoption of the technology. More than being considered multipurpose plants, which improves systems diversification, legumes must be profitable.

There is a lack of conceptualization concerning legumes and grass-legume associations in a broad, ecological sense to be applied in their use in tropical and sub-tropical agricultural systems. Success stories are insignificant comparing to available germplasm. Legumes are usually the weak component of these complex mixtures, but are a vital component, with clear ecological functions, and not a way to support grass production. Research and management orientation must take it into account, and consider legumes at the same level of importance as grasses for the sustainable use of grass-legume associations. Grazing control is vital in the management because the ecological adaptations of each component are quite different. The dynamic of nutrients is also very important, phosphorus being one of the most determinants of legume content which frequently interacts with grazing intensity, but the possibility to manage it, in spatial and temporal scales, is less than grazing intensity and animal preference. The focal point to grazing management is, thus, flexibility. Besides that, in the case of legumes, there is a lack of basic knowledge about plant-*Rhizobium* interaction, which certainly has contributed to their poor persistence.

The many different morphological types and the great diversity of forage species which can be used potentially in mixtures makes the development of management strategies a case-by-case research, but the philosophy generally used should be reviewed.

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