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Leucaena feeding systems in Argentina. I. Five decades of research and limitations for adoption

Sistemas de alimentación con leucaena en Argentina: I. Cinco décadas de investigación y limitantes para su adopción

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Abstract

This review describes the history of research in *Leucaena leucocephala* (leucaena) feeding systems carried out by the National Institute of Agricultural Technology (INTA) over the last 5 decades and discusses the main limitations resulting in poor adoption in Argentina. Leucaena was introduced in the subtropical region of the north of the country in the late 1960s and early 1970s. Since then, INTA has conducted research to evaluate forage and animal productivity, leucaena accessions, rhizobial strains, contribution to soil carbon and total nitrogen and density effects on competition and other ecosystem interactions in silvopastoral systems. In spite of the convincing research results showing the excellent potential of leucaena to increase forage quality and animal production in suitable areas, there has been poor adoption of this forage tree legume on a broad scale.

Keywords: Beef cattle, Chaco region, forage tree legumes, protein banks, silvopastoral systems.

Resumen

Esta revisión describe la historia de investigación conducida por el Instituto Nacional de Tecnología Agropecuaria (INTA) en la utilización de *Leucaena leucocephala* (leucaena) en sistemas ganaderos en las últimas 5 décadas, y analiza las principales limitantes que resultaron en su escasa adopción en Argentina. Leucaena fue introducida en la región subtropical del norte de Argentina a finales de la década de 1960 y comienzos de los 70s. Desde entonces, INTA ha conducido investigaciones para evaluar la productividad forrajera y ganadera, accesiones de leucaena, cepas de rizobio, contribución de carbono y nitrógeno al suelo, y efectos de la densidad de leucaena sobre competencia y otras interacciones ecosistémicas en sistemas silvopastoriles. A pesar de los alentadores resultados de dichas investigaciones, que mostraron el excelente potencial de leucaena para incrementar la producción forrajera y ganadera en áreas aptas para su crecimiento, se observa escasa adopción de esta leguminosa forrajera arbórea en gran escala.

Palabras clave: Bancos de proteína, Chaco, ganado de carne, leguminosas arbóreas, sistemas silvopastoriles.

Introduction

In the subtropical region of the north of Argentina, livestock feed mainly on pastures and grasslands dominated by grasses, which are deficient in protein for most of the year. *Leucaena leucocephala* (leucaena) has excellent potential to increase forage quality and animal production in suitable areas for its growth (Goldfarb et al. 2005; Radrizzani and Nasca 2014). In the late 1960s and early 1970s the National Institute of Agricultural Technology (INTA) investigated

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the role of leucaena in feeding systems for this region by evaluating its persistence in different environments and farming systems. This paper reviews the history of research carried out by INTA on leucaena feeding systems over the last 5 decades and discusses the main limitations affecting adoption of leucaena by farmers.

History of research

Although several tropical forage legumes have been tested as possible solutions to the protein deficiencies of grasslands and pastures, only leucaena has stood out against other perennial legumes in terms of forage production and persistence (Royo Pallarés and Fernández 1978; Goldfarb et al. 1986; Goldfarb and Casco 1994). During the last 5 decades, leucaena has been evaluated in terms of forage and animal productivity, performance of various accessions, nodulation, contribution to soil carbon (C) and total nitrogen (N) and density effects on competition and synergistic effects.

Forage and animal productivity

Since the early 1980s, experiments have been conducted to test forage and animal production of pastures incorporating leucaena. Cattle liveweight gains (LWGs) with and without leucaena in the diet were compared in the following 7 experiments, that are summarized in Table 1.

Leucaena protein bank, INTA Mercedes Research Station. On the Experimental Farm located in the center of Corrientes province (29º22'18.88" S, 57º40'36.48" W; 95 masl) with a mean annual rainfall (MAR) of 1,380 mm, more than 1,000 accessions of forage legumes were introduced in 1965 and their adaptation and forage characteristics were evaluated. Leucaena stood out for its yield, quality and persistence (Royo Pallarés and Fernández 1978). Two decades later leucaena was still vigorous and productive, so Pizzio et al. (1989) evaluated forage and animal productivity of native grasslands with and without access to leucaena protein banks comparing the effect of 0, 10 and 20% of the grassland area sown to leucaena cv. Peru. Grazing periods were 288 days/year (June–March) over 3 years. Mean annual LWGs with 20% leucaena protein banks were 38% higher than on pure grassland (Table 1a). Annual LWGs with 20% leucaena were 143 kg/head and 190 kg/ha compared with 103 kg/head and 137 kg/ha for grassland only. Since large steers lost little weight (-8%) during winter and small steers gained weight (+4%) with 20% leucaena, an increased proportion (30%) of leucaena was recommended. Steers 32 months old with access to 20% leucaena could be finished at heavier weights (476 kg) than steers grazing pure native grassland (410 kg). Animals grazing leucaena showed no symptoms of mimosine toxicity under these conditions.

Table 1. Cattle liveweight gains (LWGs) on treatments with and without leucaena in 7 experimental trials in Argentina.

Experiment and treatments	LWG (kg/hd/d)	Increment due to leucaena	Toxicity	Reference
a. Protein bank, INTA Mercedes				Pizzio et al. 1989
- Leucaena, 20% of available area	0.497a[1]	38%	No	
- Native grassland	0.358b			
b. Protein bank, INTA Corrientes				Gándara et al. 1986
- Leucaena, 18% of available area	0.385a	75%	No	
- Native grassland (winter)	0.220b			
c. Silvop. syst., INTA Corrientes				Gándara and Casco 1993
- Leucaena	0.436a	35% (70%)[2]	No	
- Native grassland	0.322b			
d. Protein bank, INTA Cerro Azul				Lacorte et al. 1987
- Leucaena, 20% of available area	0.408a	57%	No	
- *Cynodon plectostachyus* pasture	0.259b			
e. Supplement, INTA Cerro Azul				Lacorte 2001
- Leucaena supplementation	0.657a	No difference	No	
- Comercial protein supplement	0.586a			
f. Protein bank INTA El Colorado				Roig 1992
- Leucaena, 10% of available area	0.454a	22%	No	
- Pangola pasture	0.373b			
g. Silvop. system, INTA Leales				Radrizzani and Nasca 2014
- Leucaena, 40% of available area	1.070a	65% (195%)	Yes	
- Brachiaria pasture	0.650b			

[1]Values within experiments followed by different letters differ at P<0.05.
[2]Values within parentheses indicate the increase in production per hectare.

Leucaena protein bank, INTA Corrientes. During 3 consecutive winters (May–September 1981, 1982 and 1983) on a cattle farm located in 'Empedrado', Corrientes province (27º54'41.25" S, 58º44'47.81" W; 71 masl; MAR 1,350 mm), Gándara et al. (1986) compared LWGs of heifers and cows grazing native grasslands with access to protein banks of leucaena cv. Peru for 4 h/d with those of heifers and cows grazing only native grassland. LWGs/head of animals with daily access to leucaena were 44, 130 and 110% greater in 1981, 1982 and 1983, respectively, than on native pasture alone (mean increase 75%, 0.39 vs. 0.22 kg/hd/d; Table 1b). The improved gains were directly related to the additional quantity and quality of forage provided by leucaena. In this trial, animals grazing leucaena also showed no symptoms of mimosine toxicity

Leucaena silvopastoral system, INTA Corrientes. In the same area as the previous experiment, Gándara and Casco (1993) conducted an exploratory trial to assess the LWGs of steers in a silvopastoral system with leucaena in hedgerows in comparison with steers on straight grassland over 2 years (August 1989–August 1990 and November 1990–November 1991). Leucaena (cv. Cunningham) had been established in spring 1987 in hedgerows 5 m apart with *Digitaria eriantha* (syn. *D. decumbens*, Pangola grass) as a companion grass in the inter-rows. LWGs of steers grazing the leucaena silvopastoral system were 34 and 36% greater in 1989–90 and 1990–91, respectively, than those on grass only (Table 1c). Animal production per hectare from leucaena-Pangola grass was 170% greater than on grass only as a result of a doubling of stocking rate (2 vs. 1 head/ha). Between 1992 and 1996, Goldfarb et al. (2005) explored different cutting regimes to maintain a dense leafy canopy within the browse height (<2 m) and improve forage quality. This work, also conducted at the Corrientes Research Station, showed that cutting regime did not affect forage quality (protein and phosphorus concentrations).

Leucaena protein bank, INTA Cerro Azul Research Station. In the 'Cuartel Río Victoria' Experimental Farm, located in the center of Misiones province (MAR 1,650 mm), Lacorte et al. (1987) evaluated LWGs of steers grazing protein bank systems in comparison with a pure grass control pasture during 1984–85 and 1985–86. Leucaena protein banks had been planted in September 1981 in 20% of the area of a *Cynodon dactylon* pasture, which was sown in summer 1980/81. The pure grass pasture was dominated by *Cynodon plectostachyus* ('pasto estrella'). Steer LWGs were 57% higher in the leucaena protein bank systems than in pure grass pastures (Table 1d). Recommendations from this study were to reduce the proportional area of the protein banks since there was an oversupply of leucaena forage, and to use protein banks in winter when the difference in LWG was greatest, viz. 0.7 kg LWG/d for protein banks vs. a loss of 0.4 kg/d for pure grass pastures. However, to maintain leucaena green leaf in winter, protein banks must be established in elevated areas protected by tree windbreaks to reduce damage from frosts and cold winds.

Leucaena supplementation, INTA Cerro Azul. Lacorte (2001) used fresh leucaena to replace commercial protein supplements for heifers and showed that weight gains in the leucaena and protein supplement treatments were similar (Table 1e). The author recommended leucaena cut-and-carry for reducing feeding costs in small farming systems. Furthermore, Pachas et al. (2011; 2012) carried out collaborative experiments with dairy producers using 'intensive silvopastoral system' configurations with leucaena planted at high densities (10,000–20,000 plants/ha) in single rows spaced 1.6 m apart with companion grass between rows and high-quality timbers planted in alleys 10–20 m apart. These collaborative trials helped to involve smallholders in leucaena utilization to improve the quantity and quality of forage produced and increase dairy cattle productivity.

Leucaena protein bank, INTA El Colorado Research Station. On the Experimental Farm located in the southeast of Formosa province (MAR 1,150 mm) in the years 1980, 1981, 1983, 1987, 1988 and 1989, Roig (1992) studied LWGs of weaner and yearling steers grazing Pangola grass pastures or Pangola grass with 10% of area as a leucaena protein bank. Pangola grass pastures were continuously grazed, while pastures with leucaena were rotationally grazed with access to protein banks for 2–3 h/d. Mean daily LWGs were higher in steers with access to leucaena during the first, second and fourth years (Table 1f), but not in the other years. Both age groups responded, but the effect was stronger in younger animals that require forage with higher nutritive value. The absence of responses in LWG in the other years was attributed to the abundance of native and naturalized legumes, e.g. *Desmodium incanum*, annual *Vicia* spp. and *Melilotus* sp., in the Pangola grass pastures.

Leucaena silvopastoral system, INTA Animal Research Institute of the Semi-arid Chaco region. On the Experimental Farm located in Leales, Tucumán, with a subtropical subhumid climate and MAR of 880 mm, Radrizzani and Nasca (2014) conducted a trial in the 2009/10 summer to evaluate the effects on beef productivity and its toxicity of planting leucaena in a *Urochloa brizantha* (syn. *Brachiaria brizantha*) cv. Marandú (brachiaria) pasture established in 1995. Leucaena cv. K636 was zero till-planted into the pasture in hedgerows (single or twin rows) with 5 m inter-row spacings in December 2009 to form 3 treatments with different proportions of the total area planted to leucaena (0, 20 and 40%). For the first 45 days, mean LWGs were 0.65, 1.00 and 1.07 kg/hd/d for straight brachiaria, brachiaria with 20% leucaena and brachiaria with 40% leucaena, respectively, with corresponding gains per unit area of 1.33, 3.08 and 4.32 kg/ha/d (Table 1g). At this point animal LWGs on pastures containing leucaena began to decline significantly, maintaining this trend until the end of the trial. This coincided with signs of mimosine toxicity, despite high yields of available leucaena. This study suggested that, before putting animals on a pasture containing a high proportion of leucaena (e.g. 40%) in the Chaco region, the value of ruminal inoculation with mimosine- and DHP-degrading bacteria (as used in other tropical and subtropical areas) must be assessed.

Leucaena accessions

Temperatures in the subtropical region of Argentina are favorable for leucaena growth during most of the year (7–9 months) but frost can significantly slow or stop its growth in winter when leucaena forage is needed most to supplement ruminant diets. To identify tolerance to low temperature while maintaining adequate forage yield and quality, Goldfarb and Casco (1998) selected 56 accessions of *Leucaena* species and hybrids. The study was conducted in 2 phases: in Phase 1, 3-month-old seedlings were subjected to temperature treatments of either -8 or -3 °C for 14 h. After the -8 °C treatment, only 1 plant of a single accession (*L. leucocephala* × *L. diversifolia* SF 9043) survived. After -3 °C treatment, 17 plants retained 50% of their leaves. In Phase 2, these 17 plants were planted out in the field to measure agronomic features. Eight plants, representing 4 cultivars and accessions of *L. leucocephala* and 4 plants of different *L. leucocephala* × *L. diversifolia* hybrids, showed good agronomic adaptation and chilling tolerance but only a single plant of *L. leucocephala* K72 (SF8073) maintained green stem and meristematic tissue after a frost event of -8.8 °C.

In 2000, other field trials evaluated the sensitivity of *Leucaena* species to low temperatures in winter and leucaena production in hedgerow silvopastoral systems (Goldfarb and Altuve 2002; Goldfarb 2005; Goldfarb et al. 2005; Rolhaiser 2013). All *Leucaena* spp. survived the frost, reshooting vigorously from the stem base as temperatures rose. Accessions of *L. leucocephala* that persisted until 2018 and have continued under evaluation are: 368 (Lot 2 Zwai 1985), Cunningham P13, Cunningham P14, CIAT 17481, CIAT 17479, Hawaiian Giant and ecotypes 'Piquete' and 'Colorado'. Other *Leucaena* spp. that persisted and are still under evaluation are: *L. collinsii*, *L. glabrata*, *L. esculenta*, *L. pulverulenta*, *L. stenocarpa* (CIAT 17268), *L. diversifolia* (CIAT 17461, CIAT 17264, 11677 Lot 5 Zwai 1989 and 11676 Lot 7 Zwai 1989), *L. pallida* (CPI 84581), *L. retusa* (CIAT 17267), *L. macrophylla* (CIAT 17481, CIAT 17245 and 55/58 ILCA Kenya), *L. gregii* (CPI 91198), *L. lanceolata* var. *lanceolata* (CPI 95571). The hybrids that persisted until 2018 and are still under evaluation are: *L. leucocephala* × *L. diversifolia* (Line 7, Line 18, Batch 283-050-10).

In another study Acosta (2008) selected 19 accessions (*L. leucocephala*, *L. diversifolia* and their hybrids) from the INTA Corrientes collection to evaluate forage yield in acid soils; results showed good yields for most of these accessions, with the top 5 producing between 4,238 and 5,685 kg DM/ha/year.

In 2011, 57 accessions of *Leucaena* species and hybrids from the INTA Corrientes collection were established at the Animal Research Institute of the Semi-arid Chaco region, INTA, Leales, Tucumán, to preserve and allow evaluation of these genetic resources in another environment.

Rhizobial strains and nodulation

Effective nodulation is essential for vigorous leucaena growth and it is known that the presence of inadequate or ineffective rhizobial strains may limit both biological N fixation and forage yield in many subtropical soils. In the year 2000, farmers from northeast Argentina sought inoculum to establish leucaena, given the absence of effective nodulation due to a lack of specific rhizobia in these soils (A. Perticari unpublished data). Facing this demand, Bryant (2007) evaluated nodulation capacity and leucaena biomass production under controlled conditions of 40 strains stored in the collection of the Institute of Microbiology and Agricultural Zoology (IMYZA-INTA) in comparison with a control strain (CB81, *Bradyrhizobium* sp. introduced from CSIRO, Australia and recommended since the first introductions of leucaena in the 1960s). The 40 strains were collected either from leucaena nodules from other countries or from *Phaseolus vulgaris* nodules. Four strains were preselected for their symbiotic effectiveness (100% of plants nodulated with more than 3 nodules per plant and plants had a dark green color): CB81, C215 (*Bradyrhizobium* sp. from soils cropped with *P. vulgaris* in Salta province, northwest Argentina) plus C191 (*Bradyrhizobium* sp. from the Central University of Venezuela) and CIAT899 (*Rhizobium tropici*, from CIAT, Colombia that had been recommended for inoculation of *P. vulgaris*). The effectiveness study was carried out with cvv. Cunningham and K636 in a growth chamber over 50 days, using 2 control treatments: uninoculated and N-fertilized leucaena plants. Strains CIAT899 and C215 were the most effective in terms of total shoot biomass accumulated and nodule size, while nodule number was highest with strains CB81 and C191. *Rhizobium tropici* (strain CIAT899) showed the fastest growth rate compared with *Bradyrhizobium* spp., known as having slow to moderate growth. The shorter generation time of CIAT899 facilitates the production of inoculum by reducing fermentation time, costs and contamination risks. From this study, 2 new strains, CIAT899 and C215, were recommended for inoculating leucaena in northeast Argentina in preference to the CB81 strain (these 3 strains are currently available in IMYZA-INTA). Strains CIAT899 and C215 continue to be evaluated in field trials showing excellent nodulation and plant growth (A. Perticari unpublished data).

In another study to evaluate the effectiveness of naturalized rhizobia, Eöry et al. (2010) collected soil samples from 28 sites in northeast Argentina (Corrientes, Chaco and Formosa provinces), where leucaena had been growing for up to 50 years since establishment. They found little or no presence of nodulating rhizobia in these soils, though some of the naturalized rhizobia were more effective than the control strain CB81 (Eöry et al. 2010). This collection was added to the IMYZA-INTA collection for future studies. In these regions a high and persistent response to inoculation of leucaena is expected.

By contrast, in northwest Argentina (Salta, Jujuy, Tucumán and Santiago del Estero provinces), rhizobia strains that nodulate leucaena have been detected and the nodules are assumed to be formed by native *Rhizobium etli* or other species of rhizobia associated with cultivated *P. vulgaris* and other native wild beans. According to Martínez-Romero (2009) these species of rhizobia have the ability to nodulate several legumes, particularly *P. vulgaris* and *L. leucocephala*. Nevertheless, even in northwest Argentina, field trials are warranted to ensure that apparently effective strains are competitive in leucaena feeding systems.

Contribution to soil organic carbon and total nitrogen levels

Banegas et al. (2019) determined concentrations and vertical distribution of organic C (OC) and total N (TN) and their fractions (particulate and associate forms) in the profiles (0–100 cm) of a 4-year-old leucaena-grass pasture and an adjacent grass-only pasture at the Animal Research Institute of the Semi-arid Chaco region, INTA, Leales, Tucumán (27º11' S, 65º14' W; 335 masl), in the west of the Chaco region, northwest Argentina. Leucaena introduction increased OC concentration in the subsoil (20–100 cm) by 45%, particularly the stable form (associate OC) in the deepest horizon (50–100 cm). This was attributed to a greater abundance of leucaena roots than of grass roots deeper in the profile. Leucaena also enhanced N concentration by 7.6% (0.13 vs. 0.14%) in the topsoil (0–20 cm) associated with an increment in the labile form (particulate organic N), due to leaf deposition, recycling of animal feces and nodule-N turnover from N fixation. Introduction of leucaena into tropical grass pastures has the potential to improve soil fertility and hence N availability for companion grass growth.

Density effects on competition and facilitation

The effect of leucaena density on forage biomass was studied by Gándara et al. (2019) in a silvopastoral system at INTA Corrientes Research Station. Leucaena hedgerows consisting of twin rows 1 m apart with inter-row spacings of 8, 4 and 2 m (22,222, 40,444 and 66,666 trees/ha, respectively) were planted in October 2016. The companion grass, *Urochloa brizantha* (syn. *Brachiaria brizantha*) cv. Marandú, was sown in October 2017. Tree density was positively and linearly related to total leucaena biomass and inversely related to grass yield ($R^2 = 0.99$). Maximum total biomass was obtained in hedgerows with inter-row spacing of 2 m (leucaena 11 t DM/ha and grass 2.5 t DM/ha) but maximum grass yield was obtained with 8 m inter-row spacing (6.7 t DM/ha). Apart from leucaena density, the decline in grass yield was directly related to the increase in degree of shading with higher leucaena density. Level of shade was estimated from the luminous intensity measured by a ceptometer. Edible leucaena biomass was linearly and directly related to leucaena density ($R^2 = 0.99$) and it was highest with 2 m inter-row spacing (6.2 t DM/ha), but the percentage of edible biomass was not significantly different at the 3 leucaena densities. Substantial changes in forage production arise from diverse leucaena densities, i.e. combinations of single or twin rows and different inter-row spacings, in silvopastoral systems. The low radiation available under high density (2 m inter-row spacing) limits grass growth but moderate density (4 m inter-row spacing, 40,444 plants/ha) allows an efficient combination with grasses that produces an adequate fiber:protein balance in available forage.

Limitations to adoption

In spite of the convincing research results showing that leucaena introduction in tropical pastures or grasslands improves forage and animal production, there has been poor adoption of this forage tree legume on a wide and intensive scale in Argentina. Based on our experience, we identify 8 main reasons for the slow adoption over the last 5 decades:

The contradiction of planting trees on cleared land

Most cropping land in north Argentina, a region dominated by forest vegetation, was developed by clearing trees. Therefore, it is contradictory for farmers to plant trees in a paddock where trees and shrubs have been systematically controlled and removed. Moreover, some farmers have concerns accepting that a pasture formed with trees can be as productive as a cleared pasture, as with a silvopastoral system. Traditionally for a cattle farmer, a pasture is formed by pure grass only and all shrubs and trees have to be cleared.

Rigidity of land uses

Some farmers have issues about the loss of flexibility associated with conversion of land suitable for dryland cropping into long-term leucaena silvopastoral systems (soils suitable for leucaena are generally also suitable for cropping). The expected life of leucaena hedgerows (>30 years) makes it difficult to conduct a rotational management program in which crops and pastures are alternated over time in the same paddock. Moreover, in mixed farming systems, leucaena establishment reduces the possibility of allocating more or less land for crops or animal production, according to the expected net returns of cropping and livestock (a relationship that has been changing frequently in recent years).

Slow establishment of leucaena

The slow early growth of leucaena seedlings makes them vulnerable to ant attacks, weed and grass competition and predatory wildlife, e.g. rabbits. Consequently, leucaena must be planted as a crop using current cropping techniques, e.g. zero-till for sowing leucaena into grass pastures, selective herbicides for weed control and appropriate insecticides for ant control. Further, some cattle farmers have insufficient experience and machinery, e.g. sowing and spraying machines. Moreover, erratic leucaena establishment owing to the unreliable summer rain of the semi-arid Chaco region demands a careful approach to successful establishment.

Leucaena-grass pastures are more expensive to establish than pure grass pastures

The establishment costs of leucaena hedgerows and the companion grass, plus costs of seed scarification, and control of ants, weeds and rabbits is higher (about double that for a pure-grass pasture). Therefore, the higher initial investment in establishing leucaena means the payback period is extended unless returns from leucaena are much higher than from grass only. Alternatively, the lifespan of a leucaena stand must be long to ensure sufficient time for cost recovery to be complete.

Inexperience in managing silvopastoral systems

Livestock farmers are unfamiliar with managing shrubs/trees as forage plants, an uncommon practice among cattle farmers in Argentina. Even farmers from the Pampa region (dominated by grasslands) with experience in establishing and grazing herbaceous legumes in mixed pastures, e.g. clover-grass pastures, have to gain new knowledge to manage hedgerow trees with companion grasses in silvopastoral systems. Although it is known that leucaena plants need time to recover carbohydrate reserves during the regrowth phase before they are grazed again (Stür et al. 1994), some farmers are unaware that successive severe grazings combined with frost damage can seriously affect leucaena survival.

Excessive leucaena height

To ensure stock can access leucaena forage in direct grazing systems, animal pressure should be managed to maintain leucaena hedgerows at up to 2–3 m tall with a dense leafy canopy within the browse height (Dalzell et al. 2006). However, tall-growing leucaena cultivars, e.g. K636 or Tarramba, can easily grow beyond the browse height, making forage inaccessible to stock, even in frost-prone areas where frost can help to control plant height. Consequently, farmers must develop skills to control leucaena height through heavy grazing pressure and/or cutting back plants by trimming machines, e.g. slashers/mulchers, tree pruners or roller-choppers.

Misinformation regarding mimosine toxicity

Farmers in Argentina have a poor understanding and awareness of the occurrence and significance of leucaena toxicity. They are uncertain if their animals are suffering from chronic toxicity since animals may still be performing better in systems with leucaena than in those without it, but rarely use urine tests to diagnose if a problem exists. Research and extension programs to inform farmers of upgraded inoculation protocols and improved management practices are needed urgently (Halliday et al. 2018).

Scarce funding for research and development programs

There have been no well-supported research and extension programs to promote the utilization of tropical legumes in Argentina in recent decades. Nowadays, there is a lack of technical information on leucaena feeding systems in a form accessible to both technicians and farmers. Effective research programs and extension services are urgently needed to improve establishment methods, management practices and grazing systems. Utilizing successful leucaena farmers as 'champions' to promote the practice and demonstrate it on commercial farms seems a promising approach. Greater involvement of experienced and successful leucaena growers in the technology transfer process is essential to improve the future uptake and success of leucaena feeding systems.

Conclusion

Experiments involving forage and animal productivity have shown that leucaena has excellent potential to increase animal production in areas suitable for leucaena in the subtropical region of northern Argentina. However, when leucaena was introduced to fill the winter forage gap, this expectation was not always fulfilled and will be difficult (if not impossible) to achieve in frost-prone areas without new cold-tolerant leucaena varieties. Moreover, to avoid toxicity associated with a high proportion of leucaena in the diet, e.g. 40%, appropriate management practices are needed. Studies to assess the effectiveness of rhizobial strains and soil C and N contributions have revealed the potential of leucaena to fix N and to improve soil fertility and C storage. However, there is still a gap in knowledge about how much N leucaena can fix associated with different rhizobial strains under different environmental conditions and management practices. With regard to competition studies and the effective integration of leucaena and grass, there is still limited information on how to optimize planting layout and management of leucaena, grass and animals in grazing systems. In spite of the convincing research results showing that leucaena introduction in tropical pastures and grasslands can improve forage and animal production, the limited adoption of this technology is a major concern. It has been attributed to a mix of social, economic and agronomic constraints and education and extension programs are needed to address this issue.

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(Note of the editors: All hyperlinks were verified 11 August 2019.)

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