Tropical Grasslands -Forrajes Tropicales

Online Journal

VOL. 12 N. 3

SEPTEMBER 2024

ISSN: 2346-3775

CIAT
International Center for Tropical Agriculture
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Published by:
International Center for
Tropical Agriculture
(CIAT), Cali, Colombia

www.tropicalgrasslands.info

Cover photos:
Above: Napier grass or *Cenchrus purpureus*, by Georgina Smith/CIAT.
Below: *Urochloa humidicola* and livestock, by CIAT.
Back: *Urochloa humidicola* in the Llanos, Colombia, by CIAT.
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doi: 10.17138/TGFT(12)124-141

Review Article

Paspalum lepton - a valuable adjunct to the suite of grasses used in grazing systems in the subtropics or a potential weed

Paspalum lepton - *un complemento valioso para el conjunto de pastos utilizados en sistemas de pastoreo en los subtrópicos o una maleza potencial*

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Abstract

Native and exotic C4 grasses currently used in grazing systems in the subtropics have specific limitations with management, decline in feed quality as they mature and variable adaptation to soils and climates, providing opportunities to identify alternative species to complement or replace them. One option is *Paspalum lepton* (syn. *P. nicorae*), a sward-forming, rhizomatous grass native to subtropical South America with recognized forage value. An early maturing form of this species has become naturalized in Northern New South Wales since its introduction in the 1940s. More recent introductions with forage and amenity potential are being established vegetatively and by seed as it becomes available. This paper reviews published work on *P. lepton* and reports largely unpublished results and observations on its performance in research and development studies in subtropical Eastern Australia. The potential value of and threats posed by *P. lepton* in relation to its adaptation, productivity, competitiveness and role in limiting ingress of existing weedy species are discussed. APG 54281 and APG 54325 are palatable, productive and persistent lines of this grass that have proven to be adapted to livestock production systems in most of the humid lowland subtropics, and to a specific niche in the subtropical uplands of Southeast Queensland where there is a lack of adapted C4 grasses and C3 grasses are only marginally adapted.

Keywords: Adaptation, *Paspalum nicorae, Poaceae*.

Resumen

Las gramíneas C4, nativas y exóticas, que se utilizan actualmente en los sistemas de pastoreo en los subtrópicos tienen limitaciones específicas en cuanto a su manejo, una disminución de la calidad del forraje a medida que maduran y una adaptación variable a los suelos y climas, lo que brinda oportunidades para identificar especies alternativas que las complementen o reemplacen. Una opción es *Paspalum lepton* (sin. *P. nicorae*), una gramínea rizomatosa nativa de América del Sur subtropical con un valor forrajero reconocido. Una forma de maduración temprana de esta especie se ha naturalizado en el norte de Nueva Gales del Sur, luego de su introducción en la década de 1940. Introducciones más recientes, con potencial forrajero y recreativo, se están estableciendo en forma vegetativa o por semilla, a medida que se hacen disponibles. Este artículo revisa el trabajo publicado sobre *P. lepton* e informa resultados y observaciones en gran parte inéditos sobre su desempeño en estudios de investigación y desarrollo en el área subtropical del Este de Australia. En este artículo se discute el valor potencial y las amenazas que plantea *P. lepton* en relación con su adaptación,

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productividad, competitividad y papel en la limitación del ingreso de especies de malezas existentes. APG 54281 y APG 54325 son líneas palatables, productivas y persistentes de esta gramínea que han demostrado estar adaptadas a los sistemas de producción ganadera en la mayoría de tierras bajas de los subtrópicos, y a un nicho específico en las tierras altas subtropicales del sudeste de Queensland, donde hay una falta de gramíneas C4 adaptadas y las gramíneas C3 están adaptadas solo marginalmente.

Palabras clave: Adaptación, *Paspalum nicorae, Poaceae.*

Introduction

Pastoral industries have played an increasingly important role in Australia's economy since British colonization in 1788. However, livestock production has been limited by low productivity and quality of native grasses in most of the natural pasture zones and districts (Burrows et al. 1988). Since the early to mid-1900s, forage and soil conservation research agencies have collected or acquired provenances of higher quality species, primarily grasses and legumes, from tropical, temperate and Mediterranean regions around the world (Smith et al. 2021). Variation within these species has been assessed and accessions showing benefits in animal production potential and adaptation over a range of habitats identified and released to industry as commercial cultivars (Oram 1990). These have been of exceptional economic value to Australia's grazing industries on a wide range of soils and climate in sub-mesic and mesic rainfall zones on about 5% of Australia's grazing lands (EC Wolfe, pers. comm.). This paper draws on research in the subtropical zone of Australia as well as data from similar areas in South and North America. In Australia, the subtropics comprise an area of Eastern coastal and subcoastal land, extending from about 30° S to the Tropic of Capricorn (23.5° S), together with elevated tropical areas in the Mackay and Cairns hinterland that experience similar edaphic and climatic conditions. Geographic and climatic details for evaluation sites in Australia and elsewhere discussed in this paper are listed in Table 1.

Table 1. Evaluation site details.

Site	Latitude	Altitude (masl)	Average annual rainfall (mm)
Australia			
Brisbane, Queensland	27.5° S	30	1,150
Gympie, Queensland	26.1° S	150	1,120
Samford, Queensland	27.4° S	50	1,100
Monduran, Queensland	24.9° S	60	800
Mt Mee, Queensland	27.1° S	460	1,500
Oakey, Queensland	27.4° S	400	685
Stanthorpe, Queensland	28.4° S	805	770
Toowoomba, Queensland	27.6o S	690	960
Rappville, New South Wales	29.1° S	50	1,060
Grafton, New South Wales	29.6° S	10	1,000
Argentina			
Colonia Tatacuá, Corrientes	28.4° S	75	1,270
Brazil			
Bagé, Rio Grande do Sul	31.4° S	210	1,500
Eldorado do Sul, Rio Grande do Sul	30.1° S	110	1,440
Philippines			
Los Baños, Laguna	14.2° N	35	2,100
United States			
Americus, Georgia	32.1° N	145	1,240
Brunswick, Georgia	31.2° N	5	1,140

The humid subtropics of Eastern Australia support various livestock industries, primarily beef and dairy, the latter being dependent on improved pasture to supply the quantity and quality of feed required. Invasive poor-quality grasses such as *Sporobolus* spp. and *Paspalum notatum* Flüggé 'Pensacola' threaten the longevity and productivity of improved pastures. The cooler upland area of Southeast Queensland near the town of Stanthorpe was chosen as an evaluation location owing to a dearth of C4 grasses well-adapted to that area, allied with the need to arrest current ingress of weedy forms of *Eragrostis curvula* (Schrad.) Nees into grazing lands in the area.

Few native grasses with productive value occur in this region of Eastern Australia, and are limited in either their adaptive range, their productivity compared with other exotic species or their susceptibility to uncontrolled grazing by exotic hoofed animals. Those with value include *Bothriochloa bladhii* (Retz.) S. T. Blake, *Dichanthium sericeum* (R. Br.) A. Camus, *Heteropogon contortus* (L.) P. Beauv. and *Themeda triandra* Forssk. Introduced grasses from 14 genera (*Axonopus*, *Bothriochloa*, *Cenchrus* (formerly *Pennisetum*), *Chloris*, *Cynodon*, *Dichanthium*, *Digitaria*, *Eragrostis*, *Megathyrsus, Melinis, Panicum, Paspalum, Setaria* and *Urochloa* (formerly *Brachiaria*) are naturalized or have been commercialized (Cook et al. 2020). They now form an important component of grass-legume and intensive, nitrogen-fertilized grass grazing systems in the humid, sub-humid and semi-arid subtropics of Eastern Australia.

Selection criteria for introduced subtropical grasses include ease of establishment; high yields of quality, palatable forage with no or minor anti-production qualities; long growing season; moderate frost tolerance; relative freedom from pests and disease; commercially viable seed production capacity; and minimal threat to the natural environment.

Nevertheless, introduced species also have shortcomings. Some such as *Chloris gayana* Kunth and *Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs are intolerant of uncontrolled grazing. Many, including *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone (Cook and Mulder 1984a), are strongly nitrophilous requiring high levels of nitrogen for persistence and production. Some are susceptible to plant-debilitating disease, with *C. clandestinus* susceptible to 'yellows' disease (Wong and Wilson 1983) and *Digitaria eriantha* Steud. 'Pangola' to rust and virus (Cook et al. 2020). Others accumulate toxic or sub-toxic levels of anti-production compounds, such as oxalate in *Setaria sphacelata* (Schumach.) Stapf & C. E. Hubb. 'Kazungula' and 'Splenda' and *C. clandestinus* (Jones and Ford 1972; Bourke 2007) and cyanide in *Cynodon aethiopicus* Clayton & J.R. Harlan. The strengths and weaknesses of introduced grasses with potential in subtropical Australia are described by Oram (1990) and Cook et al. (2020).

Research studies identified *Paspalum lepton* Schult. as a grass with potential to address many of the shortcomings of native and introduced pasture grasses. Other *Paspalum* introductions have been successfully used in grazing industries in humid and sub-humid areas in the subtropics of Australia, most notably ecotypes of *P. dilatatum* Poir., *P. notatum* and *P. plicatulum* Michx. Two ecotypes of *P. lepton* identified as having value in soil conservation by the USDA Natural Resources Conservation Service were 'Amcorae' (=APG 54281) in 1969, but not released for commercial use, and 'Doncorae' (=APG 54461), which was released in 1993 (Belt and Englert 2008). Neither is currently available commercially (NRCS 2022). 'Amcorae' was discontinued owing to its perceived invasiveness, and 'Doncorae' owing to discontinued seed production. Two cultivars have been commercialized in Eastern Australia, 'Blue Dawn' (Progressive Seeds Pty Ltd 1998) and 'Blue Eve' (Enviroseeds Pty Ltd 1999), both derived from the American 'Amcorae' (Table 2) and used primarily for recreational groundcover. Most of the studies carried out in Australia have been conducted using 2 early introductions of *P. lepton*. APG 54281 from Argentina was initially selected in nursery and grazed plot observations based on palatability, persistence under grazing and its additional potential use as ground cover. APG 54325 from Brazil was chosen on the strength of its productivity, broad palatable leaves and seed production.

This paper reviews strengths and weaknesses of *P. lepton*, focusing on its potential as forage in subtropical Australia, while acknowledging and addressing its potential weediness (Blount et al. 2022). It reports on Australian studies evaluating accessions of *P. lepton* from the Australian Pastures Genebank (APG) to clarify the adaptation, value and potential role of the species in the location specified, focusing especially on the potential benefits and threats.

Taxonomy and Morphology

The morphology of *P. lepton* is described by Cook et al. (2020). This informal Plicatula group species was classified as *P. nicorae* Parodi until a revision by Oliveira and Valls (2008), who assigned it *P. lepton*, based on *Paspalus leptos*, the name given by Josef August Schultes in 1824. It is taxonomically very closely related to *P. plicatulum* (an earlier synonym being *P. plicatulum* var. *arenarium* Arechav.), yet few ecotypes share the characteristics commonly associated with that species (Cook et al. 2020). *P. lepton* commonly has a non-stoloniferous, deeply rhizomatous, sward-forming growth habit and is thus readily distinguished from the caespitose *P. plicatulum*. Leaf color of *P. lepton* varies between greenish yellow, green and greyish green (Reis et al. 2010). Ecotypes reported in our more detailed studies have the greyish-green foliage that has given rise to the Brazilian common name, grama cinzenta (grey grass). An alternative common name used in the USA is Brunswick grass (or brunswickgrass), named for the city of Brunswick on the Southeast coast of Georgia, USA, where *P. lepton* has become naturalized. Splits of this type were forwarded to the Americus Plant Materials Center (APMC), Georgia, in March 1945, where seed was produced and catalogued as SC 20-672 (Hanson 1972).

Reis et al. (2010) compared the morphology of 53 accessions of *P. lepton* from Rio Grande do Sul, Brazil. They noted a high level of morphological variation among the accessions that was not related to their geographical location, and that "this richness of variation represents an extremely valuable source to select better accessions to be used as forage plants".

Origin and Introduction into Australia

P. lepton is native to South America, with a distribution extending from about 16° S in Bolivia to about 35° S in Argentina and Uruguay. It is widely distributed in Brazil (States of Mato Grosso do Sul, Paraná, Rio Grande do Sul, and Santa Catarina), Argentina (Buenos Aires, Chaco, Córdoba (Figure 1), Corrientes, Entre Ríos, Formosa, and Santa Fe), Paraguay (Central, Concepción, Cordillera, Guaira, Itapúa and San Pedro), Uruguay (Canelones) and Bolivia (Santa Cruz) (GRIN 2024; Tropicos 2024a; 2024b).

P. lepton was first introduced to Australia from the USA by a farmer in the late 1940s (B Clarke, pers. comm.) and established in the Rappville district of Northern New South Wales (NSW) (Table 1), where it is now naturalized. Since SC 20-672 was the only accession of *P. lepton* held in the American collection until 1963 (Anon. 1993), it is reasonable to assume that the Rappville ecotype, now conserved in the Australian collection as APG 54488 (Figure 2), is derived from that original Brunswick (USA) accession.

The 44 accessions of *P. lepton* now held in APG have been introduced from Brazil, Argentina, Uruguay and the APMC. They are listed in Table 2 with Australian APG and CPI/ATF accession number together with American PI equivalent where available.

For consistency, APG accession numbers are used throughout the paper to refer to specific ecotypes of the species. Collection details (passport data) for each accession can be sourced at Australian Pastures Genebank (APG, bit.ly/4elcX1y) and Genesys (bit.ly/3BrQ0Ld).

Figure 1. B.G. Cook collecting *P. lepton* APG 54481, W of Tanti, Córdoba, Argentina (1,120 masl, 720 mm AAR). Photograph: B.C. Pengelly.

Figure 2. *P. lepton* APG 54281 (left) and rapidly maturing APG 54488 (right) 6 November 1991. Photograph: B.G. Cook.

Table 2. Accessions of *Paspalum lepton* currently held in Australia and the USA.

APG	CPI/ATF	PI	Origin	APG	CPI/ATF	PI	Origin
	ATF1016	404857	URY	54455	ATF1021	337562	ARG
	ATF1023	331129	URY	54456	ATF1022	337014	BRA
54281	21370	202044[2]	ARG	54457	ATF1024	310135	BRA
54291	21382	209983	ARG	54458	ATF1025	310134	BRA
54306	27657		BRA	54459	ATF1026	310133	BRA
54307	27660		URY	54460	ATF1027	310132	BRA
54320[1]	27693		BRA	54461	ATF1028	310131[3]	BRA
54325	27707		BRA	54462	ATF1029	310130	BRA
54347	37526		URY	54463	ATF1030	310129	BRA
54442	ATF1007	508821	ARG	54464	ATF1031	310128	BRA
54443	ATF1008	508820	ARG	54465	ATF1032	310061	BRA
54444	ATF1009	508819	ARG	54466	ATF1033	304004	BRA
54445	ATF1010	508818	ARG	54467	ATF1034	304003	BRA
54446	ATF1011	490364	USA	54468	ATF1035	284171	AUS
54447	ATF1012	490363	USA	54469	ATF1036	283020	URY
54448	ATF1013	404860	URY	54470	ATF1037	276249	URY
54449	ATF1014	404859	URY	54471	ATF1038	276248	URY
54450	ATF1015	404858	URY	54472	ATF1039	209983	ARG
54451	ATF1017	404471	BRA	54473	ATF1040	202044[2]	ARG
54452	ATF1018	404470	BRA	54481	ATF3124		ARG
54453	ATF1019	404469	BRA	54488	CQ3639		AUS
54454	ATF1020	337563	ARG	54839	CPI 39970		BRA

[1]Re-identification necessary; possibly *P. plicatulum*; [2]'Amcorae', 'Blue Dawn'; [3]'Doncorae', CPI 125877

Adaptation

Soils

While *P. lepton* is found mostly on sandy soils in its native habitat (Nabinger and Dall´Agnol 2019), in Australia it has been found to be adapted to a wide range of friable soils with varying texture and pH ranging from acidic to slightly alkaline (Cook et al. 2020). It has proven poorly adapted to compacted soils and soils with a hard-setting surface in observations on red-brown earth at Oakey, Qld (WJ Scattini, pers. comm). APG 54488 has colonized a large area of low fertility, sandy, sandstone-derived soils of pH 4.5–5 in Northern NSW, where native grasses, including *Imperata cylindrica* (L.) Raeusch., are of poor quality. McCaskill et al. (2019) assessed phosphorus response of a range of 18 grasses and legumes, including APG 54281, and found that most species growing in low soil P environments (Olsen et al. 1954) also had critically low P concentrations in dry matter for livestock production. APG 54281 was 1 of 2 exceptions, having among the highest P concentrations in the dry matter (0.26% P) when grown at the critically low soil P level of 6.6 ppm.

Nursery studies incorporating *P. lepton* were commenced in Queensland in the 1970s at Mt Mee north of Brisbane and at Toowoomba on the Darling Downs (Table 1). Promising accessions were evaluated at regional on-farm sites on the eastern and southern Downs of Southeast Queensland commencing in 1983. APG 54281 proved well adapted to friable, acid sandy soils formed on granite in the Stanthorpe district and to the deep, friable, basalt-based, acid red loams of Mt Mee and the Toowoomba plateau. It also grew well at Monduran on a fertile, brown, non-cracking clay, spreading into native vegetation, predominantly *H. contortus* (BG Cook, observation), and on a dark cracking clay soil at Los Baños in the Philippines in a tropical environment (WW Stür, unpublished). However, APG 54281 failed to persist when sown on a hard-setting, compacted red earth on a grassed airfield runway at Oakey west of Toowoomba, and when sown in a mixture with turf grasses on a compacted recreational football field in Brisbane, Queensland (WJ Scattini, MJ Conway and B Johnson, unpublished). Additionally, a number of accessions have grown well and persisted on a yellow podzolic-soloth soil with a Dy of 5.41 (Northcote 1979) and pH 5.6, on red podzolic soils and on a neutral dark sandy clay loam river alluvium in the Gympie district (BG Cook, unpublished). The studies in the Toowoomba and Gympie districts were complemented by more detailed studies reported later in this paper.

While well drained sandy clay loam soils are considered ideal for *P. lepton* (Anon. 1993), APG 54839 was both persistent and productive on a poorly drained sandy loam meadow podzolic soil at Samford in SE Queensland (Strickland 1978).

Climate

Average annual rainfall at collection sites for *P. lepton* accessions held in APG ranges from 700–820 mm (Córdoba, Argentina) to 1,300–1,900 mm (Rio Grande do Sul, Brazil). P. lepton has persisted well in subtropical Australia where average annual rainfall ranges from 800–1,500 mm. Winter frost frequency at the various subtropical sites varies from 0–10/yr (Gympie, Mt Mee) to 70/yr (Stanthorpe). Frosts are experienced from May to September at Gympie (average of 5.5 in July) and April to October (20 in July) at Stanthorpe. *P. lepton* has been observed to be at least as frost tolerant as the more frost tolerant subtropical C4 grasses, *C. clandestinus* and *S. sphacelata* 'Narok'. Observations indicate that foliage of *P. lepton* is largely unaffected by moderate frost but suffers "leaf burn" by severe frost (defined as occurring at -2 °C) as experienced at Stanthorpe. Affected plants regrow readily from rhizomes with the onset of warmer, seasonal weather. A number of accessions of *P. lepton* from APG exhibit a significant degree of shade tolerance, growing well in light to moderate shade as found under open eucalypt forests.

Persistence

P. lepton is a resilient species when exposed to varying grazing and fertilizer management. When established in areas of suitable soils and climate, it has persisted for at least 20 years, and up to 50 years (limit of observation), even with little or no further management following establishment.

However, for over 30 years, a condition known as "pasture dieback" has spread, afflicting grasses, initially most obviously *Cenchrus ciliaris* L. in Central Queensland. This is now being experienced widely in stands of introduced and native grasses, extending from North Queensland to Northern New South Wales (Buck 2017). Stand decline in several hectares of *P. lepton* APG 54325 near Gympie may be attributable to 'dieback' syndrome. The causal agent of pasture dieback has not yet been identified with confidence, although the paspalum mealybug, *Heliococcus summervillei* Brookes (Pseudococcidae), or a close relative, has been associated with 'dieback' in many stands investigated. This minute sucking insect was thought to be the cause of pasture grass dieback in Southern Queensland in the 1920s in *P. dilatatum*, which was then being increasingly used in pasture improvement. Despite this, long-term persistence of *P. lepton* seems unlikely to be under threat since some affected stands are showing signs of recovery.

Phenology and seed production

When managed effectively, most accessions of *P. lepton* flower profusely and set large amounts of seed. Burson and Bennett (1970) determined that *P. lepton* was an obligate apomict, reproducing by apospory and pseudogamy, although nursery observation at Gympie suggests some outcrossing does occur. Seed collected from a nursery row of APG 54281 growing adjacent to a row of morphologically distinct APG 54320 produced plants that were morphologically different from the maternal parent. Seed proteins from the progeny plants that were compared with those of APG 54281 using sodium dodecyl sulfate-polyacrylamide gel electrophoretic analysis, exhibited major band characteristics more akin to APG 54320 than to APG 54281 (AM Vieritz, unpublished). This suggested that the progeny resulted from fertilization rather than apomixis, supported by Nabinger and Dall´Agnol (2019), who noted that *P. lepton* had been the subject of selection and evaluation, and used in interspecific crosses in the forage improvement program at the Federal University of Rio Grande do Sul.

P. lepton accessions studied in Queensland exhibit a long day photoperiodic flowering response (Figures 3A, 3B) similar to other C4 grasses from higher latitudes (Loch et al. 1999), including *P. dilatatum* and *P. notatum* 'Argentine' and 'Pensacola'. Dates of initial flowering in the study at Samford (Hacker et al. 1999), which ranged from 15 December for APG 54281 to 3 February for APG 54291, were not consistent with flowering time at other sites in the same geographical region. This suggests that like *P. dilatatum*, 'Argentine' and 'Pensacola', *P. lepton* exhibits a qualitative rather than quantitative long day photoperiodic flowering response. The fact that APG 54281 failed to flower at 14.6° N in the Philippines (WW Sturr, pers. comm.) accords with this observation. While harvest date varies widely with time of flowering, it is also subject to environmental conditions and to the management of the seed crop. At Gympie, management comprised maintaining the *P. lepton* sward in a low leafy (ca. 10 cm high) condition to maximize tiller numbers prior to first flowers emerging. At that stage the area was mown to a height of about 4 cm and fertilized with a complete fertilizer including 100 kg N/ha. Under this management, a seed crop started in December–January was ready for harvest in February–March (Cook et al. 2020). Starting the crop prematurely can lead to excessive vegetative growth and lodging of the crop. A second but lower yielding crop in April or early May is achievable with the same procedure if management has created an early harvest. Unlike *P. plicatulum* where ripe seed shatters, *P. lepton* retains the seed in head at maturity, enabling high levels of seed recovery.

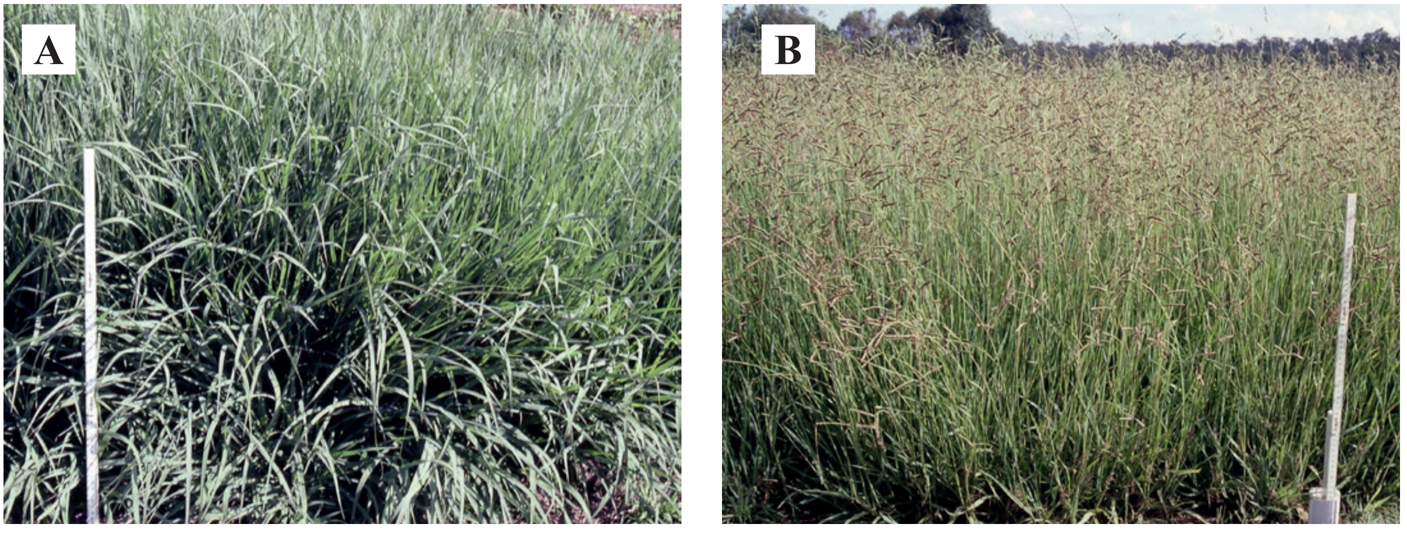

Figure 3. **(A)** N fertilized APG 54325 with 60 cm measure 16 November 1992 (late spring, vegetative). Photograph: B.G. Cook; **(B)** Same plot as in 3a, 20 January 1993 (mid-summer, heavily in seed).

The ergot fungus, *Claviceps paspali* (Sordariomycetes, Ascomycota), infects the ovary in susceptible ecotypes of a number of *Paspalum* species, including *P. lepton*, forming a fungal sclerotium in place of the caryopsis in the spikelet. Seed production of susceptible genotypes is accordingly much reduced. A suite of 34 accessions of *P. lepton* of diverse origins (Table 2) was imported into Australia from the APMC in 1993 and grown in unreplicated nursery microplots to gauge variability within the species. Entries varied considerably in vigor, growth habit, rhizome development, leaf color, leaf width and hairiness, fertile tiller density and susceptibility to ergot, the incidence varying from disease-free to severely infected (BG Cook, observation). The disease has not been recorded in any of the earlier Australian introductions (APG 54281–54347, 54488, 54839), which include the 2 most promising ecotypes.

Seed yields of 4 elite accessions (APG 54281, 54457, 54461 and 54466) at APMC (USDA SCS, unpublished, 1978) averaged 204, 178, 241 and 174 kg seed/ha respectively. An early seed crop of APG 54281 at Grafton (GPM Wilson, unpublished) yielded 350 kg seed/ha in January 1972, and a further 90 kg seed/ha from a follow-up harvest in April the same year. However, small-plot seed crops of APG 54307, 54461 and 54325 at Gympie gave single seed harvest yields equivalent to 689, 1,034 and 1,178 kg seed/ha respectively in late January–early February 1992 (BG Cook, unpublished). After harvest, seed must be dried to a moisture level of 10% (Loch and de Souza 1999) and stored in a low-humidity environment to maintain quality. As with its relatives in the Plicatula group, *P. atratum* and *P. plicatulum*, dried seeds of *P. lepton* rapidly absorb moisture from the atmosphere with a consequent reduction in germinability (JM Hopkinson, pers. comm.).

Forage and Soil Conservation Value

Dry matter production

The sound yielding ability and responsiveness to nitrogen fertilizer of *P. lepton* have been demonstrated in its native environments as well as in the USA and Australia. Pereira et al. (2011) compared performance of 53 accessions of *P. lepton* with that of 'Pensacola' and other grasses at 2 contrasting sites in Rio Grande do Sul, Brazil. Most accessions of *P. lepton* were more productive than 'Pensacola', the 2 most productive achieving 2 to 4 times the amount of dry matter and leaf compared with 'Pensacola' at both sites. In a study at Americus, Georgia, USA, Beaty et al. (1970) measured the responsiveness of an unidentified accession of *P. lepton* to nitrogen fertilizer at 0, 112, 224 and 336 kg N/ha, when cut at 3 mm at 1, 2, 3, 4, 5 and 6-week intervals. Annual DM yields of 4.2, 7.4, 9.2 and 10.6 t DM/ha were measured with the application of 0, 112, 224 and 336 kg N/ha respectively. Harvest frequency had less effect on yield than nitrogen treatment, with annual yields of about 7.0 t DM/ha at 1 and 2-week frequencies to 8.7 t DM/ha when cut at 8-week frequency. In another study at the same site, DM production and N response of *P. lepton* APG 54281 was compared with that of 8 Brazilian accessions (USDA SCS Report 1970). Plots were fertilized with 0, 56, 112 and 224 kg N/ha and cut at 5 cm every 4 weeks after the first cut. Average DM yield across accessions increased almost linearly between 0 and 224 kg N/ha, at a rate of about 48 kg DM/ha for each additional kilogram of nitrogen. Highest annual yields at 224 kg N/ha ranged from 14 to 14.5 t DM/ha from APG 54459, APG 54461 and APG 54464, compared with 12.2 t DM/ha for APG 54281 and 10.8 t DM/ha for APG 54458, the lowest yielding accession.

In an experiment at Samford in Southeast Queensland, Strickland (1978) found that seasonal DM productivity of *P. lepton* APG 54839 measured over 2 years compared well with or exceeded that of 14 other warm season grasses, including *C. clandestinus*, Pangola and *S. sphacelata* APG 55726. Grasses received a standard basal and annual maintenance fertilizer application and were harvested at a height of 5 cm every 30 or 60 days. Nitrogen fertilizer was applied in split applications totaling 476 kg N/ha after every 60-day harvest. Frosts were experienced both years. APG 54839 ranked first for both mean annual and cool season growth over 2 years with 27.9 and 4.5 t DM/ha respectively, significantly better than 18.2 and 1.8 t DM/ha from Pangola. In another study at Samford in 1981, yields of 133 *Paspalum* accessions from several species, including 8 accessions of *P. lepton* (Hacker et al. 1999) were rated on a 1–10 basis at the end of the season. APG 54306 (8 rating) and APG 54325 (7 rating) were the highest yielding *P. lepton* accessions and were among the highest yielding of all species tested.

Following the early nursery sowings in Southeast Queensland and Northern NSW that demonstrated the productive potential and apparent palatability of a number of lines of *P. lepton* on friable soils, more detailed evaluation was carried out at Stanthorpe and Gympie to confirm its productive ability, determine its compatibility with adapted legumes, assess its persistence and spread, and assess its ability to suppress endemic weeds.

The initial study was carried out in 1987–1991 (DL Lloyd, unpublished) near Stanthorpe on the 'granite belt' of upland Southeast Queensland (annual average maximum temperature 21.8 °C, annual average minimum temperature 8.9 °C, average of about 70 frosts/yr). Productivity and persistence of APG 54281 (rhizomatous) and its compatibility with legumes, were compared with 4 other C4 grasses, *P. notatum* 'Competidor' (rhizomatous), *D. eriantha* 'Premier' (caespitose), *C. gayana* 'Katambora' (stoloniferous), *P. dilatatum* 'Common' (shortly rhizomatous), and *C. clandestinus* 'Noonan' (rhizomatous, stoloniferous). The experiment was sown in a replicated, split plot array in which dry matter production and persistence of the grasses were compared with and without the addition of N fertilizer in mixtures with *Trifolium subterraneum* L. subsp. *subterraneum* 'Seaton Park' (annual) or *T. repens* L. 'Haifa' (perennial), all sown at commercial rates. Grasses were sown from seed in December 1987 and legumes oversown in July 1988. Plots were defoliated by grazing in early spring (August) before making the first DM production harvests in December 1988. Grass persistence and ground cover were measured in January each year as % frequency in 10 × 10 cm grids within 1 m^2 quadrats. Nitrogen as ammonium nitrate was applied at 100 kg N/ha/yr in 2 split dressings, the first before growth commenced in late spring and again after the first harvest. Grass harvests were made at approximately 2 monthly intervals during the summer season and all plots were fully defoliated and the forage removed using a self-propelled mower after each harvest. Legume harvests were made during the winter and spring months at times determined by growth. A basal application of 200 kg superphosphate/ha was made at planting and again in June 1989.

'Katambora', 'Common' and 'Noonan' were not well adapted and performed poorly. Data for the first 3 only are presented in Table 3 and 4.

Table 3. Dry matter (DM) production (kg/ha) of *P. lepton* APG 54281, *D. eriantha* 'Premier' and *P. notatum* 'Competidor'.

Treatments	Total DM Production (kg/ha)								
	1988/89			1989/90			1990/91		
	Grass	Weed	Legume	Grass	Weed	Legume	Grass	Weed	Legume
Control									
APG 54281	1,554	1,166		2,908	934		2,139	208	
'Premier'	1,692	1,220		3,126	1,290		1,846	362	
'Competidor'	218	1,916		2,570	1,552		3,023	164	
+ 100 kg N/ha									
APG 54281	3,908	1,722		10,166	326		5,519	108	
'Premier'	3,802	1352		6,552	1856		4,993	198	
'Competidor'	628	4,520		4,766	2,604		4,740	216	
+ *T. subterraneum*									
APG 54281	1,600	868	465	3,553	715	273	2,455	19	839
'Premier'	1,539	616	490	2,023	1,313	565	1,939	345	2,428
'Competidor'	182	1,468	622	2,133	1,747	106	2,629	408	1,053
+ *T. repens*									
APG 54281	1,778	1,130	216	3,131	876	547	2,963	40	358
'Premier'	2,094	1,066	256	2,046	1,755	1,219	3,101	923	1,127
'Competidor'	272	1,488	368	1,840	1,353	893	2,464	344	388

Table 4. Changes in groundcover (% frequency) of *P. lepton* APG 54281, *D. eriantha* 'Premier' and *P. notatum* 'Competidor'.

Treatments	Grass Ground Cover			
	% Frequency (January)			
	1989	1990	1991	1992
Control				
APG 54281	73	85	96	93
'Premier'	74	63	79	81
'Competidor'	35	55	78	92
+ 100 kg/ha N				
APG 54281	73	98	100	100
'Premier'	79	76	87	90
'Competidor'	20	30	87	98
+ *T. subterraneum*				
APG 54281	66	95	100	100
'Premier'	72	68	78	80
'Competidor'	23	47	74	90
+ *T. repens*				
APG 54281	59	93	100	100
'Premier'	69	54	80	80
'Competidor'	23	42	72	89

Over the 3-year period, the total DM production of APG 54281 increased from 6,600 kg DM/ha in the control to 19,600 kg DM/ha in the 100 kg N/ha treatment, compared with 5,900 kg DM/ha to 10,100 kg DM/ha for 'Competidor' and 5,700 kg DM/ha to 15,300 kg DM/ha for 'Premier'. Relatively high levels of production were sustained into the third year by these better adapted grasses, even without N fertilizer. Notably, production of APG 54281 and 'Premier' was high in each year, but production of 'Competidor' was lower in the establishment year, reflecting its low growth rate from seedling to maturity. These 3 grasses consistently produced more DM than the other 3 in the study. 'Noonan', 'Katambora' and *P. dilatatum* produced total 3-year DM production of 1,300, 3,700, and 3,600 kg DM/ha respectively when fertilized with N or sown with legumes (data not shown).

DM production of APG 54281 was unaffected by competition from both legumes when unfertilized. The legumes persisted and increased production with time in a grass stand whose density increased with age (Table 3, Table 4). Total 'Seaton Park' DM production when associated with APG 54281 was 1,600 kg DM/ha, with 'Competidor' 1,800 kg DM/ha, and with 'Premier' 3,500 kg DM/ha, reflecting the competitive effect of the almost complete groundcover produced by the sward-forming *Paspalum* grasses compared with the more open stand of the caespitose 'Premier' (Table 3). 'Seaton Park' production associated with 'Katambora' with a ground cover of only 8% after its establishment year was 5,700 kg DM/ha. However, production of 'Seaton Park' growing with APG 54281 increased from 470 to 830 kg DM/ha from the first to the third year, indicating that while legume DM production was suppressed, it remained productive at a low level as the grass ground cover increased (Table 4). Summarizing, both rhizomatous grasses suppressed the associated legume (total production 1,470 and 1,570 kg DM/ha respectively), more than the 'Premier' (3,490 kg DM/ha), but all yields were lower than 'Seaton Park' grown without significant sown grass competition (6,400 kg DM/ha). Associated grass production of 7,600, 4,900 and 5,500 kg DM/ha respectively was much lower than when fertilized with 100 kg N/ha, and similar to the 6,600, 5,900 and 5,700 kg DM/ha respectively when the grasses were not fertilized with N. The legumes nevertheless provided useful protein for grazing livestock.

Grass DM production trends were similar when the grasses were sown with the perennial legume 'Haifa'. However, DM production of the 'Haifa' component was lower with 'Haifa' than with the annual 'Seaton Park', possibly because of the greater overlap in the production rhythm of *T. repens* with that of the grasses. 'Haifa' produced 7,800 kg DM/ha associated with the poorly adapted 'Katambora'.

Ground cover data, expressed as frequency, show that APG 54281 established well in the first year, but 'Competidor' was slow to develop, its frequency increasing to be equivalent of APG 54281 only after 3 years (Table 4). The cutting management in this study enabled the associated legume to persist and achieve a low level of production. Observation elsewhere suggests that astute grazing management is necessary to enable legumes to produce significant dry matter when grown with APG 54281 and 'Competidor'. Further research involving cutting frequency and/or grazing pressure would be required to test this.

APG 54281 at the same time suppressed the weed component (Table 3), mainly *Eragrostis* sp. and *Sporobolus* sp., particularly in the 2 years following establishment. The ability of *P. lepton* to suppress these weeds to a generally greater extent than that of other well adapted grasses could have strong practical consequences in the Stanthorpe district, if seed of the grass became commercially available. In this area, and more widely, *Eragrostis curvula* has become a serious weed of pastures. It has little nutritive value except in its youngest stage of growth. It sets large quantities of seed that is wind-borne, and therefore has spread rapidly, mainly on sandy and loamy surfaced soils across Southeast Queensland and Northern New South Wales (Csurhes et al. 2016).

In a separate study (DL Lloyd, unpublished) at the same site carried out in the summer of 1992–1993, in the first year after establishment, the productivity of 5 lines of *P. lepton* was compared without fertilizer application. The DM production of the promising, palatable lines, APG 54325 and APG 54281, was 4,400 and 3,900 kg DM/ha respectively. Both may well have a role in combatting the invasion of *E. curvula*.

Beaty et al. (1970) working at Americus, Georgia, endorsed the potential forage value of *P. lepton*, adding that, by virtue of its stability of cover under frequent defoliation and dense tillering, it also had potential to be used in soil erosion control.

Palatability

There are differences of opinion regarding the palatability of *P. lepton*. Barreto (1956) considered it to be a grass with forage potential, noting among other things that it "appears to be very palatable to animals". Observation at the APMC in Georgia, USA supports this view, indicating that *P. lepton* APG 54281 was more productive and more palatable than 'Pensacola' (data unpublished). Palatability of the 8 *P. lepton* accessions in the Samford *Paspalum* evaluation (Hacker et al. 1999) was rated once seed had been harvested at completion. Ratings for the *P. lepton* accessions ranged from 2–8 (mean 4.7 on a 1–10 scale, with 10 the most palatable). The most palatable accessions in an assessment in early winter, when plants were mature and less attractive to stock, were APG 54306, APG 54839 (8 rating) and APG 54281 (6 rating). Least palatable was APG 54291 (2 rating). Only one of the 133 *Paspalum* accessions in the experiment, a *P. plicatulum*, received a rating of 10.

However, in studies in Florida, USA, 2 ecotypes of *P. lepton* have been classified with poor palatability, 1 with dark blue-green leaves, the other with lighter green-yellow leaves (A. Blount, pers. comm.). These are eaten when young, but mature quickly and are avoided by cattle, thereafter outcompeting all relatively more palatable associated grasses. Accordingly, *P. lepton* is now considered a serious weed in perennial grass pastures and 'Pensacola' seed production areas in Florida, Alabama and Georgia (Blount et al. 2022).

In Australia, concerns regarding the palatability and weediness of a mature stand of *P. lepton* APG 54281 led to the termination of *P. lepton* evaluation at Grafton Agricultural Research Station in the early 1970s (GPM Wilson, unpublished). Concerns have also been expressed about the narrow-leafed, low growing and rapidly maturing *P. lepton* 'Rappville ecotype', APG 54488. The authors' observations of APG 54488 in farm pastures in association with native *Digitaria didactyla* Willd., *I. cylindrica* and naturalized *Axonopus fissifolius* (Raddi) Kuhlm., are that it is moderately well grazed when young, becoming fibrous and much less palatable for grazing livestock as it matures. It is less palatable than lines of *P. lepton* and other species, considered more suitable for grazing. For example, APG 54281, which has persisted under regular farm grazing in a number of abandoned species evaluation sites, is always grazed low, and preferentially to invading 'Pensacola', now widely naturalized in the Australian subtropics.

In a study near Gympie, *P. lepton* APG 54281, APG 54307, APG 54325, APG 54461 and APG 54839 were sown in November 1998 into plots on a sandy, clay-loam river alluvium previously dominated by naturalized 'Pensacola'. Once a complete cover was obtained, the area was opened to grazing by cattle. All *P. lepton* plots were equally well-grazed (BG Cook, observation). Further, the *P. lepton* spread through associated grasses, predominantly 'Pensacola', with all *P. lepton* lines being grazed in preference to 'Pensacola'.

In summary, the reputation of *P. lepton* as an unpalatable grass has not been sustained among the more recently introduced accessions of the species, providing they are subjected to regular defoliation.

Nutritive value

Barreto (1956) commented favorably not only on the palatability of *P. lepton* but also on the observation that "pastures where this species predominates support good stocking rates and stock fatten well", suggesting that the grass has sound productivity and quality characteristics. In a field experiment conducted in *P. lepton* grassland in Corrientes Province, Argentina, Bernardis et al. (2001) assessed macro and microelements chemical composition and in vitro organic matter digestibility (IVOMD) of the grass cut at 4 (±2) cm above ground at 4 and 8-week intervals. Cutting frequency did not significantly affect crude protein levels, which were consistently around 7%, but other nutrients were differentially affected. Levels of P, K, Ca, Cu and Zn in the dry matter of *P. lepton* were generally marginal to adequate to satisfy nutritional requirements of growing cattle, but Na levels were low. IVOMD was 74 ±11% and 64 ±15% at 4 and 8 weeks respectively.

Nutritive value of *P. lepton* was assessed by sampling 6-week regrowth of APG 54281 and APG 54325 at Gympie (October 1992, February 1993, November 1993) and Stanthorpe (November 1992, January 1993, February 1993) and submitting the dried material for analysis (Tables 5 and 6). Soluble and total levels of oxalate were determined from bulked samples from the 3 harvests at Gympie (Table 4). Comparable analyses for the subtropical grasses *C. clandestinus*, *C. gayana* and *S. sphacelata* are presented in Feedipedia (Heuzé and Tran 2024), nodes 398, 480 and 381 respectively, and Cook and Mulder (1984b). Pereira et al. (2011) observed a similarity between crude protein levels for *P. lepton* and those measured in other grasses in the experiment, including 'Pensacola', *Paspalum guenoarum* Arechav. and *Chloris uliginosa* Hack. (syn. *Eustachys uliginosa* (Hack.) Herter).

Mineral nutrient levels in the dry matter produced about 6 weeks after the prior harvest were similar at the Gympie and Stanthorpe sites, and for the 2 accessions tested. These values do not express seasonal differences, nor do they identify differences occurring at different growth stages. For example, N % in grass harvested in January was considerably lower than from those in the earlier or later samplings (data not shown) for both accessions at both sites. This may have been attributable to plant growth towards seeding during that period. However, in dairy production systems, a *P. lepton* sward without legume, used as a sole forage would not sustain dairy production (Fulkerson 2007) (Table 5) without N, P and Na supplementation. C4 grasses in general do not have the nutritive value to support high level dairy production without supplementation, except for very short periods in their early regrowth (Milford 1960; Crush and Rowarth 2007). Mineral levels measured in both *P. lepton* accessions were adequate to support growth of beef cattle.

Table 5. Mean percentage from 3 harvests of nutrient in the dry matter of 6-week regrowth of 2 accessions of *Paspalum lepton* grown in 2 locations in Queensland, Australia, and critical values required (Fulkerson 2007) to sustain dairy and beef production.

Accession	N	P	K	Ca	Mg	Na	S	Cl
APG 54281								
Gympie	1.61	0.16	1.64	0.56	0.26	<0.05	0.16	0.97
Stanthorpe	1.71	0.20	1.75	0.51	0.17	<0.05	0.16	1.04
APG 54325								
Gympie	1.56	0.17	1.62	0.51	032	<0.05	0.15	0.99
Stanthorpe	1.63	0.20	1.66	0.58	0.24	<0.05	0.14	1.04
Critical level								
Dairy cattle	2.4	0.33	0.9	0.51	0.2	0.18	0.2	
Beef cattle[1]		0.2–0.3	0.6–0.7	0.45–0.56	0.1–0.2	0–05–0.1		

[1]University of Georgia Extension (2017)

Table 6. In vitro dry matter digestibility (IVDMD), fiber (ADF, NDF) and oxalate determinations on 6-week regrowth samples of 2 accessions of *Paspalum lepton* grown at Gympie, Queensland, Australia.

Accession	Date sampled	IVDMD (%)	ADF (%)	NDF (%)	Oxalate %	
					Total	Soluble
APG 54281	13.10.92	60.2	40.0	70.3	<0.01	<0.01
	16.2.93	56.5	41.3	69.6		
	11.5.93	64.4	35.1	61.7		
APG 54325	13.10.92	62.3	41.2	67.3	<0.01	<0.01
	16.2.93	54.0	39.0	69.7		
	11.5.93	63.7	34.4	62.8		

Digestibility and fiber levels in both lines shown in Table 6 were similar to those of most C4 grasses reported by Milford (1960). Tissue oxalate levels were below the level of determination (<0.01%) in *P. lepton*, which is a point of distinction from 2 of the main grasses used in the humid subtropics and upland tropics, *C. clandestinus* and *S. sphacelata*, both of which can have levels of oxalate that can cause metabolic problems in grazing cattle and horses (Rahman et al. 2013).

In summary, the nutritive value of *P. lepton* APG 54281 and APG 54325 tested in Queensland were in the same range as for other *Paspalum* spp. and in the same domain as other subtropical grasses used commercially (Feedipedia). They did not accumulate undesirable levels of oxalate in their tissues.

Animal performance

Recognizing the limitations of short-term grazing studies, particularly regarding adjustment of the rumen flora in the first 4–6 weeks of diet change, grazing behavior was observed to obtain a rough assessment of productivity on this new species to Australian agriculture. In an unreplicated study of the performance of animals grazing *P. lepton* APG 54325 pasture at Gympie, liveweight gain of a group of Holstein-Friesian heifers averaging 265 kg liveweight with *P. lepton* as the sole nutrient source, was measured over a period of 3 months (March–May). The established grass stand was fertilized with 110 kg N/ha and set-stocked at 5 hd/ ha. The heifers gained an average of 1.3 kg/hd/ day in the first month, declining to an overall average of 0.6 kg/hd/day as feed on offer declined during a period of low rainfall and declining temperatures (Cook et al. 2020). By comparison, Evans and Hacker (1992) in a study with steers grazing *S. sphacelata* 'Narok' at Beerwah in Southeast Queensland, measured liveweight gain of 0.45 kg/hd/day, averaged on a year-round basis over 3 years.

In another unreplicated grazing study near Stanthorpe in which *P. lepton* APG 54325 and *D. eriantha* 'Premier' were sown in separate 0.6 ha paddocks with *T. subterraneum* ssp. *subterraneum* 'Seaton Park' and 'York', the liveweight gain in Hereford steers, average liveweight 390 kg, was measured over a period of 120 days in the year following establishment (DL Lloyd, unpublished). Rainfall measured during the time was 371 mm, compared with the long-term average of 378 mm for the same period. Grazing with a stocking rate of 3.3 steers/ha began in late September 1998 and the final liveweight measurement was made in late February 1999. Prior to commencement of grazing treatments, the collective area was defoliated by grazing heavily with 35 steers for 56 days, and the area closed during the cool months when grasses were relatively dormant, before measurement began. Animal liveweight was measured every 30 days. In the first 30 days until late October (the spring period), average liveweight gains from APG 54325 and 'Premier' were 2.55 kg/hd/day and 1.68 kg/hd/day respectively, the high levels primarily attributable to their association with an excellent *T. subterraneum* component. In the following 90 days the liveweight gains were 1.02 and 0.69 kg/hd/day respectively. In the final 30-day period, stock lost weight probably owing to a combination of low feed quality associated with grass seed production in a drier than average month, and the absence of the annual legume that had set seed and senesced. Average liveweight gains for the 120-day grazing period were 1.02 kg/hd/day for APG 54325 and 0.58 kg/hd/day for 'Premier'.

In summarizing both studies, pastures based on *P. lepton* performed at least equally as well as, perhaps slightly better than, those based on other subtropical species, reflecting the comparable nutritive quality of the grass. Comparability is more significant when assessing the value of the species than the quantitative values measured, which will vary with soil fertility/fertilizer used, seasonal conditions and age of pasture.

Compatibility with legumes

Benefits of incorporating legumes into beef and dairy production systems have been well-demonstrated (Hill et al. 2009; Mannetje 1997). Legume genera including *Medicago*, *Trifolium* and *Adesmia* have been found in *P. lepton* dominant native pastures (Barreto 1956), although no reference is made to legume frequency or grazing management applied. Grass-legume mixtures are an important component of intensive sown forage systems in the subtropics of Australia where, in more humid parts of the region, they are often complemented by nitrogen-fertilized grass. However, the competitive ability of *P. lepton* that enables it to suppress weeds (see Weed Suppression below) also leads to some or total suppression of sown legumes in pastures (Table 3).

While cool season legumes (*Trifolium* spp.) were able to persist with *P. lepton* in the cool (24 hr average annual temperature 15 °C) upland subtropical Stanthorpe environment (Table 3), the outcome in a similar experiment with warm season legumes at Gympie in a mesic sub-tropical lowland environment (24 hr average annual temperature 20 °C) was different (BG Cook, unpublished). *P. lepton* APG 54325 was sown on a degraded red podzolic soil and compared under intermittent grazing with related sward-forming grasses of contrasting growth habits: *P. notatum* 'Competidor' (rhizomatous); naturalized *P. dilatatum* (caespitose) and *A. fissifolius* (stoloniferous). *Arachis glabrata* Benth. 'Prine' (rhizomatous) and *Vigna parkeri* Baker 'Shaw' (stoloniferous), both well adapted perennial legumes known to grow with sward grasses under grazing (Cook et al. 2020), were established with each grass. 'Shaw', which has formed stable combination with the stoloniferous and rhizomatous *C. clandestinus* in farm pastures, grew well with *P. dilatatum* and *A. fissifolius*, and initially with 'Competidor' before sward closure late in the second year. Although it established well with APG 54325, its vigor and frequency declined in the rapidly establishing grass. 'Prine' established slowly from rhizomes, but its frequency gradually increased in combination with all grasses.

Observation elsewhere suggests more controlled, regular grazing may have favored persistence of the test legumes. Under such grazing management, more competitive species such as *Arachis pintoi* Krapov. & W. C. Greg. (stoloniferous), *T. repens* 'Haifa' (stoloniferous) and *Lotus uliginosus* Schkuhr 'Grasslands Maku' (stoloniferous, rhizomatous) have grown successfully with *P. lepton* in mesic locations and *Aeschynomene falcata* (Poir.) DC. in drier locations (AD Robertson, unpublished). Observed over time in some locations, suppressed legumes became more vigorous, despite *P. lepton* cover being maintained. This was presumed to be associated with a decline in soil mineral nitrogen over time following seedbed preparation. A similar pattern of legume growth and persistence has been observed elsewhere when sown with the rhizomatous and stoloniferous *C. clandestinus*.

Summarizing, *P. lepton* has a strong suppressive effect on associated legumes, with the level potentially controlled by grazing management and legume growth form. This is a topic for further study.

Weed suppression

The suppressive quality of *P. lepton* demonstrated with some legumes (Table 3) is potentially valuable in suppressing some of the more serious pasture weeds. Grasses, including *E. curvula, I. cylindrica, Hyparrhenia hirta* (L.) Stapf, *Sporobolus indicus* (L.) R. Br. var. *major* (Büse) Baaijens, *Sporobolus indicus* (L.) R. Br. var. *pyramidalis* (P. Beauv.) Veldkamp, *Sporobolus natalensis* (Steud.) T. Durand & Schinz and non-poaceous species such as *Senecio madagascariensis* Poir. (Asteraceae) and *Pteridium esculentum* (G. Forst.) Cockayne (order Polypodiales, Dennstaedtiaceae), have become weeds of sown pastures in many parts of the Australian subtropics. These are largely unpalatable and/or rapidly maturing species whose low nutritive value limits production from grazed pastures. Farmers who have established *P. lepton* and researchers working with the species have confirmed the ability of *P. lepton* to compete vigorously with these species. Thus, it may become part of an integrated weed control strategy that commonly includes heavy grazing and use of selective chemical herbicides in which recommended stock withholding periods are observed.

Observation in the Stanthorpe animal production studies suggests *P. lepton* has been more effective than *D. eriantha* 'Premier' in suppressing invasion by *E. curvula*, supported by observation in commercial pasture sown to *P. lepton* APG 54325 nearby (AD Robertson, unpublished). Critically, *P. lepton* seedlings develop quickly, forming a dense stand that suppresses seedling regeneration of the weed species (Tables 3 and 4). Further, the established grass is resistant to continuous heavy grazing, a treatment that can suppress or eliminate *I. cylindrica* by the intensive, regular defoliation of its young growth.

Suppression and control of taller grasses (*Sporobolus, Eragrostis, Hyparrhenia, Imperata*) is important because they reduce productivity of land and, at the same time, develop a fuel load that poses a substantial fire threat. This would be almost eliminated if mature and dry tall grasses were replaced by palatable *P. lepton*.

Difficulty to control

The potential of palatable lines of *P. lepton* to become a weed unless well managed is exacerbated by a difficulty to effect control, either chemically or with cultivation. Studies in Georgia indicated that 3 years of cultivation and cropping with corn (*Zea mays* L.) was necessary for complete control of *P. lepton* (USDA Soil Conservation Service, unpublished). Attempts to control APG 54281 by spraying with 2, 2-DPA and cultivation and cropping with soybean (*Glycine max* (L.) Merr.) has proved unsuccessful at Grafton Research Station (GPM Wilson, unpublished). Blount et al. (2022) support the view that *P. lepton* is not readily controlled by cultivation alone, adding that cultivation may result in favoring vegetative spread of the grass through movement of rhizome pieces. Additionally, they note that it is tolerant of a number of herbicides including metsulfuron and glyphosate that are effective on other species of *Paspalum*. Studies carried out at Gympie have demonstrated that mature stands of *P. lepton* are weakened by recommended rates of glyphosate but recover quickly; and stands that are severely weakened (and sometimes killed) by double rates of glyphosate may still recover (BG Cook, unpublished). Herbicide screening has found that mature plants in pots were not affected by haloxyfop, triclopyr, sulfometuron methyl and metsulfuron methyl at normal or double rates (DS Loch, in Cook et al. 2020). The only chemical to control P. lepton was the pre-emergence herbicide, dithiopyr (24%) at 3.5 L/ha. Hexazinone, a chemical not included in the above screening, has been found effective in controlling *P. lepton* in Florida, and is recommended there at rates of 1.12–2.24 kg/ha (Blount et al. 2022). Since *P. lepton* has a low level of seed dormancy (Cook et al. 2020), seed is unlikely to accumulate within the soil seed bank. Using this chemical, the grass is therefore unlikely to regenerate once the vegetative stand is controlled and further seed set prevented. However, as also occurs with *P. notatum*, in areas where mature seed has been set, small colonies of *P. lepton* have developed in nearby swards of *A. fissifolius* and *P. dilatatum*.

Conclusions

All grasses currently used in the subtropics have weaknesses and strengths with regard to their adaptation, flexibility in production systems, nutritional value, seasonal growth patterns and productivity. *P. lepton* is no exception:

Weaknesses

- Some ecotypes of *P. lepton* mature rapidly and become unpalatable (e.g., APG 54488), enhancing their ability to invade natural and modified systems;
- *P. lepton* is competitive, with a propensity to suppress many potentially associated legumes, particularly in more fertile, humid environments;
- *P. lepton* is difficult to control with herbicide and/or cultivation;
- As with most C4 grasses, *P. lepton* may be susceptible to “pasture dieback”, although not well substantiated.

Strengths

While there are clearly forms of *P. lepton* with certain undesirable traits, our studies have confirmed that 2 promising lines, APG 54281 and APG 54325 have the following beneficial qualities:

- Well adapted to friable sandy and loamy-surfaced soils;
- One of only 3 C4 grasses well adapted to the relatively cool subtropical uplands;
- Establishes quickly with production in establishment season, superior to *P. notatum*;
- Moderate to good drought and frost tolerance;
- Responsive to N fertilizer application yet persistent without fertilizer on soils of low nitrogen fertility;
- Forage yields at least comparable with those of other adapted grasses during a long growing season;
- Forage of similar quality to other useful C4 grasses, with no anti-production factors recorded;
- Readily accepted by livestock resulting in sound animal performance when well managed;
- High seed yield, providing potential for low-cost seed;
- Resistance to ergot disease;
- Colonization and persistence with a high level of groundcover under regular defoliation;
- Tolerance of prolonged heavy grazing;
- Soil conservation potential;
- Compatible with some legumes including *Trifolium subterraneum* and *Arachis glabrata* in appropriate environments;
- Suppression of weeds, including low quality, unpalatable, invasive grasses;
- Acceptance by commercial livestock producers.

From the studies in subtropical Eastern Australia and the experience of others, we may conclude that the more desirable forms of *P. lepton* have characteristics that identify them as addressing many of the inherent shortcomings of other grasses currently used in its zone of adaptation. Thus, this is a species with significant commercial forage/pasture potential, although caution should be exercised and management applied to minimize the environmental threat.

Acknowledgments

The authors are indebted to the many farmers on whose land we conducted *P. lepton* research over many years, and to the laboratory scientists who carried out the various soil and plant analyses so necessary in gaining an understanding of a "new" species. We would also like to acknowledge the support readily provided by Dr Gilbert Lovell, formerly of the Americus Plant Materials Center, Georgia, USA, by way of discussion and provision of seed, and to Emer. Prof. Ann Blount, formerly of University of Florida, for her valuable discussion regarding issues with *P. lepton* in Florida and Georgia.

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(Note of the editors: All hyperlinks were verified 24 September 2024).

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(Received for publication 13 September 2023; accepted 30 August 2024; published 30 September 2024)

doi: 10.17138/TGFT(12)142-153

Research Paper

Agronomic evaluation of 15 warm season grasses grown in temporarily waterlogged soils in Northeastern Argentina

Evaluación agronómica de 15 gramíneas de estación cálida cultivadas en suelos temporalmente anegados del noreste argentino

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Abstract

Soils with temporarily waterlogged conditions are common in Northeastern Argentina. Fifteen accessions and hybrids of cultivated and native warm season grasses (*Acroceras macrum*, *Urochloa* species, *Hemarthria altissima* and *Paspalum* species) were planted in Basail, Chaco, in a completely randomized block design in November 2019. Initial, autumn and spring forage yield were measured in February 2020, July 2021 and December 2021, respectively. Plant height and plant diameter were evaluated in February 2020. Cold tolerance was estimated after the first frost in July 2021. Initial forage yield was between 29 and 181 g/plant. *Urochloa mutica* exhibited the greatest initial forage yield. Autumn and spring forage yield varied from 306 to 2,183 g/m^2 and from 153 to 710 g/m^2, respectively. *U. mutica* showed the highest autumn forage yield, however, it was the most damaged by cold weather. *H. altissima* hybrids were the most productive during spring and were cold tolerant. There were differences in plant height (7.5–49 cm) and plant diameter (68–268 cm) among the grasses. Grasses with prostrate, intermediate and upright growth habits were identified. Results indicate all grasses tested were adapted to humid Northeastern Argentina and varied in their morphological and agronomic traits.

Keywords: Cold tolerance, forage yield, growth habit.

Resumen

Los suelos con anegamiento temporario son comunes en el Nordeste de Argentina. El objetivo fue evaluar las características agronómicas de un grupo de gramíneas estivales nativas y cultivadas. Un grupo de quince híbridos y accesiones de *Acroceras macrum*, *Urochloa* spp., *Hemarthria altissima* y *Paspalum* spp. fueron plantados en Basail, Chaco, en noviembre de 2019, en un diseño de bloques completos al azar. La producción de forraje inicial, otoñal y primaveral de forraje fue evaluada en febrero 2020, julio 2021 y diciembre 2021, respectivamente. Se evaluó la altura y diámetro de plantas en febrero 2020. La tolerancia al frío fue evaluada en julio 2021, luego de ocurrida la primera helada. La producción inicial de forraje varió entre 29 y 180.7 g/planta, donde *Urochloa mutica* mostró la mayor producción inicial. La producción otoñal y primaveral de forraje varió entre 306 y 2,183 g/m^2, y entre 153 y 710 g/m^2, respectivamente. *U. mutica* mostró la mayor producción otoñal, sin embargo, fue la más dañada por las bajas temperaturas. Los híbridos de *H. altissima* fueron los más productivos en la primavera y los más tolerantes al frío. Se detectaron diferencias en altura (7.5–49 cm) y el diámetro (68–268 cm) de plantas, las que permitieron distinguir grupos de hábito de crecimiento postrado, semierecto y erecto. Los resultados indican que todas las accesiones e híbridos se adaptaron a las condiciones del Nordeste húmedo de Argentina, variando en sus características agronómicas y morfológicas.

Palabras clave: Hábito de crecimiento, producción de forraje, tolerancia al frío.

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Introduction

Beef production systems are essential to the economy of Argentina, providing employment for 470,000 ranchers (Rodriguez Zurro and Terré 2022). Argentina is among the largest beef consumer and exporter countries of the world (Ramseyer and Terré 2023). Beef production is conducted throughout the country in areas with high diversity of plant species, climate and soil conditions (Arelovich et al. 2011). Among the different livestock regions of the country, the Northeast is the second most important with around 30% of total cattle (Arelovich et al. 2011). This region is characterized as subtropical with a mean temperature of 22 °C and mean annua rainfall that decreases from east to west from 1,800 to 600 mm. Due to the high variations in soil type and rainfall, Northeast Argentina is divided into different sub-regions, including the humid Chaco which covers around 12 million ha in the Eastern parts of the provinces of Chaco and Formosa and the Northern part of Santa Fe province. Grasslands in this sub-region usually remain wet to waterlogged for long periods (Skerman and Riveros 1992; Burns et al. 2004).

Livestock production is one of the main activities in the humid Chaco with around 6 million cattle raised mostly in cow-calf systems (Barbera et al. 2018). Warm season forage grasses are the principal source of feed (Barbera et al. 2018). The mean rainfall is between 1,200 and 1,800 mm with mean temperature of 25 °C and 2 to 3 frost events per year. This region is characterized by flat terrain with slow water runoff. The soil has a high clay content with reduced permeability leading to waterlogging during the rainy season (end of spring, summer and autumn) (Ginzburg and Adámoli 2005). This zone is dominated by native grasses, such as *Coleataenia prionitis* (Nees) Soreng (Molina and Rúgolo de Agrasar 2006), with limited acceptance by cattle. Therefore, beef production is low with an offtake of around 30 kg beef/ha (Barbera et al. 2018). Researchers from the School of Agricultural Science, National University of the Northeast and the Botanical Institute of the Northeast receive numerous enquiries from local cattlemen about which forage species could be used for those systems.

Among the cultivated and native forage species that could be used in the rangelands of the humid Chaco are the genera *Acroceras*, *Urochloa*, *Hemarthria* and *Paspalum* (Moser et al. 2004). *Acroceras macrum* Stapf is a C3 warm season grass native to Africa. It is vegetatively propagated and adapted to humid areas with poorly drained soils (Skerman and Riveros 1992). The species has been introduced to the Northeast of Argentina and a breeding program was initiated by the Instituto Nacional de Tecnología Agropecuaria (INTA) (Ferrari Usandizaga et al. 2014; 2020). After some years of ecotype selection and hybridization, researchers were able to select some outstanding accessions and also breed some hybrids adapted to the humid areas of Corrientes, Argentina (Ferrari Usandizaga et al. 2020).

Urochloa species are among the most cultivated forage species in tropical and subtropical South America, with Brazil having most adoption (Jank et al. 2014). Common cultivated species are mainly adapted to well drained, infertile acid soils. However, *U. mutica* (Forssk.) T. Q. Nguyen and *U. arrecta* (Hack. ex T. Durand & Schinz) Morrone & Zuloaga grow in waterlogged soils (Miles et al. 2004). *U. mutica* is a C4 warm season grass native to Africa and adapted to swampy and seasonally flooded conditions (Miles et al. 1996). It forms hollow long stolons and is vegetatively propagated (Skerman and Riveros 1992). Another *Urochloa* species adapted to poorly drained soils is a natural hybrid between *U. arrecta* and *U. mutica* (Tangola grass) (Andrade et al. 2009). Tangola grass is a stoloniferous perennial warm season grass that roots easily, allowing fast establishment (Andrade et al. 2009). *Hemarthria altissima* (Poir.) Stapf & C. E. Hubb. (limpograss) is another species that is well adapted to seasonally wet areas. It is a stoloniferous perennial warm season grass native to East to Southern Africa and exhibits good cold tolerance. The species is valued in subtropical regions because it is one of the first C4 grasses to start growing after the cold season in the subtropics (Quesenberry et al. 2004). The University of Florida, USA, has released cultivars with improved forage yield, persistence under grazing and nutritive value (Quesenberry et al. 1979, 1987, 2017).

There are around 300 species of *Paspalum* from the Americas growing in diverse environments (Zuloaga and Morrone 2005) and about 8 of them are cultivated as forage or turf grasses (Acuña et al. 2019). *P. atratum* Swallen is one of the most adopted grasses, characterized by a high forage yield and rapid growth during the warm season. It is an upright species that grows on well drained to waterlogged soils (Evers and Burson 2004) and is propagated by seeds with apomictic reproduction (asexual reproduction through seed). *P. lenticulare* Kunth is an apomictic species that grows throughout swampy savannas of East Bolivia, Paraguay and central Western Brazil (Marcón et al. 2018). The species produces a good amount of forage during the warm season but is cold sensitive (Marcón et al. 2018). Other species of the genera are *P. modestum* Mez, *P. palustre* Mez and *P. repens* P.J. Bergius. These species are prostrate, stoloniferous and grow in waterlogged soils. They are native to Northeast Argentina and considered good forages, however, information about their agronomic performance is scarce (Zuloaga and Morrone 2005).

Considering the characteristics of these species, they are considered as options to increase beef cattle production in the humid Chaco. However, little is known about the performance of these species in the region, especially the native ones. It is important to evaluate the agronomic characteristics and adaptability to the humid Chaco environment of cultivated and native warm season grasses. The objectives of this research were to evaluate a series of morphological, ecophysiological and forage quality traits in *A. macrum*, *U. mutica*, *U. mutica* × *U. arrecta* hybrid, *H. altissima* and *Paspalum* species and determine their adaptability to temporary waterlogging based on an integrated analysis of evaluated traits.

Materials and Methods

Plant material and experimental site

Three accessions of *A. macrum*, 1 cultivar of *U. mutica*, 1 hybrid *Urochloa*, 4 cultivars of *H. altissima*, 1 cultivar of *P. atratum* and 5 accessions of *Paspalum species* (*P. lenticulare*, *P. palustre*, *P. modestum* and *P. repens*) were used for the trial (Table 1). Portions of stolons of each vegetatively propagated grass and seeds for others were planted in the greenhouse of the Faculty of Agricultural Science, National University of the Northeast, Corrientes, Argentina, in September 2019. Plants were transplanted in rows of 20 m in a completely randomized block design with 2 replications (Figure 1) after 60 days of growth in November 2019 into the field of Amarilla Agropecuaria Company, located near Basail, Chaco, Argentina (27°42’20.52” S; 59°14’24.96” W). Each row contained 21 plants spaced 1 m between plants and 1 m between rows. The soil was classified as clayey with 36.2% clay, 34.5% sand and 29.2% silt, pH 6.1, electric conductivity of 0.5 mS, organic matter concentration of 4.5 mg/kg, P concentration of 7.3 mg/kg and total N concentration of 0.23 mg/kg. Basail has a sub-humid to humid subtropical climate with a mean temperature of 21.5 °C and an annual mean rainfall of 1,300 mm. The experimental site was waterlogged at planting and for the following 2 months (November 2019 to the end of January 2020), and again from January to March 2021. The monthly rainfall, historic monthly rainfall, average monthly temperatures and minimum and maximum monthly temperatures reported for the region are shown in Figure 2. The mean temperature was similar to the historic mean temperature.

Table 1. Origin, main characteristics and source of 3 accessions of *A. macrum*, 2 cultivars of *Urochloa*, 4 cultivars of *H. altissima*, 1 cultivar of *P. atratum* and 5 accessions of *Paspalum* species cultivated in Basail, Chaco, Argentina.

Accessions, cultivars and hybrids	Origin and main characteristics	Source
Acroceras macrum Hybrid 5	Argentina. Hybrid 5 developed by the Agricultural Research Council (ARC) in South Africa and introduced and selected in Argentina by INTA. Stoloniferous. Vegetative propagation. C3 photosynthetic pathway.	Ferrari Usandizaga et al. 2020
Acroceras macrum cultivar 'Cedera Select'	East Africa. Released by the ARC in South Africa and introduced in Argentina by INTA. Vegetatively propagated. Adapted to wet soils with poor drainage. Vegetative propagation. C3 photosynthetic pathway.	Rhind and Goodenough 1979
Acroceras macrum Hybrid 165	Argentina. Hybrid 165 generated by INTA. Vegetative propagation. C3 photosynthetic pathway.	Ferrari Usandizaga et al. 2020
Urochloa mutica	Africa. Vegetative propagation. Stoloniferous. Adapted to seasonally flooded soils.	Miles et al. 1996
Urochloa spp. cultivar 'Tangola'	Brazil. Natural hybrid between *U. arrecta* × *U. mutica*. Stoloniferous. Vegetative propagation. Adapted to seasonally flooded soils. Cold sensitive.	Andrade et al. 2009
Hemarthria altissima cultivar 'Bigalta'	United States. Direct selection from a collection from South Africa. Released by the Institute of Food and Agricultural Sciences (IFAS), University of Florida and the Soil Conservation Service, United States Department of Agriculture, USA. Selected for good in vitro dry matter digestibility. Adapted to wet areas. Stoloniferous. Vegetative propagation.	Quesenberry et al. 1979
Hemarthria altissima cultivar 'Floralta'	United States. Selection released by IFAS. Improved herbage mass production and persistence under intensive grazing compared to 'Bigalta'. Stoloniferous. Vegetative propagation.	Quesenberry et al. 1987
Hemarthria alttisima cultivar 'Gibtuck'	Hybrid between the cultivars "Floralta" and "Bigalta" produced by the University of Florida Agronomy Department. Selected for superior forage yield, persistence under grazing, improved nutritive value, and utility as stockpiled forage. Stoloniferous. Vegetative propagation	Quesenberry et al. 2017
Hemarthria alttisima cultivar 'Kenhy'	Hybrid between the cultivars "Floralta" and "Bigalta" produced by the University of Florida Agronomy Department. Selected for superior forage yield, persistence under grazing, improved nutritive value, and utility as stockpiled forage. Stoloniferous. Vegetative propagation	Quesenberry et al. 2017
Paspalum atratum cultivar 'Cambá-FCA'	Argentina. Released by the Facultad de Ciencias Agrarias, Universidad Nacional del Nordeste. High herbage biomass production during the warm season. Tolerant to seasonal flooding. Seed propagation. Apomictic reproduction.	Evers and Burson 2004
Paspalum lenticulare TK2396	Santa Cruz, Bolivia. Available from the germplasm bank of the Instituto de Botánica del Nordeste (IBONE). Good herbage biomass production during the warm season, and seed yield. Seed propagation. Apomictic reproduction	Marcón et al. 2018
Paspalum modestum	Corrientes, Argentina. Available from the germplasm bank of the IBONE. Grows in waterlogged soils. Stoloniferous.	Zuloaga and Morrone 2005
Paspalum palustre 2x Q3648	Chaco, Argentina. Diploid cytotype. Available from the germplasm bank of IBONE. Grows in waterlogged soils. Stoloniferous.	Zuloaga and Morrone 2005
Paspalum palustre 4x Bordon110	Formosa, Argentina. Tetraploid cytotype. Available from the germplasm bank of IBONE. Grows in waterlogged soils. Stoloniferous.	Zuloaga and Morrone 2005
Paspalum repens	Argentina. Available from the germplasm bank of IBONE. Aquatic. Grows near riversides and wetlands.	Zuloaga and Morrone 2005

Figure 1. Planting site of 15 warm season grasses belonging to the genera *Acroceras*, *Urochloa*, *Hemarthria* and *Paspalum*.

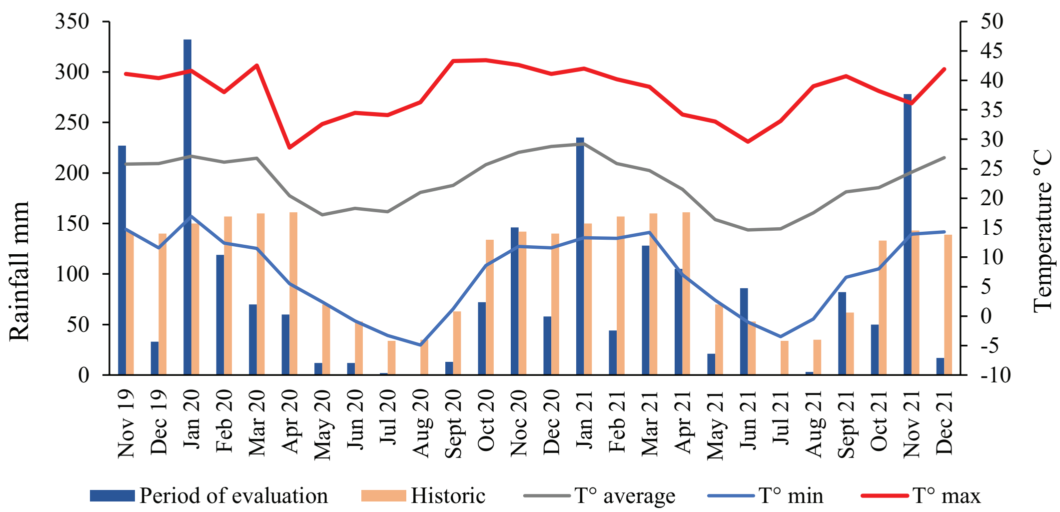

Figure 2. Monthly rainfall (mm), historic monthly rainfall (mm), average monthly temperatures (°C) and minimum and maximum monthly temperatures (°C) from November 2019 to December 2021.

Morphological evaluation

Morphological traits of plant height, plant diameter and length of longest stolon were measured on 5 February 2020. Plant height (cm) was measured from the base of the plant to the top of the canopy on 4 different plants in the line. Plant diameter (cm) was measured on 2 different plants in the line and then calculated as the average between the longest and the shortest diameter of each plant. The length of the longest stolon (cm) was measured from the center of the plant to the tip of the longest stolon on 2 different plants in the line.

Initial forage yield and proportion of established plants

The initial forage yield was determined on 5 February 2020 by harvesting 2 plants per row at 5 cm stubble height. The harvested material was weighed and dried at 60 °C for 48 h. The dried material was weighed and the amount of dry matter was obtained (g/plant). After this evaluation, all accessions were harvested at 5 cm stubble height. The percentage of established plants was determined on 10 October 2020 by counting the number of remaining plants per row and expressing as a percentage of established plants.

Summer growth and cold tolerance

Summer growth was estimated on 25 March 2021 using a visual scale from 1 to 5, where 1 represented the plants exhibiting the least aboveground growth, and 5 represented the plants with the greatest growth. Plant growth was estimated considering leaf abundance and ground cover. Cold tolerance was estimated 2 days after the first frost event (2 July 2021) using the same 1-5 visual scale, where 1 represented the least cold tolerant plants and 5 the most tolerant plants considering the abundance of dead material tissue. The minimum temperature reached was -1 °C during 1 h on 30 June 2021, however, the temperature was under 0 °C during 2 h on 28 June 2021, 1 h on 29 June 2021 and 4 h on 30 June 2021.

Forage yield and nutritive value

Autumn and spring forage yield were evaluated on 2 July 2021 and 3 December 2021, respectively. An area of 0.25 m^2 from each accession was harvested by hand at 5 cm stubble height. The harvested material was weighed and a subsample of approximately 400 g was taken. The subsample was dried at 60 °C for 48 h, weighed and the dry weight of the harvested material was calculated. All lines were grazed at 10 cm stubble height at the end of March. After the harvest in December 2021, the dried subsample was used to determine nitrogen concentration, nitrogen content, neutral detergent fiber, acid detergent fiber and total digestible nutrients following the methods of the Association of Official Analytical Chemists (AOAC 1990). Nitrogen concentration was determined using the Kjeldahl method and the nitrogen content (g/m^2) was determined based on dry matter forage yield and nitrogen concentration.

Statistical analysis

All traits were analyzed using the software InfoStat (Di Rienzo et al. 2022) as a completely randomized bock design with 2 replications, except for nutritive value data where samples were not replicated. Analysis of variance and separation of means by the Tukey test at a significance level of 5% were carried out. Principal component analysis and biplot graphical representation were done with InfoStat.

Results

Morphological evaluation

Significant differences among grasses were observed for plant height, plant diameter and the length of the longest stolon 3 months after planting (Table 2). Three groups were identified based on plant height and diameter. One group included short plants (7.5–20 cm) with a prostrate growth habit and higher diameter (114–174 cm) including *P. palustre* 2x and 4x, *P. modestum* and *P. repens*. The second group included taller plants (21–43 cm) with high diameter (131–268 cm) and intermediate growth habit including *Urochloa* and *Hemarthria* cultivars. The final group included taller plants (36–48 cm) with smaller diameter (36–155 cm) and an upright growth habit, characterized by cultivars of *P. atratum* and *P. lenticualre* and *A. macrum*. Among the stoloniferous accessions and hybrids, differences in the length of the longest stolon were observed, with the upright *A. macrum* accessions exhibiting the lowest values.

Initial forage yield and proportion of established plants

Initial forage yield of all evaluated accessions measured 65 d after planting was significantly different (Figure 3) and varied between 29 g/plant and 180.7 g/plant. *U. mutica* exhibited the highest yield and *A. macrum*-165 the lowest. The percentage of established plants after 1 year of planting differed among grasses (Table 2). *P. lenticulare* had lowest survival of established plants (5%) while survival of Tangola grass and *H. altissima* 'Bigalta' and 'Kenhy' was more than 95% of established plants.

Summer growth and cold tolerance

Significant differences among accessions were observed for summer growth (Table 2), except for *P. repens* that did not survive. Plants with abundant aboveground biomass included *U. mutica* and some *H. altissima* accessions, while *P. lenticulare* and some *A. macrum* accessions exhibited the lowest growth. A high variation in cold tolerance among accessions was observed (Table 2) with plants with abundant green leaves and plants with completely damaged leaves observed. *A. macrum* and *H. altissima* accessions were the most cold tolerant, *P. modestum*, *P. palustre* 2x and *P. atratum* exhibited an intermediate tolerance while the *Urochloa* accessions and *P. lenticulare* and *P. palustre* 4x were the least tolerant.

Table 2. Morphological and agronomical traits of 15 warm season grasses adapted to waterlogged soils evaluated in 2020 and 2021.

Grasses	February 2020			October 2020	March 2021	July 2021
	Plant height (cm)	Plant diameter (cm)	Stolon length (cm)	Established plants (%)	Summer growth	Cold tolerance
AM-5	36.3	96.9	95.0	52.38	3.5	5
AM-S	40.0	155.6	107.5	71.43	2	5
AM-165	48.8	36.3	67.5	26.19	2	4
BM-Pará	30.0	268.1	212.5	90.48	5	1
Bh-Tangola	24.4	262.5	266.3	97.62	4	1
HA-Bigalta	21.9	131.3	112.5	97.62	4	5
HA-Floralta	35.0	221.3	162.5	92.86	5	5
HA-Gibtuck	21.3	131.9	127.5	90.48	4.5	4.5
HA-Kenhy	43.1	181.3	176.3	95.24	4.5	4.5
PA-Cambá	38.1	74.4	0.0	64.29	4	2.5
PL-TK2396	39.4	68.1	0.0	4.76	1.5	1
PM	18.8	114.4	85.0	59.52	2.5	3
PP-2x	18.1	163.8	146.3	73.81	3.5	3
PP-4x	20.0	148.8	113.8	76.19	2.5	1
PR	7.5	174.4	232.5	23.81	.	.
Mean	29.5	148.58	127	66.77	3.5	3.25
CV	27.23	23.67	17.74	21.73	21.87	10.19
MSD	11.43	50.07	32.09	31.39	1.50	0.75

A. macrum (AM-5, AM-S and AM-165); *U. mutica* 'Pará' (BM); *Urochloa* sp. 'Tangola' (Bh-Tangola); *H. altissima* 'Bigalta' (HA-Bigalta), 'Floralta' (HA-Floralta), 'Gibtuck' (HA-Gibtuck) and 'Kenhy' (HA-Kenhy); *P. atratum* 'Cambá' (PA-Cambá); *P. lenticulare* (PL-TK2396); *P. modestum* (PM); *P. palustre* 2x and 4x (PP-2x and PP-4x); *P. repens* (PR); CV=coefficient of variation; MSD=minimum significant differences.

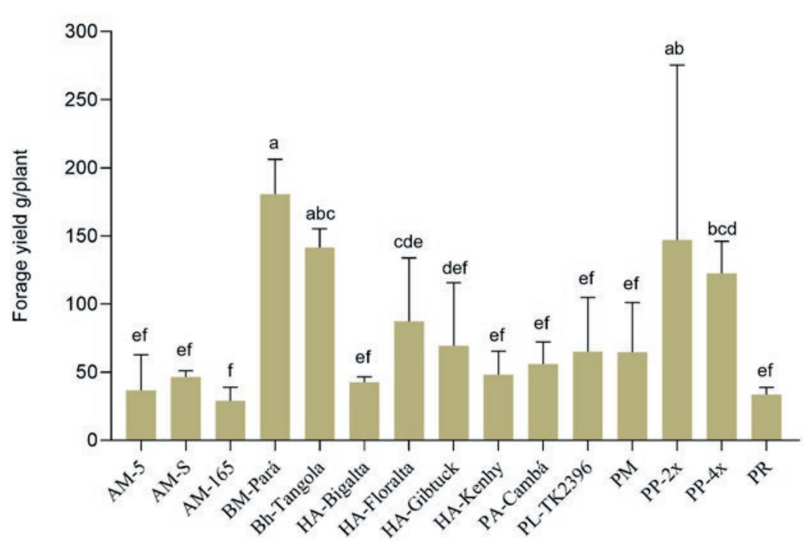

Figure 3. Forage yield (g/plant) of 15 warm season grasses 65 d after planting. *A. macrum* (AM-5, AM-S and AM-165); *U. mutica* (BM); *Urochloa* sp. 'Tangola' (Bh-Tangola); *H. altissima* 'Bigalta' (HA-Bigalta), 'Floralta' (HA-Floralta), 'Gibtuck' (HA-Gibtuck) and 'Kenhy' (HA-Kenhy); *P. atratum* 'Cambá' (PA-Cambá); *P. lenticulare* (PL-TK2396); *P. modestum* (PM); *P. palustre* 2x and 4x (PP-2x and PP-4x); *P. repens* (PR). Different letters on bars indicates significant differences by the Tukey test ($P<0.05$). Vertical lines on bars represent the standard deviation.

Forage yield and nutritive value

Forage yield was significantly different among all evaluated grasses during autumn (92 regrowth days) and spring (151 regrowth days) (Figure 4). Autumn forage yield varied from 306 g/m^2 to 2,183 g/m^2. *U. mutica* had the highest yield, while *P. modestum* and *P. palustre* 2x and 4x the lowest yields. Spring forage yield was between 153 g/m^2 and 710 g/m^2 with *H. altissima* accessions and *U. mutica* showing the highest forage yield and *P. lenticulare* and *A. macrum*-5 the lowest yields.

The nutritional value of all grasses during the spring with 5 months of growth was variable (Table 3). *A. macrum* grasses had the highest crude protein (CP) and nitrogen concentration and *H. altissima* grasses the lowest. However, *H. altissima* 'Gibtuck' had the highest nitrogen content (5 g/m^2) followed by *U. mutica* (3 g/m^2), with *P. palustre* 2x and *P. lenticulare* having the lowest nitrogen content. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) varied from 59% to 69% and from 29% to 35%, respectively. The *Paspalum* grasses had the lowest NDF and ADF. The total digestible nutrients concentration was between 64% and 69% with *P. atratum* 'Cambá' having the highest value.

Principal component analysis

The biplot showed a high diversity among the 14 grasses distributed into the 4 quadrants (Figure 5). All traits analyzed in this work contributed equally to this variation. The biplot identified 3 groups; 1 with grasses showing outstanding performance (*H. alttissima* cultivars), 1 with grasses with moderate performance (*Urochloa* cultivars) and 1 of grasses with poor performance (*Paspalum* species and *A. macrum* accessions). This analysis showed some traits were negatively correlated, including plant height and initial forage yield.

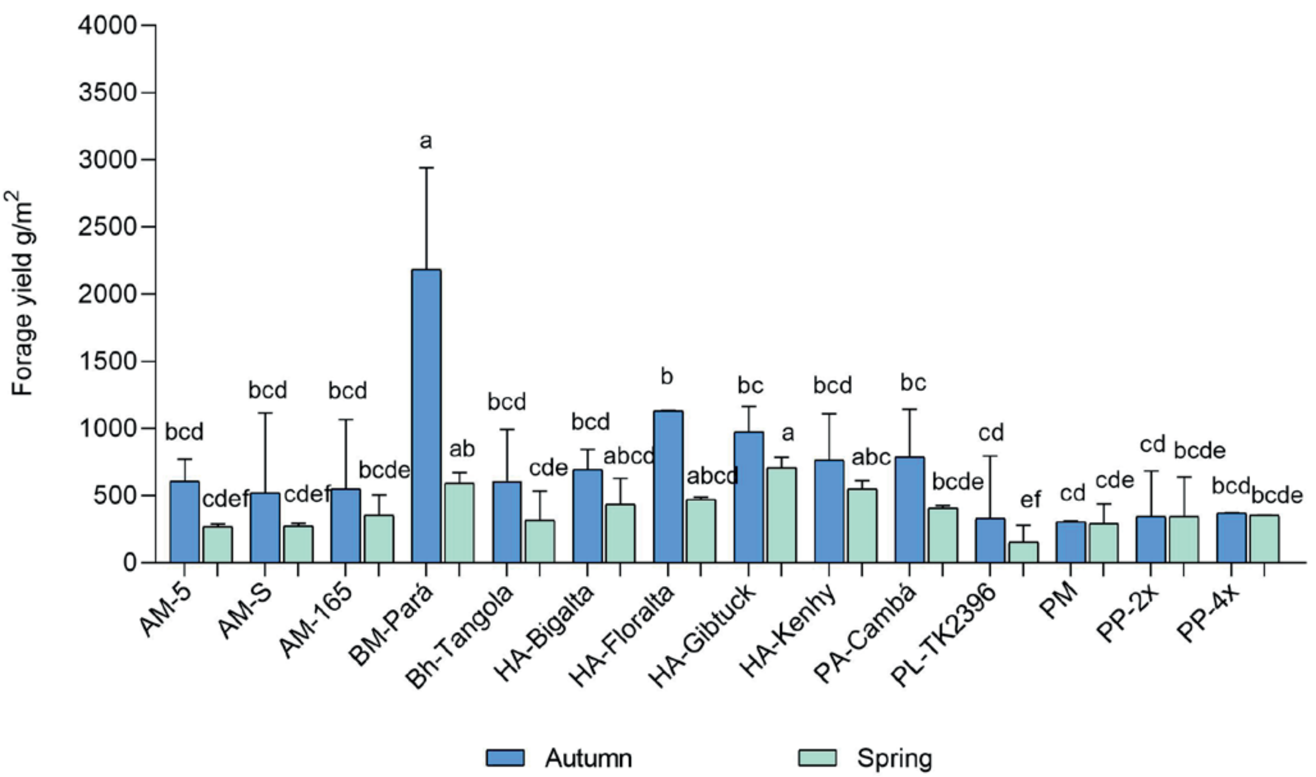

Figure 4. Forage yield (g/m^2) of a group of 14 warm season grasses adapted to waterlogged environments during the autumn (92 regrowth days) and spring (151 regrowth days). *A. macrum* (AM-5, AM-S and AM-165); *U. mutica* (BM); *Urochloa* sp. 'Tangola' (Bh-Tangola); *H. altissima* 'Bigalta' (HA-Bigalta), 'Floralta' (HA-Floralta), 'Gibtuck' (HA-Gibtuck) and 'Kenhy' (HA-Kenhy); *P. atratum* 'Cambá' (PA-Cambá); *P. lenticulare* (PL-TK2396); *P. modestum* (PM); *P. palustre* 2x and 4x (PP-2x and PP-4x); *P. repens* (PR). Different letters on bars indicates significant differences by the Tukey test (P<0.05). Vertical lines on bars represent the standard deviation.

Table 3. Crude protein (CP), nitrogen concentration (nitrogen), nitrogen content (Nit. Cont.), neutral detergent fiber (NDF), acid detergent fiber (ADF) and total digestible nutrients (TDN) of 14 grasses during the spring after 5 months of growth.

Grasses	CP (g/kg)	Nitrogen (%)	Nit. Cont. (g/m^2)	NDF (%)	ADF (%)	TDN (%)
AM-5	60.1	0.96	2.46	62.08	30.98	67.84
AM-S	57.1	0.91	2.39	64.78	33.92	65.49
AM-165	69.6	1.11	2.72	63.3	31.71	67.25
BM-Pará	39.5	0.63	3.40	63.47	31.50	67.42
Bh-Tangola	43.9	0.70	1.12	62.5	30.56	68.17
HA-Bigalta	27.4	0.44	1.32	68.7	31.96	67.05
HA-Floralta	32.9	0.53	2.55	67.58	35.41	64.31
HA-Gibtuck	41.0	0.66	5.00	65.2	35.31	64.39
HA-Kenhy	28.1	0.45	2.27	66.16	30.65	68.10
PA-Cambá	46.9	0.75	1.96	61.09	29.14	69.30
PL-TK2396	46.9	0.75	0.48	62.31	29.36	69.13
PM	53.5	0.86	3.39	58.67	31.01	67.81
PP-2x	41.3	0.66	0.86	62.65	29.77	68.85
PP-4x	53.5	0.86	3.01	61.61	31.29	67.59

A. macrum (AM-5, AM-S and AM-165); *U. mutica* cultivar 'Pará' (BM); *Urochloa* sp. cultivar 'Tangola' (Bh-Tangola); *H. altissima* cultivars 'Bigalta' (HA-Bigalta), 'Floralta' (HA-Floralta), 'Gibtuck' (HA-Gibtuck) and 'Kenhy' (HA-Kenhy); *P. atratum* cultivar 'Cambá' (PA-Cambá); *P. lenticulare* (PL-TK2396); *P. modestum* (PM); *P. palustre* 2x and 4x (PP-2x and PP-4x).

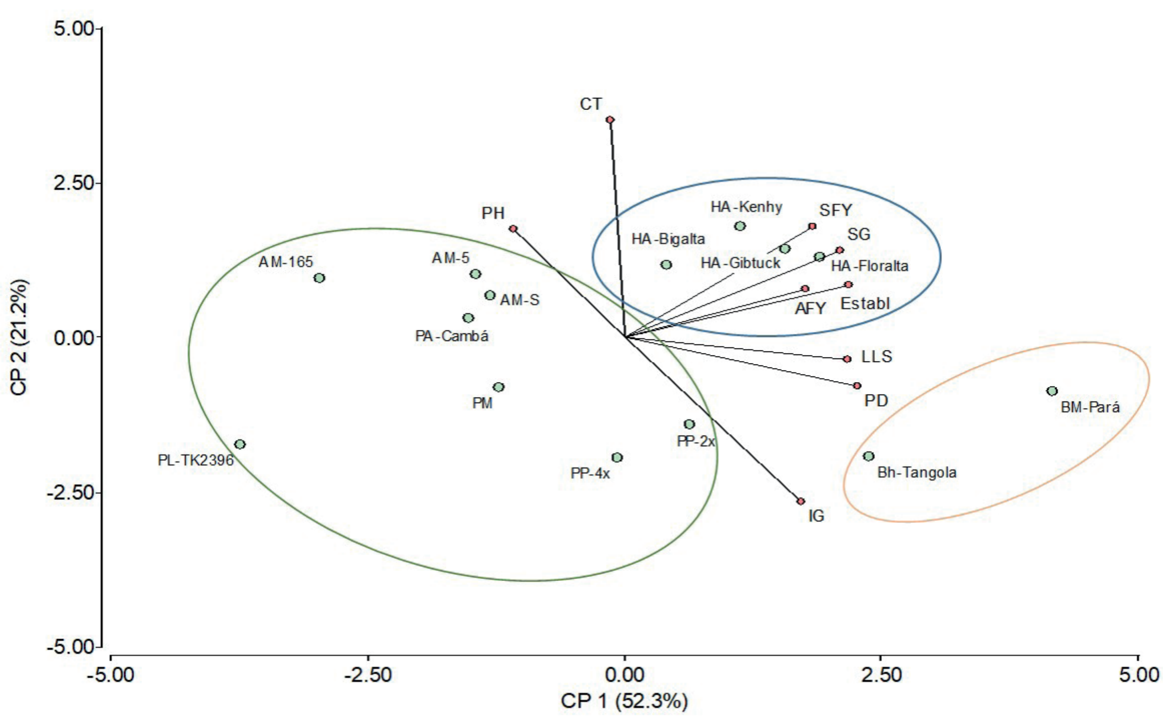

Figure 5. Biplot for 9 morphological and agronomic traits of 14 grasses. *A. macrum* (AM-5, AM-S and AM-165); *U. mutica* 'Pará' (BM); *Urochloa* sp. 'Tangola' (Bh-Tangola); *H. altissima* 'Bigalta' (HA-Bigalta), 'Floralta' (HA-Floralta), 'Gibtuck' (HA-Gibtuck) and 'Kenhy' (HA-Kenhy); *P. atratum* 'Cambá' (PA-Cambá); *P. lenticulare* (PL-TK2396); *P. modestum* (PM); *P. palustre* 2x and 4x (PP-2x and PP-4x); PH=plant height; PD=plant diameter; LLS=length of the longest stolon; IG=initial forage yield; Establ=established plants; SG=summer growth; CT=cold tolerance; AFY=autumn forage yield; SFY=summer forage yield. The blue circle groups *H. altissima* cultivars, the orange circle groups *Urochloa* cultivars, and the green circle groups *Paspalum* species and *A. macrum* accessions.

Discussion

The productive potential of the beef cattle production systems in the humid Chaco could be increased through the introduction of the more productive warm season grasses able to grow in poorly drained to waterlogged soils identified in this study. Rapid initial growth of *Urochloa* cultivars has been previously reported (Miles et al. 1996; Andrade et al. 2009), while *A. macrum* required more time to establish as observed by Rhind and Goodenough (1979) in Southern Africa. In this trial 1 year after planting (October 2020), differences in survival were observed which could be related to their low drought tolerance because the monthly rainfall of the experimental site was below the historic mean from March 2020 to October 2020. *P. lenticulare* and *P. repens* showed the lowest survival which could be associated with adaptation to their native environmental conditions. *P. lenticulare* grows across seasonally inundated savannas of South America and *P. repens* across the riverside and swampy areas of the Northeast of Argentina (Marcón et al. 2018; Zuloaga and Morrone 2005). However, *H. altissima* and *Urochloa* cultivars showed high survival and good summer growth, indicating both species were adapted to fluctuations of flooding and drought common to this environment.

H. altissima and *A. macrum* exhibited a high cold tolerance as was previously observed in subtropical regions (Rhind and Goodenough 1979; Quesenberry et al. 2004; Ferrari Usandizaga et al. 2014). Cold tolerance of *A. macrum* could be related to its C3 pathway while cold tolerance in *H. altissima* could be associated with its geographical origin because most of the accessions introduced into America were collected from areas between 24° to 30° S (Quesenberry et al. 1982). In Southern Florida, *H. altissima* cultivars are winter hardy and the hybrids 'Kenhy' and 'Gibtuck' have improved forage yield, persistence under grazing and nutritive value (Quesenberry et al. 2017) and can be used as stockpiled forage during winter and early spring. Testing *H. altissima* cultivars for making hay in the humid Chaco could be another use of this species. Analyzing the spring forage yield, the accessions of *H. altissima* were among the most productive for spring forage yield producing around 5,400 kg/ha despite the scarce monthly rainfall during the period. These results are similar to those observed during a dry winter-spring period in Florida, USA (Quesenberry et al. 2004), indicating *H. altissima* is more adapted to dry periods than the other grasses in the trial. The principal component analysis considering all traits confirmed grouping of accessions better adapted to the humid Chaco, especially to alternating wet and dry periods. It is possible that the other grasses tested were unable to reach their full potential owing to the fluctuating wet and dry periods and further studies during wet periods are recommended to test their performance under sufficient moisture.

Crude protein of all grasses in the study was lower than expected and previously reported (Skerman and Riveros 1992; Andrade et al. 2009; Quesenberry et al. 2017; Marcón et al. 2018). This could be related to age at sampling because the analyzed material was from samples taken after 5 months regrowth. Further studies are needed at different regrowth times and growing seasons with animal performance trials to determine superior grasses.

Within the genotypes evaluated, *H. altissima* accessions adapted better to growing conditions with alternating wet and dry periods. They began to grow quickly, produced a high amount of forage and tolerated low temperatures. It is expected that the use of these improved pastures will have a significant impact on beef cattle production systems in Northeastern Argentina. These systems are dominated by C4 species with very limited acceptance by cattle, and the cultivation of these improved species is expected to increase the offtake of the system by improving the intake and digestibility of the available forage. However, research is needed to evaluate animal performance in grazing systems based on the improved pastures.

Conclusions

The 15 grasses evaluated grew in the humid Chaco and varied in morphological and agronomical traits. Grasses varied from prostrate to upright growth habit and in initial forage yield. *Urochloa* grew rapidly during establishment and *H. altissima* and *Urochloa* grasses showed better survival 1 year after planting and after a dry period. Cold tolerance was variable among accessions with *A. macrum* and *H. altissima* the most tolerant. *U. mutica* 'Pará' and *H. altissima* cultivars showed highest autumn, spring and dry season forage yield, with most of the leaves of *H. altissima* remaining green due to its cold tolerance. Both genera were more adapted to alternating wet and dry periods than the other grasses and it would be interesting to evaluate the performance of all grasses in a period with monthly rainfall similar or superior to the higher historic monthly rainfall. The biplot grouped species more adapted to alternating wet and dry periods. *H. altissima* accessions showed the best performance across all traits and have potential to be cultivated in the humid Chaco.

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(Note of the editors: All hyperlinks were verified 18 September 2024).

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(Received for publication 10 October 2023; accepted 13 August 2024; published 30 September 2024)

Tropical Grasslands-Forrajes Tropicales (2024) Vol. 12(3):154–161
doi: 10.17138/TGFT(12)154-161

Research Paper

Agronomic performance and nutritive value of *Urochloa* species, Desho and Rhodes grass grown in sub-humid Central Ethiopia

Desempeño agronómico y valor nutritivo de las especies de Urochloa*, pastos Desho y Rhodes cultivados en en la zona Central subhúmeda de Etiopía*

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Abstract

Improved forage grasses with high quality and biomass are a crucial additional feed source for cereal-livestock farming in Ethiopia. This study compared the performance of 4 *Urochloa* species [*U. brizantha* (DZF-13379), *U. humidicola* (DZF-9222), *U. decumbens* 'Basilisk' (DZF-10871) and *U. mutica* (DZF-483)] with other 2 commonly used grasses, Rhodes grass (*Chloris gayana* 'Massaba') and Desho grass (*Pennisetum glaucifolium* local variety Kindu kosha), over 3 years during the main rainy season in Bishoftu in a sub-humid area of Ethiopia. The experiment was conducted using a completely randomized block design. There was significant variation among species for agronomic parameters. The species × year interaction was significant for dry matter yield, plant height, and plot cover but not significant for leaf-to-stem ratio. Nutritional value [ash, acid detergent fiber (ADF), crude protein (CP) and in vitro dry matter digestibility (IVDMD)] was significantly different among species with no differences for neutral detergent fiber (NDF) and acid detergent lignin (ADL). All species showed potential as alternative ruminant feeds with *U. mutica* and *U. brizantha* the highest yielding in the sub-humid environment.

Keywords: Dry matter yield, grass species, leaf-to-stem ratio, plant height, quality.

Resumen

Las gramíneas forrajeras mejoradas con alta calidad y biomasa son una fuente adicional de alimento crucial para la ganadería de cereales en Etiopía. Este estudio comparó el desempeño de 4 especies de *Urochloa* [*U. brizantha* (DZF-13379), *U. humidicola* (DZF-9222), *U. decumbens* 'Basilisk' (DZF-10871) y *U. mutica* (DZF-483)] con otras 2 gramíneas comúnmente utilizadas, la hierba Rhodes (*Chloris gayana* 'Massaba') y la hierba Desho (*Pennisetum glaucifolium* variedad local Kindu kosha), durante 3 años durante la temporada principal de lluvias en Bishoftu, en una zona subhúmeda de Etiopía. El experimento se realizó utilizando un diseño de bloques completos al azar. Hubo una variación significativa entre las especies en cuanto a los parámetros agronómicos. La interacción especie × año fue significativa para el rendimiento de materia seca, altura de la planta y cobertura, pero no fue significativa para la relación hoja/tallo. El valor nutricional [cenizas, fibra detergente ácida (FDA), proteína cruda (PC) y digestibilidad in vitro de la materia

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seca (DIVMS)] fue significativamente diferente entre las especies, sin diferencias para la fibra detergente neutra (FND) y la lignina detergente ácida (LDA). Todas las especies mostraron potencial como alimento alternativo para rumiantes, siendo *U. mutica* y *U. brizantha* las de mayor rendimiento en el ambiente subhúmedo.

Palabras clave: Altura de la planta, calidad, especies de pastos, relación hoja-tallo, rendimiento de materia seca.

Introduction

Feed shortages in quantity and quality are a recurrent challenge to cattle production and productivity in tropical Africa. In Ethiopia's highland crop-livestock mixed farming system, the availability of year-round feed is limited (FAO 2018; Feyissa et al. 2022; Mekonnen et al. 2022). The combination of feed scarcity and low feed quality makes it difficult to meet the maintenance requirements for livestock throughout the year (Feyissa et al. 2022). Currently, pressures from climate change exacerbate these long-standing feed problems (Habte et al. 2022). Introducing improved forages in such systems has been proposed to offer alternative good-quality feeds to improve livestock productivity and close feed gaps (Feyissa et al. 2022).

Urochloa includes many tropical grass species that originated on the African continent and are extensively grown in tropical Latin America and South Asia (Cheruiyot et al. 2020). Although there are over 100 species in this genus, many are underutilized and only a few, such as *Urochloa brizantha* (syn. *Brachiaria brizantha*) (A. Rich.) Stapf (palisade grass), *U. decumbens* (syn. *Brachiaria decumbens*) Stapf (signal grass) and *U. humidicola* (syn. *Brachiaria humidicola*) (Rendle) Schweick (Koronivia grass) are commercially exploited as forage crops (Miles et al. 2004). Recently, improved *Urochloa* grass has been introduced and cultivated by thousands of farmers in eastern Africa to provide alternative high-quality feed resources for livestock producers (Cheruiyot et al. 2020; Maina et al. 2020).

In addition to providing better quality, *Urochloa* grasses show adaptability to a wide range of agroecology and soil types (Cheruiyot et al. 2018). Their deep root systems allow them to extract nutrients and moisture, which helps them tolerate low soil fertility and dry spells in tropical regions (Ndayisaba et al. 2020). They also contribute to carbon sequestration, enhanced nitrogen use efficiency via biological nitrification inhibition (BNI), effective soil erosion control and management of crop pests through push-pull pest management techniques (Arango et al. 2014; Moreta et al. 2014; Rao et al. 2014). *Urochloa* grasses have shown promising results in improving livestock productivity through better quality and higher biomass (Maina et al. 2020).

Currently, there is interest in evaluating the adaptability and performance of *Urochloa* grass species under climatic conditions for the highland smallholder livestock producers of Ethiopia. Comparative yield evaluation of *Urochloa* with other important grass species was identified as the main research approach to demonstrate the suitability of forages for wider adoption in Ethiopia (Feyissa et al. 2022). In the present study, the agronomic performance of four *Urochloa* species [*U. mutica* (DZF-483), *U. decumbens* 'Basilisk' (DZF-10871), *U. brizantha* (DZF-13379), and *U. humidicola* (DZF-9222)], and 2 other grass species [Desho grass (*Pennisetum glaucifolia* Kindu kosha) and Rhodes grass (*Chloris gayana* 'Massaba')] was evaluated to compare the growth, herbage accumulation, and nutritive value in the highlands of central Ethiopia.

Materials and Methods

The experiment was conducted during the main rainy season from 2020 to 2022 at the Debre Zeit Agricultural Research Center (Bishoftu) (08º 44' N, 38º38' E; elevation 1,900 masl) in the sub-humid agroclimatic zone of Central Ethiopia. The center is 47 km East of Addis Ababa, on the road to Adama. The soil type (Tafesse and Esayas 2003) for the experimental plots was Eutric Vertisols.

Four *Urochloa* species [*U. brizantha* (DZF-13379), *U. humidicola* (DZF-9222), *U. decumbens* 'Basilisk' (DZF-10871) and *U. mutica* (DZF-483)] were compared to Desho grass (*Pennisetum glaucifolia* Kindu kosha) and Rhodes grass (*Chloris gayana* 'Massaba'). *Urochloa* species were selected based on their superior performance from earlier trials, while a recently released local variety of Desho grass and Rhodes grass, a popular grass species, were used for comparison.

The experiment was conducted using a completely randomized block design with 3 replicates. Vegetative root splits of 12 month age were transplanted using 2–3 splits per hole at a depth of 10 cm in mid-June

2020 under rainfed conditions without supplementary irrigation in well-prepared 12 m^2 plots with 50 cm between row and 25 cm within row spacing. Nitrogen and phosphorus fertilizers were applied at the rate of 18 kg N/ha and 46 kg P/ha (as DAP), and 46 kg N/ha as urea at transplanting and immediately after each harvest in a band along the planting furrow. Weed management and regular monitoring of disease and insects were performed as appropriate.

Data Collection

Dry matter (DM) yield, plant height, plot cover and leaf-to-stem ratio were measured during the rainy season (June–Sept). The first harvest was carried out 3 months after establishment in the first year (2020) and at intervals of 60 days (2 cuts/rainy season) in 2021 and 2022. Plant height from the soil surface to the uppermost point of the stem was measured on 5 randomly selected plants/plot and expressed as a mean. Visual observation for plot cover was rated on a 1–10 scale (where 1=poor and 10=excellent). The leaf-to-stem ratio was determined by cutting plants from 2 randomly selected consecutive rows and separating by hand into leaf (lamina) and stem (leaf sheath+stem). Samples of each plant part were weighed, homogenized and subsampled and dried in a forced draft oven at 65 °C for 72 h. Fresh herbage yield was sampled by cutting the entire plot at a stubble height of 10 cm by hand using a sickle and weighing immediately. A subsample of 300 g of freshly harvested biomass was cut into small pieces and dried at 65 °C for 72 h in an oven to calculate dry matter yield as:

$$\text{DM yield (t/ha)}=(10\times TFW\times SSDW)/(HA\times SSFW),$$

where:

TFW is the total fresh weight of the harvested area (kg);
SSDW is the subsample dry weight (g);
HA is the harvest area (m^2);
SSFW is the subsample fresh weight (g).

A sample of 400 g from each treatment was collected at harvest and dried under the shade for laboratory analysis. Nutritional analyses of feed samples were performed at the Bishoftu Agricultural Research Center Food and Nutrition Laboratory and Holetta Agricultural Research Center Animal Feed and Nutrition Laboratory. Grass samples were dried at 105 °C overnight and ground to pass through a 1 mm sieve. The total ash content was determined in a furnace at 550 °C for 6 h. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined according to Van Soest and Robertson (1985). Nitrogen (N) was determined using the Kjeldahl method and in vitro dry matter digestibility (IVDMD) was determined using the modified Tilley and Terry method (Tilley and Terry 1963).

Statistical analysis

The Linear mixed-effect model (LME) approach was used to analyze the forage yield and nutritive value data using the 'lme4' package (Bates et al. 2015) in R. Pasture species, year and interaction of pasture and year were considered as fixed effects and the effects of plots within replicated blocks were included as random effects of the model. Harvesting years were included as repeated measures because they were measured from the same plot. Mean comparisons of the effects were performed using the 'lsmeans' package (Lenth 2016) in R for the cultivar across years. Nutritive value was separately analyzed using one-way ANOVA to determine significant differences among the pasture species. The statistical model used was:

$$Y_{ijkx}=\mu+C_j+Y_x+(C_j\times Y_x)+\varepsilon_{ijkx},$$

where:

Y_{ijkx} is the response variable;
μ is the overall mean;
C_j is the effect of jth grass cultivar;
Y_x is the effect of jth year;
$C_j\times Y_x$ is the interaction between cultivar and year;
e_{ijxk} is the random error.

Tukey's honestly significant difference post hoc test was used to separate significant differences between pasture species.

Results

Average annual rainfall for the experimental years (2020–2022) was 814.8 mm with a long-term mean (1990–2020) of 473.2 mm (Table 1). Compared with the long-term climatic data, the trial period had higher rainfall, especially during the Kiremt season (June to September), the main rainy season in Ethiopia.

Effects of species, year and their interaction on agronomic traits.

A combined analysis of variance for DM yield, plant height, plot cover and leaf-to-stem ratio on dry matter basis of the four *Urochloa* species, Rhodes grass and Desho grass showed there was significant variation among species (P<0.01) for DM yield, plant height, plot cover and leaf-to-stem ratio (Table 2). Significant (P<0.05) species × year interactions were observed for all the parameters except for leaf-to-stem ratio dry basis.

The combined analysis indicated significant differences in forage dry matter yield among species (Table 3). *U. mutica* followed by Desho grass had the highest DM yield, but they did not differ significantly from other species, except for *U. humidicola*. Variation among species in experimental periods was also significant except for 2021. Low dry matter yields were observed during the establishment year compared to 2021 and 2022.

Table 1. Mean rainfall and temperature variation over the trial years and long-term (1990-2020).

Months of the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall, trial years (mm)	5.9	4.8	28.3	39.2	71.4	117.5	217.9	213.9	96.0	19.4	0.0	0.4
Rainfall, long-term mean (mm)	7.5	10.7	34.6	29.6	29.4	65.3	129.9	107.4	42.5	8.2	3.5	4.6
Mean daily min temperature trial years (°C)	7.2	8.5	10.3	11.7	11.1	11.5	11.5	11.1	10.4	7.0	5.2	5.1
Mean daily max temperature trial years (°C)	26.6	27.7	29.2	29.4	28.1	26.4	21.3	22.3	23.2	24.3	24.3	24.6
Mean daily min temperature long-term (°C)	9.3	10.4	11.8	13.2	12.9	12.6	13.5	13.5	12.5	9.3	7.8	7.5
Mean daily max, temperature long-term (°C)	26.7	28.0	28.9	28.9	29.2	27.9	25.0	24.4	25.4	29.2	26.2	25.8

Table 2. Species, year and their interaction effects on agronomic traits in Bishoftu.

Parameters	Species	Year	Species × Year
DM yield (t/ha)	**	***	**
Plant height (cm)	***	**	***
Plot cover	***	**	***
Leaf-to-stem ratio dry basis	**	ns	ns

ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.

Table 3. Dry matter yield of grass species tested for 3 years at Bishoftu.

Species	Dry matter yield (t/ha)			
	2020	2021	2022	Combined analysis
U. brizantha (DZF-13379)	2.61[b]	14.53	17.23[a]	11.46[ab]
U. humidicola (DZF-9222)	2.13[b]	11.6	11.98[ab]	8.57[b]
U. decumbens (DZF-10871)	4.38[ab]	15.75	13.44[ab]	11.19[ab]
U. mutica (DZF-483)	6.72[ab]	17.02	16.96[a]	13.57[a]
Rhodes grass ('Massaba')	8.52[a]	14.97	9.84[b]	11.11[ab]
Desho grass (Kindu kosha)	8.66[a]	17.2	12.97[ab]	12.94[a]
Mean	5.03	15.18	13.74	11.47
SEM	1.38	1.38	1.38	0.83

Means with different letters are significantly different. SEM=standard error of the mean.

The combined analysis indicated that *U. mutica* was the tallest (P<0.05) followed by Rhodes grass and *U. brizantha* (Table 4). Species varied significantly across all the experimental periods. Low plant height was observed in *U. humidicola* throughout the experimental period.

The combined analysis indicated that *U. mutica*, Desho, *U. brizantha*, and *U. decumbens* had higher plot cover than *U. humidicola* and Rhodes grass (Table 5). There was also significant variation in plot cover among the species across the experimental period.

Nutritional Value

Ash, ADF, CP and IVDMD were significantly different (P<0.05) among species, while NDF and ADL were not significantly different (Table 6).

Table 4. Plant height (cm) of grass species tested for 3 years at Bishoftu.

Species	Plant height (cm)			
	2020	2021	2022	Combined analysis
U. brizantha (DZF-13379)	96^{bc}	99^{b}	94.5^{a}	96.5^{b}
U. humidicola (DZF-9222)	75^{d}	83.5^{c}	79.2^{b}	79.8^{d}
U. decumbens (DZF-10871)	92^{bcd}	100.7^{b}	80.5^{b}	91.1^{bc}
U. mutica (DZF-483)	132.7^{a}	116.5^{a}	99.3^{a}	116.2^{a}
Rhodes grass (‘Massaba’)	107^{b}	99^{b}	88.5^{ab}	98.2^{b}
Desho grass (Kindu kosha)	84.7^{cd}	81.8^{c}	90.8^{ab}	85.8^{cd}
Mean	97.9	96.75	88.8	94.6
SEM	4.68	4.68	4.68	2.28

Means with different letters are significantly different. SEM=standard error of the mean.

Table 5. Plot cover and 3 year mean leaf-to-stem ratio on a dry matter basis of grass species tested for 3 years at Bishoftu.

Species	Plot cover				Three year mean leaf-to-stem ratio[1]
	2020	2021	2022	Combined analysis	
U. brizantha (DZF-13379)	6^{b}	8^{ab}	9^{a}	7.67^{a}	0.92^{a}
U. humidicola (DZF-9222)	6^{b}	7^{a}	7.3^{bc}	6.78^{b}	0.91^{a}
U. decumbens (DZF-10871)	6^{b}	8.7^{a}	8^{abc}	7.56^{a}	0.96^{a}
U. mutica (DZF-483)	7.7^{a}	8.3^{a}	8.3^{ab}	8.11^{a}	0.87^{a}
Desho grass (Kindu kosha)	7^{ab}	8.7^{a}	7.7^{bc}	7.78^{a}	0.87^{a}
Rhodes grass (‘Massaba’)	7^{ab}	8.3^{a}	7^{c}	7.44^{b}	0.72^{b}
Mean	6.6	8.2	7.9	7.6	0.83
SEM	0.32	0.32	0.32	0.27	0.07

[1]Leaf-to-stem ratio presented as 3 year mean (no species × year interaction); Means with different letters are significantly different; SEM=standard error of the mean.

Table 6. Nutritional value of perennial forage grass species evaluated in Bishoftu.

Species	Ash%	NDF%	ADF%	ADL%	CP%	IVDMD%
U. brizantha (DZF-13379)	7.96[b]	73.4	43.9[ab]	10.58	12.73[a]	54.2[b]
U. decumbens (DZF-10871)	9.66[ab]	73.1	43.4[ab]	10.01	10.23[ab]	51.4[bc]
U. humidicola (DZF-9222)	11.98[a]	70.6	41.1[ab]	9.18	12.93[a]	57.8[a]
U. mutica (DZF-483)	9.04[ab]	76	38[b]	8.6	12.43[a]	52.6[b]
Desho grass (Kindu kosha)	8.91[ab]	73.7	43.9[ab]	9.79	8.27[b]	54.6[ab]
Rhodes grass ('Massaba')	8.69[b]	77.1	48.3[a]	9.79	9.43[ab]	48.6[c]
Mean	9.37	73.98	43.1	9.66	11	53.2
SEM	1.14	2.53	1.88	2.06	0.78	1.27

NDF=neutral detergent fiber; ADF=acid detergent fiber; ADL=acid detergent lignin; CP=crude protein; IVDMD=In vitro dry matter digestibility. Means with different letters are significantly different. SEM=standard error of the mean.

Discussion

The occurrence of species × year interactions for agronomic traits was expected because of climatic variation between the test years. There was a change in the ranking order of grass species over the years owing to the nonuniformity of growing conditions (rainfall, temperature) during the experimental period. These results agree with those of Wassie et al. (2018), who reported significant species × accession × year interactions. All species were able to persist throughout the dry season from year to year.

Given the feed supply challenges faced by smallholders in mixed crop-livestock systems, cultivating *Urochloa* grasses can alleviate feed shortages (Midega et al. 2018). This study showed they are capable of producing a similar herbage yield to the naturally occurring pasture Desho grass and higher yield than the commonly used Rhodes grass. They can be easily integrated into cropping systems, providing additional benefits such as soil conservation and land rehabilitation (Cheruiyot et al. 2018a; Horrocks et al. 2019; Damene et al. 2020). *Urochloa* grasses are adaptable to rainfed conditions, enabling farmers to produce surplus feed during the growing season that can be stored for use during periods of scarcity (Cezário et al. 2015).

The results confirmed the high forage yield of *U. mutica* (DZF-483) in sub-humid environments, as reported previously by Assefa et al. (2016) and Bantihun et al. (2022). Dry matter yield of *U. mutica* (DZF-483) obtained for 2022 (16.96 t/ha) was higher than the 13.3 t/ha reported during variety registration (Assefa et al. 2016) and also higher than 11.8 t/ha reported in the northwest highlands of Ethiopia by Bantihun et al. (2022). *U. decumbens* 'Basilisk' dry matter yields (11.26 t/ha) were comparable with the results of Faji et al. (2022), who reported 11.40 t/ha in Holetta, Ethiopia. *U. brizantha* (DZF-13379) displayed increasing forage dry matter yield each year, indicating the potential and importance of this cultivar as a candidate variety for registration (unpublished data). Dry matter yield of *U. brizantha* of 11.2 t/ha was higher than yields of 5.09 t/ha reported for other *U. brizantha* ecotypes grown in Northwestern Ethiopia (Wassie et al. 2018). *U. humidicola* had the lowest yield but has additional advantages such as restoration ability when established on degraded lands (Damene et al. 2020).

Dry matter yield of Desho grass was lower than those reported in other studies at higher altitudes in Ethiopia (Asmare et al. 2017; Faji et al. 2022). This is supported by Mengistu et al. (2024), who indicated that the origin of Desho grass was highland and mid-elevation areas and that highland environments were better for the growth and development of Desho grass. Rhodes grass ('Massaba') dry matter yields were much lower than those reported by Faji et al. (2022) under supplementary irrigation in Holetta. This difference could be due to weather, soil type and irrigation.

All species had CP concentrations greater than 7%, meeting the minimum crude protein requirements for the synthesis of microbial proteins in the rumen needed to support the maintenance requirements of ruminants (Van Soest 1994). *U. humidicola*, *U. brizantha* and *U. mutica* were classified as medium protein feed sources and the remaining species were categorized as low-protein feed sources using the classification of Lonsdale (1989). CP concentrations of *U. mutica*, *U. decumbens*, Desho, and Rhodes grass were higher than those reported by Bantihun et al. (2022) and Faji et al. (2022).

Ash ranged from 8–12%, which is in agreement with the report of Wassie et al. (2018). NDF was higher than the values (65%) for tropical grasses reported by (Van Soest 1994), classifying them as a low-quality roughage. The variable ADF reported may be due to the different grass genotypes and species. Faji et al. (2022) reported that the nutritive value can vary with genotype, harvesting stage and environment. *U. humidicola* is more digestible than the other perennial grass species evaluated, although IVDMD showed a decline with an increase in NDF, ADF and ADL. This could be attributed to lignin deposition in the cell wall and an increased proportion of stem in the forage with ageing. Results for nutritive value of *U. decumbens*, Desho grass and Rhodes grass in the current study were higher than those reported by Faji et al. (2022). Differences between these results and those of other studies are probably due to the differences in the edaphic, climatic, and biotic conditions of the study environment as well as the maturity stage at harvest, management and supplementary irrigation.

Conclusions

The *Urochloa* grasses compared well with other grasses evaluated in this study with the potential to produce forage with good nutritive value and serve as alternative options for smallholders in rainfed sub-humid environments in Central Ethiopia. These grasses demonstrated optimal organic matter digestibility and remarkably high crude protein (CP) concentration, making them excellent forage supplements in systems where crop residues are the primary feed resource. *U. mutica*, followed by *U. brizantha*, may be particularly recommended due to their higher biomass production and adequate forage nutritive value. Further studies should be conducted on the performance of animals fed these grasses as a basal diet to make feeding recommendations to livestock producers in the area.

Acknowledgments

The authors thank the Ethiopian Institute of Agricultural Research for its financial support. The authors are also grateful to the technical and field assistants of the Forage and Pasture Research Program, Debre Zeit Agricultural Research Center for their support during the fieldwork and Debre Zeit and Holetta laboratory technicians and researchers working in animal nutrition for their support during laboratory analysis.

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(Note of the editors: All hyperlinks were verified 10 September 2024).

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(Received for publication 11 August 2023; accepted 29 August 2024; published 30 September 2024)

Tropical Grasslands-Forrajes Tropicales (2024) Vol. 12(3):162–172
doi: 10.17138/TGFT(12)162-172

Artículo Científico

Desempeño de dos accesiones de *Urochloa humidicola* manejadas bajo pastoreo rotacional en el Nordeste Antioqueño (Colombia)

Performance of two accessions of Urochloa humidicola *managed under rotational grazing in the Antioquian Northeast (Colombia)*

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Resumen

La actividad ganadera en el neotrópico se desarrolla mayormente en suelos ácidos y de baja fertilidad, y la *Urochloa humidicola* es una alternativa de pasto tropical perenne para esas condiciones. El objetivo de este estudio fue comparar la respuesta forrajera y animal de las accesiones *U. humidicola* CIAT-16886 versus CIAT-679, bajo un sistema de pastoreo rotacional en el Nordeste Antioqueño colombiano. Entre agosto 2016 y octubre 2017, en el Centro de Investigación El Nus (Agrosavia), en un área de 5 ha por accesión, se evaluó la biomasa, altura de planta (AL), cobertura (CO), contenidos de proteína cruda (PC) y fibra detergente neutro (FDN), digestibilidad *in situ* de la materia seca (DISMS), asignación de forraje (AF), y ganancia de peso acumulada (GPA) y por ciclo de pastoreo (GPC), utilizando ganado de raza Blanco Orejinegro (BON). Se utilizaron modelos lineales generalizados mixtos para analizar los datos. Se observaron diferencias ($P<0.05$) entre las accesiones de forraje para las variables AL, biomasa, CO, PC, y AF, mientras que no hubo diferencias entre ellas para las variables FDN y DISMS. Para la GPA, se observó significancia ($P=0.033$) para la interacción Accesión × Sexo, donde las hembras pastoreando la accesión CIAT-679 presentaron una mayor ganancia de peso, mientras que en el caso de los machos no se observaron diferencias significativas entre accesiones. La accesión CIAT-679 presentó mejor desempeño en variables agronómicas y ganancia de peso, por lo cual podrá seguir siendo recomendada para su uso en sistemas de manejo racional del pastoreo en condiciones similares a las de este estudio.

Palabras clave: Biomasa forrajera, bovinos de carne, calidad nutritiva, ganancia de peso, raza Blanco Orejinegro (BON).

Abstract

Livestock activity in the neotropics is carried mainly on soils characterized as acidic and of low fertility, and *Urochloa humidicola* is a perennial tropical grass option for use in such conditions. The objective of this study was to compare the forage and animal performance of the accessions *U. humidicola* CIAT-16886 versus CIAT-679 managed under rotational grazing systems in the northeastern region of Antioquia, Colombia. Between August 2016 and October 2017, at El Nus Research Center (Agrosavia), in a 5 ha area for each accession, biomass availability, plant height (PH) and cover (CO), the contents of crude protein (CP) and neutral detergent fiber (NDF), the *in situ* dry matter digestibility (ISDMD), the forage allocation (FA), and the cumulative (CLWG) and by cycle (LWGpC) live weight gain were measured, using cattle of the local Blanco Orejinegro (BON) breed. Generalized linear mixed models were used

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for data analysis. Significant differences ($P<0.05$) between both grass accessions were detected for forage biomass availability, PH, CO, CP and FA; whereas no differences between accessions were detected for NDF and ISDMD. A significant interaction between Accessions × Sex ($P=0.033$) was observed for CLWG, with females showing a higher LWG when grazing the CIAT-679 accession, while no significant differences between accessions were detected with males. Accession CIAT-679 showed a better performance for several agronomic variables and cattle live weight gain; hence, it could still be recommended for rational grazing systems under similar conditions to the ones of this study.

Keywords: Beef cattle, BON breed, forage biomass, live weight gain, nutritive value.

Introducción

Muchas de las ganaderías de carne en el trópico están caracterizadas por establecerse en suelos con pH ácido, niveles altos de aluminio en todos los horizontes del suelo, y baja disponibilidad de nutrientes y materia orgánica debido a la alta solubilidad del aluminio presente en estos suelos. Esto, sumado a un deficiente manejo de las praderas y baja persistencia de las especies forrajeras introducidas, resulta en una baja productividad animal (Cruz-López et al. 2011).

Una de las estrategias utilizadas para incrementar la ganancia de peso por animal y por hectárea, es el uso de forrajes mejorados y agronómicamente adaptados a los diferentes sistemas ganaderos, capaces de aumentar la masa forrajera y proporcionar mayor valor nutricional. Los pastos del género *Urochloa*, principalmente la especie *Urochloa humidicola*, se presentan como alternativas para estos suelos ácidos y de baja fertilidad (Bastidas et al. 2023).

U. humidicola es una especie que ha mostrado excelente capacidad de adaptación a diferentes condiciones edafoclimáticas, buen rendimiento (7–34 ton/ha/año), mediano valor nutricional en términos de proteína cruda (PC) (5–13%) y digestibilidad de la materia seca (DMS) (51–67%), lo cual es dependiente del manejo que se le dé a la pastura (Reyes-Purata et al. 2009; Avella 2018; Rincón et al. 2018). Además, *U. humidicola* puede soportar alta carga animal en época lluviosa y seca (3.6 y 2.0 UA/ha, respectivamente) (Montenegro et al. 1995). El aporte de biomasa de esta forrajera es dependiente de la frecuencia de corte y época de cosecha (Pérez y Lascano 1992; Keller-Grein et al. 1996; Borgues et al. 2012).

Aunque la respuesta en productividad animal con *U. humidicola* no ha sido la más sobresaliente, mayormente debido a su bajo contenido de proteína con relación a otras especies del mismo género, las características de crecimiento y adaptación a condiciones de suelos ácidos y de baja fertilidad le confieren la capacidad de desarrollar alta cobertura y mayor enraizamiento, ayudando a prevenir la erosión del suelo, factor prevalente en los sistemas ganaderos manejados en condiciones de ladera (Canchila et al. 2011; Hernández y Cruzate 2020). Es más, el comportamiento de la especie estará influenciado por condiciones tales como la carga animal (1.7–4.0 animales/ha), frecuencia de pastoreo (21–90 días), época de evaluación (seca vs lluviosa), método de pastoreo (e.g. rotacional, continuo, alterno, racional), el asocio con leguminosas y el tipo de animales que pastorean, sean estos de cría, levante o ceba (Gonzáles et al. 1997; Villegas et al. 2022).

En evaluaciones agronómicas de diferentes accesiones de *U. humidicola*, realizadas en la región Santandereana y el Magdalena Medio de Colombia sobresalieron las accesiones CIAT-16867, CIAT-16888 y CIAT-16886, destacando esta última por presentar un rendimiento de materia seca alto, mayor proporción de hojas y buen contenido de proteína cruda, por lo que se considera un pasto atractivo para sistemas ganaderos del trópico colombiano medio y bajo (Canchila et al. 2011).

Se ha realizado estudios en la sabana del piedemonte llanero para la accesión CIAT 679 de *U. humidicola* (pasto aguja) en términos de respuesta animal con bovinos de levante (Bastidas et al. 2023), y con frecuencia ha sido empleada como testigo comercial en varios estudios, reportado ganancias diarias de peso (GDP) entre 150–740 g/animal, y niveles de productividad entre 200 y 700 kg de carne/ha/año.

Por lo anterior, el objetivo de este trabajo fue evaluar y comparar la productividad forrajera y animal de la accesión *U. humidicola* CIAT-16886 identificada como promisoria en estudios agronómicos previos versus el testigo *U. humidicola* CIAT-679 (pasto aguja), manejados bajo condiciones de pastoreo rotacional en ladera en el Nordeste Antioqueño.

Materiales y Métodos

Localización

El experimento se realizó entre los meses de agosto del 2016 y octubre del 2017, en un área experimental denominada "Himalaya" dentro del Centro de Investigación (C. I.) El Nus de Agrosavia, en San Roque, Antioquia, Colombia (6° 29' 0.677634" N 74° 50' 34.066002" W), en selva tropical (AF, clasificación internacional de Köppen). Esta región tiene una precipitación media anual de 2,200 mm, temperatura media de 24.1±7.1 °C, y altitud de 842 m.s.n.m. Los meses de mayor precipitación son mayo, junio, agosto, septiembre, octubre, mientras que el periodo seco se presenta en los meses de enero, febrero, abril, y cada mes corresponde en su orden a un ciclo de pastoreo relacionado (julio 2016–primer ciclo, hasta septiembre 2017–15º ciclo) (Figura 1).

Descripción de las condiciones experimentales iniciales

La accesión CIAT-679 de *U. humidicola* se utilizó como testigo comercial en comparación con la accesión CIAT-16886. El establecimiento de las parcelas se realizó en el año 2015, en un área experimental de 10 ha para las dos accesiones. El área experimental presentó una pendiente promedio del 45%, con suelos de textura arcillo-arenosa (Ar-A) y franco-arenosa (38, 18 y 45% para arcilla, limo y arena, respectivamente), pH ácido (4.9), con saturación de aluminio del 15%, concentración de P menor a 3.5 ppm y Ca, Mg y K de 2.2, 1.0 y 0.14 cmol/kg, respectivamente, y un contenido promedio de MO de 2.6%.

Se establecieron dos parcelas de 5 ha cada una, conteniendo las accesiones CIAT-679 y CIAT-16886. Ambas se sembraron de manera simultánea con una densidad de 40.000 plantas por hectárea, realizando una fertilización de establecimiento con roca fosfórica (200 kg/ha), y una corrección edáfica con cal dolomítica de 500 kg/ha. Después de un año del establecimiento, las 5 ha de cada accesión fueron divididas en 15 franjas de aproximadamente 3.300 m^2 cada una. Para el control de *Aeneolamia* sp. se utilizó Engeo® (Tiametoxam y Lambdacihalotrina) a 200 ml/ha. Para las arvenses de hoja ancha se usó Tordon® (Aminopyralid + 2.4-D) (400–3000 ml/ha) y Roundup® (glifosato) (1.5–5 L/ha) para las arvenses de hoja angosta.

Animales y su manejo

El experimento tuvo una duración de 405 días, correspondiente a 15 ciclos de pastoreo (CP), bajo un sistema de pastoreo rotacional de 26 días de descanso (PD) y 2 días de ocupación (PO) en ambas accesiones evaluadas. Para cada accesión se utilizó 5 novillos y 8 hembras de la raza Blanco Orejinegro (BON), con edad y peso inicial promedio de 17.4±1.5 meses y 221.6±23 kg, resultando en una carga animal inicial promedio por sistema de 572±4.52 kg PV/ha y terminando el periodo experimental la carga fue de 884±9.47 kg PV/ha para ambos sistemas.

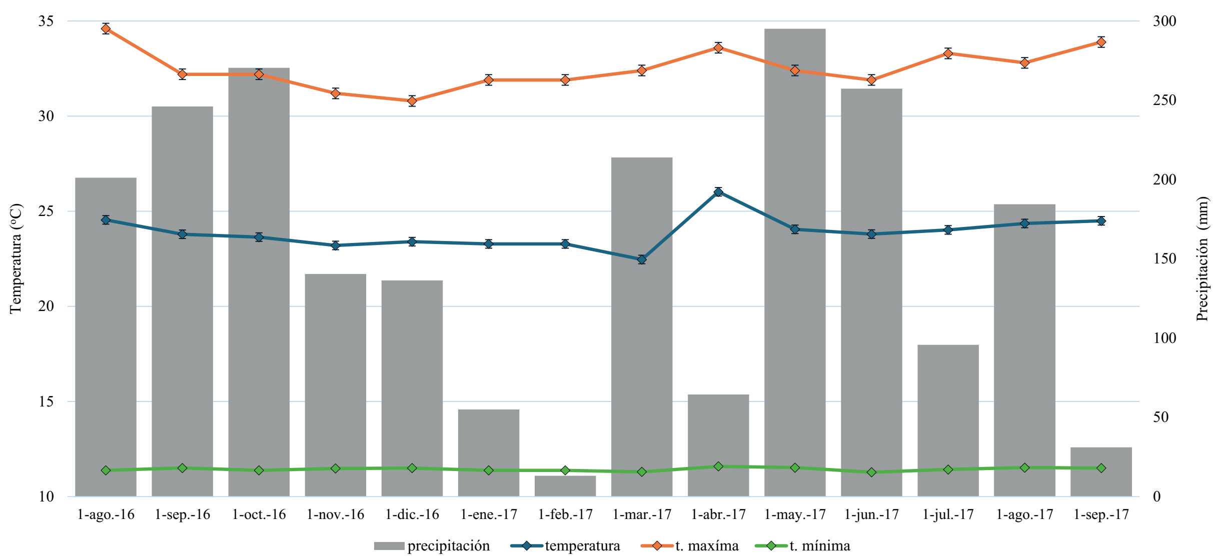

Figura 1. Precipitación y temperaturas registradas durante la ejecución del experimento en el lote Himalaya, Centro de Investigación El Nus de Agrosavia, en San Roque, Antioquia, Colombia.

Variables del forraje

Para cada ciclo de pastoreo, el día anterior al ingreso de los animales, se estimó la masa de forraje en kg de forraje verde (FV) y materia seca (MS) por hectárea, utilizando el método de rendimiento comparativo descrito por Haydock y Shaw (1975). Se utilizaron 5 cuadrantes de 0.25 m^2 definidos como puntos de referencia (SP) y un rango de 40 cuadrantes definidos como puntos visuales (VP), acorde a lo descrito por Valencia-Echavarría et al. (2022). El corte del forraje se realizó a 5 cm sobre el suelo. La estimación de la disponibilidad de forraje verde en kg MS/ha se realizó a partir de un modelo de regresión lineal entre SP y VP (Balehegn y Berhe 2016). Luego, se estimó la biomasa seca de forraje (kg MS/ha) a partir del contenido promedio de materia seca (%MS) determinado en muestras tomadas en cada SP, utilizando para el secado de las muestras una estufa de aire forzado a 60 °C, durante 72 horas.

Para determinar la cobertura (CO) en por ciento de las especies presentes en cada sistema evaluado, se evaluó la composición botánica, tanto en los puntos de referencia (SP) como en los puntos visuales (VP), utilizando el método del rango en peso seco (Mannetje y Haydock 1963). La altura del dosel vegetal (AL) fue medida utilizando un "sward stick", siguiendo el procedimiento descrito por Valencia-Echavarría et al. (2022) con 150 mediciones por potrero dentro de cada sistema.

El nivel de asignación de forraje (AF) en cada ciclo de pastoreo (CP) fue estimado como la relación a la masa de forraje seco disponible (MF) y la carga animal (CA), ambos expresados en kilos por hectárea, utilizando la ecuación descrita por Savian et al. (2014) con algunas modificaciones: AF (kg MS/100 kg PV)=(MF/CA)×100

Al finalizar cada ciclo se tomó una submuestra seca de aproximadamente 500 g de cada accesión para el análisis de proteína cruda (PC) y fibra en detergente neutro (FDN), la cual fue cuantificada usando NIRS con ecuaciones desarrolladas con muestras de forrajes de uso común en Colombia (Ariza-Nieto et al. 2018). La digestibilidad *in situ* de la materia seca (DISMS) se determinó utilizando la técnica de la bolsa de nailon (Giraldo et al. 2008), en un período de incubación en rumen de 48 horas. Esas determinaciones se hicieron usando 4 novillos fistulados de la raza Romosinuano, los cuales eran alimentados con forrajes tropicales similares a los evaluados.

Productividad animal

El peso vivo de cada animal fue medido con una báscula digital al inicio y final de cada ciclo de pastoreo, en cada pastura bajo evaluación. La medición siempre fue realizada en horas de la mañana, sin ayuno previo, permitiendo que los animales tuvieran un reposo de 60 minutos. Esta información se usó para calcular la ganancia de peso diaria (GDP) y por ciclo (GPC), así como la ganancia de peso acumulada (GPA).

Análisis de datos

Todos los análisis estadísticos se realizaron en R versión 4.3.0 (R Core Team 2021). Para comparar las variables evaluadas en los pastos (AL, biomasa, CO, PC, FDN, DISMS y AF), así como cambios ocurridos a través del tiempo, se utilizaron modelos lineales generalizados con distribución normal, utilizando la función "lm" en R. Para cada variable se creó un modelo de rendimiento, el cual incluyó la accesión de forraje, el ciclo de pastoreo y la interacción entre ambos factores, así como la precipitación total durante cada ciclo de pastoreo.

Para evaluar el efecto del tipo de forraje sobre la ganancia de peso del ganado por ciclo (GPC) y acumulada (GPA), se utilizó modelos lineales generalizados mixtos (GLMM) con distribución normal utilizando el paquete glmmTMB (Brooks et al. 2024). Se crearon modelos para cada variable de ganancia de peso, en donde el modelo completo incluyó como efectos fijos la accesión de forraje, sexo de los animales y CP, así como la interacción de dos vías entre factores. Para tener en cuenta el diseño de mediciones repetidas del experimento, se incluyó un intercepto aleatorio para la identidad de los individuos y pendiente aleatoria para el ciclo de pastoreo (CP).

Para todos los modelos se evaluó la significancia de los términos con una prueba de razón de verosimilitud de X^2, utilizando la función "Drop1" en R. Se removieron los términos no significativos ($P>0.05$) y se comparó el ajuste del modelo completo y el reducido usando los valores AIC. Se realizaron contrastes post-hoc para los factores del modelo con ajuste de Tukey HSD utilizando la función "emmeans" del paquete emmeans (Lenth et al. 2024). Para revisar los supuestos de los modelos se usaron gráficas QQ de los residuales y residuales versus predichos usando el paquete DHARMa (Hartig y Lohse 2022).

Resultados

Rendimiento del forraje

El nivel de precipitación aparentemente no afectó las variables de rendimiento y calidad nutritiva, por lo que esta variable no se incluyó en los modelos finales.

El modelo con mejor ajuste para altura de planta (ALT) incluyó los efectos fijos de la accesión de forraje y el ciclo de pastoreo, los cuales fueron significativos (Cuadro 1). Ambas accesiones mostraron una tendencia a disminuir en altura a medida que avanzaba el experimento, pero la accesión CIAT-679 mostró una altura promedio mayor que la CIAT-16886 (t=3.98, DF=27, P=0.0005) a lo largo del experimento (Fig. 2A).

El modelo con mejor ajuste para la biomasa disponible incluyó los efectos fijos de la accesión de forraje y el ciclo de pastoreo (CP), así como la interacción entre ambos factores (Cuadro 1). En ambas accesiones, la biomasa disponible (kg MS/ha) tendió a incrementar a lo largo del experimento, sin embargo, la tasa de incremento fue significativamente mayor para la accesión CIAT-679 (55% por ciclo) que para la CIAT-16886 (31% por ciclo) (t=3.20, DF=26, P=0.0003) (Fig. 2B).

En cuanto a la cobertura (CO) del pasto, el modelo con mejor ajuste incluyó únicamente el efecto de la accesión (Cuadro 1), indicando que la cobertura de cada forraje prácticamente no cambió a lo largo del experimento, siendo la accesión CIAT-16886 la que mostró mayor cobertura (F=26.11, DF=1, P<0.0001) (Fig. 2C).

Para el contenido de proteína cruda (PC), el modelo que mejor se ajustó incluyó únicamente el efecto del ciclo de pastoreo, sin diferencias significativas entre accesiones (Cuadro 1). Esta variable mostró una tendencia a disminuir en ambos tipos de forraje a lo largo del experimento, con un promedio de reducción del 12% en cada ciclo con respecto al ciclo anterior (Fig. 1D). A su vez, para la fibra detergente neutro (FDN) el modelo con mejor ajuste incluyó únicamente el efecto de la accesión de forraje; sin embargo, no se detectó significancia para el efecto de las accesiones (Cuadro 1, Fig. 2E).

Cuadro 1. Resumen de los resultados de los modelos con mejor ajuste para las variables de rendimiento, calidad nutricional de forraje, y ganancia de peso para el ganado.

Variables	Efectos fijos retenidos en el modelo final	Prueba estadística, valor de P
Rendimiento y calidad nutritiva del forraje		
Altura (ALT)	Accesión de forraje	F_1= 15.84, P=0.0005
	Ciclo de pastoreo (CP)	F_1= 4.22, P=0.049
Biomasa disponible	Accesión de forraje	F_1= 17.69, P=0.0002
	Ciclo de pastoreo (CP)	F_1= 56.67, P<0.000$_1$
	Accesión de forraje × ciclo de pastoreo (interacción)	F_1= 4.25, P=0.049
Cobertura (CO)	Accesión de forraje	F_1= 26.11, P<0.0001
Proteína cruda (PC)	Ciclo de pastoreo	F_1= 6.56, P=0.016
Fibra en detergente neutro (FDN)	Accesión de forraje	F_1= 3.51, P=0.071
Digestibilidad in situ (DISMS)	Accesión de forraje	F_1= 3.28, P=0.08
Asignación de forraje (AF)	Accesión de forraje	F_1= 9.41, P=0.004
Ganancia de peso acumulada del ganado		
Ganancia de peso acumulada (GPA)	Accesión de forraje	X^2_1=19.56, P<0.0001
	Sexo individuos	X^2_1=1.454, P=0.228
	Ciclo de pastoreo	X^2_1=1303.2, P<0.0001
	Accesión de forraje × Sexo individuos (interacción)	X^2_1=4.55, P=0.033
Ganancia de peso por ciclo (GPC)	Accesión de forraje	X^2_1=0.775, P=0.379
	Sexo individuos	X^2_1=0.268, P=0.604
	Ciclo de pastoreo	X^2_1=0.284, P=0.594
	Accesión de forraje × ciclo de pastoreo (interacción)	X^2_1=6.766, P=0.009

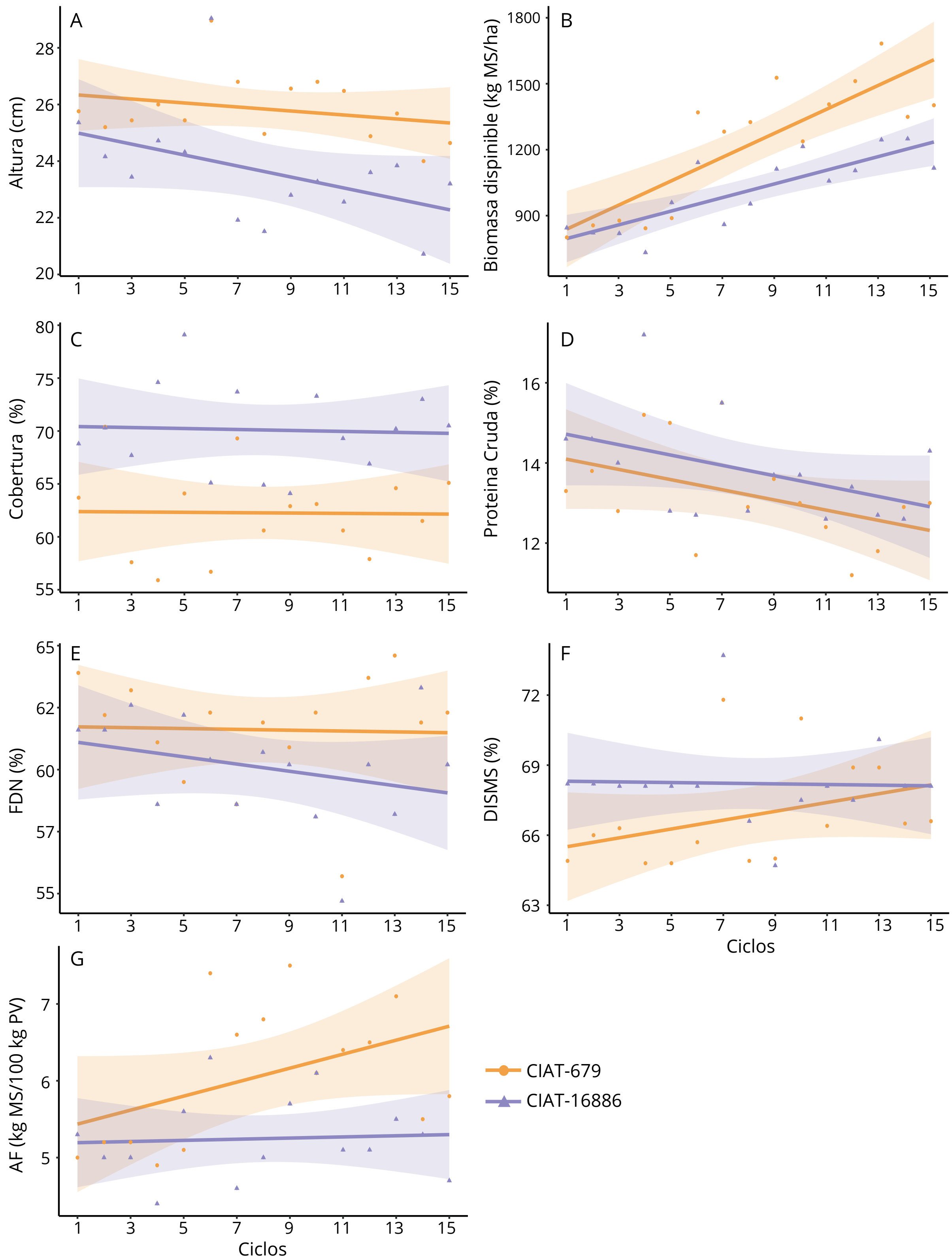

Figura 2. Variables de rendimiento de las dos accesiones de *U. humidicola*. **(A)** Altura del forraje; **(B)** Biomasa disponible; **(C)** Cobertura; **(D)** Proteína cruda; **(E)** Fibra detergente neutro (FDN); **(F)** Digestibilidad in situ de la materia seca (DISMS); **(G)** Nivel de asignación de forraje (AF).

Con relación a la digestibilidad in situ de la materia seca (DISMS), el modelo con mejor ajuste incluyó únicamente el efecto de la accesión de forraje (Cuadro 1), sin que llegara a ser significativo (P=0.08). Esta variable tampoco cambió de manera significativa a lo largo del experimento (Fig. 2F). Para la asignación de forraje (AF), el modelo con mejor ajuste incluyó únicamente el efecto de la accesión (Cuadro 1), donde la CIAT-679 mostró valores de AF significativamente mayores que la CIAT-16886 (F=9.41, DF=1, P=0.004) (Fig. 2G). A pesar que los valore de AF para la accesión CIAT-679 tendieron a incrementar a lo largo del experimento, el efecto de los ciclos de pastoreo no se retuvo en el modelo final, indicando que este factor no tuvo un efecto significativo sobre la variable AF.

Efecto sobre la ganancia de peso del ganado

El modelo con mejor ajuste para la ganancia de peso acumulada (GPA) incluyó el efecto de la accesión, el sexo del individuo, CP, y la interacción entre la accesión y el sexo del individuo (Cuadro 1); sin embargo, el efecto simple del sexo no alcanzó significancia (P=0.228). Al explorar la interacción entre la accesión de forraje y el sexo de los individuos, se encontró que las hembras tienen una GPA significativamente mayor con la accesión CIAT-679 en comparación con la accesión CIAT-16886 (t=4.727, DF=381, P<0.0001), mientras que para los machos no se presentaron diferencias significativas en GPA entre accesiones de forraje (t=1.35, DF=381, P=0.1778) (Fig. 3A-B).

En cuanto a la ganancia de peso por ciclo (GPC), el modelo con mejor ajuste incluyó la accesión, el ciclo de pastoreo (CP), el sexo de los individuos y la interacción accesión × ciclo de pastoreo (Cuadro 1); pero de todos estos, solamente la interacción fue significativa (P=0.009). Al explorar esta interacción, se encontró que la GPC tendía a incrementar con los ciclos de pastoreo en la accesión CIAT-16886, mientras que ocurrió lo opuesto con la accesión CIAT-679. Este efecto fue más evidente en el caso de las hembras (Fig. 3C-D).

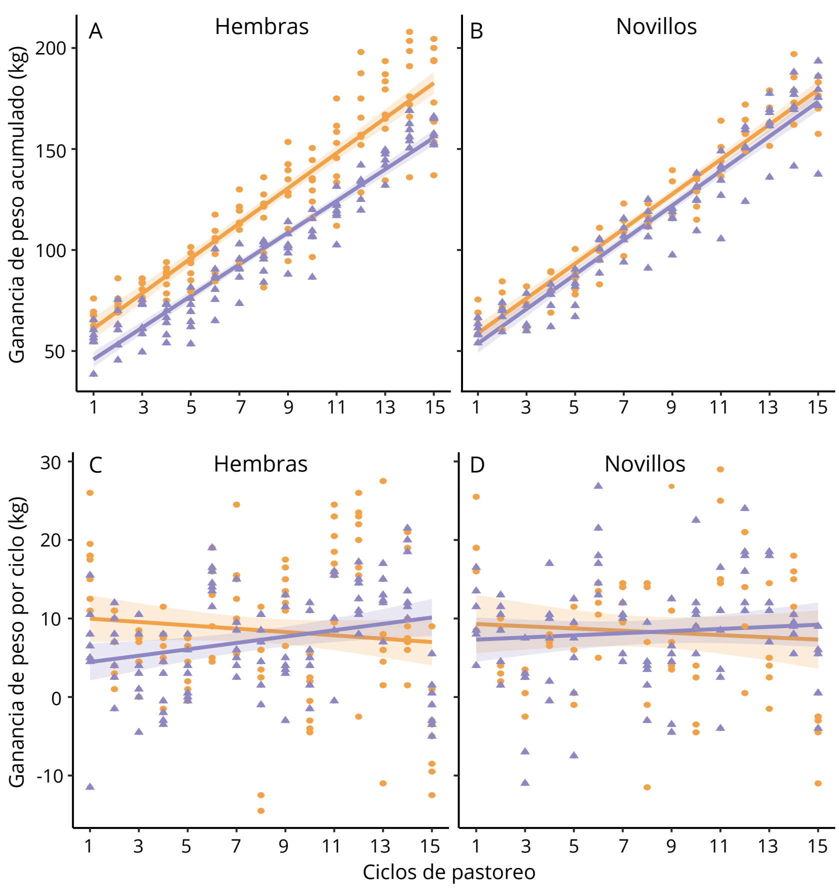

Figura 3. Ganancia de peso acumulada (GPA) para hembras **(A)** y novillos **(B)**; ganancia de peso por ciclo (GPC) para hembras **(C)** y novillos **(D)** de ganado Blanco Orejinegro manejados en rotación en potreros de las accesiones CIAT-679 y CIAT-16886 de *U. humidicola*.

Discusión

A la hora de escoger el forraje a utilizar en un sistema de pastoreo rotacional, es determinante tener en cuenta factores tales como su desempeño agronómico, así como el tiempo e intensidad de defoliación al cual será sometida la pastura. Además, es importante considerar los atributos relacionados con la composición química y la digestibilidad del forraje, ya que estos definen la calidad nutritiva del forraje (Avella 2018; Gomes et al. 2018).

Las pasturas de *U. humidicola* bien manejadas ofrecen un aporte constante de biomasa y estabilidad de la cobertura a través del tiempo, a pesar del desgaste que puede causar la defoliación frecuente ejercida por el ganado en sistemas de pastoreo rotacional (Rincón 2011; Laiton-Medina et al. 2021). En el caso particular de este estudio, la altura de ambas accesiones tendió a disminuir con los ciclos de pastoreo (Figura 2A) y la cobertura tendió a permanecer constante (Figura 2C); en cambio, la disponibilidad aumentó con el tiempo (Figura 2B), y eso resultó en un incremento constante en la ganancia de peso acumulada (GPA) por los animales (Figura 3A), lo cual confirma que el manejo rotacional aplicado en las pasturas fue adecuado.

Cabe anotar que los ciclos de pastoreo en que se presentaron los mayores niveles de disponibilidad correspondieron primero al mes con mayor temperatura (abril, ciclo 10º), seguidos de meses con mayor precipitación (mayo y junio, ciclos 11º y 12º), (Figura 1). Si bien se reconoce que la especie *U. humidicola* se adapta a condiciones extremas de sequía y anegamiento (Gonzáles et al. 1997; Borgues et al. 2012; Guevara 2022), eso no quita que la mayor temperatura y buenas condiciones de humedad favorezcan su crecimiento (Cruz-Hernández et al. 2017).

La composición nutricional y la cantidad de biomasa aportada por forrajes es altamente influenciada por las condiciones ambientales y el manejo que se aplica a las pasturas (Jarma-Orozco et al. 2014; Torres Salado et al. 2020; Guevara 2022). Por ejemplo, el contenido de proteína cruda (PC) tiende a ser más alta en los periodos húmedos, pero bajo las condiciones del estudio parece ser que la precipitación no fue limitante (Figura 1), y por eso la disminución en el contenido de PC a lo largo del ensayo fue relativamente pequeña (Figura 2D); es más, los valores de PC observados se consideran altos para la especie (Jarma-Orozco et al. 2014).

Los valores de FDN fueron altos, en promedio de 66.8% y 68.1% para CIAT-679 y CIAT-16886 respectivamente, lo cual es esperado en el caso de gramíneas tropicales (Lee 2018). Otros estudios realizados en condiciones similares con *U. humidicola* (Jarma-Orozco et al. 2014; Avella 2018; Villegas et al. 2022) reportan valores de FDN ligeramente menores (entre 64–66%), pero en dichos estudios los pastos fueron manejados bajo corte. En contraste, Vergara-López y Araujo-Febres (2006) encontraron valores más altos de FDN en *U. humidicola*, con edades de rebrote superiores y bajo condiciones de bosque seco tropical.

Las ganancias diarias por animal obtenidas para *U. humidicola* CIAT-679 y CIAT-16886 (315 y 258 g/animal/día, respectivamente), fueron inferiores a las reportadas en otro estudio realizado bajo condiciones similares en los Llanos Orientales de Colombia (Laiton-Medina et al. 2021), quienes obtuvieron una ganancia diaria de 643 g/animal en *U. humidicola* spp, pero la mayor diferencia con respecto a este estudio fue que ellos emplearon una carga animal más baja, lo que favoreció un mayor nivel de asignación de forraje (AF), lo que permite una mayor selectividad y posiblemente un mayor consumo de alimentos (Hill et al. 2009).

Algunos estudios (Cruz-López et al. 2011; Villegas et al. 2022) muestran que *U. humidicola* CIAT-679 presenta buena producción de materia seca en comparación con otros cultivares de la misma especie en diferentes ambientes. En este estudio la accesión CIAT-679 tuvo un mejor desempeño frente a CIAT-16886 con respecto a la disponibilidad de biomasa, altura de plantas, digestibilidad in situ, y asignación de forraje (Figura 2 A, B, E, F, G) y un buen comportamiento en general, lo que coincide con lo reportado para esta accesión por otros autores (Reyes-Purata et al. 2009; Cruz-López et al. 2011).

Es posible que la mayor altura, biomasa, digestibilidad in situ de la materia seca (DISMIS) y mayor asignación de forraje (AF) de CIAT-679 (figura 2 A, B, F, G) hayan contribuido a la mayor GPA especialmente en el caso de las hembras (Figura 3). No encontramos una explicación clara del por qué las hembras mostraron una mayor diferencia en GPA en la accesión CIAT-679, y valores muy similares en la CIAT-16886, en comparación con los machos castrados, pues incluso en animales de la raza Blanco Orejinegro (BON), los machos han mostrado mayores ganancias que las hembras, lo cual se ha atribuido a diferencias hormonales y de dimorfismo sexual (Londoño-Gil et al. 2023). Lo mismo se ha observado en bovinos de raza Reyna y Jersey pastoreando pasto Estrella Africana (Vargas-Rodríguez 2008), en Charolais × Simmental alimentados con forrajes de zona templada (Bureš y Bartoň 2012) y en los de raza

Pirenaica en dietas a base de concentrados (Blanco et al. 2020). Además, en el estudio de Blanco et al (2020), las ganancias en machos fueron superiores a las de novillos y hembras, pero con pequeñas diferencias entre estos dos últimos, las cuales se relacionaron con diferencias en la concentración de las hormonas de crecimiento tipo insulina IGF-1 e IGFBP-3.

El nivel de consumo de materia seca explica un 70% de la variación en el desempeño productivo de los rumiantes (Waldo 1986; Velásquez et al. 2018), y en varios estudios las variaciones en estos explican las diferencias en GDP entre machos enteros, novillos y hembras (Bureš y Bartoň 2012; Puzio et al. 2019; Blanco et al. 2020), pero esa variable no se midió en el presente estudio.

Según observación, la ganancia de peso por ciclo (GPC) para CIAT-679 tuvo un leve decrecimiento con el paso de los ciclos de pastoreo, lo cual no concuerda con el aumento en el nivel de asignación de forraje (Figura 3), a menos que la calidad del pasto haya declinado en los pastoreos posteriores. Esto último parece ser cierto desde el punto de vista del contenido de PC, pero, por el contrario, la DISMS mostró la tendencia opuesta (Figura 2). En contraste, en el caso de la accesión CIAT-16886, la GPC tendió a aumentar con el pasar de los ciclos de pastoreo, especialmente en el caso de las hembras (Figura 3), posiblemente en respuesta a una mayor disponibilidad de forraje (Figura 2), pues ninguna de las variables de calidad nutritiva mostró una tendencia a mejorar a medida progresaron los ciclos de pastoreo.

Conclusiones

Bajo condiciones de pastoreo rotacional en ladera en el Nordeste Antioqueño, la accesión CIAT-679 de *U. humidicola* es una mejor opción que la CIAT-16886 en términos agronómicos y de productividad ganadera, por lo que se considera es un forraje óptimo para promocionar su uso. Sin embargo, se recomienda continuar las evaluaciones de estas accesiones en condiciones similares a las de este estudio, incluyendo variables como el consumo de forrajes, que ayuden a explicar posibles diferencias en ganancia de peso.

Consideraciones éticas

Todos los procedimientos experimentales fueron aprobados por el Comité de Bioética de la Corporación Colombiana de Investigación Agropecuaria-Agrosavia (Aprobación FUA no.2016.X.17.015).

Agradecimientos

Los autores expresan gratitud por el apoyo financiero y logístico para realizar esta investigación en el marco de la agenda dinámica corporativa de la Corporación Colombiana de Investigación Agropecuaria (Agrosavia) y al Centro Internacional de Agricultura Tropical (CIAT), por el material vegetal proporcionado para la realización del experimento.

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(Recibido para publicación 11 marzo 2024; aceptado 22 agosto 2024; publicado 30 de septiembre 2024)

Tropical Grasslands-Forrajes Tropicales (2024) Vol. 12(3):173–190
doi: 10.17138/TGFT(12)173-190

Artículo Científico

Simulación de sistemas de engorde de bovinos en pastoreo en el trópico húmedo de Costa Rica en función de carga animal, nivel de melaza suplementaria y época del año

Simulation of grazing cattle fattening systems in the humid tropics of Costa Rica depending on stocking rate, level of supplemental molasses and time of the year

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Resumen

Los sistemas silvopastoriles (SSP) son una alternativa sostenible para producir carne bovina en el trópico. En el presente estudio se obtuvieron ganancias diarias de peso (GDP) por animal de 0.64 kg en pasturas de *Urochloa brizantha* 'Toledo' + *Arachis pintoi* o *U. decumbens* sola, las que han persistido por más de 10 años, con cargas que van de 1.9 a 3.2 UA/ha (UA=400 kg PV) en ciclos de 10 meses. Los potreros tenían cercas vivas de *Gliricidia sepium* y árboles dispersos de *Erythrina poeppigiana* y *Cordia alliodora*. Se simuló el comportamiento observado con el modelo Life-Sim y se encontró que el promedio del error absoluto (MAE), para 25 comparaciones de GDP, fue de 0.056 kg. El suministro de melaza al 18.32% del consumo potencial de MS, aportó la energía requerida para un mejor aprovechamiento de la proteína contenida en el forraje consumido, alcanzando una GDP de 0.85 kg, pero su uso no resultó económicamente factible. Se evaluó, además, el efecto de la fluctuación de los precios de compra y venta de bovinos para la actividad de engorde a lo largo del año. El máximo margen bruto por animal correspondió al inicio del engorde en febrero (US$ 621), el mínimo para marzo (US$ 445) y la media anual fue US$ 544. Cuando se utilizaron los precios de los últimos 10 años, no se encontró diferencia entre los meses de inicio del engorde. Otros parámetros evaluados fueron consumo de N (139.66±3.88 g/animal/día); retención de N (25.60±0.58%); cantidad de N urinario (49.74±0.63 g/animal/día), y fecal (54.12±1.50 g/animal/día); y emisiones de CH_4 (80.48±4.76 kg/año).

Palabras clave: Análisis económico, *Arachis pintoi*, modelo Life-Sim, simulaciones, sistemas silvopastoriles, *Urochloa*.

Abstract

Silvopastoral systems (SSP) are a sustainable alternative to produce beef in the tropics. In the present study, the average daily weight gain (ADG) per animal was 0.64 kg in pastures of *Urochloa brizantha* 'Toledo', associated with *Arachis pintoi* and *U. decumbens* as a monoculture. These pastures have persisted for over ten years, with stocking rates ranging from 1.9 to 3.2 AU/ha (UA=400 kg) in 10-month rotation cycles. The paddocks had live fences of *Gliricidia sepium* and scattered trees of *Erythrina poeppigiana* and *Cordia alliodora*. The Life-Sim model was used to simulate the response using 25 comparisons of ADG with a mean absolute error (MAE) of 0.056 kg. Supplementing molasses at 18.32% of the potential DM intake provided the energy required to improve the utilization of the excess protein contained in the forage consumed, resulting in higher ADG (0.85 kg), but its inclusion was nonprofitable.

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Another scenario evaluated was the effect of fluctuating prices on the purchase and sale of fattened cattle throughout the year. The maximum gross margin per animal was for February (US$ 621), the minimum for March (US$ 445), and the annual mean was US$ 544. No difference among the starting months for fattening was detected when the prices for the last ten years were used. Other parameters evaluated were N consumption (139.66±3.88 g/animal/day); N use efficiency (25.60±0.58%); urinary N excretion (49.74±0.63 g/animal/day), fecal N (54.12±1.50 g/animal/day); and CH_4 emissions (80.48±4.76 kg/year).

Keywords: *Arachis pintoi*, economic analysis, Life-Sim model, silvopastoral systems, simulations, *Urochloa*.

Introducción

La demanda de proteína de origen animal se ha incrementado significativamente en las últimas décadas en los países en desarrollo, no solo como consecuencia del crecimiento de la población, sino porque el consumo per cápita ha crecido en función del incremento en el ingreso promedio de la población (Adesogan et al. 2020) y del aumento en la proporción de población urbana (Hawkes et al. 2017). En el caso de la carne, este incremento ha sido más evidente en América Latina, donde los niveles de consumo se están aproximando a los de países desarrollados (Parlasca y Qaim 2022); mientras en estos últimos el consumo de carne tiende a estancarse (Henchion y Zimmerman 2021).

Este incremento en la demanda de carne ha traído como consecuencia un aumento en la población de animales, acompañado de impactos negativos en la cobertura boscosa, así como sobre varios de los servicios ecosistémicos provistos por tierras bajo manejo ganadero (Gill et al. 2021; Henchion et al. 2021). Por ello, la intensificación sostenible de los sistemas de producción debe buscar mejorar la eficiencia a través de: cambios en las prácticas de alimentación haciendo un mejor uso de los recursos locales (forrajes y suplementos), el descarte de animales improductivos, la mejora de la fertilidad y salud del hato, y la utilización racional de genotipos animales adaptados (Adesogan et al. 2020; Greenwood 2021; Parlasca y Qaim 2022).

El desarrollo de opciones de intensificación de los sistemas ganaderos en el trópico puede partir del análisis de experiencias locales exitosas, y hacer uso de herramientas tecnológicas como son los modelos determinísticos-estocásticos de simulación, para evaluar el impacto de intervenciones potenciales bajo diferentes escenarios de producción. En el caso de los sistemas basados en pasturas, es importante considerar el efecto de las variaciones climáticas a lo largo del año sobre la disponibilidad y calidad nutritiva de los forrajes (Rao et al. 2015), las cuales se han visto exacerbadas como consecuencia del cambio climático (Pezo 2017).

En el caso de Costa Rica, el ganado de carne representa el 61.7% del hato nacional, con más del 92.5% manejado bajo pastoreo, con una distribución casi igual entre pasturas mejoradas y naturalizadas (INEC 2023), manteniendo una carga promedio de 1.29 animales/ha como media nacional, y 1.51 animales/ha en la región tropical húmeda (MAG 2022), donde se realizó el presente estudio. En términos generales, el sector todavía presenta baja productividad por unidad de espacio y tiempo, debido a la estacionalidad en producción y calidad de los forrajes, una edad de sacrificio superior a los 3 años y bajas tasas de natalidad, entre otros factores (Pérez et al. 2006; MAG 2022), todo lo cual redunda en un bajo nivel de ingreso por hectárea, comparado con los altos costos del capital invertido en tierra, lo cual hace la actividad poco competitiva (Holmann et al. 2008). Sin embargo, existen oportunidades para mejorar la eficiencia productiva y económica de la actividad, dado el incremento en la adopción de especies forrajeras mejoradas (Holmann et al. 2004), acompañados de nuevas oportunidades de mercado local e internacional como producto del reconocimiento al país por sus esfuerzos para incrementar la eficiencia productiva, el fomento de la reforestación en fincas ganaderas, la adaptación al cambio climático y la reducción de las emisiones de gases de efecto invernadero (Lerma et al. 2022; MAG 2015).

El presente estudio evaluó el comportamiento biológico y económico de un sistema de engorde de novillos en pastoreo en la región tropical húmeda. El modelo de finca analizado en el estudio es un esfuerzo para mostrar que es factible la intensificación sostenible de procesos de engorde en pastoreo, basados en pasturas mejoradas con manejo rotacional intensivo, dentro de sistemas silvopastoriles. El propósito del estudio fue evaluar cómo los cambios en la estrategia de suplementación, la carga animal y las fechas de compra y venta de animales pueden modificar la ganancia de peso por animal y por hectárea, así como el beneficio económico del sistema y su impacto sobre el ambiente.

Materiales y Métodos

Descripción del área de estudio

El estudio se realizó en una finca ganadera de solo cuatro hectáreas (Figura 1), de las cuales, tres están en pasturas dedicadas al engorde de bovinos y una se encuentra cubierta por un bosque secundario, donde predomina la especie *Erythrina poeppigiana*. El área de pasturas está dividida en 12 potreros, de los cuales cuatro fueron seleccionados para la toma de muestras del estudio.

La finca se encuentra localizada en el Distrito Tres Equis, Cantón de Turrialba, Provincia de Cartago, Costa Rica, a 9°57'18" N y 83°34'11" E, a 712 metros sobre el nivel del mar (m.s.n.m.), con precipitación promedio anual de 3,200 mm, distribuida mayormente entre marzo y noviembre, y temperatura media de 24 °C (Figura 2). La topografía es ondulada con pendientes entre 25% y 35%. Los suelos en la zona son del Orden Inceptisoles, con textura franco-arcillosa, caracterizados por la presencia de incrustaciones calcáreas y horizontes de cenizas volcánicas.

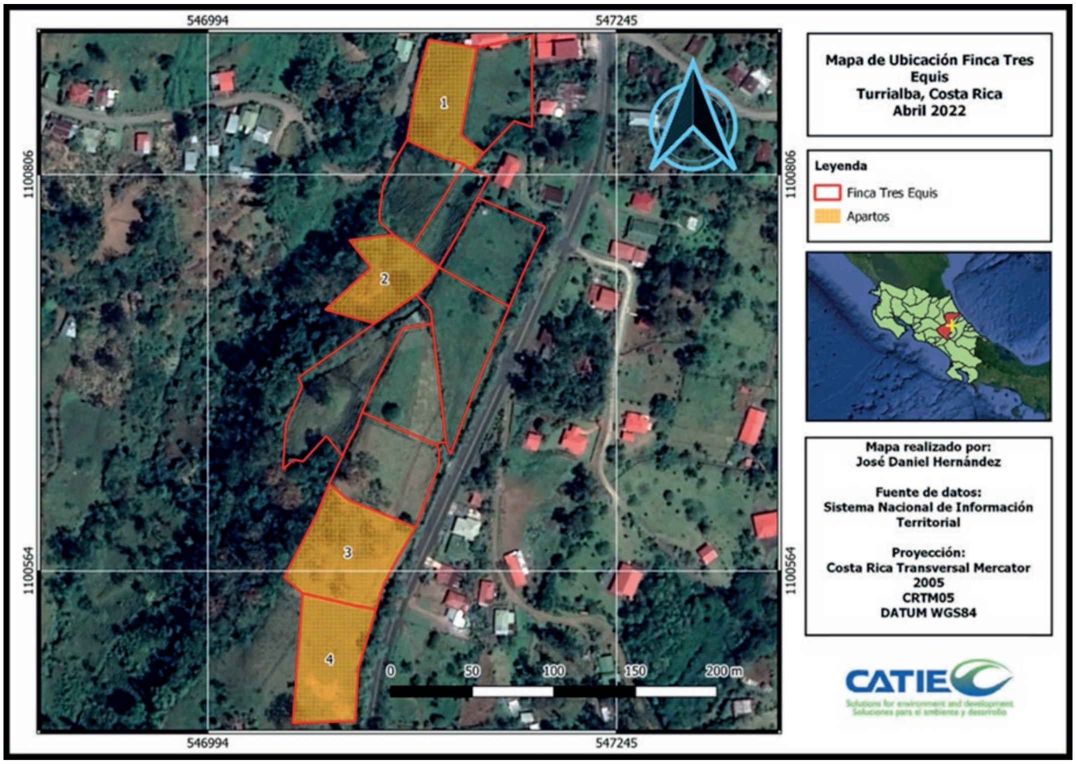

Figura 1. Localización del área de estudio Distrito Tres Equis, Cantón de Turrialba, Costa Rica. El contorno en rojo delimita las divisiones de los 12 potreros de la finca. En color naranja aparecen los potreros seleccionados para la toma de muestras de este estudio.

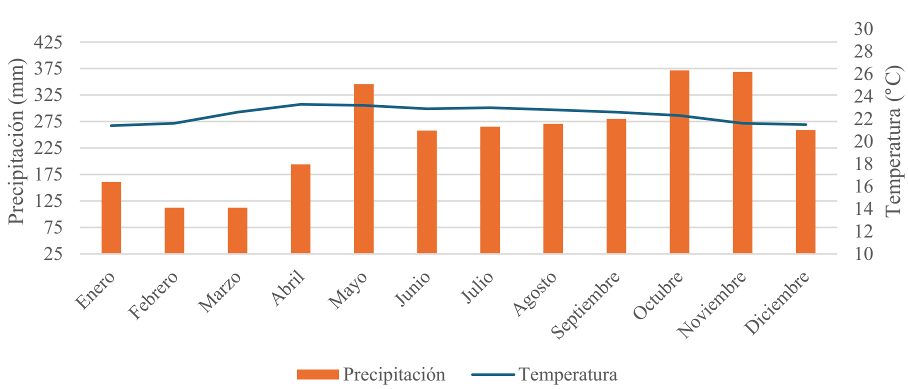

Figura 2. Precipitación y temperatura promedio en el Distrito Tres Equis, Cantón de Turrialba, Provincia de Cartago, Costa Rica (1988-2017). Adaptado de Zepner et al. (2020).

Manejo del sistema (pasturas y bovinos)

La finca cuenta con un área de tres hectáreas en pasturas, distribuidas en 12 potreros de 2,500 m^2 cada uno, con dominancia de *Urochloa brizantha* 'Toledo' en asocio con *Arachis pintoi* y otras de *U. decumbens* sola. El periodo de ocupación de cada potrero fue de tres días, proporcionando un descanso de al menos 30 días entre pastoreos. La carga animal promedio (CA), al inicio del ciclo anual de engorde (10 meses de pastoreo dos de descanso) fue de aproximadamente 1.9 UA/ha (1 UA=400 kg de PV), pero ésta se incrementó hasta 3.2 UA al final del ciclo de engorde de 10 meses. Los potreros se encuentran delimitados por cercas vivas, en su mayoría de especies multipropósito como *Gliricidia sepium* (Jacq.) Kunth ex Walp, de la que se aprovecha el follaje y ramas tiernas para preparar ensilaje, el cual es utilizado para suplementación de los animales en el período más crítico. Otra especie que compone las cercas vivas es la *Erythrina poeppigiana*, que conforma el estrato más alto y aporta nutrientes al suelo a través de la hojarasca y ramas caídas. La *E. poeppigiana* y la especie maderable *Cordia alliodora* se encuentran también dispersas en los potreros como resultado de la regeneración natural y de algunos esfuerzos de reforestación hechos por le productor.

La finca cuenta con dos áreas pequeñas techadas donde, además de ser la zona de descanso para los animales, es donde se proporciona agua, sales minerales y otros alimentos a los animales. Todos los potreros tienen acceso a una de las áreas techadas y el desplazamiento de los animales hacia éstas se logra con la ayuda de portones y cercas eléctricas movibles.

Análisis de suelos

En cada potrero se tomaron cinco muestras de suelo en el horizonte A (0 a 20 cm de profundidad), y con ellas se preparó una muestra combinada para los análisis en laboratorio. Para determinar la textura se utilizó el método de Bouyucos (granulometría), con lectura inicial de 40 s y una lectura final de 2 h. En cuanto a fertilidad, se utilizaron tres métodos. Las extracciones se realizaron usando el método de Olsen Modificado, pH 8.5, para determinar los valores de Cu, Zn, Mn, Fe, K y P y en KCl 1N para determinación de Ca, Mg, y acidez intercambiable. Por último, se utilizó el método de combustión total en un auto analizador marca ThermoFinnigan, modelo Flash EA 1112 series Italia para el pH en agua, C y N. El detalle de los procedimientos utilizados se describe en Díaz-Romeu y Hunter (1978).

Mediciones en las pasturas

Para validar los estudios que existen de la zona donde se condujo la investigación, la disponibilidad (Dis) de las pasturas, en kg de materia seca (MS), se determinó en el mes de junio (época de lluvia), utilizando la técnica BOTANAL® (Tothill et al. 1978). Se tomaron cinco muestras reales y entre 64 y 147 muestras visuales por potrero, en función de la variabilidad observada. Se utilizó un marco cuadrado de 0.25 m^2 (0.5 × 0.5 m). Las mediciones se realizaron un día antes de la entrada de los animales a pastoreo (oferta de pasto).

De cada potrero se extrajeron dos tipos de muestra para el análisis de digestibilidad in vitro de la MS (DIVMS). Una muestra fue tomada simulando la cosecha por el animal, teniendo en cuenta la selectividad de éstos (Villalobos y Arce 2014). La otra, fue el resultado de la combinación del material vegetal obtenido en las muestras reales, las cuales fueron cortadas a 10 cm sobre la superficie del suelo, pesadas por separado y mezcladas para la obtención de la submuestra que fue analizada en el laboratorio de Análisis de Productos Animales y Vegetales de la Escuela de Ciencias Agrarias de la Universidad Nacional (UNA) de Costa Rica. Para la determinación de DIVMS se utilizó la metodología descrita por Van Soest y Robertson (1980), y el protocolo recomendado por el fabricante para el incubador Daisyll® (ANKOM Technology, Fairport, NY-USA).

El porcentaje de materia seca (% MS) se obtuvo al secar las muestras en horno de ventilación forzada a una temperatura de 65 °C hasta alcanzar un peso constante, para luego ser pesada y conocer la diferencia entre el peso seco y el peso fresco de la muestra. Para el nitrógeno total (NT) y carbono total (CT) las muestras se analizaron en el Laboratorio de Análisis de Suelos, Tejidos y Aguas del CATIE. El NT (%) se determinó usando el método de Kjeldahl, y la proteína cruda (PC, %) se estimó multiplicando el NT por 6.25; el CT (%) se determinó por el método de combustión, ambos citados por Díaz-Romeu y Hunter (1978). Todos estos datos fueron usados como insumos para las corridas en el modelo de simulación Life-Sim.

Modelación de la respuesta animal con el modelo LIFE-SIM (carne)

El software "Livestock Feeding Strategies Simulation Models", LIFE-SIM (León-Velarde et al. 2006), fue desarrollado con el objetivo de evaluar los efectos de diferentes estrategias de alimentación sobre la producción animal. Cada uno de los cuatro modelos de rumiantes (vacas lactantes, bovinos en crecimiento, caprinos y búfalos) incluye subrutinas específicas para el crecimiento o disponibilidad de las pasturas, la ingesta voluntaria, el uso de suplementos, los requerimientos de nutrientes, la regulación térmica, con los cuales se estiman la producción de leche o carne, la producción de estiércol, las emisiones de metano y además incluye un análisis económico. Los detalles del modelo de simulación están descritos en León-Velarde et al. (2006).

En el presente estudio se utilizó el modelo de bovinos en crecimiento, con el cual se estimó la ganancia de peso de animal en pastoreo, en función del consumo de energía y proteína. Para ese fin, el modelo requiere como insumos información apropiada sobre: las características del ganado, los pastos y forrajes, las condiciones climáticas, la suplementación y los precios de los alimentos y productos. La información requerida para el componente animal es: el potencial de producción (medido en función de curvas de crecimiento), la edad, la condición corporal y la composición química de la carne, la carga animal (número de unidades animales por hectárea), así como la ingesta potencial de alimento (como porcentaje del peso corporal) y la variación esperada (experimental) en la ingesta de alimento.

Además, se usaron dos rutinas adicionales que posee el modelo, una para estimar la emisión diaria de CH_4 con base en la ecuación propuesta por Blaxter y Clapperton (1965), y otra para calcular la proporción de la rentabilidad explicada por sus componentes, a saber: 1) el componente de precio, el cual es la proporción de la rentabilidad explicada por la variación del precio a lo largo del período de engorde, si el peso no ha cambiado; 2) el componente de peso es la proporción de la rentabilidad explicada por el cambio de peso, si el precio no ha cambiado y, 3) el componente interacción entre los cambios de precio y peso durante el período de engorde, el cual afecta la rentabilidad.

La parametrización del modelo se llevó a cabo utilizando insumos obtenidos de los registros de la finca y declaraciones del productor, referente a los tres últimos ciclos productivos de la finca, así como de la literatura (Cuadrado et al. 2004). Los datos secundarios fueron complementados con muestreos de campo. Los valores ingresados fueron: Peso inicial (220 kg), edad al inicio (1 año), disponibilidad de forraje (950 y 3,192 kg MS/ha/año) y DIVMS (62.5 y 65.7%), para las épocas de menor (diciembre a marzo) y mayor precipitación (abril a noviembre), respectivamente. El pasto tuvo un contenido promedio de PC del 8.69% y se utilizó una carga animal promedio de 3 UA/ha.

Para calcular el nivel de precisión de las estimaciones realizadas por el modelo, se utilizaron tres índices: el error medio absoluto (MAE), medida común del error de pronóstico; el error cuadrático medio (RMSE) y su coeficiente de variación (CVRMSE) (Willmott 1982; Castellaro et al. 2007; Fontoura Junior et al. 2007; Candelaria-Martínez et al. 2011; Quiroz et al. 2017). Las variables de respuesta utilizadas fueron la ganancia diaria de peso observada (GDPO) y la simulada (GDPS),

$$MAE = \frac{\sum_{i=1}^{n} |E_i - O_i|}{n}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Ei - Oi)^2}{n}}$$

$$CV(RMSE) = \frac{RMSE}{Media\ GPDO}\ x\ 100$$

donde:
GDPO: Ganancia diaria de peso observada (kg),
GDPS: Ganancia diaria de peso simulada (kg),
CV: Coeficiente de variación (%),
Y_i-X_i: GDPS-GDPO,
n: Número de observaciones

Suplementación energética y carga animal

Para la determinación del nivel de suplementación energética requerido para las condiciones de la finca de estudio, se simuló el sistema de alimentación practicado con el modelo validado, y se encontró que la energía era el factor limitante. Por ello, se diseñó un experimento simulado para determinar la tasa de ganancia de peso en función del nivel se suplementación con melaza. Se evaluaron los siguientes niveles de melaza, expresados como porcentaje del consumo potencial de MS (ó 3 % PV): 0 (T_0), 10 (T_{10}), 20 (T_{20}), 30 (T_{30}) y 40% (T_{40}). Los datos de la melaza usados como insumos para el modelo fueron: 73.5% de MS, 5.74% de PC y 85% de DIVMS (Araiza et al. 2013). El consumo de melaza fue ajustado de acuerdo con el PV y varió a lo largo del ciclo de engorde entre 1.1 y 2.3; 2.2 y 4.6; 3.3 y 6.8; y 3.6 y 7.5 kg de MS/animal/día, para T_{10}, T_{20}, T_{30} y T_{40}, respectivamente. El punto de paridad- donde no hay ni excedente ni déficit de energía o proteína en la dieta- se estimó igualando las ecuaciones lineales de regresión para las GDP limitadas por energía y proteína, en función del incremento en la suplementación energética y despejando el valor de X (nivel de melaza). Para el análisis financiero se utilizó el costo local de US$ 0.35 por kilo de melaza.

Con el fin de analizar la interacción entre la suplementación energética y la carga animal, se diseñó un experimento simulado para determinar la combinación óptima de los tratamientos evaluados. Se usó un diseño de Superficie de Respuesta Rotable de Composición Central (Montgomery 1984). Los tratamientos se diseñaron y corrieron en Excel con el programa desarrollado por León-Velarde y Quiroz (1999). Se evaluaron 4 tratamientos factoriales (2^k), 4 axiales (2k) y el tratamiento central (n_0). El tratamiento central se repitió cinco veces. El total de tratamientos evaluados fue de nueve, producto de 2^k+2k+n_0, (donde k=2 factores). Para que el diseño fuera rotable, se requirió de un valor (α) que dependía del número de puntos en la porción factorial del diseño. El valor de "α" se estimó como $\alpha=P^{1/4}$, donde $P=2^k$ y k=2 (número de tratamientos) entonces α=1.414:

$$\alpha=P^{1/4}$$
$$\alpha=(2^2)^{1/4}$$
$$\alpha=1.414$$

El diseño de los tratamientos evaluados, tanto en código como los valores estimados de niveles de carga animal y melaza, se muestran en la Figura 3. Las variables X_1=carga animal (UA/ha) y X_2=melaza (% consumo potencial de MS) variaron de 1 a 5 y de 0 a 40, respectivamente. Los tratamientos centrales, con código 0, correspondieron a 3 UA/ha y 20% de melaza.

Mes de inicio del ciclo de ceba y su efecto sobre ganancia de peso

Para determinar si hay un efecto de la fecha de inicio de la ceba, se corrieron simulaciones iniciando ésta en los diferentes meses del año, desde enero a diciembre.

Análisis financiero

Para el análisis financiero se realizó una proyección de la actividad a 12 años, considerando esa como la vida útil, tanto de la pastura como de las cercas. El costo de producción de 1 kg de forraje fresco se estimó usando el registro de los gastos en los que incurre el productor en el establecimiento de la pastura de *Urochloa*, el manejo y los costos de depreciación anual de una determinada

	TRAT.	CA UA/ha	Melaza %CV	CA UA/ha	Melaza %CV
Factorial	1	-1	-1	2.00	10.00
	2	1	-1	4.00	10.00
	3	-1	1	2.00	30.00
	4	1	1	4.00	30.00
Axial	5	-1.414	0	1.59	20.00
	6	1.414	0	4.41	20.00
	7	0	-1.414	3.00	5.86
	8	0	1.414	3.00	34.14
Central	9.1	0	0	3.00	20.00
	9.2	0	0	3.00	20.00
	9.3	0	0	3.00	20.00
	9.4	0	0	3.00	20.00
	9.5	0	0	3.00	20.00

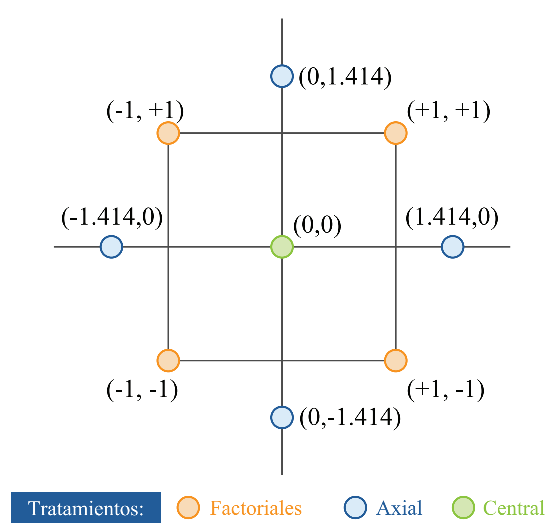

Figura 3. Descripción de tratamientos, carga animal y melaza para un experimento simulado con un diseño de Superficie de Respuesta Rotable de Composición Central.

área dedicada a la nueva pastura, considerando también las cercas vivas, dividido por el área total de la misma.

Los precios por kilo de peso vivo utilizados fueron los oficiales registrados por la Corporación de Fomento Ganadero de Costa Rica (Corfoga 2022). Se utilizaron los valores obtenidos para los últimos 10 años, para incluir la variabilidad de precio entre años. Se seleccionó el precio para animales con pesos entre 251 y 300 kg como rango de pesos de compra y, entre 401 y 500 kg como el rango de peso de venta. El análisis de simulación se realizó teniendo en cuenta el mes de inicio del ciclo de engorde. El análisis de beneficio-costo se realizó para el año 2021, período para el que se tenían datos medidos en la finca, y un período de engorde de 10 meses. Se repitió el análisis considerando los precios oficiales para los 10 años previos y así evaluar su repercusión en la distribución probabilística de la relación beneficio-costo. Además, se realizó un análisis financiero considerando el valor actual neto (VAN), la tasa interna de retorno (TIR) con una tasa de descuento de 9%, y la relación beneficio-costo (B/C).

Resultados

Condiciones de Suelo

El suelo presentó una textura franco-arcillosa en los primeros 20 cm del perfil del suelo, y pH ácido, en un rango de 5.1 a 5.7. La relación C:N osciló entre 8.4 y 9.8, donde los mayores niveles de estos dos elementos se encontraron en la asociación *Urochloa brizantha* 'Toledo'-*Arachis pintoi*. (Cuadro 1). Los potreros con *Urochloa decumbens* sola (D) o con árboles dispersos de *Erythrina poeppigiana* (D+E) mostraron los mayores valores de Ca y Mg.

Características de las pasturas (disponibilidad y calidad nutritiva)

La disponibilidad en los diferentes tipos de potreros varió de 2.4 a 3.9 t MS/ha, mientras que los contenidos de materia seca, proteína cruda y digestibilidad *in vitro* de la MS oscilaron entre 17.6 y 25.0; 4.5 y 13.4; y 56.8 y 70.0%, respectivamente (Cuadro 2). Los mayores valores de digestibilidad y proteína cruda se obtuvieron en los potreros que tenían árboles dispersos, mayormente de *E. poeppigiana*. Los potreros con pasto *Urochloa brizantha* 'Toledo' mostraron una mayor disponibilidad de biomasa forrajera que aquellos con *U. decumbens*.

Validación del modelo LIFE-SIM con datos de campo

Los valores de ganancia diaria de peso mínima, máxima y la media general observados (GDPO) y simulados (GDPS), para los 25 animales engordados entre los años 2019 y 2021 se muestran en la Figura 4A. El valor promedio del error absoluto (MAE) fue de 0.056 kg, y el error cuadrático medio (RMSE) y su coeficiente de variación (CV) fueron de 0.07 kg y 10.56%, respectivamente.

Cuadro 1. Fertilidad y textura del suelo en las parcelas seleccionadas en los primeros 20 cm de profundidad.

Tipo de pastura	pH	Acidez	Ca	Mg	K	P	N	C	Arena	Limo	Arcilla	Textura
	H_2O	cmol(+)/l				Mg/l	%					
T+A	5.4	0.20	5.64	3.53	0.23	3.1	0.44	4.03	47.0	27.8	25.2	Franco arcilloso arenosos
T+A+E	5.1	0.48	4.84	3.22	0.10	5.4	0.33	2.79	37.0	23.7	39.3	Franco arcilloso
D+E	5.3	0.33	8.21	4.80	0.20	4.2	0.30	2.61	41.1	27.6	31.3	Franco arcilloso
D	5.7	0.18	7.15	5.36	0.22	4.6	0.25	2.44	46.0	29.7	24.3	Franco

T=*Urochloa brizantha* 'Toledo'; A= *Arachis pintoi*; E= *Erythrina poeppigiana*; D= *Urochloa decumbens*.

Cuadro 2. Disponibilidad, contenido de materia seca, proteína y digestibilidad in vitro de la materia seca en función de las especies dominantes en los potreros: muestreo de validación de datos existentes para la zona de estudio.

Potrero	Muestras visuales	Tipo de pastura	Disponibilidad (kg MS/ha)	MS (%)	PC (%)	Dig (%)
1	85	T+A	3,793	24.9	4.5	56.8
2	64	T+A+E	3,901	25.0	9.9	63.7
3	147	D+E	2,991	21.2	13.4	70.0
4	113	D	2,399	17.6	8.6	59.7

MS=materia seca; PC=proteína cruda; Dig=digestibilidad; T=*Urochloa brizantha* 'Toledo'; A=*Arachis pintoi*; E=*Erythrina poeppigiana*; D=*Urochloa decumbens*.

Los datos de GDPO y GDPS se dispersaron alrededor de la línea 1:1 (línea de 45° o X=Y), distribuyéndose aleatoriamente alrededor de la línea 1:1, con intercepto igual a cero y pendiente igual a 1 (Figura 4B).

Efecto de la suplementación con melaza sobre la ganancia de peso

En los resultados de la simulación de la ganancia de peso en función de la energía y la proteína consumidas, usando como insumos los datos observados, se aprecia que a través de todo el ciclo de engorde (300 días), el consumo de energía fue el limitante principal (Figura 5).

En la Figura 6 se presenta la ganancia de peso esperada, en función de la energía y la proteína consumidas, cuando se suplementa con niveles crecientes de melaza de 0 a 40% del consumo potencial. Al igualar las dos ecuaciones y despejar X se obtuvo que la ganancia de peso por energía y proteína se igualaba cuando el nivel de melaza era del 18.32%. Por debajo de ese nivel de suplementación había un déficit de energía y por encima un exceso de ese factor. La GDP para ese nivel de suplementación con melaza es de 0.854 kg/día; es decir, 256 kg/animal/ciclo de 300 días; en cambio, en ausencia de suplementación energética la ganancia de peso por todo el ciclo de engorde fue de apenas 205 kg/animal.

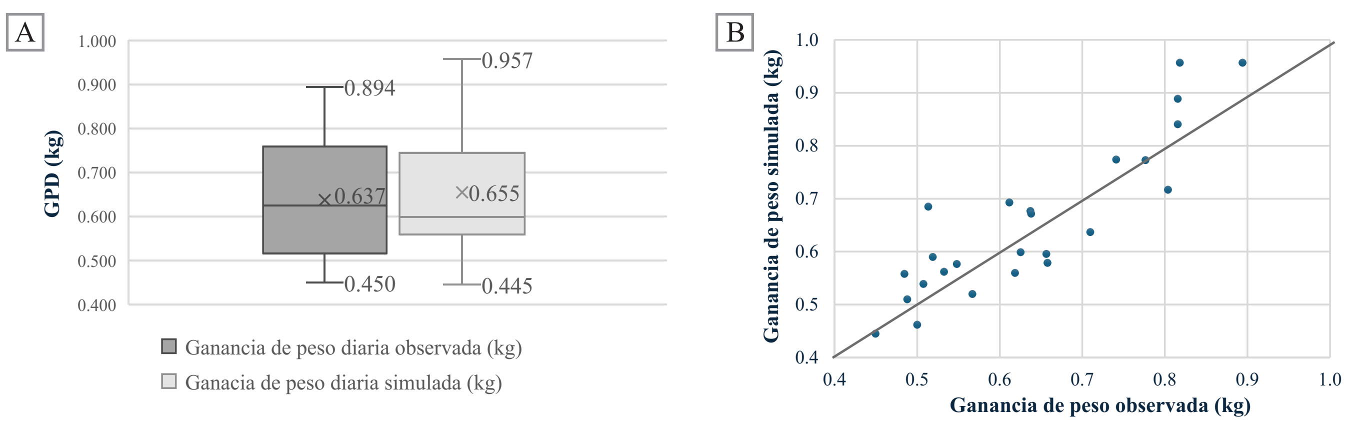

Figura 4. Evaluación del desempeño del modelo Life-Sim para estimar la ganancia diaria de peso: **(A)** intervalo de confianza de las GDP observada y simulada; (**B)** Distribución de los pares de puntos de las GPD observada y simulada alrededor de la línea X=Y; intercepto=0 y pendiente=1.

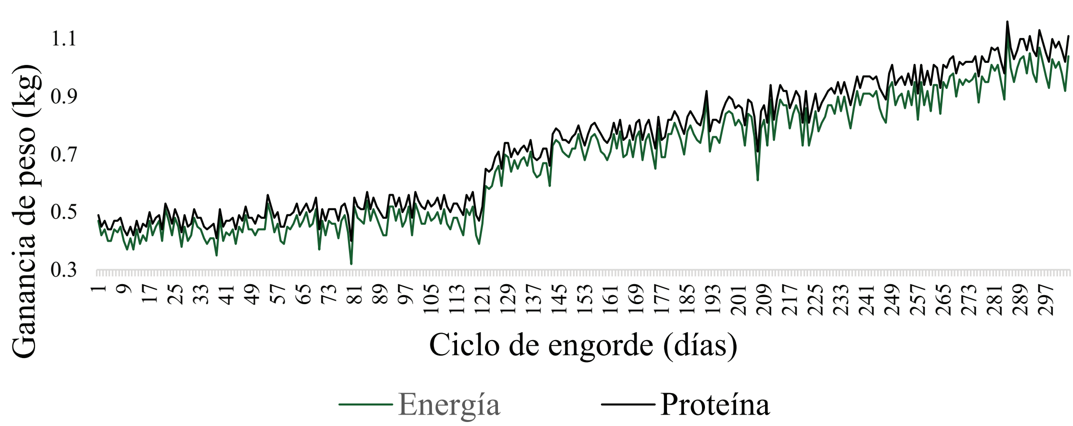

Figura 5. Simulación de la ganancia de peso (kg día^{-1}) en función de la energía y la proteína consumidas, usando como insumos los datos observados (registros del productor) de la ganancia diaria de peso en los tres últimos ciclos de engorde.

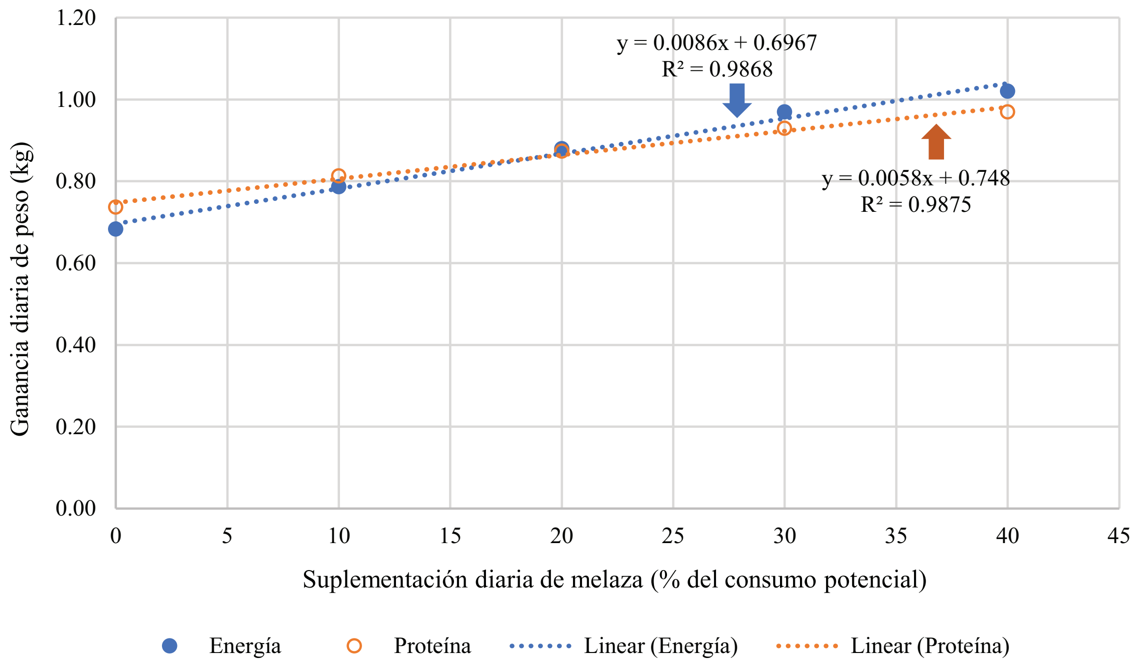

Figura 6. Ganancia de peso (GDP, kg/día) esperada en función del consumo de energía y proteína, para diferentes niveles de suplementación con melaza, expresados como por ciento del consumo potencial de materia seca del animal.

Efecto de la interacción suplementación con melaza × carga animal sobre la ganancia de peso

El análisis de varianza y la evaluación de los coeficientes del polinomio de segundo grado para la combinación de diferentes niveles de suplementación con melaza y carga animal y su efecto sobre la ganancia diaria de peso (GDP) mostraron que tanto los componentes lineal y cuadrático, como la interacción de efectos simples de esas variables, fueron significativos (P<0.01) y todos los coeficientes de la regresión fueron diferentes de cero (P<0.01).

La superficie de respuesta de la GDP en función de la carga animal y nivel de melaza (Figura 7) se describe con la siguiente ecuación:

$$Y=0.8648-0.01058 \times X_1 + 0.06955 \times X_2-0.00471 \times X_1^2-0.01597 \times X_2^2 + 0.008 \times X_1 \times X_2,$$

donde:

X_1=carga animal (UA/ha),

X_2=nivel de melaza suplementaria (% del consumo total potencial).

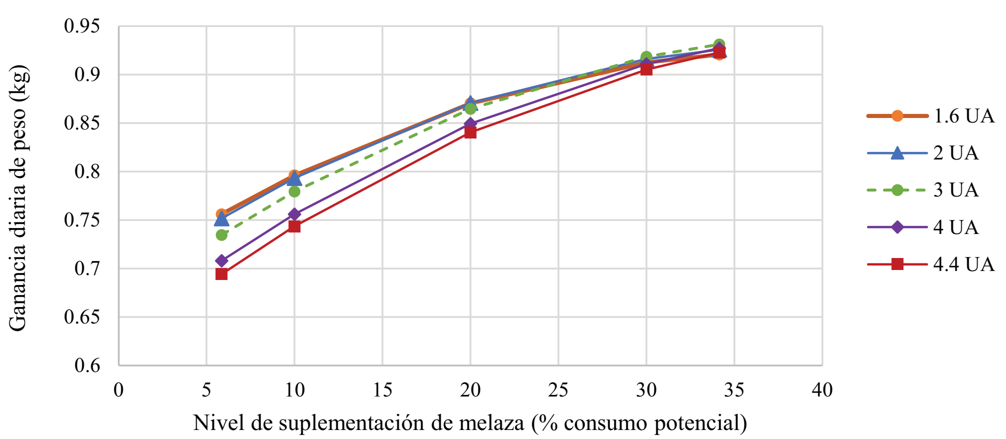

Figura 7. Ganancia diaria de peso (kg) en función de carga y nivel de suplementación con melaza.

El punto de inflexión para la respuesta animal en función de nivel de suplementación con melaza y carga animal se encontró para la combinación de X_1=3.922 UA/ha y X_2=44.09% de melaza, con una GDP de 0.944 kg/animal/día.

Efectos de los niveles de melaza y carga animal sobre la excreción de nitrógeno y emisión de CH_4

No se encontró diferencias (P>0.05) entre los tratamientos para los estimados de excreción y retención del N dietético. En el Cuadro 3 se presentan los promedios de consumo de N y de excreción de N urinario, fecal, y total, por animal por día a lo largo del ciclo de engorde, para los diferentes niveles de inclusión de melaza en la dieta. También, se presentan los valores promedios de metano emitido por año, por kg de MS consumida y por kg de peso ganado en el periodo de engorde.

El análisis de varianza y la evaluación de los coeficientes del polinomio de segundo grado para la combinación de diferentes niveles de suplementación con melaza y carga animal sobre la emisión de CH_4, mostró que los componentes lineal y cuadrático fueron significativos (P<0.001), y todos los coeficientes de regresión fueron diferentes de cero (P<0.01).

La superficie de respuesta de la emisión de CH_4 en función de la carga animal y nivel de melaza (Figura 8) se describe con la siguiente ecuación:

$$Y=63.57202-1.08838 \times X_1+ 7.15968 \times X_2 + 7.85579 \times X_1^2 + 7.88330 \times X_2^2 + 0.74 \times X_1 \times X_2,$$

donde:

X_1=carga animal (UA/ha),

X_2=nivel de melaza suplementaria (% del consumo total potencial).

Cuadro 3. Valores promedio de todos los tratamientos de consumo de N y su partición en productos, en la orina y heces y emisión de CH_4.

Variable	T0	T10	T20	T30	T40	Promedio
Consumo de MS, g/kg PV	25.74	26.82	27.51	27.45	27.22	26.95 (0.33)
Consumo N, g/animal/día	126.08	136.03	143.52	145.97	146.69	139.66 (3.88)
N urinario, g/animal/día	47.72	48.98	50.02	50.74	51.26	49.74 (0.63)
N fecal, g/animal/día	48.86	52.71	55.62	56.56	56.84	54.12 (1.50)
N total excretado, g/animal/día	96.58	101.69	105.63	107.31	108.10	103.86 (2.13)
Retención de N, %	23.40	25.40	26.40	26.49	26.31	25.60 (0.58)
Emisión CH_4, kg/año	64.71	77.53	80.55	86.57	93.04	80.48 (4.76)
Emisión CH_4, g/kg MS consumida	24.33	25.27	26.60	28.11	30.06	26.87 (1.02)
Emisión CH_4, kg/kg GP total	3.17	3.25	3.28	3.21	3.08	3.20 (0.03)

GP=Ganancia de peso durante el ciclo de 304 d. Todos los valores fueron estimados por el modelo Life-Sim. Valor en paréntesis corresponde al error estándar del promedio.

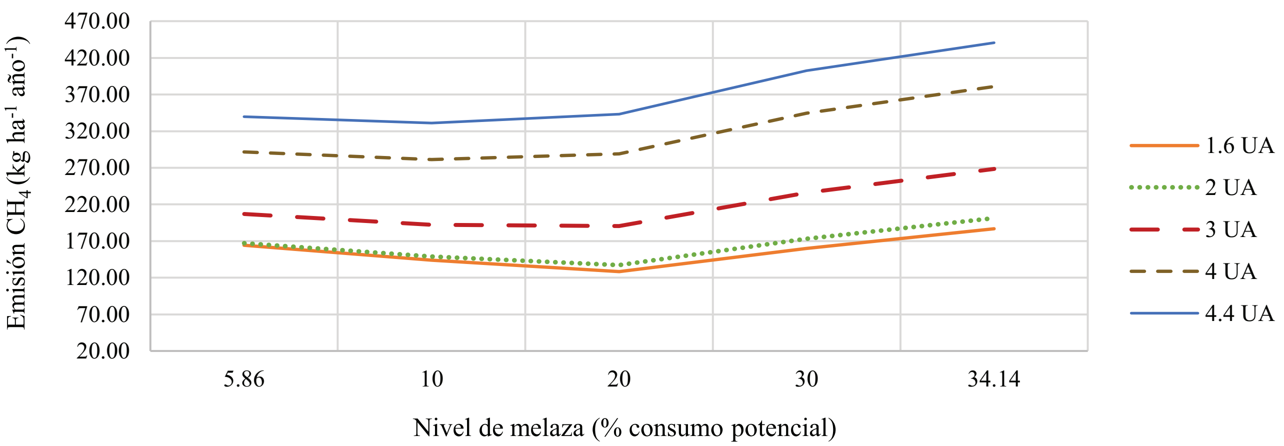

Figura 8. Emisión de CH_4 en función de carga y nivel de suplementación con melaza.

El punto de inflexión (valor más bajo) para la emisión de CH_4 (kg/ha/año) ocurrió para la carga de 3.09 UA/ha y suplementación con melaza del 15.42% del consumo potencial de materia seca. Para esta combinación, la emisión de CH_4 fue de 61.88 kg/animal/año.

Efecto de la fecha de compra y venta de animales para engorde

Cuando se consideró los costos y beneficios reportados para el año 2021, los mejores resultados en GDP se presentaron para el inicio del ciclo de engorde en abril (Figura 9A); sin embargo, las variaciones debidas al mes de inicio del engorde no fueron grandes, siendo la mayor diferencia entre diciembre y abril, pero esta alcanzó apenas un 5.4%. Pero, cuando se consideraron los precios de compra y venta de animales, el mejor margen bruto correspondió al inicio del engorde en febrero (Figura 9B), y los valores más bajos fueron para el mes de marzo. El análisis sobre los factores que inciden sobre el margen bruto mostró que, para los meses de noviembre a febrero, la variación positiva en los precios explicó entre el 6 y el 20% de los beneficios; en cambio, para el resto de los meses, la variación de los precios osciló entre -2% y -8%.

En lo que respecta a la GDP en función de mes de inicio de la fase de engorde en el 2021, con suplementación energética (Figura 10), se encontró que cuando se suplementó con melaza al 20% (T_{20}) del consumo potencial se presentaron aumentos en la ganancia de peso del 27.1% en promedio, independientemente del mes de inicio.

Cuando se estimó el margen bruto para el manejo actual de la finca sin suplementación y con 20% de melaza (T_{20}), se encontró que, independientemente de los meses de inicio y finalización del engorde, en todos los casos se redujo el margen bruto como consecuencia del uso de melaza como suplemento (Figura 11).

Los resultados del análisis beneficio-costo, considerando la variabilidad interanual de los precios de animales durante 10 años, mostraron que la relación beneficio-costo osciló entre 1.69 1.87, con una media general de 1.80 y un error estándar de ±0.07 (Figura 12), sin diferencias (P>0.05) debidas al mes en que se inició el proceso de engorde.

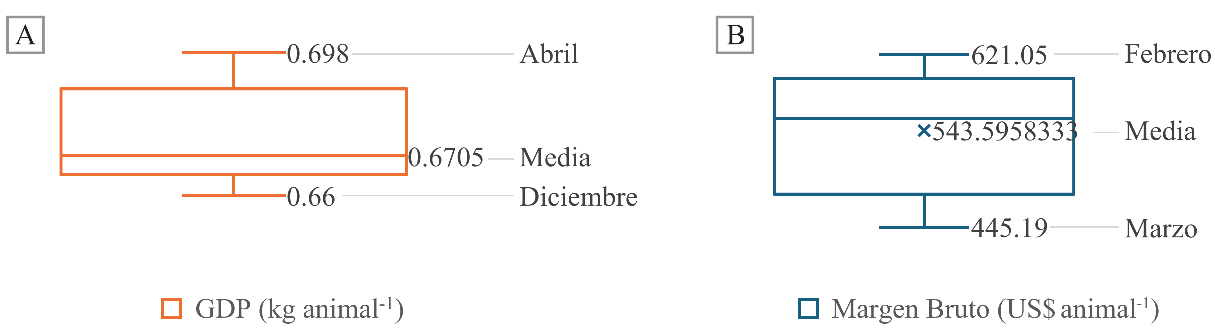

Figura 9. Efecto del mes en que se efectúa la compra y la venta de animales de engorde: **(A)** Ganancia diaria de peso (GDP, kg $^{d-1}$) según el mes de inicio del ciclo de engorde para el 2021; **(B)** Margen Bruto (MB, US$/animal/año) en función del mes de inicio del engorde.

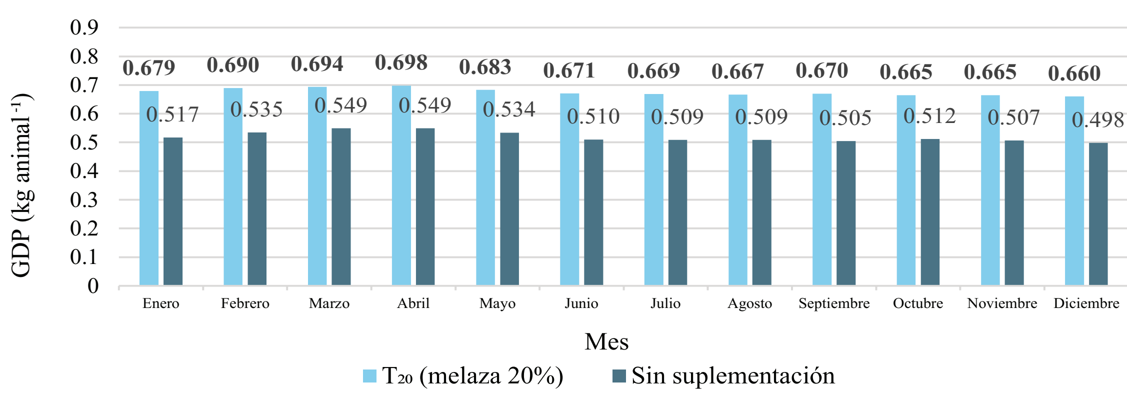

Figura 10. Ganancia diaria de peso (GDP, kg animal^{-1}) sin suplementación vs. melaza al 20% del consumo potencial (T_{20}), en función del mes de inicio del ciclo de engorde.

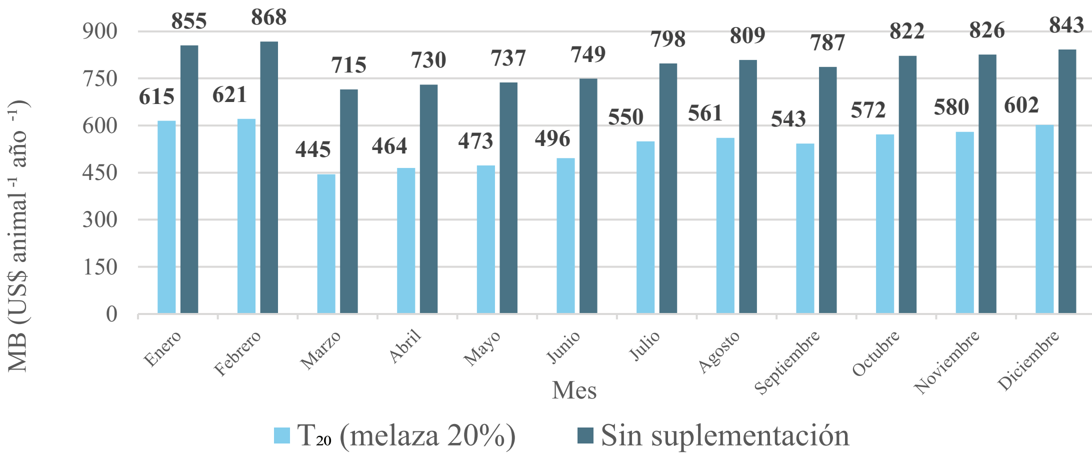

Figura 11. Margen bruto (US$/animal/año) en ausencia de suplementación (Línea base) vs. suplementación con melaza al 20% del consumo potencial (T_{20}).

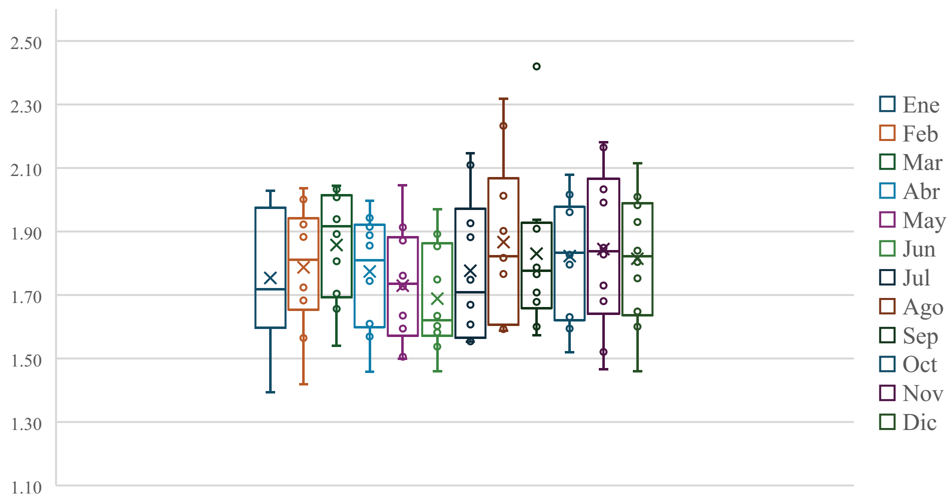

Figura 12. Análisis beneficio-costo para la actividad de engorde, iniciando en diferentes meses del año considerando los precios de animales al inicio y a la finalización del engorde, durante 10 años.

Análisis financiero

En el Cuadro 4, se presentan los indicadores de análisis financiero para la situación real de la finca, con engorde que inicia en diciembre del 2021, y simulaciones para inicios del engorde en diciembre y febrero. Los resultados del análisis de la simulación iniciando el ciclo de engorde en diciembre no difieren de los obtenidos para la situación real (inicio en diciembre). En cambio, el inicio del engorde en febrero, resultó en la mejor eficiencia financiera respecto a cualquiera de los otros meses del año. El incremento relativo en los parámetros de eficiencia financiera cuando se comparó el inicio en febrero vs. diciembre fueron de $10,727, 14% y 0.30 para el VAN, TIR y la relación B/C, respectivamente.

Aplicando el modelo de León-Velarde et al. (2006) para estimar el impacto de los precios, la GDP, así como sus interacciones, se obtuvo que el 20 y 17% de las diferencias entre marzo y febrero eran explicadas por los cambios en los precios de compra y venta de los animales, el 67 y 71% por la diferencia en GDP y el 14 y 12% restante por su interacción. En el resto de los meses, excepto noviembre y diciembre, el impacto de los precios de compra y venta y la interacción GDP x precio fueron negativos. Ello explicaría la disminución importante en el MB, aún en meses en que presentaron las mayores GDP. No obstante, cuando se incluye en el análisis la distribución de precios de 10 años, no se encontró diferencias (P>0.05) debidas al mes de inicio del engorde.

Cuadro 6. Resultados del análisis financiero en función del mes de inicio del engorde.

Análisis financiero	Situación real de finca (diciembre)	Simulado (diciembre)	Simulado (febrero)
Valor Actual Neto (VAN), US$	19,324	19,787	30,050
Tasa Interna de Retorno (TIR), %	37	38	51
Relación beneficio/costo (B/C)	1.33	1.33	1.63

Discusión

Ganancia diaria de peso (GDP)

La ganancia diaria de peso (0.637 kg/animal/día) obtenida bajo las condiciones del estudio, superó a las observadas en diversos estudios que han evaluado sistemas silvopastoriles similares, las cuales variaron entre 0.369 y 0.500 kg/animal/día (Iglesias et al. 2006, 2017; Pérez et al. 2008). Estas diferencias se asocian con condiciones climáticas favorables (Figura 2) para el crecimiento del pasto que se presentan en el área de estudio durante todo el año, caracterizado por un déficit de presión de vapor mayor a 0.5 kilo Pascales, nivel que no limita la producción de biomasa (Ríos-Gutiérrez 2021). Además, la biomasa producida y la calidad de ésta a través del año, así como la persistencia de especies deseables en praderas que tiene más de 12 años de uso, son poco frecuentes en esta región. Estos resultados confirman que los SSP manejados adecuadamente, como es el caso de la finca donde se realizó este estudio, mejoran la productividad y rentabilidad con respecto a los sistemas típicos de engorde practicados en Costa Rica (Pezo et al. 2018).

A pesar de la complejidad de los factores que involucran los SSP (Fontoura Junior et al. 2007), estos han mostrado ventajas sobre los sistemas pastoriles tradicionales en términos de productividad de leche y carne (Bacab-Pérez y Solorio-Sánchez 2011; López et al. 2017; Russo 2015); así como un mayor potencial de sostenibilidad ambiental (Iglesias et al. 2017; Pezo 2017).

Capacidad predictiva de la ganancia de peso usando el Modelo Life-Sim

Las predicciones de la ganancia de peso (GDPS) obtenidas usando el Modelo Life-Sim fueron similares a las observadas (GDPO) (Figura 4), con una diferencia en promedio de apenas 0.056 kg/día, lo cual representa un 9.3% de la ganancia diaria de peso. Además, el coeficiente de variación (CV) de la raíz del error cuadrático medio fue de 10.56%, el cual resultó menor al CV de los pesos de los 25 animales engordados en la finca en el período 2019–2021, que fue del 20%. Todo esto evidencia la robustez del modelo Life-Sim para predecir ganancias de peso en animales de engorde manejados bajo pastoreo, como fue el caso de este estudio, pues no hubo evidencia que la simulación tendiera a sobre- o subestimar las GDP, ya que los puntos se distribuyen aleatoriamente alrededor de la línea x=y, con intercepto=0 y pendiente=1 (Figura 5).

Todas las métricas (MAE, RMSE, CVRMSE) estimadas corresponden a modelos con un alto nivel de predicción de los datos medidos. Los resultados obtenidos concuerdan con parámetros estándar utilizados en la literatura (Castellaro et al. 2007; Candelaria-Martínez et al. 2011; Fontoura Junior et al. 2007; Quiroz et al. 2017) y confirman que las métricas evaluadas (MAE y RMSE) son buenos descriptores para evaluar la robustez de los modelos de simulación (Willmott 1982).

En un estudio previo, Orden et al. (2004) aplicaron el mismo submodelo carne del modelo Life-Sim a tres diferentes sistemas de engorde de bovinos a base de forrajes practicados en Filipinas y encontraron un CV de 9.37%. Por otra parte, cuando Castellaro et al. (2007) utilizaron un modelo desarrollado en la versión 7.1 de Visual Basic Excel®, para simular la ganancia de peso de toretes Hereford en pastoreo, con pesos iniciales entre 169 y 192 kg/animal, obtuvieron valores ligeramente menores de CVRMSE (9.98 y 5.11%) al obtenido en este estudio. En contraste, Maquivar-Linfoot et al. (2006), en un estudio de simulación de ganancia de peso en bovinos manejados en el trópico húmedo de Costa Rica, utilizando el nivel 1 del modelo de simulación NRC, detectaron sub- y sobreestimación de las ganancias de peso, las cuales atribuyeron a la variabilidad en las condiciones presentes en el sistema estudiado por ellos.

Efecto de la suplementación energética

Las simulaciones efectuadas con el modelo Life-Sim validado en este estudio, detectaron que bajo las condiciones de la finca donde se desarrolló el estudio, se presentaba un desbalance de energía vs. proteína a lo largo de todo el ciclo de engorde, pese a que las pasturas estaban bien manejadas. Un comportamiento similar ha sido reportado por otros autores (Sánchez 2007; Lauric et al. 2021).

Dada la disponibilidad y el costo de la melaza de caña en el área de estudio, se consideró que esta podría ser una buena opción como suplemento energético en este tipo de sistemas. Su inclusión a un nivel de 18.63% del consumo potencial fue capaz de proporcionar la energía necesaria para el mejor uso de la proteína aportada por el pasto; sin embargo, a pesar de las bondades biológicas detectadas, las condiciones de precio hicieron que el margen de utilidad con esta alternativa fuera menor que cuando no se ofreció suplemento (Figura 11). En cambio, cuando las condiciones de las pasturas fueron muy contrastantes debido a la época del año, Carrera et al. (1963) encontraron que en pasturas de pasto guinea (*Megathyrsus maximus*) con buena calidad durante la época de lluvias, no pagaba suplementar con 0.730 kg de melaza/animal/día; en cambio durante la época seca, se logró un aumento de hasta el 82% en la GDP en animales suplementados vs. no suplementados, y esa práctica fue económicamente rentable.

Efecto de la carga animal y suplementación con melaza sobre ganancia de peso, emisiones de CH_4, y eficiencia en el uso del nitrógeno

La generación de superficies de respuesta producto del uso de un diseño Rotable de Composición Central, permite encontrar la mejor combinación de variables independientes (punto de inflexión) tanto en experimentos reales como de simulación (Figueroa Preciado 2003; León-Velarde y Quiroz 1999). En este estudio, con el uso de ese diseño se encontró que el punto de inflexión para la GDP (0.769 kg/animal/día) se logró con una carga animal de 3.9 UA/ha y una suplementación de melaza equivalente al 44.09% del consumo potencial. En cambio, cuando se analizó la emisión de CH_4 a lo largo del ciclo de engorde de 304 días, el punto de inflexión (61.882 kg CH_4/animal) se obtuvo con niveles más bajos de carga animal y de suplementación con melaza (3.1 UA/ha y 15.42%, respectivamente).

La GDP obtenida en el punto de inflexión entre las variables carga y suplementación con melaza fue muy superior a lo reportado en la literatura para varios ensayos de ganancia de peso en sistemas basados en el uso de pasturas tropicales (Iglesias et al. 2006, 2017; Pérez et al. 2008) y un 20% superior a lo estimado para no suplementación y manejo con una carga animal de 3.0 UA/ha. La emisión promedio de metano para un ciclo anual de engorde, en el punto de inflexión se redujo en solo un 2% respecto al valor obtenido (63.15±4.33 kg CH_4/animal/año) bajo las condiciones del sistema practicado en la finca.

Los valores de metano entérico obtenidos en este este estudio son mayores a los reportados por Meo Filho et al. (2022) 219 vs. 110 kg/ha/año, lo cual puede deberse a la mayor carga animal utilizada en la finca donde se efectuó este estudio (3.0 vs 1.8 UA/ha). La emisión anual de metano se encuentra dentro del rango de 32 y 83 kg/animal/año que ha sido reportado por DeRamus et al. (2003) para ganado de carne. La intensidad de emisión de 26.86±1.82 g CH_4/kg de MS consumida obtenida en este estudio (Cuadro 4), fue muy similar al valor reportado para bovinos de carne que no recibieron suplementación (26.04 g CH_4/kg de MS consumida) en el metaanálisis de datos de emisiones en sistemas de producción de carne a nivel global (Cottle y Eckard 2018) y a datos obtenidos en Costa Rica con ganado de carne alimentado con heno de *Digitaria decumbens* de buena calidad (Montenegro et al. 2016).

La intensidad de emisiones expresada como porciento del consumo de energía digestible y consumo de energía bruta fueron 12.1 y 7.8%, respectivamente (datos no mostrados). Estos resultados son similares a los reportados por Kennedy y Charmley (2012) y cercano al rango recomendado por Eggleston et al. (2006) para rumiantes consumiendo forrajes de bajo valor nutricional (5.5 a 7.5% del consumo de energía bruta). Berndt y Tomkins (2013) destacan la importancia de aumentar la eficiencia de la producción ganadera por medio de una mejor genética del ganado y calidad de los forrajes para reducir la proporción de energía perdida en forma de metano y, consecuentemente, disminuir la intensidad de emisiones. Además, al mismo tiempo se debe mejorar la productividad y rentabilidad del sistema de engorde.

El uso de diseños de superficie de respuesta en estudios de modelación, como parte del planeamiento de ensayos de campo, permite ahorrar tiempo, espacio y dinero en el proceso de investigación, al reducirse el número de tratamientos, sin perder la ortogonalidad de estos (Carrera et al. 1963; Soca et al. 2007). Para propósitos de modelación, este diseño permite definir *ex ante* qué tratamientos evaluar en ensayos con animales, los cuales son costosos y de mayor complejidad en cuanto a su implementación (León-Velarde et al. 2006; Candelaria-Martínez et al. 2011). Sin embargo, para lograr resultados más robustos de las modelaciones se requiere de información secundaria de calidad, lo cual fue evidenciado en el presente estudio.

Cuando se comparó el consumo diario de N, así como su excreción a través de orina y heces, con los resultados reportados por Beltrán et al. (2022) para ganado de carne en crecimiento criado en zonas templadas, se encontró que los valores de consumo obtenidos en este estudio fueron inferiores, pero los de retención de N fue similar a los valores obtenidos por ellos. En dicho estudio el consumo de N varió entre 173 y 328 g/día y la retención de N en ganado de carne fue de 23.84%. Esas diferencias en el consumo de N son esperadas, dado que las pasturas de zona templada utilizadas en dicho estudio regularmente presentan un mayor contenido de N que las tropicales (Van Soest 1994; Fulkerson et al. 2007), y además ellos suplementaron los animales con concentrados.

Cambios de precio en la compra y venta y su efecto en la rentabilidad

El mes de inicio del engorde no afectó (P>0.05) el margen bruto cuando se consideraron las variaciones de precios en un periodo de 10 años. Este hallazgo no aplicaría para zonas tropicales donde hay una época seca marcada, pues bajo esas condiciones, hay mayor oferta de animales a inicios de la estación seca, cuando hay escasez de alimento, como una estrategia para reducir la carga animal en las fincas, lo que genera una baja en los precios (Grajales-Cedeño et al. 2021).

Por tanto, la respuesta a la pregunta ¿cuándo iniciar un ciclo de engorde? va a depender de las condiciones locales y la ciclicidad intra anual de los precios, pues va a ser muy diferente entre años y entre zonas, con o sin época seca definida. Además, esas variaciones se están haciendo cada vez más marcadas como consecuencia del cambio climático (Reyer et al. 2017). Esto significa que el uso de las estadísticas de precios de compra y venta de varios años constituyen un insumo clave para los procesos de simulación y así identificar los mejores meses de compra de ganado para optimizar las utilidades de la operación.

Conclusiones

Life-Sim mostró ser una herramienta valiosa para la simulación de escenarios de alimentación debido a que posee una robusta capacidad de predicción de la respuesta animal en hatos manejados bajo pastoreo en un sistema silvopastoril, pues el error de estimación fue de apenas 10.56%, y el valor promedio del error absoluto (MAE) de todas las observaciones de 0.056 kg.

El uso de melaza como suplemento para compensar el exceso de proteína cruda respecto al valor energético en el forraje se traduce en incrementos en la ganancia de peso, pero no siempre esta práctica es económicamente rentable.

Los valores de intensidad de emisión de CH_4 y de retención de N en el sistema estudiado son similares a los reportados en la literatura para otros sistemas basados en el uso de pasturas.

La relación beneficio-costo estimada a partir de los registros del productor y la simulada por el modelo Life-Sim para el 2021 fue favorable, con un valor de 1.33, donde el 71% era explicado por los cambios en ganancia de peso y el resto por los cambios de precio y por la interacción de este último con los cambios en el peso.

El uso de estadísticas de precios y venta de ganado con herramientas de simulación como Life-Sim son claves para identificar el periodo de engorde que optimiza los ingresos.

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(Nota de los editores: Enlaces verificados el 15 de septiembre de 2024).

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(Recibido para publicación 9 noviembre 2023; aceptado 30 agosto 2024; publicado 30 de septiembre 2024)

Tropical Grasslands-Forrajes Tropicales (2024) Vol. 12(3):191–199
doi: 10.17138/TGFT(12)191-199

Short Communication

Screening pre-emergence herbicides for weed control during early elephant grass growth

Evaluación de herbicidas preemergentes para el control de malezas en el desarrollo temprano del pasto elefante

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Abstract

Two experiments were carried out in the municipality of Coronel Pacheco, Minas Gerais State, Brazil in 2020 and 2021 to identify additional herbicide options for weed control during early elephant grass pasture establishment. Thirteen pre-emergence herbicides were compared to weed-free and weedy controls in a randomized complete block design with 4 replications. Forage yield losses were significant as a result of weed interference throughout the entire crop cycle. The most phytotoxic treatments were trifluralin and diuron + hexazinone. Weed control was effective for all treatments, except for trifluralin applied alone. Elephant grass dry matter yield was not influenced by diuron, ametryne, flumioxazin and metribuzin, identifying them as potential pre-emergence herbicides for weed control in elephant grass pastures.

Keywords: *Cenchrus purpureus*, napier grass, pastures, *Pennisetum purpureum*, selectivity, tolerance.

Resumen

Se realizaron dos experimentos en el munícipio de Coronel Pacheco, Estado de Minas Gerais, Brasil, el 17 de marzo de 2020 (experimento 1) y el 26 de febrero de 2021 para identificar opciones adicionales de herbicidas para el control de malezas en el desarrollo temprano del pasto elefante. El diseño experimental fue de bloques completos al azar, con cuatro repeticiones. Se compararon trece herbicidas preemergentes versus tratamientos control desmalezado y enmalezado. Las pérdidas en el rendimiento del forraje fueron significativas como resultado de la interferencia de malezas durante todo el ciclo de cultivo. Los tratamientos más fitotóxicos fueron trifluralina y diurón + hexazinona. El control de malezas fue efectivo para todos los tratamientos, excepto para la aplicación de trifluralina sola. El redimiento de materia seca de pasto elefante no fue influenciado por el diurón, ametrina, flumioxazina y metribuzina, siendo estos herbicidas preemergentes de uso potencial para el control de malezas en pasto elefeante.

Palabras clave: *Cenchrus purpureus*, pasto napier, pasturas, *Pennisetum purpureum*, selectividad, tolerancia.

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Introduction

Elephant grass [*Cenchrus purpureus* (Schumach.) Morrone formerly *Pennisetum purpureum* (Schumach.)] is one of the tropical forage grasses with potential for high dry matter yield that is used mainly for cattle in Brazil (Rosa et al. 2019). In addition, it can be used as raw material for biofuel as energy (Borges et al. 2016; Silva et al. 2017; Rocha et al. 2018) and conserved forage as silage (Bonfá et al. 2015; Lira Júnior et al. 2018).

Elephant grass breeding programs have been established in Brazil to identify cultivars with desirable agronomic characteristics, including high forage production, and excellent nutritive value (Rosa et al. 2019; Pereira et al. 2021). Cultivars 'BRS Capiaçu' and 'BRS Kurumi' were recently developed and provide options for cutting, grazing and silage (Pereira et al. 2016; Pereira et al. 2021). The rapid expansion of elephant grass cultivation in Brazil prompted research on optimum management of the crop.

Despite elephant grass 'BRS Capiaçu' and 'BRS Kurumi' having rapid initial development and covering the soil surface, weed competition can cause serious yield losses (Rosa et al. 2019). In some cases, productivity losses of elephant grass dry matter can reach 41% due to 17.5 plants/m^2 total weed density of *Urochloa decumbens*, *Megathyrsus maximus* (syn. *Panicum maximum*), *Ipomoea grandifolia*, *Commelina benghalensis*, *Amaranthus retroflexus* and *Portulaca oleracea* (Brighenti et al. 2017a).

Narrow-leaf weed control is a specific problem in elephant grass pastures. Grass weeds such as *Urochloa* species and *Megathyrsus maximus* are especially difficult to control in elephant grass fields (Abreu et al. 2006; Pereira et al. 2021). Morning glories (*Ipomoea* species) are another long-standing weeds in elephant grass crops (Pereira et al. 2021). Vines wrap tightly around the plants and migrate laterally across the rows. Clusters of stems choke farm equipment, making elephant grass harvest a struggle for smallholders (Pereira et al. 2021). Yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*) are also considered invasive weeds in elephant grass crops (Pereira et al. 2021). The total growth period for preventing interference from *C. esculentus* was 42 d after elephant grass planting (Brighenti and Oliveira 2018).

Although some preliminary results in chemical weed control in elephant grass were recorded previously (Silva et al. 2002; Brighenti et al. 2017b), none of them evaluated herbicides that control both broad-leaf weeds, such as morning glories, and grass weeds, mainly *Urochloa* and *Megathyrsus maximus*. Herbicides which have been on the market for a long time, including trifluralin, ametryne, diuron, and metribuzin, could be used because they tend to be found more easily at affordable prices in different regions of Brazil. Identifying correct weed management strategies during early elephant grass establishment is crucial to achieve successful weed control in the subsequent stages of cultivation. The objective of this study was to identify additional pre-emergence herbicide options for simultaneous control of broad and narrow-leaf weeds during early elephant grass development.

Materials and Methods

Two experiments were carried out in the experimental field of Embrapa Dairy Cattle, municipality of Coronel Pacheco, Minas Gerais State, Brazil (21°33`03.45" S, 43°15'23.30" W). The climate was identified as Cwa (Köppen 1948). This is the typical climate of the middle East region of Brazil, characterized by dry winters and rainy summers (Alvares et al. 2013). The average values of air temperature (maximum and minimum) and rainfall during the experimental period are shown in Table 1.

Table 1. Average maximum and minimum monthly air temperatures (T) (°C) and rainfall (mm) during the experimental periods in years 2020 and 2021 at Coronel Pacheco, Minas Gerais State, Brazil.

Air temperatures/ Monthly precipitation	Experiment 1 (2020)					Experiment 2 (2021)				
	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun
Maximum Temperature (ºC)	25.9	24.1	21.4	21.8	21.9	26.7	27.3	24.1	22.7	20.9
Minimum Temperature (ºC)	25.0	23.2	20.3	20.5	20.7	25.5	25.8	22.5	21.3	19.5
Rainfall (mm)	237.8	48.20	33.38	11.0	2.20	279.4	88.00	69.40	22.00	18.20

The soil of the area is classified as Red-Yellow Argisol (Santos et al. 2018). Soil texture properties are 44% clay, 11% silt and 45% sand. The soil chemical properties (0–20 cm depth) of the experiments 1 and 2 are pH (H_2O)=4.8 and 5.6, P=2.7 and 5.0 mg/dm^3, K=140 and 135 mg/dm^3, Ca^{2+}=0.34 and 1.7 cmol$_c$/dm^3, Mg^{2+}=0.22 and 0.96 cmol$_c$/dm^3, Al^{3+}=0.6 and 0.0 cmol$_c$/dm^3, H+Al=4.29 and 3.63 cmol$_c$/dm^3, CEC$_{(t)}$=1.52 and 3.08 cmol$_c$/dm^3, CEC (T$_{pH=7.0}$)=5.2 and 3.08 cmol$_c$/dm^3, V%=17.7 and 45.9, and C organic 1.56 and 2.11 dag/kg, respectively.

The experiments were implemented on March 17, 2020 (experiment 1) and February 26, 2021 (experiment 2) arranged in randomized complete blocks with 4 replications. Treatments of pre-emergence herbicide applications of trifluralin (1.5 kg ai/ha), trifluralin + atrazine (0.75+1.25 kg ai/ha), pendimethalin (1.5kg ai/ha), atrazine + S-metolachlor (1.48+1.16 kg ai/ha), diuron (2.0 kg ai/ha), diuron + hexazinone (1.17+0.33 kg ai/ha), tebuthiuron (1.0 kg ai/ha), sulfentrazone (0.15 kg ai/ha), ametryne (3.0 kg ai/ha), flumioxazin (0.045 kg ai/ha), S-metolachlor (2.4 kg ai/ha), metribuzin (0.96 kg ai/ha), metribuzin + S-metolachlor (0.48+0.96 kg ai/ha) were used. Weed-free (hand-weeded) and no weeding treatments were also included as controls.

A preliminary survey of the main weed species in the plots was carried out before planting. Predominant weeds inside a 0.25 m^2 quadrat were counted at 10 randomly chosen points and values converted into plants/m^2. Prevalent weed species and their densities were *Amaranthus spinosus* (117 and 32 plants/m^2); *Ipomoea purpurea* (17 and 1 plants/m^2); *Commelina benghalensis* (16 and 12 plants/m^2); *Megathyrsus maximus* (20 and 29 plants/m^2); *Portulaca olearaceae* (2 and 8 plants/m^2), and *Triumfetta bartramia* (1 and 2 plants/m^2) for experiments 1 and 2, respectively.

The experimental areas were ploughed, harrowed and levelled before planting elephant grass stem cuttings. Plots of 20.8 m^2 were planted in furrows at 0.3 m deep in 4 rows of 4 m length with 1.3 m between rows. Fertilizer application was done using 400 kg NPK/ha (08% N, 28% P, 16% K). Stem cuttings of elephant grass ('BRS Capiaçu') of 3 m length were laid in furrows and cut with a large knife to approximately 0.4 m. Furrows were covered with a thin layer of soil. Elephant grass plants were side dressed with 400 kg NPK/ha (20% N, 05% P, 20% K) 40 days after planting.

Herbicide treatments were applied the day after planting using a backpack sprayer (Herbicat Ltda, Catanduva, São Paulo State, Brazil). The pressure of CO_2 was maintained at 2 kgf/cm^2 to deliver a volume of 150 L/ha. The sprayer boom (1.5 m length) comprised 4 flat fan nozzles (110.02 - Magno ADGA). The environmental conditions during the herbicide spraying were temperatures of 26 °C and 28 °C, relative humidity of 67% and 69% and wind speed of 3 m/s and 2 m/s for the experiments 1 and 2, respectively. Sprinkler irrigation was once after the herbicide sprays (20 mm water layer).

Phytotoxicity symptoms on elephant grass plants were assessed at 7, 14 and 21 days after herbicide applications (DAA). Weed control was evaluated at 7 and 21 DAA. Both evaluations were done by using a scale of 0–100% (Velini et al. 1995), where zero corresponded to no symptoms of phytotoxicity on elephant grass plants or no weed control, and 100% to elephant grass death or complete weed control.

Weed densities were obtained for both experiments at 30 and 60 DAA by counting the species in a 0.25 m^2 quadrat randomly placed inside the plots and counts converted to plants/m^2. In experiment 2, a second evaluation of weed density was performed at elephant grass harvest using the same procedure. Weed species were cut at soil level in a 0.25 m^2 quadrat at 30 and 60 DAA (experiment 1) and at elephant grass harvest (experiment 2). Plants were placed in paper bags and dried in a forced ventilation air oven at 55 °C for 72 h. The dry matter was weighed and data converted to g/m^2.

Elephant grass plants were harvested at 120 days after planting. Two central rows of 4 m length were cut close to soil level and weighed. Values for fresh matter yield were converted to kg/ha. Sub-samples of the harvested fresh matter were taken from each plot, weighed and packed in paper bags and placed in an oven with forced air ventilation at 55 °C for 72 h. The samples were reweighed, and data converted to kg/ha for elephant grass dry matter.

The percentage values of phytotoxicity on elephant grass plants and the weed control percentages were normalized by square root tansformation (x + 1) to perform analysis of variance (ANOVA). Data were subjected to ANOVA and mean values were compared using Scott-Knott test ($P<0.05$). The joint analysis was used for elephant grass dry matter yield to confirm the most selective herbicides. Statistical analyses were performed using SAEG software (Ribeiro Júnior 2001).

Results and Discussion

Treatments with pendimethalin and the formulated mixture of diuron + hexazinone caused slight symptoms of injury on elephant grass plants in experiment 1 (Table 2). The characteristic symptoms of pendimethalin were yellowing on younger leaves. However, the symptomatology for diuron + hexazinone were higher than pendimethalin with total plant chlorosis. Intensity of symptoms decreased during the evaluation period. However, injury signs were still visible for both treatments at 21 DAA (2.5%). Similar results were obtained by Brighenti et al. (2017a) when using diuron + hexazinone. Although the treatment provided efficient weed control (99–100%), injury symptoms were extremely severe. Assimilation of carbon dioxide (CO_2) after hexazinone application in post-emergence of elephant grass plants (Cutts et al. 2011) showed carbon dioxide assimilation was reduced to zero, indicating plant death of treated elephant grass 2 days after herbicide application.

The treatment with trifluralin + atrazine caused slight symptoms of injury on elephant grass plants in experiment 2 (Table 3). However, phytotoxicity symptoms disappeared at the last evaluation.

The formulated mix of diuron + hexazinone was the most phytotoxic treatment in experiment 2 (Table 3), similar to that observed in experiment 1. Injured plants had symptoms of generalized chlorosis and necrosis on the leaf tips, which is typical of photosynthetic inhibitors. As in experiment 1, injury symptoms declined over time, but injury was still present at the last evaluation. Similar results were obtained by Brighenti et al. (2017a). The mix of diuron + hexazinone was one of the most phytotoxic treatments for elephant grass plants, with 29% of injury compared to the control at 23 d after planting. Although the formulated mixture of diuron plus hexazinone is registered for similar crops in Brazil, such as sugarcane (*Saccharum officinarum*) (MAPA 2024), some cultivars (‘RB925345’, ‘RB867515’, ‘RB855146’ and ‘SP80-1816’) showed different degrees of sensitivity, varying according to genotype (Ferreira et al. 2012). Diuron + hexazinone caused decreases of 63% and 40% in dry matter yield of cultivars ‘RB925345’ and ‘RB867515’ when compared to the control without application, respectively. Losses in sugarcane dry matter productivity were even greater in ‘RB855146’ and ‘SP80-1816’, reaching values greater than 70% (Ferreira et al. 2012).

Table 2. Percentage elephant grass injury at 7 (P7), 14 (P14) and 21 (P21) days after herbicide application (DAA) and percent weed control at 7 (WC7) and 21 (WC21) DAA in experiment 1 at Coronel Pacheco, Minas Gerais State, Brazil, 2020.

Treatments	P7	P14	P21	WC7	WC21
Trifluralin	0.0(1.0)[1b]	0.0(1.0)[b]	0.0(1.0)[b]	79.00(8.94)[d]	77.25(8.84)[f]
Trifluralin + Atrazine	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	99.25(10.0)[a]	99.50(10.0)[a]
Pendimethalin	5.50(2.54)[a]	4.0(2.2)[a]	2.5(1.8)[a]	99.25(10.0)[a]	85.75(9.31)[d]
Atrazine + S-metolachlor	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	99.25(10.0)[a]	99.50(10.0)[a]
Diuron	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	96.25(9.86)[c]	82.25(9.12)[e]
Diuron + Hexazinone	5.75(2.59)[a]	3.75(2.1)[a]	2.5(1.8)[a]	100.0(10.0)[a]	99.75(10.0)[a]
Tebuthiuron	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	100.0(10.0)[a]	99.75(10.0)[a]
Sulfentrazone	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	98.50(9.97)[a]	89.25(9.49)[c]
Ametryne	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	99.50(10.0)[a]	98.75(9.98)[a]
Flumioxazin	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	96.50(9.87)[c]	89.50(9.51)[c]
S-metolachlor	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	98.00(9.94)[b]	95.75(9.83)[b]
Metribuzin	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	99.75(10.0)[a]	97.50(9.92)[b]
Metribuzin + S-metolachlor	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	100.0(10.0)[a]	97.50(9.92)[b]
Weed free	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	100.0(10.0)[a]	100.0(10.0)[a]
Weedy	0.0(1.0)[b]	0.0(1.0)[b]	0.0(1.0)[b]	0.00 (1.0)[e]	0.00 (1.0)[g]
Coefficient of variation (%)	3.13	4.86	5.06	0.49	0.97

[1]Mean values of control percentages (x) transformed into square root (x + 1).
Mean values followed by different letters are significantly (P<0.05) different by Scott-Knott test.

Table 3. Percentage elephant grass injury at 7 (P7), 14 (P14) and 21 (P21) days after herbicide application (DAA) and percent weed control at 7 (WC7) and 21 (WC21) DAA in experiment 2 at Coronel Pacheco, Minas Gerais State, Brazil in 2021.

Treatments	P7	P14	P21	WC7	WC21
Trifluralin	0.00(1.0)[1c]	0.00(1.0)[c]	0.0(1.0)[b]	95.7 (9.83)[c]	99.5 (10.02)[a]
Trifluralin + Atrazine	1.00(1.36)[b]	0.5(1.20)[b]	0.0(1.0)[b]	100.0(10.04)[a]	100.0(10.04)[a]
Pendimethalin	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	96.0 (9.84)[c]	98.5 (9.97)[b]
Atrazine + S-metolachlor	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	95.7 (9.83)[c]	100.0(10.04)[a]
Diuron	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	96.7 (9.88)[c]	92.5 (9.66)[d]
Diuron + Hexazinone	2.75(1.92)[a]	1.75(1.65)[a]	0.75(1.31)[a]	100.0 (10.04)[a]	100.0 (10.04)[a]
Tebuthiuron	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	100.0 (10.04)[a]	100.0 (10.04)[a]
Sulfentrazone	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	89.5 (9.51)[d]	95.2 (9.81)[c]
Ametryne	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	99.2 (10.01)[b]	100.0(10.04)[a]
Flumioxazin	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	88.0 (9.43)[e]	95.0 (9.79)[c]
S-metolachlor	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	98.7 (9.98)[b]	100.0 (10.04)[a]
Metribuzin	2.50(1.86)[a]	1.50(1.57)[a]	0.5(1.20)[a]	99.2 (10.01)[b]	100.0(10.04)[a]
Metribuzin + S-metolachlor	2.50(1.86)[a]	1.50(1.57)[a]	0.25(1.10)[b]	99.0 (9.99)[b]	100.0 (10.04)[a]
Weed-free	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	100.0 (10.04)[a]	100.0 (10.04)[a]
Weedy	0.00(1.0)[c]	0.00(1.0)[c]	0.0(1.0)[b]	0.00 (1.0) f	0.00 (1.0)[e]
Coefficient of variation (%)	11.80	8.94	9.03	0.41	0.25

[1]Mean values of control percentages (x) transformed into square root (x + 1).
Mean values followed by different letters are significantly (P<0.05) different by Scott-Knott test.

Metribuzin and metribuzin + S-metolachlor caused mild symptoms of injury on elephant grass leaves at the first evaluation in experiment 2 (Table 3). Symptoms declined over time but were still present at 21 DAA.

Herbicide performance on weed control reached satisfactory values in both experiments with percent means higher than 82% at 21 DAA (Tables 2 and 3), except for trifluralin applied alone in experiment 1 (77.2%) (Table 2).

All treatments presented densities statistically equal to the weed-free control when analyzing the densities and dry matter of weeds at 30 DAA (experiment 1) (Table 4). However, trifluralin, flumioxazin and treatments with metribuzin resulted in higher density values than the weed-free control at 60 DAA. Also, trifluralin, ametryne, S-metolachlor, and those treatments with metribuzin resulted in higher weed dry matter than the weed-free control at 60 DAA (Table 4).

The mean values of weed density at 30 and 60 DAA, as well as, the weed dry matter were statistically the same as the weed-free control for all herbicide treatments in experiment 2 (Table 5).

Metribuzin was the only treatment statistically different from the weed-free control for the weed density at elephant grass harvest (Table 5). Considering results from both experiments for elephant grass dry matter weight and the joint analysis for this variable, the herbicides that resulted in higher values when compared with weed-free controls were diuron, ametryne, flumioxazin and metribuzin (Table 6). These 4 herbicides were selective for elephant grass plants and provided satisfactory weed control in both experiments (Figures 1 and 2).

The yield decrease in amount of elephant grass dry matter due to coexistence with weeds throughout the entire cycle is evident when comparing weedy and weed-free controls. Elephant grass dry matter losses were 69% and 65% for experiments 1 and 2, respectively (Table 6).

Table 4. Weed density (plants/m^2) at 30 (WD30) and 60 (WD60) days after herbicide application (DAA) and dry matter of weeds (g/m^2) at 30 (DMW30) and 60 (DMW60) DAA, in function of the treatments in Experiment 1 at Coronel Pacheco, Minas Gerais State, Brazil in 2020.

Treatments	WD30	WD60	DMW30	DMW60
Trifluralin	31.0^b	37.0^b	12.10^b	64.84^c
Trifluralin + Atrazine	7.0^b	12.0^c	1.83^b	28.44^d
Pendimethalin	6.0^b	17.0^c	5.28^b	46.79^d
Atrazine + S-metolachlor	4.0^b	19.0^c	2.09^b	31.68^d
Diuron	8.0^b	10.0^c	3.10^b	42.21^d
Diuron + Hexazinone	1.0^b	5.0^c	0.72^b	20.67^d
Tebuthiuron	1.0^b	6.0^c	0.70^b	20.99^d
Sulfentrazone	7.0^b	15.0^c	1.46^b	26.26^d
Ametryne	5.0^b	14.0^c	1.78^b	82.60^c
Flumioxazin	12.0^b	26.0^b	6.48^b	55.27^d
S-metolachlor	6.0^b	10.0^c	3.20^c	93.78^c
Metribuzin	25.0^b	34.0^b	6.09^b	134.67^b
Metribuzin + S-metolachlor	8.0^b	26.0^b	6.21^b	73.52^c
Weed-free	0.0^b	0.0^c	0.0^b	0.0^d
Weedy	175.0^a	90.0^a	204.38^a	554.75^a
Coefficient of variation (%)	89.98	36.91	89.67	33.78

Mean values followed by different letters are significantly (P<0.05) different by Scott-Knott test.

Table 5. Weed density (plants/m^2) at 30 (WD30), 60 (WD60) days after herbicide application and at elephant grass harvest (WDH) and dry matter of weeds (g/m^2) at 60 (DMW60) DAA, in function of the treatments in Experiment 2 at Coronel Pacheco, Minas Gerais State, Brazil in 2021.

Treatments	WD30	WD60	WDC	DMW60
Trifluralin	10.0^b	7.0^b	8.0^c	2.0^b
Trifluralin + Atrazine	7.0^b	6.0^b	10.0^c	6.1^b
Pendimethalin	9.0^b	11.0^b	7.0^c	1.9^b
Atrazine + S-metolachlor	6.0^b	4.0^b	8.0^c	2.5^b
Diuron	6.0^b	11.0^b	9.0^c	4.4^b
Diuron + Hexazinone	0.0^b	5.0^b	10.0^c	0.4^b
Tebuthiuron	3.0^b	5.0^b	9.0^c	2.4^b
Sulfentrazone	11.0^b	10.0^b	8.0^c	5.0^b
Ametryne	9.0^b	11.0^b	12.0^c	9.3^b
Flumioxazin	9.0^b	12.0^b	16.0^c	5.9^b
S-metolachlor	9.0^b	6.0^b	13.0^c	3.3^b
Metribuzin	8.0^b	10.0^b	26.0^b	6.3^b
Metribuzin + S-metolachlor	9.0^b	7.0^b	13.0^c	8.8^b
Weed-free	0.0^b	0.0^b	13.0^c	0.0^b
Weedy	91.0^a	99.0^a	49.0^a	212.3^a
Coefficient of variation (%)	87.53	110.65	48.10	93.30

Mean values followed by different letters are significantly (P<0.05) different by Scott-Knott test.

Figure 1. Weed control in elephant grass at 30 DAA (days after herbicide application) in using diuron 2.0 kg ai/ha (4.0 L cp/ha) **(A)**; weedy control **(B);** ametryne 3.0 kg ai/ha (6.0 L cp/ha) **(C)**. (ai=active ingredient, cp=commercial product).

Figure 2. Weed control in elephant grass at 30 DAA (days after herbicide application) using flumioxazin 0.045 kg ai/ha (90.0 g cp/ha) **(A)**; weedy control **(B)**; metribuzin 0.96 kg ai/ha (2.0 L cp/ha) **(C)**. (ai=active ingredient, cp= commercial product).

Table 6. Elephant grass fresh matter weight (FM) (kg/ha) and dry matter weight (DM) (kg/ha) (individual analyses for experiments 1 and 2) and joint analysis of elephant grass dry matter weight (JADM) at Coronel Pacheco, Minas Gerais State, Brazil, 2020/2021.

Treatments	Experiment 1		Experiment 2		JADM
	FM	DM	FM	DM	
Trifluralin	21,794.87[b]	9,700.63[a]	29,358.97[c]	5,405.10[b]	7,552.87[b]
Trifluralin + Atrazine	24,743.58[b]	9,385.01[a]	27,628.20[c]	4,893.08[b]	7,139.05[b]
Pendimethalin	21,538.46[b]	8,631.42[a]	26,025.64[c]	5,353.88[b]	6,992.65[b]
Atrazine + S-metolachlor	23,205.12[b]	6,606.45[b]	32,884.61[c]	6,213.80[b]	6,410.13[b]
Diuron	30,769.23[a]	8,999.05[a]	46,858.97[a]	8,282.98[a]	8,641.02[a]
Diuron + Hexazinone	23,076.92[b]	7,282.49[b]	40,128.20[b]	8,060.90[a]	7,671.70[b]
Tebuthiuron	25,769.23[b]	7,936.11[b]	43,846.15[b]	7,906.31[a]	7,921.21[b]
Sulfentrazone	22,564.10[b]	6,422.39[b]	44,871.79[b]	7,818.83[a]	7,120.61[b]
Ametryne	31,794.87[a]	11,899.99[a]	49,807.69[a]	7,354.74[a]	9,627.37[a]
Flumioxazin	33,333.33[a]	10,400.09[a]	42,948.71[b]	8,000.04[a]	9,200.07[a]
S-metolachlor	30,641.02[a]	8,913.59[a]	30,576.92[c]	5,752.18[b]	7,332.89[b]
Metribuzin	30,576.92[a]	8,888.48[a]	50,833.33[a]	9,459.41[a]	9,173.95[a]
Metribuzin + S-metolachlor	21,987.17[b]	6,997.49[b]	39,358.97[b]	7,847.04[a]	7,422.27[b]
Weed-free	32,948.71[a]	10,595.93[a]	35,512.82[c]	6,705.37[a]	8,650.65[a]
Weedy	14,487.17[c]	3,287.68[c]	13,782.05[d]	2,353.75[c]	2,820.72[c]
Coefficient of variation (%)	13.52	15.37	11.26	14.16	14.99

Mean values followed by different letters are significantly ($P<0.05$) different by Scott-Knott test.

Conclusions

One of the great difficulties faced by livestock producers in Brazil is post-emergence control of narrow-leaf weeds in elephant grass pastures. This study confirmed that forage yield losses were significant due to weed competition throughout the entire elephant grass crop cycle. Weed control was effective for all herbicide treatments except for trifluralin applied alone. The most phytotoxic treatments were trifluralin and the formulated mixture of diuron + hexazinone. Elephant grass dry matter yield was not influenced by diuron, ametryne, flumioxazin and metribuzin, supporting their use as pre-emergence herbicides for weed control in elephant grass pastures. The lack of strategies and selective post-emergence herbicides to control grasses hinders the expansion of elephant grass fields in Brazil and could be solved by using new herbicide weed management techniques supported by the development of other herbicide molecules in the future.

Acknowledgments

The author would like to express his gratitude to Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) (Processo APQ 03630-23) for the financial support.

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(Note of the editors: All hyperlinks were verified 20 September 2024).

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(Received for publication 29 March 2023; accepted 6 September 2024; published 30 September 2024)

Tropical Grasslands-Forrajes Tropicales (2023) Vol. 12(3):200–212
doi: 10.17138/TGFT(12)200-212

Nota Técnica

Valor energético del pasto kikuyo (*Cenchrus clandestinus*) para la producción de leche en el trópico de altura

Energy value of kikuyu grass (Cenchrus clandestinus) *for milk production in the highland tropics*

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Resumen

En las zonas altas del trópico de Colombia, el pasto kikuyo (*Cenchrus clandestinus*) es la opción forrajera predominante. Conocer su valor energético *in vivo* es fundamental para la formulación de raciones. Los objetivos de este trabajo fueron: (i) Determinar la densidad energética del pasto kikuyo en términos de energía digestible (ED), metabolizable (EM) y neta (EN) a partir de pruebas de balance en vacas lecheras de la raza Holstein; (ii) Evaluar el potencial del pasto kikuyo para sostener la producción de leche en animales alimentados mayoritariamente con pasto; (iii) Estimar la tasa de sustitución (TS) del pasto kikuyo, entendida como la reducción en el consumo de pasto cuando se incorpora un suplemento concentrado en la dieta. Se utilizó un diseño transeccional de naturaleza descriptiva, en el cual se emplearon cuatro vacas lactantes con 196 días en lactancia, que diariamente consumieron pasto kikuyo *ad libitum* (98.4% del consumo total) más 0.3 kg de suplemento/animal/día. Para realizar la partición energética, se cuantificaron las pérdidas energéticas a través de las heces, orina, emisión entérica de metano y producción de calor; además, se determinó la producción de leche con la dieta, basada mayoritariamente en pasto. Al restringir el suplemento concentrado, todos los animales perdieron peso (-2.4%), aumentaron el consumo de materia seca (MS) de pasto (+24.6%), disminuyeron el consumo de MS total (-17.2%) y la producción de leche corregida al 4% de grasa (LCG4, -18.3%). La densidad energética de la dieta en términos de ED y EM fue de 2.78±0.13 y 2.37±0.08 Mcal/kg MS, respectivamente, mientras su contenido de EN fue estimado en 1.39±0.26 Mcal/kg MS. La producción de leche con base en el consumo de pasto, estimada a partir del balance energético, fue 13.20±3.84, fluctuando entre 8.8 y 15.9 kg LCG4/animal/día. La TS fue 0.56±0.10 kg MS de pasto/kg MS de concentrado.

Palabras clave: Consumo de materia seca, densidad energética, desempeño productivo, tasa de sustitución, vacas lactantes.

Abstract

Kikuyu grass (*Cenchrus clandestinus*) is the predominant forage option in the highland tropics of Colombia; hence, it is quite relevant for ration formulation to know its *in vivo* energy value. The objectives of this study were: (i) To determine the energy density of kikuyu grass in terms of digestible energy (DE), metabolizable energy (ME), and net energy (NE) through balance trials with Holstein cows; (ii) To evaluate the potential of kikuyu grass to sustain milk production in animals primarily fed on pasture; (iii) To estimate the substitution rate (SR) of kikuyu grass, defined as the reduction in pasture intake when a concentrate is incorporated into the diet as a supplement. A cross-sectional design of descriptive nature was used, in which four lactating cows with 196 days in lactation were employed, consuming kikuyu grass *ad libitum* (98.4% of total intake) plus 0.3 kg of supplement/animal/day. Energy losses through feces, urine, enteric methane emissions, and heat production were quantified to perform energy partitioning; also, milk production, primarily from a

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grass-based diet, was determined. After restricting concentrate intake, all animals lost weight (-2.4%), increased grass dry matter (DM) intake (+24.6%) and reduced total DM intake (-17.2%) and fat-corrected milk yield (4% FCM, -18.3%). The energy density of the diet in terms of DE and ME was 2.78±0.13 and 2.37±0.08 Mcal/kg DM, respectively, while its estimated NE content was 1.39±0.26 Mcal/kg DM. Milk production based on pasture, as estimated through the energy balance, was 13.20±3.84, ranging between 8.8 and 15.9 kg 4% FCM/animal/day. The SR was 0.56±0.10 kg DM of grass/kg DM of concentrate.

Keywords: Dry matter intake, energy density, lactating cows, productive performance, substitution rate.

Introducción

Las zonas del trópico de altura en Colombia se han especializado en la producción de leche, con el pasto kikuyo (*Cenchrus clandestinus)* como componente forrajero predominante (Portillo et al. 2019). El pasto kikuyo es una gramínea tropical perenne de vía fotosintética C4 (García et al. 2014), cuya producción anual oscila entre 9 y 30 toneladas de materia seca (MS)/ha/año (Royani et al. 2021).

Una vez el alimento es ingerido por el animal, parte de su contenido energético se pierde en heces, orina, gases y calor disipado, quedando finalmente la energía neta (EN), que estará disponible para el mantenimiento y la retención de energía en forma de producción de leche, tejido corporal y otras funciones anabólicas (Church et al. 2002). Realizar estimaciones precisas del contenido de energía disponible de los alimentos es necesario para formular dietas y evaluar el valor nutricional y económico de las diferentes raciones.

El contenido de energía de los alimentos se puede estimar a través de ecuaciones de regresión que se basan en su composición química. En el caso de los forrajes, frecuentemente se utilizan ecuaciones basadas en el contenido de fibra detergente ácido (FDA), las cuales son insensibles a los cambios en las concentraciones de otros nutrientes, no consideran fuentes adicionales de variación sobre la digestibilidad, y no permiten descuentos variables basados en el consumo y los efectos asociativos. Además, dichas ecuaciones están basadas en alimentos usados en la zona templada (Weiss 1998).

Varios trabajos han reportado valores de EN de lactancia (EN_l) para el pasto kikuyo (Mcal/kg MS): entre 1.01–1.13 a los 60 y 30 días de rebrote, respectivamente (Soto et al. 2005); 1.18 a los 29 días (Correa et al. 2012) y entre 1.27–1.45 a los 35 días, en períodos de baja y alta precipitación, respectivamente (Portillo et al. 2019), pero los mismos son producto de estimaciones usando ecuaciones de predicción, y no de mediciones directas en ensayos *in vivo*, donde se mide primero la energía digestible (ED), luego la energía metabolizable (EM), y posteriormente la energía neta (EN) (Weiss y Tebbe 2019). Por otro lado, hay reportes del contenido de EM en pasto kikuyo medida *in vivo* (Marais 2001; Erasmus 2009), pero no de EN.

Con base en lo anterior, el presente trabajo tuvo como objetivos: 1. Determinar el valor energético del pasto kikuyo en términos de ED, EM y EN a partir de pruebas de balance con vacas lactantes de la raza Holstein; 2. Evaluar el potencial del pasto kikuyo para sostener la producción de leche en animales alimentados mayoritariamente con pasto; y 3. Estimar la tasa de sustitución (TS) del pasto kikuyo, entendida como la reducción en el consumo de pasto cuando se incorpora un suplemento concentrado en la dieta.

Materiales y Métodos

Localización

El trabajo se realizó en el Laboratorio de Calorimetría Animal del Centro de Prácticas y Desarrollo Agrario "La Montaña", propiedad de la Universidad de Antioquia, ubicado en el municipio de San Pedro de los Milagros (Antioquia, Colombia) (coordenadas: 6° 26´59.606 N y 75° 32´37.088 W) a una altitud de 2468 msnm, y con promedios de temperatura y humedad relativa de 14.5 °C y 79%, respectivamente.

Animales experimentales

Se utilizó un diseño transeccional de naturaleza descriptiva, en el cual se seleccionaron cuatro vacas adultas de la raza Holstein, con 196.3±25.3 días en lactancia, 571.5±17.7 kg de peso vivo (PV) y una producción de leche corregida al 4% de grasa (LCG4) de 19.9±2.0 kg/día. Los animales permanecieron estabulados en un galpón abierto, dotado con comedero y bebedero individual. Antes de iniciar las mediciones, fueron adaptados a las instalaciones, la alimentación y el manejo durante 15 días, lapso durante el cual se inició el suministro de óxido de cromo (Cr_2O_3) para la determinación de la digestibilidad y se realizó la reducción gradual de la suplementación de concentrado desde 7.7±0.2 hasta un mínimo de 0.3 kg/animal/día, cantidad que se mantuvo hasta finalizar el trabajo, correspondiendo al período con restricción de suplemento.

Alimentación

Los animales tuvieron libre acceso al agua y a pasto kikuyo (*Cenchrus clandestinus*) fresco de 32 días de rebrote, fertilizado con 370 kg de N/ha/año, de los cuales 310 kg fueron aportados por fertilizante sintético y 60 kg N por gallinaza compostada. El pasto fue cosechado diariamente en horas de la mañana y suministrado tres veces al día (08:00, 12:00, 16:00 h) para estimular el consumo y evitar el desperdicio. La cantidad ofertada a cada animal se calculó con base en el consumo del día anterior más un 20% adicional. El consumo de pasto se determinó diariamente por diferencia de peso entre la oferta y el rechazo.

Al momento del ordeño (06:00 y 15:00 h) se ofreció el suplemento concentrado, garantizando el consumo total. La suplementación inicial, que en promedio fue de 7.7±0.2 kg/animal/día, se restringió progresivamente, los días 10, 12 y 14 después de iniciado el experimento, a razón de 2.5±0.1 kg/animal/día (50% en cada ordeño), de tal forma que antes de iniciar la prueba de digestibilidad, en el día 16, los animales sólo recibieron 0.3 kg de suplemento/animal/día, y esa cantidad se mantuvo hasta finalizar la fase de evaluación. La composición química del pasto kikuyo y del suplemento concentrado se presenta en el Cuadro 1.

Cuadro 1. Composición nutricional del pasto kikuyo (*Cenchrus clandestinus*) y del suplemento concentrado.

Composición química	*Cenchrus clandestinus*	Suplemento
Materia seca, %	13.6	83.6
Proteína bruta, %	21.2	14.8
Extracto etéreo, %	3.1	3.9
Fibra detergente neutro, %	53.9	18.4
Fibra detergente ácido, %	24.8	7.1
Cenizas, %	12.8	11.6
Materia orgánica, %	87.2	88.4
Carbohidratos no fibrosos, %	9.0	51.3
Energía bruta, Mcal/kg MS	4.4	4.2

Prueba de digestibilidad y metabolismo

Una vez finalizada la etapa de adaptación de 15 días de duración, se inició la prueba de digestibilidad y metabolismo. La producción fecal se estimó empleando Cr_2O_3 como marcador externo (Correa et al. 2009) y la excreción urinaria a partir de la concentración de creatinina en orina como marcador interno (Escobar et al. 2010). Igualmente, se cuantificó la producción de metano (CH_4) y de calor mediante calorimetría indirecta de circuito abierto (Li Jiangong et al. 2019).

Digestibilidad. A partir del día 9 de iniciado el experimento y durante 12 días consecutivos, cada animal recibió diariamente 10 g de Cr_2O_3 (p.a. 98%) (Fisher Scientific, FairLawn, NJ, USA), 5 g en cada ordeño. Durante los últimos cinco días de suministro, entre los días 16 y 20 de iniciado el experimento, se colectaron muestras individuales de heces directamente del recto, dos veces por día (mañana y tarde), obteniendo al final una muestra compuesta por animal, en la que se determinó la concentración de MS, cromo y energía bruta (EB).

Volumen urinario. Simultáneamente con la colecta fecal, diariamente se obtuvo muestras de orina de cada animal. Completados los cinco días de colecta, se obtuvo una muestra compuesta por animal, en la que se determinó la concentración de creatinina y EB.

Emisión de metano y producción de calor. Finalizada la colecta de heces y orina, los animales ingresaron a las cámaras de respiración de circuito abierto por tres días consecutivos para la cuantificación del consumo de oxígeno y de la emisión de CH_4 y dióxido de carbono. El sistema respirométrico usado fue descrito por Rosero y Posada (2017). El intercambio respiratorio (L/día) permitió calcular la producción de calor (kcal/día) a partir de la ecuación descrita por Brouwer (1965).

Producción y composición de la leche

Las vacas fueron ordeñadas dos veces por día (06:00 y 15:00 h), usando un sistema de ordeño mecánico Alfa Laval, de cuatro puestos en tándem. La producción de leche se cuantificó diariamente de forma individual utilizando medidores automáticos (WB Ezi-Test; Tru-Test, New Zealand), mientras que su calidad composicional se analizó antes (días 6 y 7) y después de la restricción del suplemento concentrado (días 19 y 20 de iniciado el experimento), obteniendo una muestra por ordeño, en la cual se determinó el contenido de proteína, grasa, lactosa y sólidos totales (valores expresados en %) empleando equipo MilkoScan FT+ (Foss, Hillerød, Dinamarca). La composición fue ponderada de acuerdo con la cantidad de leche registrada en cada ordeño. La producción de leche fue corregida al 4% de grasa (LCG4) conforme la ecuación descrita por Hall (2023). El contenido energético de la leche se calculó de acuerdo con los lineamientos del NRC (2001).

Peso corporal.

Los animales se pesaron a los 7 y 21 días de iniciado el experimento, esto es, antes de iniciar la restricción de concentrado y al finalizar la prueba de digestibilidad y metabolismo. El pesaje se realizó a la misma hora, sin previo ayuno, justo antes de ofrecer el alimento.

Análisis químicos.

El análisis químico de las muestras (pasto, suplemento, rechazos) incluyó MS, PB, cenizas, fibra detergente neutro (FDN), FDA y EB (Balthrop et al. 2011). La concentración de extracto etéreo (EE) sólo se analizó en los alimentos, con el fin de hallar la concentración de carbohidratos no fibrosos (CNF): MS–(PB+cenizas+EE+FDN). En las heces y la orina se determinó la EB para realizar el balance energético. La concentración de cromo en las heces y en el Cr_2O_3 ofrecido se determinó por espectrometría de absorción atómica (Williams et al. 1962). La concentración de creatinina en la orina se determinó por colorimetría (Escobar et al. 2010).

Variables de respuesta

Consumo de materia seca y de nutrientes. Diariamente se tomaron muestras del alimento ofrecido y del rechazo, obteniendo una muestra compuesta por animal en dos momentos: entre los días 5 y 9 (sin restricción de suplemento concentrado) y, durante la prueba de digestibilidad, entre los días 16 y 20 (con restricción de suplemento concentrado) de iniciado el experimento. A partir del análisis químico de las muestras se calculó el consumo de MS (CMS), materia orgánica (MO), PB, FDN, FDA y EB.

Eficiencia alimenticia. La eficiencia alimenticia (EA), expresada en kg de leche y de LCG4 por kg de MS consumida, se determinó con base en el desempeño productivo y el CMS total entre los días 5–9 (sin restricción de suplemento concentrado) y 16–20 (con restricción de suplemento concentrado) después de iniciado el experimento.

Balance energético. El balance de energía (kcal/día) se determinó por diferencia entre el consumo de EB y las pérdidas a través de las heces (energía fecal, EF), la orina (energía urinaria, EU), el CH_4 emitido (EG) y el calor generado. La pérdida de energía en forma de CH_4 se estimó como el producto entre la emisión de CH_4 (L) y su densidad energética (9.45 kcal/L; Nkrumah et al. 2006). La ED correspondió a la diferencia EB-EF, la EM a la diferencia ED-EU-EG y la energía neta retenida (EN_r) fue el resultado de la diferencia entre EM y la producción de calor. El balance energético (BE) correspondió a la diferencia entre la EN_r y la energía presente en la leche. La energía neta requerida para el mantenimiento (EN_m) se estimó a partir del peso corporal vacío metabólico ($PCV^{0.75}$), que según el NASEM (2021) corresponde a 0.1 Mcal/kg $PCV^{0.75}$. La EN total correspondió a la suma de la EN_m y la EN_r, en tanto que el incremento térmico se estimó por diferencia entre la EM y la EN. La densidad energética de la dieta (kcal/kg MS) se obtuvo al dividir los resultados del balance energético (kcal/día) por el CMS (kg/día). Para la estimación del peso corporal vacío (PCV) a partir del peso vivo (PV) se utilizó la ecuación (NRC 2001):

$$PCV = PV \times 0.817.$$

Producción de leche a partir del consumo de pasto (Base forrajera). Este parámetro expresado en kg de LCG4/animal/día se estimó usando dos metodologías: i) A partir del producto entre la pérdida de PCV (kg/día) (PCV día 21–PCV día 7) y su densidad energética (Mcal/kg), estimada previa determinación de la condición corporal de los animales, que en promedio fue 3.0±0.1; y ii) A partir del balance energético negativo (BEN) cuantificado por calorimetría (Mcal/día). Las premisas contempladas fueron las siguientes: a) la pérdida de 1 kg de PCV aporta 4.68 Mcal EN_l, cada kg de LCG4 requiere 0.749 Mcal para su síntesis y, b) la eficiencia con la cual se emplea la energía movilizada desde las reservas corporales para la producción de leche es del 82%. La producción de LCG4 calculada a partir de la pérdida de peso y el balance energético negativo fue sustraída de la producción de LCG4 observada, permitiendo estimar la producción de leche a partir del consumo de pasto.

Tasa de sustitución (TS). La TS fue estimada mediante la fórmula propuesta por Bargo et al. (2003):

$$TS = (CMSp\ sin\ suplementación – CMSp\ con\ suplementación)/CMSs;$$

Donde: CMSp y CMSs hacen referencia al CMS de pasto y suplemento concentrado, respectivamente. El CMSp con y sin suplementación correspondió al promedio de consumo registrado entre los días 5–9 y 16–20 del período experimental, respectivamente.

Resultados

En el Cuadro 2 se muestra el PV, el CMS y de nutrientes, antes y después de la restricción de suplemento concentrado en cada una de las unidades experimentales. El consumo de PB, FDN, FDA, MO y EB antes de la restricción de suplemento fue de 19±0.2, 41.6±1.3, 18.7±0.7, 87.7±0.1 (% MS) y 4313±8.7 kcal/kg MS, respectivamente. Los valores correspondientes de consumo de los mismos nutrientes después de la restricción de suplemento fueron: 21.1±0.0, 53.3±0.1, 24.5±0.1, 87.2±0.0 (% MS) y 4386±9.1 kcal/kg MS.

En el Cuadro 3 se muestra la producción de leche, su composición y la eficiencia alimenticia antes y después de la restricción de suplemento concentrado para cada una de las vacas utilizadas en el estudio.

En el Cuadro 4 se muestra la variación porcentual en el PV, el CMS de pasto y total, y de los nutrientes analizados, así como el desempeño productivo entre el período previo y posterior a la restricción de suplemento concentrado. En todos los casos, el 100% corresponde al valor obtenido durante el período de suplementación.

Cuadro 2. Peso vivo, consumo de materia seca y de nutrientes antes y después de la restricción de suplemento concentrado.

Variable	Antes de la restricción de suplemento				Después de la restricción de suplemento			
	Animal 1	Animal 2	Animal 3	Animal 4	Animal 1	Animal 2	Animal 3	Animal 4
PV inicial	556	586	544	580	-	-	-	-
PV final	-	-	-	-	550	574	524	565
Consumo de materia seca								
Pasto (kg/día)	14.0	13.5	10.3	11.1	18.1	14.6	13.6	14.2
Suplemento (kg/día)	6.3	6.3	6.3	6.7	0.3	0.3	0.3	0.3
Total (kg/día)	20.3	19.8	16.6	17.8	18.4	14.9	13.9	14.5
Total (% PV)	3.6	3.4	3.1	3.1	3.3	2.6	2.7	2.6
Pasto (%)	69.0	68.2	62.0	62.2	98.6	98.3	98.2	98.3
Tasa de sustitución	-	-	-	-	0.66	0.17	0.54	0.47
Consumo de nutrientes								
PB (kg/día)	3.9	3.8	3.1	3.3	3.9	3.1	2.9	3.1
FDN (kg/día)	8.7	8.5	6.7	7.2	9.8	7.9	7.4	7.7
FDA (kg/día)	3.9	3.8	3.0	3.2	4.5	3.7	3.4	3.5
MO (kg/día)	17.7	17.4	14.5	15.6	16.0	13.0	12.2	12.6
EB (kcal/día)	87567	85648	71416	76541	80650	65397	61126	63451

Cuadro 3. Producción y composición de la leche, y eficiencia alimenticia antes y después de la restricción de suplemento concentrado.

Variable	Antes de la restricción de suplemento				Después de la restricción de suplemento			
	Animal 1	Animal 2	Animal 3	Animal 4	Animal 1	Animal 2	Animal 3	Animal 4
Producción de leche								
kg/día	19.0	18.6	20.5	22.0	15.7	15.9	17.5	18.6
kg LCG4/día	19.6	17.5	22.6	21.7	15.6	14.6	19.4	16.9
Calidad de leche								
Grasa (%)	4.2	3.6	4.7	3.9	3.9	3.5	4.7	3.4
Proteína (%)	3.1	3.1	3.4	3.0	3.2	3.2	3.4	3.0
Relación Grasa/Proteína	1.4/1	1.2/1	1.4/1	1.3/1	1.2/1	1.1/1	1.4/1	1.1/1
Sólidos totales (%)	12.4	11.1	13.6	12.0	12.3	11.5	13.7	11.5
Lactosa (%)	4.6	3.9	4.9	4.5	4.4	4.2	4.9	4.4
Energía (kcal/kg)	736.4	659.9	814.7	700.8	716.0	660.3	813.8	655.1
Eficiencia alimenticia								
kg leche/kg MS	0.94	0.94	1.24	1.24	0.86	1.07	1.27	1.29
kg LCG4/kg MS	0.97	0.88	1.37	1.22	0.85	0.99	1.40	1.17

Cuadro 4. Diferencia porcentual entre el período previo y posterior a la restricción de suplemento concentrado para el peso vivo, el consumo de materia seca y de nutrientes y el desempeño productivo.

Variable	Animal 1	Animal 2	Animal 3	Animal 4
PV	-1.1	-2.0	-3.7	-2.6
Consumo de materia seca y de nutrientes				
Pasto	+29.5	+8.1	+32.6	+28.2
Total	-9.3	-24.8	-16.0	-18.7
PB	-0.4	-17.4	-5.8	-8.7
FDN	+12.9	-6.1	+10.5	+6.9
FDA	+15.3	-4.1	+13.6	+9.8
MO	-9.7	-25.2	-16.4	-19.1
EB	-7.9	-23.6	-14.4	-17.1
Desempeño productivo				
Leche total	-17.4	-14.4	-14.3	-15.6
Leche corregida, LCG4	-20.3	-16.4	-14.2	-22.2
Grasa (%)	-5.8	-4.0	+0.3	-13.1
Proteína (%)	+5.9	+2.3	-1.6	+1.4
Relación Grasa/Proteína	-11.1	-6.1	+1.8	-14.3
Sólidos totales (%)	-0.6	+3.9	+0.2	-4.0
Lactosa (%)	-4.2	+6.5	+0.5	-0.4
Energía (kcal/kg)	-19.7	-14.4	-14.4	-21.1
EA (kg leche/kg MS)	-8.6	+14.3	+2.3	+3.5
EA (kg LCG4/kg MS)	-11.9	+11.7	+2.5	-4.5

En el Cuadro 5 se muestra el balance energético y la eficiencia de utilización de la energía durante el período de restricción de suplemento concentrado. La EM representó el 54±1.8% de la EB (metabolicidad) y el 85.1±2.3% de la ED. La relación EN/EM fue de 58.5±10.6%.

En el Cuadro 6 se muestran las estimaciones de la base forrajera a partir de la pérdida de peso y del balance energético, el cual fue negativo para los animales 2, 3 y 4. No se presenta información del animal 1 porque fue el único que presentó balance energético positivo (+9.3 Mcal/día), como se observa en el Cuadro 5.

Cuadro 5. Consumo, balance y eficiencia de utilización de la energía durante la restricción de suplemento concentrado.

Variable	Balance energético (kcal/día)				Eficiencia de utilización de la energía (% de EB)			
	Animal 1	Animal 2	Animal 3	Animal 4	Animal 1	Animal 2	Animal 3	Animal 4
Energía bruta (EB)	80,651	65,398	61,126	63,452	100	100	100	100
Heces	28,255	21,937	23,063	25,286	35.0	33.5	37.7	39.9
Energía digestible (ED)	52,396	43,461	38,063	38,166	65.0	66.5	62.3	60.1
Metano	4,758	5,101	3,179	2,538	5.9	7.8	5.2	4.0
Orina	2,420	2,878	2,078	2,792	3.0	4.4	3.4	4.4
Energía metabolizable (EM)	45,248	35,508	32,800	32,850	56.1	54.3	53.7	51.8
Calor	24,747	30,303	21,737	22,489	30.7	46.3	35.6	35.4
Energía neta mantenimiento (ENm)[1]	9,759	10,077	9,411	9,958	12.1	15.4	15.4	15.7
Incremento térmico	14,988	20,226	12,326	12,531	18.6	30.9	20.2	19.7
Energía neta retenida (EN_r)[2]	20,501	5,205	11,063	10,361	25.4	8.0	18.1	16.3
Energía en leche	11,232	10,493	14,278	12,169	13.9	16.0	23.4	19.2
Balance energético (BE)[3]	9,269	-5,288	-3,215	-1,808	11.5	-	-	-
Energía neta (EN)[4]	30,260	15,282	20,474	20,319	37.5	23.4	33.5	32.0
Densidad energética (Mcal/kg MS)								
EB	4.38	4.39	4.40	4.38				
ED	2.85	2.92	2.74	2.63				
EM	2.46	2.38	2.36	2.27				
EN	1.65	1.03	1.47	1.40				
Relación EN/EM	66.9	43.0	62.4	61.9				

[1]EN_m=100 kcal/kg $PCV^{0.75}$ × PCV; [2]EN_r=EM-Calor; [3]BE=EN_r- Energía presente en la leche; [4]EN=EN_m+ EN_r

Cuadro 6. Estimación de la base forrajera a partir del cambio en peso corporal y del balance energético.

Variable	Animal 2	Animal 3	Animal 4
Base forrajera estimada a partir de la pérdida de peso corporal			
Pérdida de peso corporal vacío (PCV) (kg/día)	-0.70	-1.17	-0.88
Energía obtenida a partir de la pérdida de PCV (Mcal/día)[1]	3.3	5.5	4.1
LCG4 estimada a partir de la pérdida de PCV (kg/día)[2,3]	3.6	6.0	4.5
Base forrajera (kg LCG4/animal/día)	11.0	13.4	12.4
Base forrajera estimada a partir del balance energético			
Balance energético negativo (BEN) (Mcal/día)[4]	5.3	3.2	1.8
LCG4 estimada a partir del BEN (kg/día)	5.8	3.5	2.0
Base forrajera (kg LCG4/animal/día)	8.8	15.9	14.9

[1]La pérdida de 1 kg de PCV aporta 4.68 Mcal EN_l; [2]0.749 Mcal/kg de leche conteniendo 4% de grasa; [3]La reserva energética se emplea con una eficiencia del 82% para soportar la producción de leche; [4]Datos obtenidos del balance energético determinado calorimétricamente

Discusión

Las mediciones del metabolismo energético, como las realizadas en este estudio, requieren del uso de sistemas calorimétricos que son costosos y cuya operación y control son laboriosos (Reynolds 2000). Esta situación limita el número de animales que pueden ser evaluados simultáneamente. Pese a ello, la información generada con esta metodología es de gran relevancia, si se compara con el valor energético de los alimentos estimado a partir de modelos matemáticos, basados en datos de composición química. Si bien varios de esos modelos tienen valor para forrajes usados en países de zona templada, su aplicabilidad es limitada en el caso de forrajes tropicales (Detmann et al. 2008), al menos hasta que se desarrollen ecuaciones para ese tipo de forrajes. Además, las ecuaciones de predicción del valor energético de los alimentos a partir de datos de composición química tienen limitaciones, ya que simplifican el complejo metabolismo animal a la composición de los alimentos, ignorando variables como el metabolismo del animal, la digestibilidad y el consumo, que son determinantes en la eficiencia del uso de la energía del alimento (Weiss 1998).

Composición química de la dieta y consumo de materia seca

La concentración de PB y FDN del pasto kikuyo (Cuadro 1) se aproxima a los valores reportados por Caro y Correa et al. (2006) para esta especie forrajera a una edad de cosecha de 32 días y bajo condiciones de manejo similares a las del presente estudio (2300 msnm, temperatura media de 16 °C y fertilización química y orgánica). Los restantes valores de composición se aproximan a los reportados por los mismos autores para 58 días de rebrote.

El CMS total de los animales antes de la restricción de suplemento (18.6 kg y 3.3% del PV) (Cuadro 2) fue ligeramente inferior al reportado por Angulo et al. (2022) (19.2 kg/día y 3.5% del PV) en vacas Holstein con 160 días de lactancia recibiendo ensilaje, pasto Ryegrass sp. (30 días), maíz extruido y suplemento concentrado; pero similar al encontrado por Correa et al. (2009) (18.3 kg/día y 3.1% del PV) en vacas Holstein con 170 días de lactancia consumiendo pasto kikuyo (20% PB y 61% FDN) y suplemento comercial. Solamente el animal 1 fue el que conservó niveles elevados de CMS luego de la restricción de suplemento (Cuadro 2). En este animal, el aumento porcentual en el CMSp fue 29.5%, similar al observado en los animales 3 y 4, a saber, 32.6 y 28.2%, respectivamente (Cuadro 4). Ese aumento se explica por la desaparición del efecto de sustitución que el suplemento genera sobre el consumo de pasto (García et al. 2014). De otra parte, el mayor CMS del animal 1 representó un consumo de 18 g FDN/kg PV/día, mientras que en los animales restantes fue de 14 g FDN/kg PV/día (Cuadro 2). En otro estudio, Mertens (1994) observó que el CMS en vacas lecheras fue máximo cuando el consumo de FDN fue 12.5±1.0 g/kg PV/día; mientras que Fulkerson et al. (2006), reportaron consumos de FDN que fluctuaron entre 16 y 22 g/kg PV.

Producción de leche y su composición

El mayor CMS del animal 1 después de la restricción de suplemento no se reflejó en la producción de leche, la cual mostró una reducción del 17.4%, comparado con el 15.0% obtenido como promedio para los animales 3 y 4 (Cuadro 4). Lo anterior resultó en una reducción de la EA en el animal 1 (-8.6%) vs. el incremento observado en los animales 3 y 4 (+2.9% en promedio). La mayor EA en los animales 3 y 4 (1.28 kg leche/kg MS), respecto el animal 1 (0.86 kg leche/kg MS), puede estar sustentada en el menor nivel de consumo de los primeros, que los hizo más eficientes en el aprovechamiento de los nutrientes consumidos (Mendoza-Martínez et al. 2008).

Las concentraciones promedio de proteína y grasa en leche, 3.2 y 4.1%, respectivamente (Cuadro 3), fueron ligeramente superiores a las descritas por Carulla y Pabón (2006) bajo condiciones de la sabana de Bogotá y en San Pedro de los Milagros (Antioquia) (proteína: 3.0–3.1%; grasa: 3.5–3.6%).

Luego de la restricción en la oferta de suplemento concentrado, la producción de leche y la LCG4 presentaron valores medios de 16.9±1.4 y 16.6±2.1 kg/animal/día, respectivamente (Cuadro 3). De acuerdo con la literatura, la capacidad máxima de producción de leche del pasto kikuyo está limitada por el CMS y su contenido de energía (Marais 2001; Correa et al. 2008).

Para todos los animales, la diferencia en producción de leche/animal/día entre el período de suplementación y de restricción fue, en promedio, 3.1±0.3 kg de leche y 3.7±0.9 kg LCG4. El balance energético negativo experimentado por los animales 2, 3 y 4 (Cuadro 5), que registraron menor CMS (Cuadro 2), apoyó la producción de leche en 3.8±1.9 kg (LCG4) (Cuadro 6) durante el período de restricción. En el animal 1, la producción de leche fue soportada por el mayor CMS respecto los demás animales (Cuadro 2), lo cual resultó en un balance energético positivo (Cuadro 5).

La media para la base forrajera (Cuadro 6) estimada a partir del cambio en peso corporal es menor (12.3±1.2 kg) y más estable que la estimada con base en el balance energético (13.2±3.8 kg). Henning et al. (1995) reportaron valores entre 9.1 y 14.6 kg/animal/día en vacas Holstein consumiendo pasto kikuyo de 30 días de edad de rebrote durante seis meses continuos, con reducción en la producción de leche conforme avanzó la lactancia. De otra parte, Reeves (1997) reportaron valores de 17.3, 14.2 y 12.5 kg/animal/día a los 3–4, 5–6 y 7 meses de lactancia, respectivamente, en vacas que consumían pasto kikuyo de 18 a 24 días de edad de rebrote.

Tomando en consideración la fase de la curva de lactancia en la cual se encuentran los animales como un factor determinante de la producción de leche, se deduce que la base forrajera del presente estudio, con independencia del método de estimación empleado, superó la informada por Henning et al. (1995) al sexto mes (9.1 kg/animal/día) y fue comparable a la obtenida por Reeves (1997) entre el quinto y séptimo mes de lactancia. La base forrajera media obtenida a partir del balance energético (13.2±3.8 kg), si bien se reduce por el valor predicho para el animal 2, aumenta a 15.4 kg cuando sólo se incluyen los animales 3 y 4, muy similar a los 15.6 kg observados en el animal 1. Esto concuerda con la conclusión de Reeves (1997) quien determinó que la producción de leche con base en pasto kikuyo bien manejado puede mantenerse en 15 kg/animal/día.

Los niveles de producción de leche con pasto Ryegrass son mayores que los obtenidos con pasto kikuyo, conforme los trabajos descritos por Mahanta et al. (2020). Con una pastura de Ryegrass se obtuvieron 20–22 kg/vaca/día, lo que supuso un mérito genético normal, ningún cambio en el PV y un nivel aceptable de utilización de la pastura. En cambio, con pasto kikuyo el cual se acepta es de menor calidad que el Ryegrass, se obtuvo un rendimiento de 15 kg/vaca/día, lo cual concuerda con los hallazgos del presente estudio.

Si bien los valores de base forrajera obtenidos a partir del balance energético pueden resultar menos conservadores, están soportados por una metodología (calorimetría indirecta de circuito abierto) mundialmente reconocida para la cuantificación de metano y de calor y, en una cuantificación directa del consumo y la excreción de heces y orina, lo que le confiere un mayor nivel de certidumbre en relación con una única variable (PV), cuyo resultado puede resultar enmascarado por el contenido digestivo.

En cuanto a la base forrajera estimada a partir del balance energético, también se puede concluir que ésta puede mostrar variaciones entre animales, bajo similares condiciones de alimentación. El valor inferior obtenido en el animal 2 (8.8 kg LCG4), puede ser el resultado de un menor incremento en el CMS de pasto (+1.1 kg/día) una vez restringido el suplemento concentrado, cuando se le compara a lo obtenido con los otros tres animales (en promedio, +3.5 kg/día). Igualmente, el animal 2 fue el que registró una mayor producción de calor (30,303 kcal/día) respecto los demás animales (22,991±1,566 kcal/día), lo cual afectó la EN_r (5,205 vs. 10,712±496 kcal/día) en promedio para los animales 3 y 4) y generó el mayor balance energético negativo (Cuadro 5).

Balance energético y valor energético del pasto kikuyo medidos

Agnew y Yan (2000) argumentaron que el aumento en el CMS de dietas altas en fibra incrementa la tasa metabólica de mantenimiento, reduce la metabolicidad y la eficiencia de uso de la energía metabolizable para el mantenimiento (k_m), lo cual resulta en mayores requerimientos de EM para el mantenimiento. En su revisión, la mayor tasa metabólica de mantenimiento obedece al incremento de la masa del tracto gastrointestinal y de la actividad metabólica de los órganos, en tanto que la menor metabolicidad es atribuida a la reducción en la digestibilidad de la energía y al incremento en la pérdida energética en forma de CH_4 como proporción del consumo de ED. Esa situación no se evidenció en este trabajo cuando se comparó la eficiencia de utilización de la energía en el animal 1, que presentó mayor CMS de kikuyo y de FDN después de la restricción de suplemento (Cuadro 2), con el promedio de eficiencia de los animales restantes (Cuadro 5). En el animal 1, el promedio de digestibilidad (ED/EB) y metabolicidad (EM/EB) fue 2.0 y 2.8% superior, respectivamente, mientras que la producción de calor, que es el resultado del incremento térmico y las funciones de mantenimiento, fue 8.4% menor.

La mayor producción de calor del animal 2 (46.3% del consumo de EB), superando el valor medio exhibido por los animales restantes (33.9±2.8%) y representada principalmente por el incremento térmico (30.9% del consumo de EB y 66.7% de la producción de calor), resultó en menor EN_r y, por tanto, en menor EN (Cuadro 5).

Tomando en consideración todos los animales, la densidad energética estimada del pasto kikuyo fue 1.39±0.26 Mcal EN/kg MS. Cuando se excluyó la información del animal 2 (1.03 Mcal EN/kg MS), la densidad energética registró un valor medio de 1.51±0.13 Mcal/kg MS.

La EN correspondió a la suma EN_m+ EN_r, y no a la suma EN_m+Energía presente en la leche, toda vez que el balance energético evidenció que los animales 2, 3 y 4 produjeron leche a partir de las reservas corporales (BEN), por lo que la energía presente en la leche no reflejó exclusivamente el contenido energético del alimento.

El alimento tiene un único valor de EN que el animal puede emplear para el mantenimiento (EN_m) o la retención de energía (EN_r). La EN_r comprende la energía de la leche, de los tejidos (retenida principalmente como proteína y grasa y, en menor grado, como glucógeno) y de los productos de la preñez (Church et al. 2002). En este trabajo, cuando se multiplica la LCG4 (observada en el animal 1 y la base forrajera estimada de los animales 2, 3 y 4) por su respectiva densidad energética (0.72±0.008 Mcal/kg) se observa que la energía retenida en la leche fue 0.65±0.18 Mcal/kg MS, correspondiente al 47.1±9.4% del valor de EN estimado (1.39±0.26 Mcal/kg MS) (Cuadro 5). A su vez, la EN representó el 58.5±10.6% de la EM (Cuadro 5), próxima a la eficiencia con la cual se emplea la EM para el mantenimiento (0.62) y la producción de leche (0.64) conforme el NRC (2001). Debido a la similitud en las eficiencias, este sistema expresa los requerimientos para mantenimiento y producción de leche en términos de EN de lactancia (EN_l), al igual que el valor energético de los alimentos.

Valor energético del pasto kikuyo estimado a través de ecuaciones de la literatura

Para propósitos comparativos, se utilizó varios modelos matemáticos disponibles en la literatura para estimar la densidad energética a partir del total de nutrientes digestibles, el contenido de FDN y FDA, la ED y EM y la metabolicidad (Cuadro 7), y con ellos se obtuvo valores que fluctuaron entre 1.37 y 1.71 Mcal/kg MS. El 58.3% de esos estimados fue superior al valor 1.51 Mcal/kg MS obtenido en este estudio, luego de excluir los datos del animal 2 que mostró una respuesta atípica. Estas discrepancias pueden explicarse porque dichos modelos se construyeron con información derivada de pastos de zonas templadas (C3) que utilizan vías metabólicas diferentes a la mayoría de gramíneas tropicales (C4) que, a menudo, conduce a una mayor tasa y grado de deposición de lignina en los tejidos de gramíneas tropicales, un factor que puede alterar el consumo voluntario y la digestión (Archimède et al. 2011), reduciendo consecuentemente la concentración de EN.

Tasa de sustitución

La tasa de sustitución (TS) para los animales 1, 3 y 4 fue en promedio de 0.56±0.10 (reducción de 560 g MS de pasto consumido/kg de concentrado), próxima al valor 0.55 observado por Bargo et al. (2003). En el caso del animal 2, la menor tasa de sustitución fue resultado del menor incremento en el CMS de pasto después de la restricción de suplemento (Cuadro 2), lo cual resultó en el mayor valor de balance energético negativo (Cuadro 5). Estos resultados sugieren que la TS debe relacionarse con la respuesta en producción y el balance

Cuadro 7. Predicción de la energía neta (Mcal/kg MS) del pasto kikuyo (*Cenchrus clandestinus*) a partir de modelos matemáticos.

Ecuación	Predicción	Fuente
EN (Mcal/kg)=(1.393 × %TNDa - 34.63) × 0.02205	1.37	Donker y Naik (1979)
EN_l (Mcal/kg)=(%TDNa × 0.0245) - 0.12)	1.58	Weiss (1993)
EN_l (Mcal/kg)=[(%TDNa × 0.01114) - 0.054)] × 2.2	1.59	Kodeš et al. (2015)
EN=2.863 - (0.0262 × %FDN)	1.45	Mertens (1987)
EN_l (Mcal/kg)=[12.9085 - 0.1276× %FDN]/4.184	1.44	Kodeš et al. (2015)
EN_l (Mcal/kg)=[1.0876 - (0.0127 × %FDA)] × 2.2	1.70	Kodeš et al. (2015)
EN_l (Mcal/kg)=1.98 - 1.73 × FDA (coeficiente)	1.55	Conrad et al. (1984)
EN_l (Mcal/kg)=2.208 - 0.0275 × %FDA	1.53	Harlan et al. (1991)
EN_l (Mcal/kg)=2.387 - 0,0273 x %FDA	1.71	Weiss (1993)
EN_l (Mcal/kg)=1.89 - 0.0184 × %FDA	1.43	Weiss (1998)
EN_l (Mcal/kg)=0.68 × ED (Mcal/kg) – 0.36	1.53	Moe et al. (1972)
EN_l (Mcal/kg)=[EM (Mj/kg) × (0.463 + 0.24 × (EM/EB))]/4.184	1.40	Homolka et al. (2012)

energético. Bajas TS son deseables en animales con mayor mérito genético para producción de leche y CMS; en cambio, bajas tasas de sustitución asociadas a un menor CMS y balance energético negativo, resultan en menor eficiencia de uso de la energía del suplemento para la producción de leche. En el caso particular de este estudio, las vacas tenían un potencial de producción de leche por encima del que podía sostener el pasto kikuyo solo (Cuadro 3), por lo que en esas condiciones debe usarse suplementos, aún reconociendo que va a ocurrir algún grado de substitución (García et al. 2014).

Conclusiones

Con base en los resultados de este estudio se puede concluir: 1. Los valores de ED, EM y EN para vacas lactantes (2.78±0.13; 2.37±0.08 y 1.39±0.26 Mcal EN/kg MS) obtenidos para pasto kikuyo fertilizado y cosechado cada 32 días, usando cámaras de respiración de circuito abierto, aparentemente son los primeros reportados en la literatura; 2. Cuando se ofrece ese pasto sin suplementación se consigue niveles de producción de leche de 13.20±3.84 kg LCG4/animal/ día, por lo que en vacas con un potencial genético mayor es necesario suplementar, aún cuando haya substitución parcial del consumo de pasto; 3. La tasa de substitución pasto:concentrado obtenida (0.56±0.10 kg MS de pasto/kg MS de concentrado) no difiere de los valores obtenidos en otros estudios con pastos tropicales de características similares.

Aspectos éticos

Este trabajo fue aprobado por el Comité de Ética para la Experimentación con Animales de la Universidad de Antioquia (Acta 142 del 05 de octubre de 2021).

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(Nota de los editores: Enlaces verificados el 5 de septiembre de 2024).

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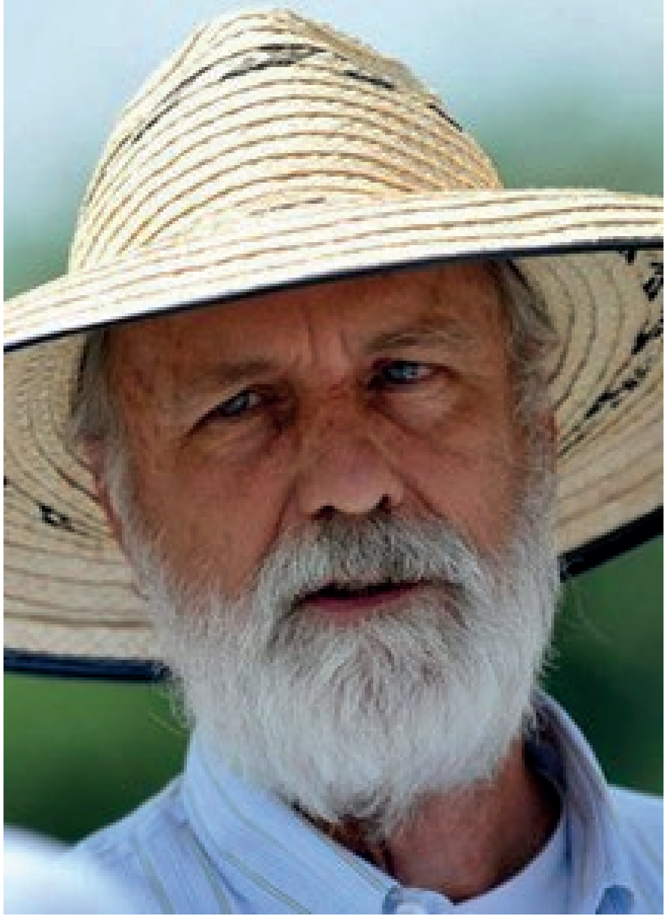
(Recibido para publicación 26 febrero 2024; aceptado 26 agosto 2024; publicado 30 de septiembre 2024)

In memory of Dr. John Williams Miles: A leader in tropical forage grass breeding



With deep respect, we bid farewell to Dr. John Williams Miles, a brilliant scientist who dedicated 37 years to improving tropical forages at CIAT (now the Alliance of Bioversity International and CIAT). His absence leaves a void in the field of tropical forage innovation.

The contribution of John Miles to forage germplasm development cannot be overstated. More than twenty years ago, working with both public and private sector partners, he contributed to the release of the first commercial *Urochloa* hybrid, Mulato. This was not only a scientific breakthrough but also had a massive impact on improving meat and milk production.

The world has lost a leading figure in tropical forage, mainly forage grass breeding. John Miles was a champion of fit-for-purpose forage breeding. He worked initially on forage legumes -Stylosanthes- but then focused mainly on *Urochloa* and later on *Megathyrsus* (*Panicum*) grasses. He overcame challenges such as genetic and reproductive incompatibilities in breeding apomictic grasses. His forage improvement efforts were interdisciplinary and he developed productive, stress-tolerant, and nutritionally superior grass varieties such as Mulato, Mulato II, Cayman, and Cobra for optimizing livestock feeding, increasing the land's carrying capacity and improving greenhouse gas emissions. He was deeply committed to supporting farmers with improved grass cultivars.

Thanks to his great efforts, *Urochloa* hybrids from his breeding program are now sown on more than 1.5 million hectares, and many more hectares have been reached through vegetative propagation of different grass cultivars. This has impacted the income and well-being of more than a million people in tropical Africa, Asia, and the Americas, and his grass cultivars are spreading into the southern United States and Europe.

In addition to these outstanding scientific achievements, we will miss John as a highly respected colleague and as a person of great empathy and willingness to help those in need. He was not very interested in social events but always enjoyed interacting with people regardless of hierarchy and status. As a leader and mentor, he was demanding and meticulous, always willing to share his knowledge. His students and colleagues remember him as a detailed planner and a great companion on all projects.

Sylvia María Pineda Ramos
Idupulapti Rao
Michael Peters
Guillermo Sotelo
Joe Tohme
Belisario Hincapié
Maya Rajasekharan

Remembering John

Dr. John Miles was an exceptionally talented forage breeder who pioneered the development of *Urochloa* grasses to improve meat and milk production in the Global South. I worked closely with him for more than two decades as a member of the Tropical Pastures Program/ Tropical Forages Program team. He insisted on the need to develop rapid and reliable phenotyping methods to evaluate the genetic adaptation of *Urochloa* hybrids for tolerance to acid soils, drought and waterlogging stress conditions. Together we published 12 journal articles and 5 book chapters on tropical forage improvement. It was my great pleasure to co-author his highly cited (224 citations) book chapter on *Brachiaria* grasses. Dr. Miles was adamant about the use of proper experimental design to collect meaningful data. He was an innovator at heart and his legacy will live on in the Alliance of Bioversity International and CIAT's Forage Breeding Program and the many tropical grass varieties he developed. Dr. Miles will be sorely missed by his colleagues, friends, and the global forage breeding research community.

Idupulapati Rao

John and I joined CIAT as postdocs the same year (1979) and were assigned responsibilities in the Tropical Pastures Program based in Palmira, Colombia. He started his career in CIAT as a legume breeder (*Stylosanthes*) and later switched to breeding *Urochloa* (*Brachiaria*), where he made significant advances in methodology applied to apomictic grasses that resulted in the development of the first hybrids commercially released. I give credit to John for being the promoter in CIAT of the Public – Private alliance with a seed company that helped fund the breeding program he led and that was key in promoting regional trials to evaluate hybrids in different sites. John was an avid reader, and I will remember him for riding a bike in the CIAT campus at lunch time always carrying homemade bread.

Carlos E. Lascano

John Miles was a dear friend and colleague, both of us giving our best to breed *Brachiaria*. He had a unique sense of humor: very dry and a mischievous look especially when something odd was being said. Shy sometimes and very bold in his forward thinking; a great travel companion on the roads of Colombia in search of experimental sites and places to eat pandebono and a cup of the excellent Colombian coffee. He will be very much missed both scientifically and personally.

Cacilda do Valle

He will always be remembered for his high scientific rigor, commitment to achieving impact at scale, and phobia of bureaucracy.

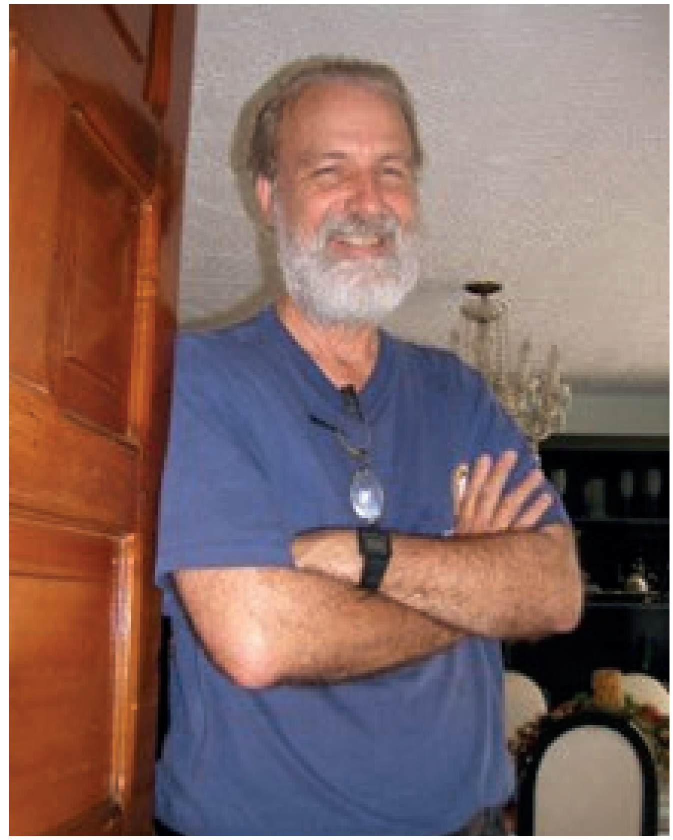
Joe Tohme

There will always be much more to say about John Miles, but his modesty gets in the way. This is a simple homage to the great work that he carried out during all those years of research at the Alliance of Bioversity International and CIAT.

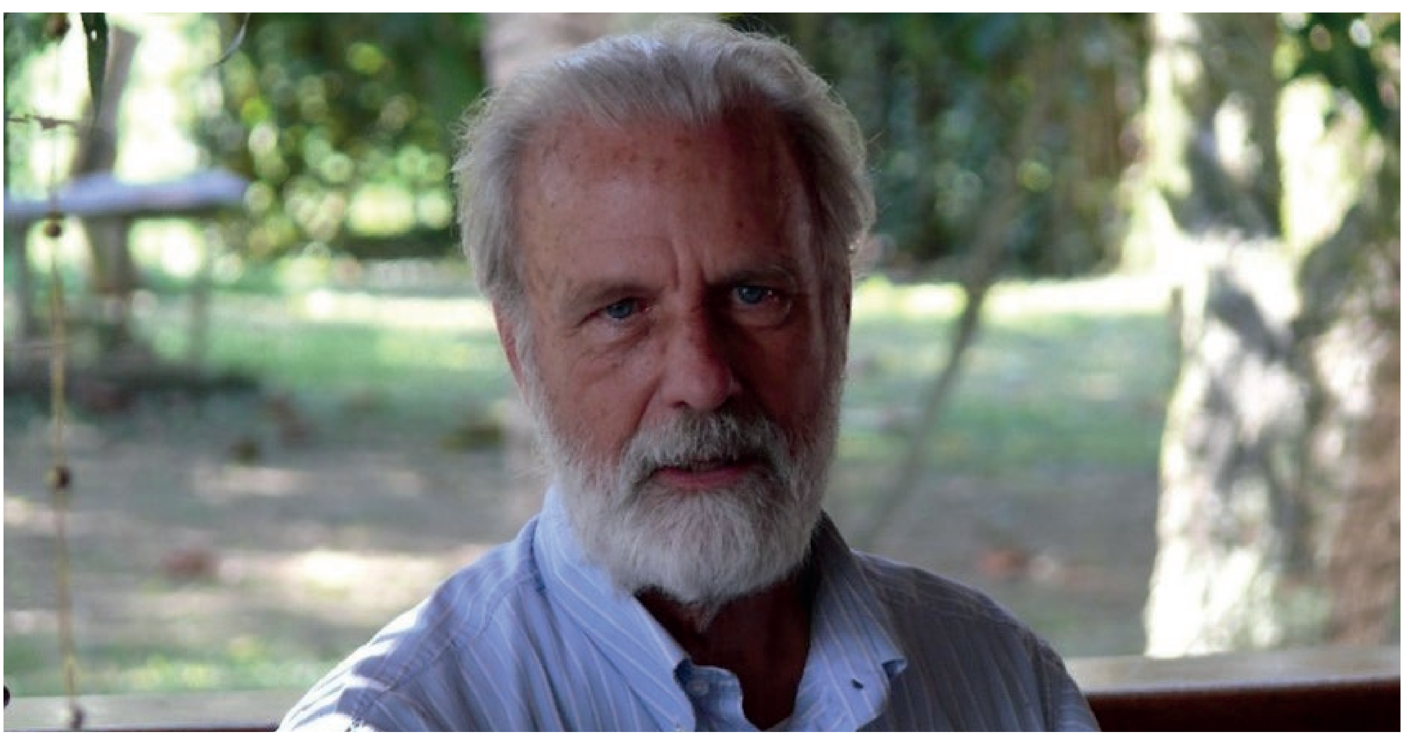
John with collaborators in the greenhouse at Palmira. To his right his assistant Guillermo Sotelo; to his left a great scientific colleague and friend the late Dr. Cesar Cardona, Entomologist in the Tropical Forages and Beans program, with whom he worked for a large part of his life. (Photograph: CIAT)

John taking a hands-on approach to field work in all weathers; planting in Llanos Orientales, Colombia. (Photograph: CIAT)

John was critical of the unnecessary use of cars, using the bus to commute between Cali and work and frequently seen on his bicycle around the CIAT campus. (Photograph: CIAT)



John at home in his house in Cali. (Photograph: CIAT)



In memory of Leonard Ross Humphreys: 12 September 1927 – 28 May 2024

Ross in 1973

Ross was born in Roseville, Sydney, NSW, Australia. He attended Roseville and Artarmon Public Schools and later the academically selective North Sydney Boys High School. Although he enjoyed English, literature, history, reading and classical music, he was encouraged by his parents to major in science. He obtained 1st class honours in chemistry and, again encouraged by his father to pursue a career in science, he won a scholarship to attend the University of Sydney and graduated in agricultural science (BScAgr 1948). Some years later he obtained a MScAgr degree (1958) from the University of Sydney and a PhD (1966) from the University of Queensland.

In 1949, Ross was appointed as a soil conservation officer in the New South Wales Soil Conservation Service, based at Scone, NSW. There he began his lifelong research career in the improvement and productivity of pastures for grazing livestock. His earliest publications were on the use of introduced pasture grasses and legumes to control soil erosion near Scone, including the response of legumes to superphosphate. Two other of Ross' lifelong characteristics were already apparent in those early years. One was his willingness to undertake leadership roles (to "make a contribution" as Ross himself put it): he was at times secretary of the Scone Chamber of Commerce, President of the Scone Churches Amateur Dramatic Society (he and his wife Lyle established the group), secretary of the Scone Churches United Youth Club, an occasional preacher at churches around Scone, and President of the Scone Men's Hockey Club (Ross represented Sydney University at hockey for several years). Leadership seemed to come naturally to Ross. It seemed instinctive.

The second of his lifelong characteristics was his pleasure in writing. An example from those earliest years survives in his 1952 review of a book on resource conservation. Ross wrote: "The book is attractively written, if flavored with occasional hyperbole and rather dramatic presentation. This, of course, may be expected from authors possessing a strong sense of mission and a keen eye for converts". Written more than 70 years ago, the style and use of words is characteristic of his writing throughout his life.

Ross's career in tropical pasture research began in 1955-1956 when he joined a team at the University of Queensland as a research officer, studying the development of improved forage systems for livestock in western Queensland. The focus was on more-productive grasses, drought-resistant fodder crops and the inclusion of legumes in the diet of livestock. In 1956, he commenced what became a decade-long appointment with the (then) Queensland Department of Agriculture and Stock (QDAS) (re-named as the Queensland Department of Primary Industries in 1963). He was appointed officer-in-charge of "Brian Pastures", a tropical pasture research station near Gayndah that had been purchased by the Australian Meat Board in 1952 and had been placed under the control of QDAS. There he led a team of about a dozen researchers and technical officers. He studied the physiology of pasture growth and published the results in a series of papers in the mid-1960s.

By 1959 Ross was Chief Agrostologist of the Department. In 1962 he was transferred back to Brisbane with his young family and in 1964 he became Assistant

Max Shelton and Ross on a field trip with members of the Tropical Grassland Society of Australia (early 1970s).

Director of Agriculture, QDPI. In 1966 he made a difficult and, in retrospect, pivotal decision to leave the QDPI and join the Department of Agriculture at the University of Queensland (UQ). He was well positioned in the QDPI and could have anticipated a respectable (perhaps eminent) career with the State Government. At his memorial service in 2024 his son Jeff recalled that Lyle encouraged Ross to make the break. Ross himself thought that the opportunities to "make a contribution" would be greater in the university environment than in the bureaucratic ranks of the State Government.

Ross spent the remainder of his scientific career at the University of Queensland. He commenced as Senior Lecturer in pasture agronomy and progressed to become Reader in 1973; Head of the Department from 1978-91; Professor with a personal chair in 1988; Pro-Vice Chancellor, Biological Sciences 1991-1993; and an Emeritus Professor and Honorary Research Consultant from 1993. At the time of his death at age 96 he was still recorded on the University's website as an Emeritus Professor.

Ross joined the University's Department of Agriculture at a time of dynamic change. He later wrote an article in Crossroads (an interdisciplinary journal for the study of history, philosophy, religion and classics – who else but Ross would have chosen such a medium?) which described the evolution of the Department from a small group of 8 academics in 1965, covering the fields of soil science, chemistry, agricultural economics and agricultural extension, to a modern agricultural science department with 20 academic staff in 1972. The new staff members (including Ross) went on to achieve global recognition in a range of fields, establishing the University as an internationally respected centre of excellence in tropical agriculture. In his article, Ross wrote: "Agriculture was an early department to commit to the globalization of UQ". At first, such "internationalization" of the department was achieved with funding provided by the Australian Development Assistance Bureau (ADAB) and its successor the Australian International Development Assistance Bureau (AIDAB) - the precursor to AusAID. Later, when the Australian Centre for International Agricultural Research (ACIAR) was established in 1982 to manage and facilitate Australian assistance in agricultural research for developing countries, the UQ Department of Agriculture was an early provider of expertise. When Bob Clements was appointed Director of ACIAR in 1995, the University of Queensland had become its second-largest research provider. Only CSIRO, with its huge scientific staff and its resources spread over more than 100 locations around Australia, provided more scientific expertise to ACIAR.

Working in such an expansionary and outward-looking scholastic environment suited Ross well, and as Head of the Department he was well-positioned to promote and champion the evolution of the university as a globally-respected centre. Access to ADAB, AIDAB and (later) ACIAR funds was a key factor in his success in attracting students to study at UQ, and among his postgraduate students were many from Southeast Asia and Latin America. The location of the department in a new building about 200 m from the CSIRO Cunningham Laboratory, where dozens of tropical pasture researchers were based, was another factor in his ability to "make a contribution" in his chosen field. Ross built friendships and partnerships with several CSIRO and QDPI scientists, enabling him to link postgraduate students to globally eminent researchers.

Ross's personal involvement in tropical pasture research in SE Asia extended over a period of about 25 years, commencing in 1967 as a short-term adviser to ADAB in tropical pasture development for a cattle project in Laos. In 1969 he became technical adviser to ADAB's Lao-Australian Pasture Improvement Project (1969-76). From 1970-1983 he held a similar advisory role in ADAB's Khon Kaen Pasture Improvement Project in Thailand. This was followed by leadership of ADAB's Thai-Australian Highland Agricultural Project in Chiangmai (1976-80) and ADAB's Faculty of Natural Resources, Prince of

Songkla University Project (1982-83). He continued as an AIDAB pasture consultant to the latter project from 1986-92. From 1983-86 he led an ACIAR project on the development of legumes for farming systems in Northeast Thailand. In the decades 1970-90 he provided countless lectures, seminars and training courses in Southeast Asia, India, Mexico, Brazil and Africa, through the auspices of organizations such as the Australian-Asian Universities Cooperation Scheme and FAO.

The Khon Kaen Pasture Improvement Project was a defining period in Ross's career. It included a large capacity-building component, and this led to extended visits by Ross to Thailand, and to the training at UQ of numerous Thai postgraduate students over a period of 13 years or more. Its significant research achievements included the naming of a new, well- adapted stylo variety (Khon Kaen stylo); the identification of nutrient limitations for tropical legume growth in the sandy upland soils of Northeast Thailand; and locally relevant methods for growing and harvesting tropical pasture seed. The still-thriving Thai pasture seed export industry is based on the concept, developed by the project, of contracting multiple Thai farmers to grow and harvest pasture seed on their small 0.5-1 ha farms. In recognition of Ross's contribution to the advancement of tropical pasture research and education in Northeast Thailand, in 1983 he received an honorary doctorate from Khon Kaen University, presented by the revered King Bhumibol of Thailand.

Ross's contribution to grassland science was world-wide and encompassed temperate as well as tropical grasslands. In the 1970s and 1980s he had several periods as a Visiting Fellow at Wolfson College, Oxford, UK and during those periods he spent time at the Grassland Research Institute, Hurley. He was also a Visiting Professor at the University of Florida (1973) and the University of California, Davis (1977) and a Visiting Fellow at Pennsylvania State University (1981).

A defining event in Ross's career was his attendance at the 8th International Grassland Congress (IGC) held at Reading, England in 1960, which was attended by about 600 scientists from 53 countries. It was his first overseas conference. In a far-sighted recognition of his capabilities, QDPI had sent him overseas on a research tour of Europe and Africa. It enabled him, at the relatively young age of 32, to expand his network and to appreciate the global significance of research on grasslands. He attended numerous successive IGCs. He was a member of the Organizing Committee of the 11th IGC (Australia, 1970) and was an invited speaker at the 16th IGC (France, 1989) and the 19th IGC (Brazil, 2001). He served on the IGC Continuing Committee, the organization tasked with the role of managing the affairs of the IGC between Congresses, for 8 years, first as a member representing Australia and New Zealand (1977-81) and then as its Chairman (1981-85). His contribution to the IGC included the publication of a book, The Evolving Science of Grassland Improvement (Cambridge University Press, UK, 1997), in which he summarized the history of the IGC from 1927-1993. He updated this history in his 2001 IGC presentation in Brazil and again in a paper published in the Proceedings of the 20th IGC (Ireland/UK, 2005). In 2021 Vivien Allen, Roger Wilkins, Garry Lacefield and Ray Smith dedicated their book, The History of the International Grassland Congress – 1927 to 2020, to Ross Humphreys, recognizing him as "The 'guru' of IGC history".

Ross supervised 50 postgraduate students, including 20 from developing countries. His global legacy includes numerous leading researchers in Australia, Southeast Asia, South America and Africa. Several of his postgraduate students are on the Editorial Board of this journal. He also trained a generation of undergraduates in agriculture at the University of Queensland. He was self-deprecating about his lecturing style which Max Shelton recalls as being "idiosyncratic". Students generally preferred to hear lectures in plain language and some described his elaborate choice of words as quirky. He was interested in his students as individuals. This applied particularly to the postgraduates, with whom he retained friendships throughout his life.

Ross retired from intense personal involvement in pasture research in the mid-1990s although he did contribute as a writer until 2005. He could have continued as a consultant on the global stage; he had already undertaken consultancies for FAO and other organizations in several countries, notably in Southeast Asia, the Caribbean region, Africa and Central and South America. Instead, he returned to his first love: literature and history. Although he had previously written a number of articles of a historical nature, his first significant contribution was a short biography of Jack Griffiths Davies (a grassland scientist who had become the first Chief of the CSIRO Division of Tropical Pastures), published in the Australian Dictionary of Biography in 1993. He followed this with his history of the IGC and numerous longer biographies, focusing on scientists who had achieved fame in a range of fields. In 2010, Ross was awarded a PhD in literature (his second PhD) at the University of Queensland at the age of 82.

Ross's research output included more than 100 scientific publications. A particular interest was seed production by tropical grasses and legumes. Another was the productivity of mixed grass/legume pastures, with a focus on their establishment, fertilizer requirements and grazing management, extending to physiological and ecological processes. The research reflected to a considerable extent the interests of his students and the requirements of his research projects, particularly in Southeast Asia. He was at his best when he pulled together results from a wide range of sources and developed an over-arching synthesis. Thus, his main personal contribution was his books, written for a wide range of readers. A striking example was the first of these, Guide to Better Pastures for the Tropics and Sub-tropics. First published in 1965 by Wright Stephenson (at that time a New Zealand/Australian stock and station agency that also sold seed and fertilizer), it provided a simple overview of some tropical pasture plant species and their utilization in improved pastures. It was tremendously helpful to a generation of farmers, students and early-career researchers who knew little or nothing about the legumes and grasses that were then emerging rapidly from a major Australian program of research on tropical pastures, which was to last for about 50 years. This book was updated 5 times over a period of 30 years (the 5th edition was co-authored by Ian Partridge) and a Spanish edition was published in 1967. Another book, Tropical Pasture Seed Production (first published by FAO in 1975) was revised 3 times (co-authored the third time by Fernando Riveros) and translated into Spanish (1976), French (1979) and Chinese (1989). Ross wrote 6 other books on aspects of pasture agronomy, and in his second career as a historian he published 8 more books, including 6 biographies.

Ross in late life (2022).

Ross achieved global recognition. His awards were too numerous to list here, but notably included Commander in the Order of the Crown of Thailand (1995). At his memorial service, he was described as a Renaissance man – one who develops skills in all aspects of knowledge; a scholar; a natural, effective and transformative leader; and a generous, colorful, quirky, optimistic, participative, buoyant man, forceful when necessary but slow to anger and almost always cheerful and polite.

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Tropical Grasslands
-Forrajes Tropicales
Online Journal

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