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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

FLORENCIA MARCÓN[1], CARLOS SIBURU[2] AND CARLOS A. ACUÑA[1]

[1]*Instituto de Botánica del Nordeste, Universidad Nacional del Nordeste, Corrientes, Argentina.* ibone.unne.edu.ar
[2]*Amarilla Agropecuaria S.A., Amarilla Gas, Chaco, Argentina.* amarillagas.com/agropecuario

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.

Correspondence: Carlos A. Acuña, Instituto de Botánica del Nordeste, Universidad Nacional del Nordeste, Corrientes, Argentina. Email: caalac77@gmail.com

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*.

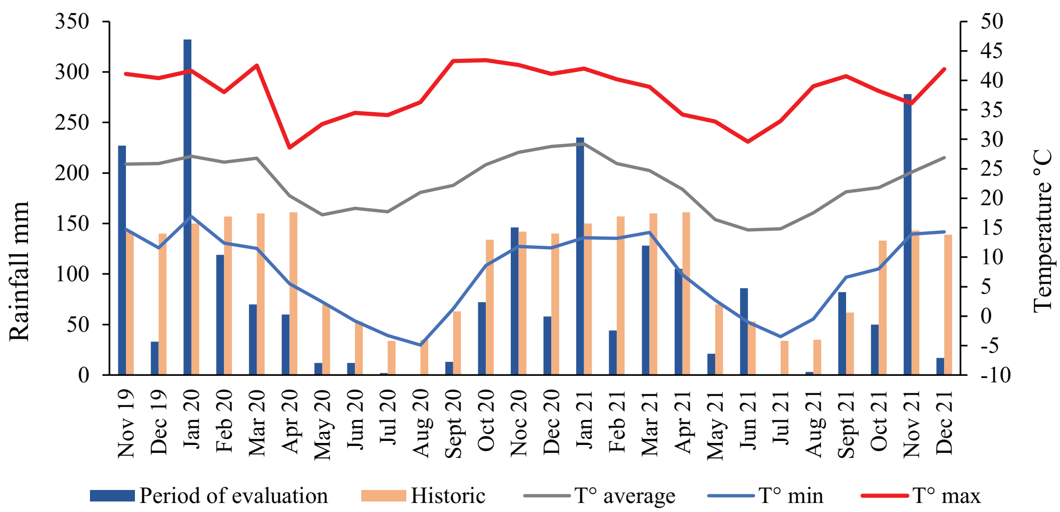

Figure 2. Monthly rainfall (mm), historic monthly rainfall (mm), average monthly temperatures (°C) and minimum and maximum monthly temperatures (°C) from November 2019 to December 2021.

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.

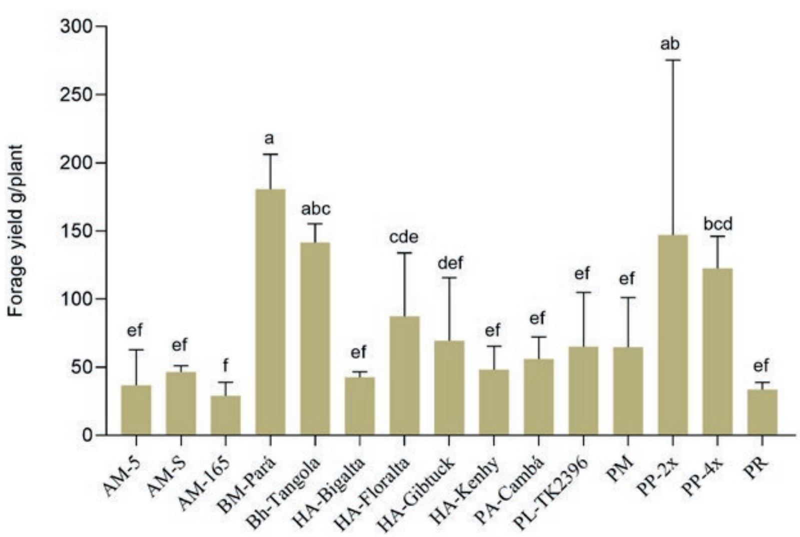

Figure 3. Forage yield (g/plant) of 15 warm season grasses 65 d after planting. *A. macrum* (AM-5, AM-S and AM-165); *U. mutica* (BM); *Urochloa* sp. 'Tangola' (Bh-Tangola); *H. altissima* 'Bigalta' (HA-Bigalta), 'Floralta' (HA-Floralta), 'Gibtuck' (HA-Gibtuck) and 'Kenhy' (HA-Kenhy); *P. atratum* 'Cambá' (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.

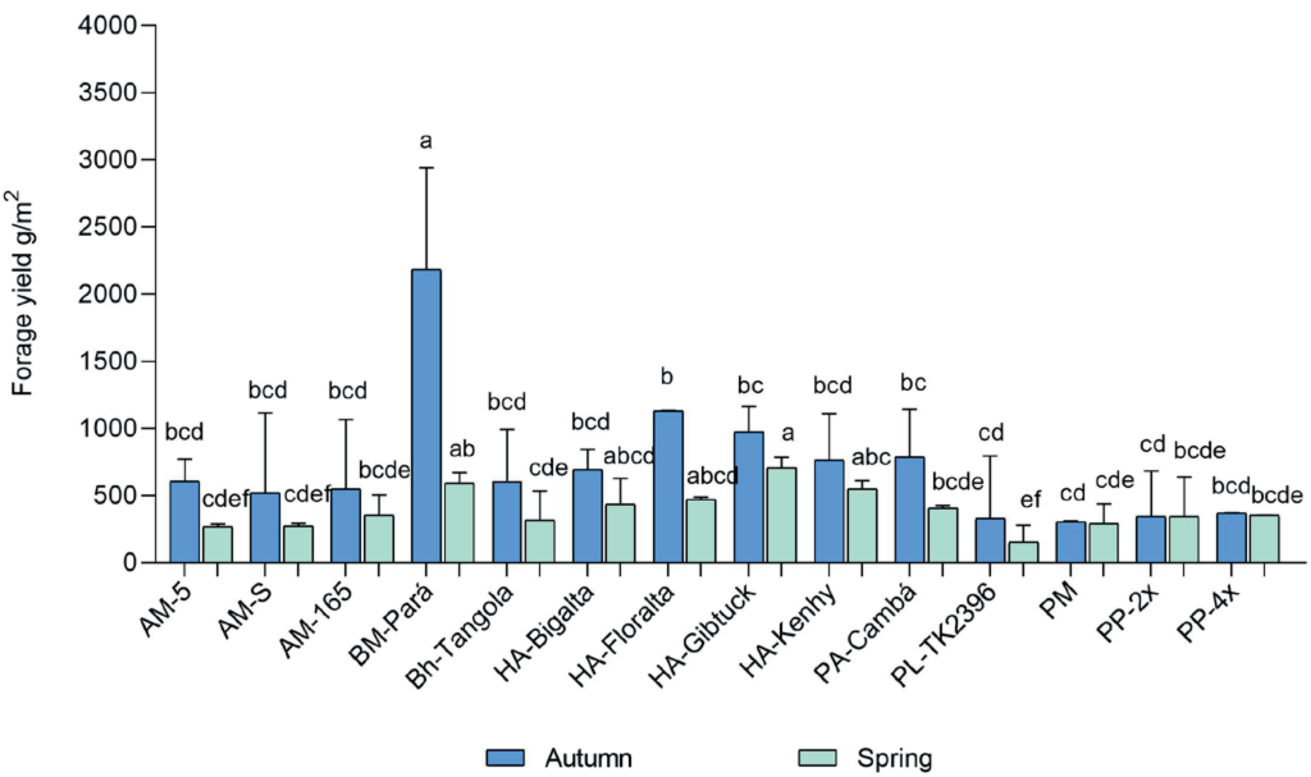

Figure 4. Forage yield (g/m^2) of a group of 14 warm season grasses adapted to waterlogged environments during the autumn (92 regrowth days) and spring (151 regrowth days). *A. macrum* (AM-5, AM-S and AM-165); *U. mutica* (BM); *Urochloa* sp. 'Tangola' (Bh-Tangola); *H. altissima* 'Bigalta' (HA-Bigalta), '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).

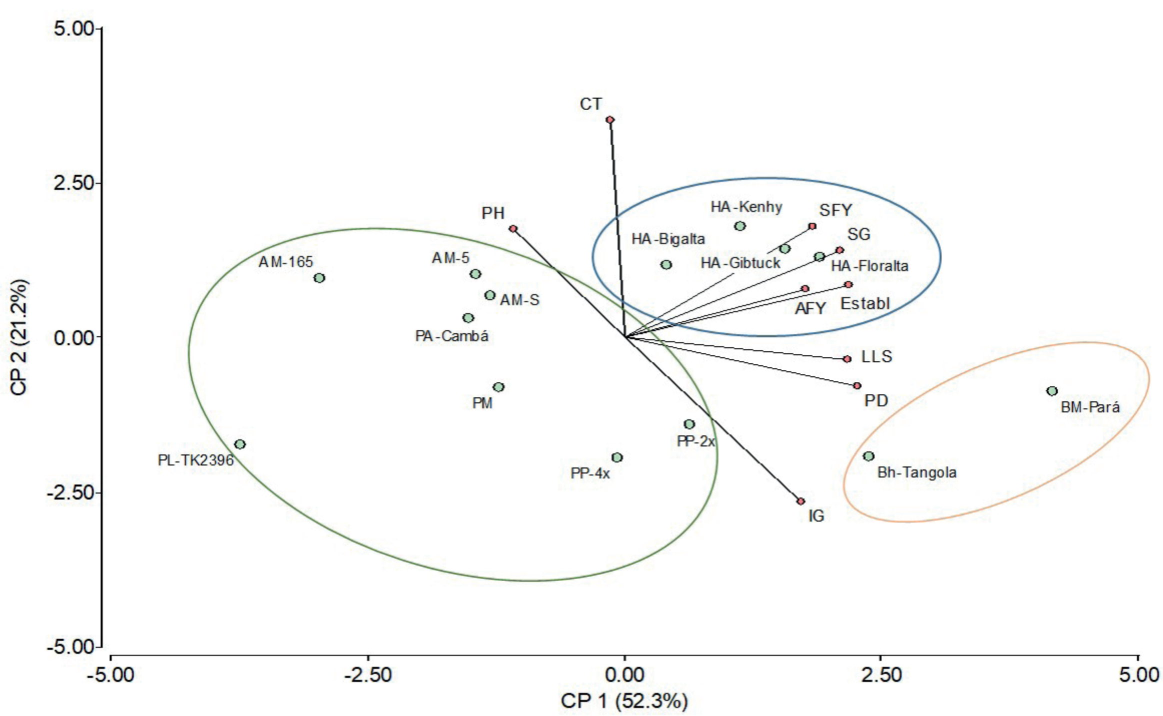

Figure 5. Biplot for 9 morphological and agronomic traits of 14 grasses. *A. macrum* (AM-5, AM-S and AM-165); *U. mutica* 'Pará' (BM); *Urochloa* sp. 'Tangola' (Bh-Tangola); *H. altissima* 'Bigalta' (HA-Bigalta), 'Floralta' (HA-Floralta), 'Gibtuck' (HA-Gibtuck) and 'Kenhy' (HA-Kenhy); *P. atratum* 'Cambá' (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.

References

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

Acuña CA; Martínez EJ; Zilli AL; Brugnoli EA; Espinoza F; Marcón F; Urbani MH; Quarin CL. 2019. Reproductive systems in *Paspalum*: Relevance for germplasm collection and conservation, breeding techniques, and adoption of released cultivars. Frontiers in Plant Science 10:1377. doi: 10.3389/fpls.2019.01377

Andrade CMS de; Assis GML de; Fazolin M; Gonçalves RC; Sales MFL; Valentim JF; Estrela JLV. 2009. Capim-tangola: gramínea forrageira recomendada para solos de baixa permeabilidade do Acre. Embrapa Acre, Rio Branco, Acre, Brazil. handle/doc/661855

Arelovich HM; Bravo RD; Martínez MF. 2011. Development, characteristics, and trends for beef cattle production in Argentina. Animal Frontiers 1(2):37–45. doi: 10.2527/af.2011-0021

AOAC. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemists, Washington, DC, USA.

Barbera P; Bendersky D; Calvi M; Cetra BM; Flores AJ; Hug MG; Pellerano LL; Pizzio RM; Rosatti G; Sampedro DH; Sarmiento NF. 2018. Cría vacuna en el NEA. Colección Divulgación. 1st Ed. Ediciones INTA, Buenos Aires, Argentina. hdl.handle.net/20.500.12123/11491

Burns JC; McIvor JG; Villalobos LM; Vera RR; Bransby DI. 2004. Grazing systems for C4 grasslands: a global perspective. In: Moser LE; Burson BL; Sollenberger LE, eds. 2004. Warm-season (C4) grasses. Agronomy Monograph 45. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA. p. 309–354. doi: 10.2134/agronmonogr45.c9

Di Rienzo JA; Casanoves F; Balzarini MG; Gonzalez L; Tablada M; Robledo CW. 2022. InfoStat versión 2022. InfoStat group, Faculty of Agricultural Sciences, National University of Córdoba. www.infostat.com.ar

Evers GW; Burson BL. 2004. Dallisgrass and other *Paspalum* species. In: Moser LE; Burson BL; Sollenberger LE, eds. 2004. Warm-season (C4) grasses. Agronomy Monograph 45. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA. p. 681–713. doi: 10.2134/agronmonogr45.c20

Ferrari Usandizaga SC; Brugnoli EA; Weiss AI; Zill AL; Shedler M; Pagano EM; Martínez EJ; Acuña CA. 2014. Genetic and morphological characterization of *Acroceras macrum* Stapf. Grass and Forage Science 70(4):695–704. doi: 10.1111/gfs.12148

Ferrari Usandizaga SC; Martínez EJ; Shedler M; Honfi AI; Acuña CA. 2020. Mode of reproduction and meiotic chromosome behavior in *Acroceras macrum*. Crop Science 60(1):330–344. doi: 10.1002/csc2.20081

Ginzburg R; Adámoli J. 2005. Situación ambiental en el Chaco húmedo. In: Brown A; Martinez Ortiz U; Acerbi M; Corcuera J, eds. La situación ambiental argentina 2005. Fundación Vida Silvestre Argentina, Buenos Aires, Argentina. p. 101–122. bit.ly/47Aohny

Jank L; Barrios SC; Valle CB do; Simeão RM; Alves GF. 2014. The value of improved pastures to Brazilian beef production. Crop and Pasture Science 65(11):1132–1137. doi: 10.1071/CP13319

Marcón F; Urbani MH; Quarin CL; Acuña CA. 2018. Agronomic characterization of *Paspalum atratum* Swallen, and *P. lenticulare* Kunth. Tropical Grasslands-Forrajes Tropicales 6(2):70–81. doi: 10.17138/tgft(6)70-81

Miles JW; Valle CB do. 1996. Manipulation of apomixis in *Brachiaria* breeding. In: Miles JW; Maass BL; do Valle CB, eds. 1996. *Brachiaria*: Biology, agronomy, and improvement. CIAT Publication no. 259. Centro Internacional de Agricultura Tropical (CIAT); Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Centro Nacional de Pesquisa de Gado de Corte (CNPGC). Cali, Colombia. p. 164–177. hdl.handle.net/10568/54362

Miles JW; Valle CB do; Rao IM; Euc1ides VPB. 2004. *Brachiaria* grasses. In: Moser LE; Burson BL; Sollenberger LE, eds. 2004. Warm-season (C4) grasses. Agronomy Monograph 45. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA. p. 745–784. doi: 10.2134/agronmonogr45.c22

Molina AM; Rúgolo de Agrazar ZE, eds. 2006. Flora Chaqueña Argentina. Formosa, Chaco y Santiago del Estero: Familia gramíneas. Colección Científica Instituto Nacional de Tecnología Agropecuaria. 549p.

Moser LE; Burson BL; Sollenberger LE, eds. 2004. Warm-season (C4) grasses. Agronomy Monograph 45. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA. doi: 10.2134/agronmonogr45

Quesenberry KH; Dunavin Junior LS; Hodges EM; Killinger GB; Kretschmer Junior AE; Ocumpaugh WR; Roush RD; Ruelke OC; Schank SC; Smith DC; Snyder GH; Stanley RL. 1979. Registration of Redalta, Greenalta, and Bigalta limpograss. Crop Science 19(2):294. doi: 10.2135/cropsci1979.0011183X001900020035x

Quesenberry KH; Oakes AJ; Jessop DS. 1982. Cytological and geographical characterizations of *Hemarthria*. Euphytica 31:409–416. doi: 10.1007/BF00021658

Quesenberry KH; Ocumpaugh WR; Ruelke OC; Dunavin Junior LS; Mislevy P. 1987. Registration of 'Floralta' limpograss. Crop Science 27(5):1087–1087. doi: 10.2135/cropsci1987.0011183X002700050060x

Quesenberry KH; Sollenberger LE; Newman YC. 2004. Limpograss. In: Moser LE; Burson BL; Sollenberger LE, eds. 2004. Warm-season (C4) grasses. Agronomy Monograph 45. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA. p. 809–832. doi: 10.2134/agronmonogr45.c24

Quesenberry KH; Sollenberger LE; Vendramini JMB; Wallau MO; Blount AR; Acuña CA. 2017. Registration of 'Kenhy' and 'Gibtuck' limpograss hybrids. Journal of Plants Registration 12(1):19–24. doi: 10.3198/jpr2017.03.0012crc

Ramseyer F; Terré E. 2023. El consumo per cápita de carnes se recupera en Argentina. Informativo Semanal de la Bolsa de Comercio de Rosario. Vol. 41, Edición 2101 - Especial Ganadería (2 de junio 2023). bit.ly/4exX1Zv

Rhind JMLC; Goodenough DCW. 1979. *Acroceras macrum* Stapf (Nile grass) - A review. Proceedings of the Annual Congresses of the Grassland Society of Southern Africa 14(1):27–36. doi: 10.1080/00725560.1979.9648855

Rodriguez Zurro T; Terré E. 2022. El sector ganadero genera 1 de cada 5 empleos agroindustriales y $20 de cada $100 de VAB Agroalimentario. Informativo Semanal de la Bolsa de Comercio de Rosario. Vol. 40, Edición 2054 - Especial Ganadería (10 de junio de 2022). bit.ly/4diL6NY

Skerman PJ; Riveros F, eds. 1992. Gramíneas tropicales. FAO Plant Production and Protection Series No. 23. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Zuloaga FO; Morrone O. 2005. Revisión de las especies de *Paspalum* para América del Sur austral (Argentina, Bolivia, sur del Brasil, Chile, Paraguay y Uruguay). Monograph in Systematic Botany from the Missouri Botanical Garden 102:1–297. bit.ly/4gpobn7

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