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Announcement from the Alliance Bioversity and CIAT

Closure of the Tropical Grasslands-Forrajes Tropicales Journal

Dear readers

This is the last issue of Tropical Grasslands-Forrajes Tropicales.

It is with great regret that it is not possible to continue the publication of the journal due to lack of financial resources.

While we tried to secure additional funding through a range of avenues with strong support from the Management committee, we were unfortunately not successful to find financing to allow us to continue publishing the journal. We explored a model of charging authors for publication but do not feel that this is in line with the access for funding for most contributors and readers located in the south. Commercial sponsorship was also explored but was not found feasible either.

We wish to thank all the supporters of the journal over more than a decade including donors (CATAS, ACIAR, an anonymous funder), editors (Rainer Schultze-Kraft, Lyle Winks, Jean Hanson, Danilo Pezo), the CIAT support staff, the management committee, the editorialboard, reviewers of submitted papers and all the other supporters who have accompanied us over the years

Dr Michael Peters, Tropical Forages Program Leader, Alliance of Bioversity International And CIAT

Final issue of the Tropical Grasslands-Forrajes Tropicales journal

The idea of the Tropical Grasslands-Forrajes Tropicales journal was conceived as a platform for knowledge dissemination on tropical pastures. It was established and published by the Centro International Agricultura Tropical (CIAT) as an open access online scientific journal to fill the gap left by the termination of the two former printed journals, Tropical Grasslands and Pasturas Tropicales[1]. It provided an opportunity for researchers to publish their research on tropical forages free of charge in English and Spanish.

Reflecting over the years since the journal was established in 2013, it has fulfilled its promise by reaching over 2,000 registered readers and publishing over 450 articles. Several of these articles have received over 1,000 views and downloads, a testimony of the value of the journal to the forage community. However, the sustainable funding of scientific publications is challenging and efforts to secure funding to continue the journal were unsuccessful. The possibility to continue with an article processing charge was considered, but this was rejected as not consistent with the spirit of the journal to provide publication free of charge for young forage and pasture researchers from the tropics. This has brought us to the point where, without funding, the journal is unable to continue. The editors would like to thank the donors, without whom the journal would not exist, for their support that made the publication of the journal possible for so many years.

The success of any journal is determined by the authors who have submitted their research for publication, the reviewers for technical and statistical review who have provided their time free of charge, the editors who have gone above and beyond to guide authors to improve their manuscripts to reach the quality needed for publication, and the readers who use and cite the published papers. The editors would like to thank all authors, reviewers and readers for their support. Special recognition is given to the founding editors, Lyle Winks and the late Rainer Schultze-Kraft, for their dedication and outstanding contribution to the success of the journal.

Publication of the journal also required strong support from the Management Committee and Editorial Board, both composed of eminent forage and livestock scientists, who provided guidance and oversight, promoting the journal's success through their role as reviewers and sometimes also as authors. Publication of the journal also required a dedicated production team at CIAT who provided professional support for consistency, layout and graphics to compile the articles into the finished journal issues. The editors would like to thank the members of the Management Committee, Editorial Board and CIAT editorial team for the time and energy they contributed to make Tropical Grasslands-Forrajes Tropicales a leading journal for publication of research on tropical forages.

Jean Hanson and Danilo Pezo, Editors,
Tropical Grasslands-Forrajes Tropicales

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[1]Schultze-Kraft, Rainer; Winks, Lyle; Bai, Changjun; Clements, Robert J.; Larbi, Asamoah; Peters, Michael; and do Valle, Cacilda Borges, "Empowering the Next Generation of Tropical Forage Researchers: A New e-Journal for the 21st Century" (2013). IGC Proceedings (1985-2023). 3. https://uknowledge.uky.edu/igc/22/3-9/3

Último número de la revista Tropical Grasslands-Forrajes Tropicales

La revista Tropical Grasslands – Forrajes Tropicales se concibió como una plataforma para la difusión del conocimiento sobre pastos tropicales. Fue creada y publicada por el Centro Internacional de Agricultura Tropical (CIAT) como una revista científica en línea, de libre acceso, para cubrir el vacío dejado por la cancelación de las dos revistas impresas predecesoras: Tropical Grasslands y Pasturas Tropicales. Esta revista ha brindado a los investigadores la oportunidad de publicar en inglés y español, y sin ningún costo, sus investigaciones sobre forrajes tropicales y temas relacionados.

Al analizar los logros de la revista desde su fundación en 2013, creemos que la revista ha cumplido su objetivo al alcanzar más de 2,000 lectores registrados y publicar más de 450 artículos científicos. Varios de estos artículos han recibido más de 1,000 visitas y descargas, lo que demuestra el valor de la revista para la comunidad forrajera. Sin embargo, siempre es un desafío la financiación sostenible de las publicaciones científicas, y desgraciadamente no tuvieron éxito los esfuerzos para asegurar la financiación necesaria para dar continuidad a la revista. Se consideró la posibilidad de cobrar por el procesamiento de artículos, pero esta idea se rechazó al no ser coherente con el espíritu de la revista, que era abrir la posibilidad para que jóvenes investigadores de pastos y forrajes, provenientes de países tropicales, pudieran publicar sus artículos sin ningún cargo económico. Esto nos ha llevado al punto en que, sin financiación, la revista no puede continuar. Los editores desean agradecer a los donantes, sin los cuales la revista no existiría, pues su apoyo fue fundamental para hacer posible la publicación de la revista durante tantos años.

El éxito de cualquier revista es producto del esfuerzo de los autores que han presentado sus investigaciones para publicación, los revisores de los aspectos técnicos y estadísticos que han dedicado su tiempo gratuitamente, los editores que se han esforzado al máximo para guiar a los autores a mejorar sus manuscritos y alcanzar la calidad necesaria para su publicación, y los lectores que utilizan y citan los artículos publicados. Por ello, los editores agradecemos a todos los autores, revisores y lectores por su apoyo. Se otorga un reconocimiento especial a los editores fundadores, Lyle Winks y el fallecido Rainer Schultze-Kraft, por su dedicación y destacada contribución al éxito de la revista.

La publicación de la revista también requirió del firme apoyo del Comité de Gestión y del Consejo Editorial, ambos compuestos por eminentes científicos especializados en forrajes, ganadería y ramas afines, quienes brindaron orientación y supervisión, impulsando el éxito de la revista mediante su labor como revisores y en algunos casos incluso como autores. La publicación de la revista también requirió del apoyo profesional de un equipo de producción del CIAT, el cual brindó su experiencia para el logro de la consistencia necesaria en la diagramación de los artículos para su presentación final en la revista. Los editores desean agradecer a los miembros del Comité de Gestión, el Consejo Editorial y el equipo editorial del CIAT por el tiempo y la energía que dedicaron para hacer de Tropical Grasslands-Forrajes Tropicales una revista líder en la publicación de investigaciones sobre forrajes tropicales.

Jean Hanson y Danilo Pezo, Editores,
Tropical Grasslands-Forrajes Tropicales

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Artículo Científico

Desempeño agronómico de seis accesiones de maní forrajero (*Arachis pintoi*) en la subregión del Nordeste de Antioquia, Colombia

Agronomic performance of six accessions of forage peanuts (Arachis pintoi) *in the Northeast Antioquia subregion, Colombia*

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Resumen

Este trabajo tuvo como objetivo evaluar el desempeño agronómico de seis accesiones de maní forrajero (*Arachis pintoi*) en el Nordeste de Antioquia, Colombia. La evaluación se realizó en el Centro de Investigación El Nus (Agrosavia), en San José del Nus, Antioquia, Colombia. Se empleó un diseño de parcelas divididas en el tiempo, con cuatro bloques. Los tratamientos resultaron de la combinación de seis accesiones, cuatro frecuencias de corte y dos épocas. Para el análisis se utilizó un modelo mixto, con la accesión, frecuencia de corte, época y sus interacciones como efectos fijos; y el bloque como factor aleatorio. Entre junio de 2021 y febrero 2023, se evaluaron variables agronómicas (rendimiento de materia seca, altura de planta, cobertura), características morfológicas (diámetro de tallo, longitud y número de estolones, ancho y largo de hoja) y calidad nutricional (PC, FDN, FDA y DIVMS). Las accesiones y época afectaron ($P<0.05$) el rendimiento de materia seca y las características morfológicas. Se detectó diferencias debidas a accesiones y frecuencia de corte para PC, FDA y DIVMS. Se encontró que la cobertura fue la única variable que presentó efecto ($P<0.05$) para la triple interacción (accesión × frecuencia de corte × época). Los resultados obtenidos confirman la variabilidad existente entre las accesiones de *A. pintoi* evaluadas en términos de producción y calidad nutritiva. La accesión CIAT 22160 destacó como promisoria para zonas de ladera del Nordeste de Antioquia, por lo que amerita continuar con su evaluación de respuesta animal a nivel de finca.

Palabras clave: Calidad nutricional, ganadería en ladera, leguminosas, rendimiento, variables morfológicas.

Abstract

This evaluated the agronomic performance of six accessions of forage peanuts (*Arachis pintoi*) in the Northeast of Antioquia, Colombia. The evaluation was conducted at the El Nus Research Center of Agrosavia, in San José del Nus, Antioquia, Colombia. A split-plot in time design, with four blocks was used. Treatments were defined by the combination of six accessions, four cutting frequencies and two seasons. A mixed model that considered accession, cutting frequency, season, and the interaction among those factors as fixed effects, and the block as a random factor was used for data analysis. Between June 2021 and February 2023, agronomic variables (dry matter yield, plant height, and coverage), morphological characteristics (stem diameter, length and number of stolons, and leaf with and length) and nutritional quality (PC, FDN, FDA, and DIVMS) were evaluated. Accessions and seasons affected ($P<0.05$) the dry matter yield and morphological characteristics. Differences due to accessions and cutting frequency were

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detected for PC, FDA, and DIVMS. Plant coverage was the only variable affected (P<0.05) by the triple interaction (accession × cutting frequency × season). The results obtained confirm variability among the accessions of *A. pintoi* evaluated, in terms of production and nutritional quality. Accession CIAT 22160 stood out as promising for the hillside areas of Northeastern Antioquia and deserves further evaluation for of animal responses at farm level.

Keywords: Forage yield, legumes, livestock production in hilly areas, morphological attributes, nutritional quality.

Introducción

En los sistemas ganaderos tropicales, la alimentación está basada principalmente en pasturas, por su bajo costo y aporte de nutrientes para mantenimiento, crecimiento y producción de los rumiantes (Molano et al. 2011). Generalmente, las pasturas tropicales son de baja calidad por sus características genéticas y manejo agronómico deficiente (Anzola et al. 2014); sumado a esto, las condiciones edafoclimáticas a las cuales se someten con frecuencia son adversas, limitando su desempeño productivo (Betancourt et al. 2012; Osorio et al. 2011; Padilla et al. 2009). El bajo rendimiento y la rápida degradación de las pasturas (Padilla et al. 2009) ha generado cuestionamientos ambientales a los sistemas de producción bovina (MADR 2021), principalmente por su contribución a la ampliación de la frontera agrícola (Ideam y MADS 2023; Castro-Castillo et al. 2022).

Una forma de mitigar estos efectos de la ganadería sobre el ambiente, es conocer el cómo integrar recursos forrajeros con características de rusticidad y adaptación que permitan incrementar la productividad y sostenibilidad en los sistemas ganaderos (Tapasco et al. 2019; Zuluaga et al. 2021). Las leguminosas son recursos forrajeros que permiten aumentar la oferta forrajera y complementar los requerimientos nutricionales de los animales aportados por las gramíneas (Bueno et al. 2015). Una de las leguminosas más usadas en los sistemas ganaderos del trópico bajo es el maní forrajero (*Arachis pintoi* Krapov. & W.C. Greg.), el cual se caracteriza principalmente por su alto contenido de proteína y habito de crecimiento postrado, lo cual le proporciona una virtud en el asocio con las gramíneas de crecimiento erecto (Rincón et al. 2020). Además, esta especie tiene múltiples usos en los sistemas agrícolas y forestales, pues se emplea como cultivo de cobertura, con el propósito de controlar las arvenses y prevenir la erosión del suelo (Andrade et al. 2016; Carvalho y Quesenberry 2009; Rincón et al. 2020)

El uso del maní forrajero en las explotaciones ganaderas ha demostrado que contribuye a mejorar indicadores productivos y económicos, además de generar importantes servicios ecosistémicos con efectos positivos sobre el suelo, así como en la calidad y persistencia del pasto y en la biodiversidad del sistema productivo (Castillo y Villalobos 2021; Enciso et al. 2021). Asimismo, se ha demostrado que favorece el incremento de la biomasa forrajera, lo cual redunda en sostener una mayor carga animal y mejorar la ganancia de peso diaria (Pereira et al. 2020).

Considerando los atributos del *A. pintoi* anteriormente mencionados se hace necesario continuar con la evaluación, identificación y selección de accesiones que se puedan integrar en sistemas ganaderos en ambientes diferentes a los previamente estudiados (Castillo y Villalobos 2021; Enciso et al. 2021; Rincón et al. 2020). Por lo anterior, este trabajo tuvo como objetivo evaluar el desempeño agronómico de seis accesiones de maní forrajero (*Arachis pintoi*) en áreas de ladera de la subregión del Nordeste de Antioquia, Colombia.

Materiales y Métodos

Condiciones experimentales y ambientales

La evaluación se realizó entre junio del 2021 y febrero del 2023 en el Centro de Investigación El Nus, adscrito a la Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA). Este se localiza en el corregimiento San José del Nus (6° 30' N, 74° 50' W), municipio de San Roque (Antioquia, Colombia), a una altura de 830 m.s.n.m., temperatura media de 22.7 °C, precipitación promedio anual de 2,539 mm y topografía de ladera, con pendientes desde 7% hasta mayores del 75% (Echeverri et al. 2020; Ideam 2024; Tobón 2004). La zona se clasifica como bosque muy húmedo premontano (Holdridge 1971; Serrano y Calderón 2016). El suelo en el área experimental presentaba condiciones fuertemente ácidas (pH 5.01), y bajas concentraciones de nitrógeno total (0.056%), fósforo (<3.87 mg/kg) y potasio (<0.09 cmol (+) /kg).

Tratamientos evaluados

Las seis accesiones de *A. pintoi* evaluadas en este trabajo fueron: CIAT 22338, 18749, 17434, 22234, 22160 y 22340. Las semillas fueron suministradas por el Programa de Recursos Genéticos del Centro Internacional de Agricultura Tropical (CIAT). Se utilizó como testigo la accesión CIAT 17434, la cual es de uso más frecuente en los sistemas productivos ganaderos, así como en cultivos agrícolas y jardines (Enciso et al. 2021). Se consideraron dos épocas de evaluación (baja y alta precipitación) y cuatro edades de rebrote (21, 28, 35 y 42 días).

Diseño experimental

Se empleó un diseño de bloques completos al azar, con un arreglo de parcelas divididas en el tiempo (Martínez et al. 2011). La época (baja y alta precipitación) constituyó la parcela principal, y las subparcelas incluyeron la combinación de las seis accesiones de maní forrajero con las cuatro edades de corte (de 21 a 42 días de rebrote). La unidad experimental fue una parcela con dimensiones de 3 × 2.5 m, con un total de 24 unidades espaciales. Adicionalmente, el experimento se estableció en cuatro bloques, teniendo en cuenta la pendiente del terreno.

Manejo agronómico

Para el establecimiento y durante las evaluaciones, no se aplicó ningún tratamiento de fertilización, enmiendas, riego o manejo de plagas y enfermedades. Lo anterior, con el propósito de observar el desempeño, persistencia, comportamiento, resistencia y/o tolerancia de las accesiones evaluadas a las condiciones propias de la zona y posibles factores adversos que estas pudieran enfrentar, tales como deficiencias, plagas o enfermedades. Para garantizar un buen desarrollo de plantas en las parcelas experimentales se aplicó controles mecánicos y manuales de las arvenses y otras plantas diferentes a las accesiones en estudio.

Variables medidas

En cada acccesión, edad de corte y época se evaluaron variables agronómicas, características morfológicas y de calidad nutritiva, aplicando las metodologías descritas por Rincón et al. (2022) y Toledo (1982).

Variables agronómicas

Rendimiento de materia seca (kg/ha/corte): Para la evaluación del rendimiento se colocó en un punto al azar dentro de cada parcela experimental un cuadro aforador (0.25 m^2), en el cual se realizó el corte del forraje a ras. Para la determinación del contenido de materia seca, se tomó una muestra de aproximadamente 200 gramos en fresco, la cual se llevó a la estufa para secado a 65 °C, durante 48 horas. El rendimiento de materia seca se estimó multiplicando el rendimiento en fresco por el porciento de materia seca, dividido por 100.

Altura de la planta (cm): En cada parcela se seleccionó cinco puntos al azar, donde se midió con una regla métrica la distancia desde el nivel del suelo hasta el punto más alto de la planta (hoja bandera), sin estirarla y sin contar la inflorescencia.

Cobertura: Se estimó visualmente en porcentaje (%) la proporción del suelo cubierta por la leguminosa dentro del área de 0.25 m^2 del cuadro.

Características morfológicas

Diámetro de tallo: Mediante un calibrador (pie de rey) se registró en milímetros (mm) el grosor en la parte media del tallo, usando tres tallos escogidos al azar.

Longitud de estolones: Mediante una regla métrica se registró el largo en centímetros (cm) de tres estolones escogidos al azar. Esta medición se hizo estirando el estolón desde el suelo hasta la yema apical.

Número de nudos: Se registró la cantidad de nudos presentes en tres tallos que fueron escogidos al azar.

Ancho y longitud de hoja: En tres hojas seleccionadas al azar se midió la distancia, en centímetros (cm), entre bordes en el tercio central de la hoja. Luego, se midió la distancia desde el ápice hasta la base de la hoja siguiendo la dirección de la nervadura central.

Características de calidad nutritiva: Los análisis de calidad nutritiva se desarrollaron en el Laboratorio de Nutrición Animal de Agrosavia ubicado en el Centro de Investigación Tibaitatá (Mosquera, Colombia). Estos se realizaron mediante la técnica de espectroscopia de reflectancia cercana al infrarrojo, con el equipo NIRS DS 2500 (FOSS Analytical A/S – Dinamarca), teniendo en cuenta los métodos de referencia desarrollados por Ariza-Nieto at al. (2017). Los atributos evaluados fueron el contenido de proteína cruda (PC) (AOAC984.13), fibra detergente neutro (FDN) (AOAC2002.04) y fibra detergente ácido (FDA) (AOAC973.18), así como la digestibilidad *in vitro* de la materia seca (DIVMS).

Análisis estadístico

Los datos se analizaron empleando un modelo mixto que consideró como efectos fijos la accesión evaluada, la frecuencia de corte, la época y la interacción entre esos factores. En la parte aleatoria del modelo se consideró el efecto de bloque, el error de la parcela principal (bloque × accesión) y las medidas repetidas dentro de cada unidad experimental. En cada modelo, se evaluó la posible violación a los supuestos de normalidad o heterogeneidad de varianza. En caso de presencia de violación de los supuestos del ANOVA, el modelo base se modificó de acuerdo con la naturaleza de la variable, considerando las distribuciones Gausiana para datos continuos, Poisson/Binomial Negativa para conteos y Beta para porcentajes.

Todos los análisis se desarrollaron con el software SAS Enterprise Guide versión 8.3. En caso de rechazo de la hipótesis nula, se realizó la prueba de Tukey para la separación de medias, con el nivel de P<0.05.

Resultados

Variables agronómicas

El rendimiento de forraje (kg/MS/ha) registró efecto (P<0.05) de los factores accesión, días de rebrote y época de evaluación, así como para la interacción edad de rebrote × época. La altura de planta presentó efecto (P<0.05) para la accesión, época y su interacción. Por su parte, la cobertura registró efecto (P<0.05) para la accesión y la triple interacción accesión × edad de rebrote × época (Cuadro 1).

Las accesiones CIAT 22160 y 17434 presentaron los mayores (P<0.05) rendimientos de materia seca, con valores de 2,286 ± 100.07 y 2,328.84 ± 100.07 kg/MS/ha, respectivamente, sin diferencia entre ellos. Para la interacción días de rebrote × época (Figura 1A), la variable rendimiento de MS/ha registró la mayor (P<0.05) producción de biomasa a los 42 días de rebrote en la época de lluvias (2,423.16 ± 88.18 kg MS/ha/corte), seguido del corte a los 35 días de rebrote en la misma época (2,201.16 ± 88.18 kg MS/ha/corte), la cual no difirió (P>0.05) a los registros obtenidos para las demás edades de rebrote en la época de lluvias, pero fue superior (P<0.05) al rendimiento de biomasa forrajera obtenida en los cortes efectuados en el período seco. Por su parte, en el período seco, los rendimientos de biomasa forrajera fueron similares entre los 28 y 42 días de rebrote (rango de 1,843 y 1,975 kg MS/ha/corte, P>0.05), pero superiores al registro obtenido para los 21 días de rebrote (1,546.4 ± 88.1 kg MS/ha/corte).

En cuanto a la altura de planta, la accesión CIAT 22160 presentó el valor más alto (P<0.05) en comparación al resto de las accesiones, tanto en el período de lluvias como en la seca; pero la altura de planta alcanzada por esta accesión en la época seca no difirió de los valores obtenidos para las accesiones CIAT 22338, 18749 y 22340 en época de lluvias (Figura 1B). En contraste, la accesión CIAT 17434 registró la menor altura de planta en ambas épocas, con una media de 7.1 y 8.3 cm en las épocas seca y de lluvias, respectivamente.

En cuanto a la variable cobertura, para la cual se detectó significancia (P<0.05) para la triple interacción accesión × época × edad, la accesión CIAT 17434 superó al resto de accesiones en el período seco, con valores entre 95 y 96% de cobertura independientemente de la edad de rebrote, seguido por la accesión CIAT 22160 con coberturas de 90 a 93% a los 42 y 35 días en la misma época; en cambio, en el período de lluvias las diferencias entre ambas accesiones desaparecieron. En contraste, la accesión CIAT 22338 tendió a presentar la menor cobertura respecto al resto, independiemente de la edad de rebrote y época. (Figura 1C).

Cuadro 1. Características agronómicas de seis accesiones de *A. pintoi* evaluadas a diferentes edades de rebrote y épocas en la subregión del Nordeste de Antioquia, Colombia.

		Rendimiento de materia seca (kg/ha/corte)	Altura (cm)	Cobertura (%)
Accesión	CIAT 22338	1,706.50 ± 100.07 c	9.78 ± 0.42 b	54.27 ± 5.78 dc
	CIAT 18749	1,879.25 ± 100.13 bc	10.28 ± 0.42 b	69.76 ± 4.92 dc
	CIAT 17434	2,328.84 ± 100.07 a	7.79 ± 0.42 c	92.95 ± 1.66 a
	CIAT 22234	2,037.56 ± 100.07 b	8.25 ± 0.42 c	69.24 ± 5.01 dc
	CIAT 22160	2,286.98 ± 100.07 a	13.18 ± 0.42 a	87.03 ± 2.74 ab
	CIAT 22340	1,975.47 ± 100.07 b	10.08 ± 0.42 b	75.63 ± 4.34 bc
Edad de rebrote (días)	21	1,839.07 ± 90.83 c	9.74 ± 0.38	78.55 ± 2.61
	28	2,017.06 ± 90.86 b	10.13 ± 0.38	74.24 ± 2.93
	35	2,088.37 ± 90.83 ab	9.92 ± 0.38	77.72 ± 2.65
	42	2,198.55 ± 90.83 a	9.79 ± 0.38	79.4 ± 2.53
Época	Lluvia	2,236.59 ± 76.75 a	10.96 ± 0.32 a	80.07 ± 2.03
	Seca	1,834.94 ± 84.55 b	8.83 ± 0.33 b	74.79 ± 3.61
Valor P	Accesión	<0.0001	<0.0001	<0.0001
	Edad de rebrote	0.0394	0.7262	0.0640
	Accesión × edad de rebrote	0.9750	0.7258	0.0025
	Época	0.0037	<0.0001	0.0859
	Accesión × época	0.1913	0.0010	0.0057
	Edad de rebrote × época	0.0150	0.5155	<0.0001
	Accesión × edad de rebrote × época	0.0725	0.7700	<0.0001

Los valores con la misma letra no presentan diferencias significativas entre medias (P>0.05).

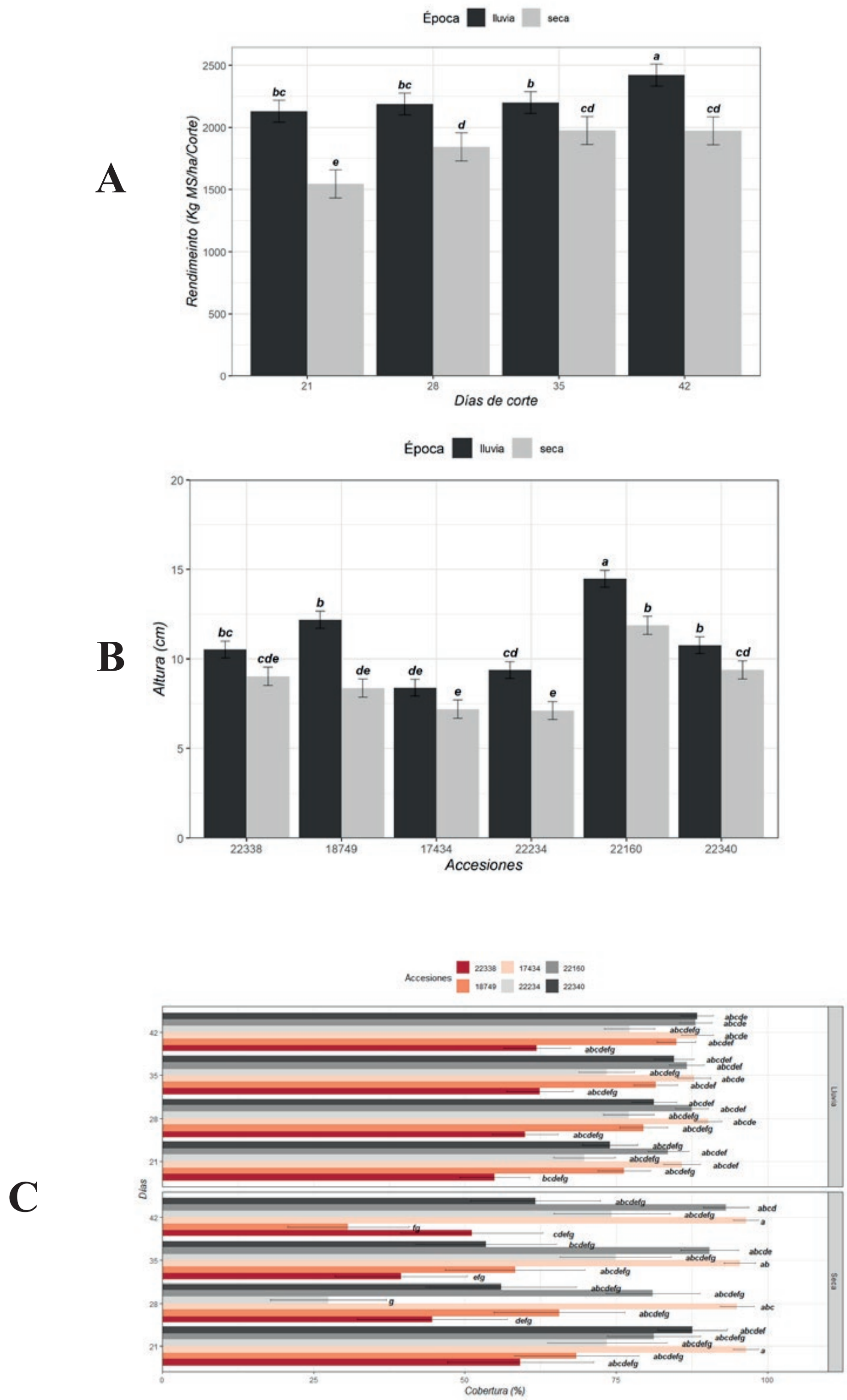

Figura 1. (A) Efecto de la época y edad de rebrote en el rendimiento (kg MS/ha/corte), de la época y la accesión en la altura de planta (B) y de la accesión, época y días de evaluación en el porcentaje de cobertura (C) y para seis genotipos de *A. pintoi* evaluados en la subregión del Nordeste de Antioquia, Colombia. Los valores con la misma letra no presentan diferencias significativas entre medias (P>0.05)

Características morfológicas

Respecto a las características morfológicas, la accesión afectó (P<0.05) todas todas ellas, excepto la longitud de estolón, la cual varió entre 18.72 ± 1.22 y 21.53 ± 1.22 cm, con la menor longitud para la accesión CIAT 22340 (Cuadro 2). En contraste, esta accesión presentó el mayor diámetro de tallo, mientras que las accesiones CIAT 22160 y 22234 tuvieron los menores diámetros, con una media de 2.1 ± 0.07 y 1.87 ± 0.07 cm, respectivamente, sin diferencias (P>0.05) entre ellas. Con relación al efecto de la edad de rebrote sobre el diámetro de tallos, los más gruesos (P<0.05) se presentaron a los 21 días en el período de mayor precipitación, y los de menor diámetro a los 42 días en el período seco (Figura 2A). En contraste, no se detectó diferencias en el ancho de hojas debidas a la edad de rebrote en el período de lluvias; mientras que en el período seco, los menores valores de ancho de hojas correspondieron a los cortes más tardíos (Figura 2B).

Cuando se analizó el efecto de las accesiones sobre la misma variable, las accesiones CIAT 18749 y 17434 presentaron las hojas más anchas (1.56 ± 0.03 y 1.58 ± 0.03 cm, respectivamente). Para el largo de hoja, la accesión CIAT 22160, con una media de 2.68 ± 0.05 cm, superó (P<0.05) a las demás. En esta característica, la accesión que registró las hojas más cortas fue la CIAT 22234, con una media de 2.40 ± 0.05 cm. Para la variable número de nudos, las accesiones CIAT 22338 y 17434 fueron superiores (P<0.05) a las demás, con 10.59 ± 0.52 y 10.87 ± 0.53 nudos, respectivamente. En el caso de esta variable, a diferencia de lo observado para las otras características morfológicas evaluadas, los valores más altos (P<0.05) se presentaron en el período de baja precipitación (Cuadro 2).

Cuadro 2. Características morfológicas de seis accesiones de *A. pintoi* evaluadas a diferentes edades de rebrote y épocas en la subregión del Nordeste de Antioquia, Colombia.

		DT (mm)	LE (cm)	NN	AH (cm)	LH (cm)
Accesión	CIAT 22338	2.39 ± 0.07 ab	21.06 ± 1.22	10.59 ± 0.52 a	1.43 ± 0.03 c	2.52 ± 0.05 b
	CIAT 18749	2.23 ± 0.07 bc	20.34 ± 1.22	8.70 ± 0.46 b	1.56 ± 0.03 a	2.51 ± 0.05 b
	CIAT 17434	2.37 ± 0.07 ba	20.14 ± 1.22	10.87 ± 0.53 a	1.58 ± 0.03 a	2.50 ± 0.05 bc
	CIAT 22234	1.87 ± 0.07 d	20.40 ± 1.22	8.95 ± 0.47 b	1.35 ± 0.03 d	2.40 ± 0.05 c
	CIAT 22160	2.10 ± 0.07 c	21.53 ± 1.22	8.06 ± 0.44 b	1.49 ± 0.03 b	2.68 ± 0.05 a
	CIAT 22340	2.50 ± 0.07 a	18.72 ± 1.22	9.17 ± 0.48 b	1.46 ± 0.03 bc	2.54 ± 0.05 b
Edad de rebrote (días)	21	2.43 ± 0.06 a	19.61 ± 1	8.80 ± 0.4	1.49 ± 0.03 a	2.55 ± 0.04
	28	2.22 ± 0.06 b	21.07 ± 1	9.15 ± 0.41	1.51 ± 0.03 a	2.49 ± 0.04
	35	2.20 ± 0.06 b	20.94 ± 1	9.65 ± 0.43	1.47 ± 0.03 ab	2.54 ± 0.04
	42	2.11 ± 0.06 b	19.86 ± 1	9.78 ± 0.44	1.44 ± 0.03 b	2.52 ± 0.04
Época	Lluvia	2.6 ± 0.03 a	24.58 ± 0.44 a	8.82 ± 0.27 b	1.53 ± 0.03 a	2.64 ± 0.04 a
	Seca	1.88 ± 0.05 b	16.16 ± 0.86 b	9.88 ± 0.42 a	1.42 ± 0.03 b	2.41 ± 0.05 b
Valor P	Accesión	<.0001	0.6872	<.0001	<.0001	<.0001
	Edad de rebrote	0.0004	0.6449	0.1467	0.0394	0.5284
	Accesión × edad de rebrote	0.8943	0.9930	0.3492	0.9750	0.7323
	Época	<.0001	0.0001	0.0019	0.0037	0.0027
	Accesión × época	0.3062	0.8521	0.7971	0.1913	0.3293
	Edad de rebrote × época	0.0110	0.6384	0.6545	0.0150	0.2286
	Accesión × edad de rebrote × época	0.9201	0.9807	0.1348	0.0725	0.8518

DT=Diámetro de tallo; LE=Longitud de estolón; NN=Número de nudos; AH=Ancho de hoja; LH=Largo de hoja.
Los valores con la misma letra no presentan diferencias significativas entre medias (P>0.05)

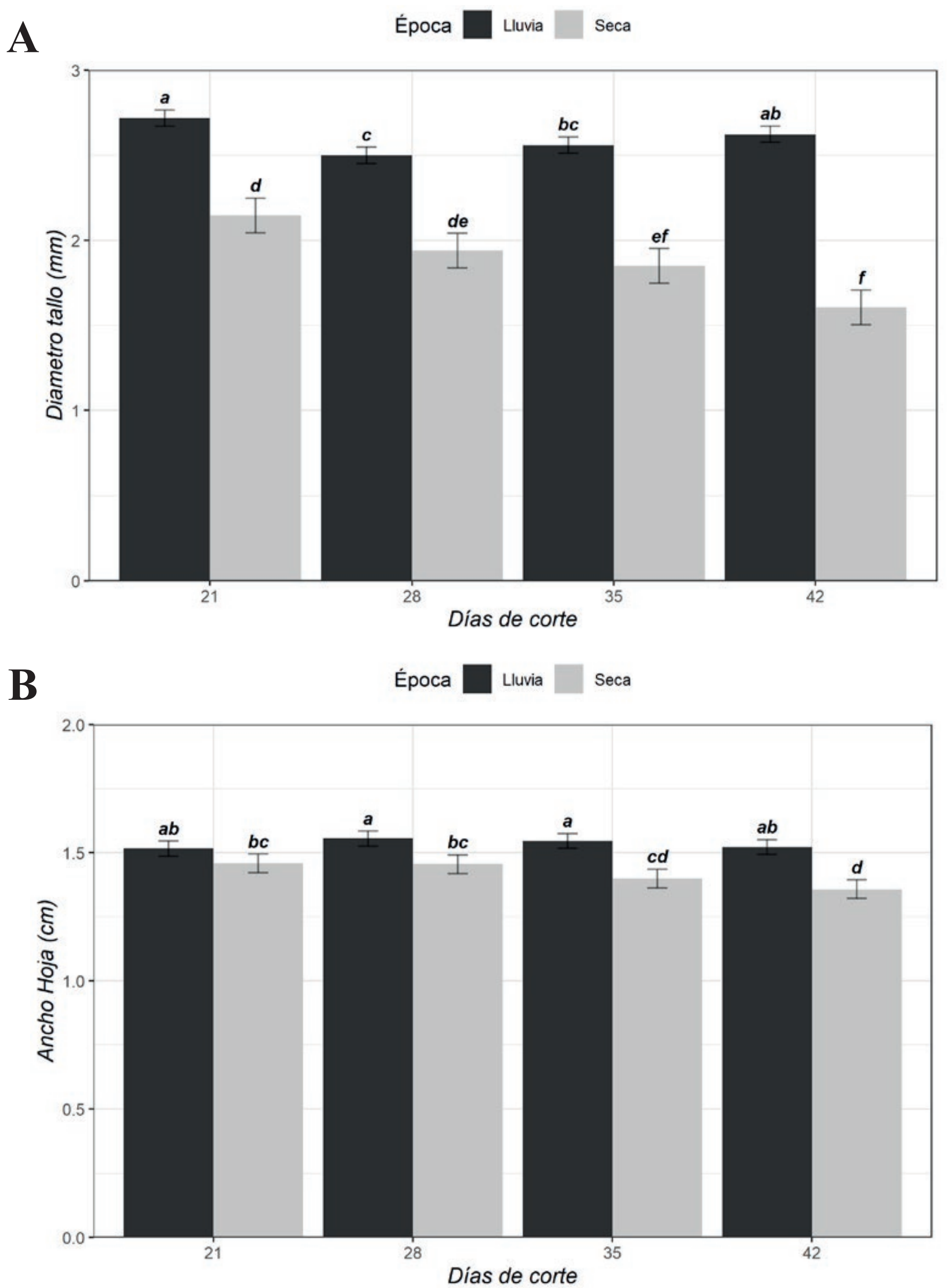

Figura 2. Efecto de la época y edad de rebrote sobre el diámetro del tallo (A) y ancho de la hoja (B) para seis genotipos de *A. pintoi* evaluados en la subregión del Nordeste de Antioquia, Colombia. Los valores con la misma letra no presentan diferencias significativas entre medias (P>0.05).

Calidad nutritiva

Desde el punto de vista de la calidad nutricional (Cuadro 3), todas las variables evaluadas fueron influenciadas (P<0.05) por la accesión, excepto en el caso del FDN. Además, el contenido de proteína cruda y la digestibilidad fueron afectados significativamente (P<0.05) por la interacción accesión × época. La edad de rebrote afectó (P<0.05) todos los atributos de calidad nutritiva, mostrando una disminución en el contenido de proteína y la digestibilidad, y un aumento en el contenido de las fracciones fibrosas, a medida se incrementó la edad de rebrote. Con relación al FDA, las accesiones que registraron la menor concentración de FDA fueron CIAT 22338 y 18749 (23.06 ± 0.29 y 23.2 ± 0.27%, respectivamente). En cuanto al efecto de la época, los mayores valores promedio para proteína cruda, FDA y digestibilidad se presentaron en la época de lluvias, pero el contenido de FDN fue más alto en el período seco (Cuadro 3).

Sin embargo, el efecto de época sobre el contenido de proteína cruda y la digestibilidad no fue consistente en todas las accesiones; así, mientras la accesión CIAT 22340 presentó un mayor contenido de proteína en la época lluviosa que en la seca (22.2 y 19.4%, respectivamente); en cambio no se registraron diferencias en el contenido de proteína debidas a época en las accesiones CIAT 17434 y 22160 (Figura 3A). Cade destacar que la accesión CIAT 22338 registró los contenidos más bajos de proteína en ambos períodos (Figura 3A).

En cuanto a la digestibilidad in vitro de la materia seca, en tres accesiones (CIAT 22338, 18749 y 17434), ésta fue ligeramente mayor en el período seco; mientras que en la época de lluvias sucedió lo opuesto para las accesiones CIAT 22234, 22160 y 22340. En la época de lluvias la accesión 22340 mostró el mayor valor de digestibilidad (69.6%) respecto a todas las accesiones evaluadas en ambas épocas, excepto para el caso de la accesión CIAT 17434 que mostró un valor similar de digestibilidad en ambos períodos (Figura 3B).

Cuadro 3. Características de calidad nutritiva para las seis accesiones de *A. pintoi* evaluadas a diferentes edades de rebrote y épocas en la subregión del Nordeste de Antioquia, Colombia.

		PC	FDN	FDA	DIVMS
Accesión	CIAT 22338	18.84 ± 0.3 d	50.33 ± 0.63	23.06 ± 0.29 c	67.28 ± 0.25 b
	CIAT 18749	19.96 ± 0.29 bc	50.48 ± 0.6	23.2 ± 0.27 c	68.12 ± 0.24 a
	CIAT 17434	21.23 ± 0.28 a	50.03 ± 0.59	24.58 ± 0.26 ab	68.7 ± 0.23 a
	CIAT 22234	19.62 ± 0.29 cd	50.94 ± 0.61	24.96 ± 0.27 a	67.3 ± 0.24 b
	CIAT 22160	20.6 ± 0.28 ab	50.46 ± 0.59	24.63 ± 0.26 ab	68.19 ± 0.23 a
	CIAT 22340	20.84 ± 0.29 a	50.72 ± 0.6	24.12 ± 0.27 b	68.53 ± 0.24 a
Edad de rebrote (días)	21	20.85 ± 0.24 a	49.5 ± 0.55 c	23.28 ± 0.22 c	68.8 ± 0.19 a
	28	20.11 ± 0.24 b	50.29 ± 0.55 bc	23.99 ± 0.23 b	68 ± 0.2 b
	35	20.16 ± 0.24 b	50.84 ± 0.55 ba	24.66 ± 0.23 ba	67.83 ± 0.2 bc
	42	19.6 ± 0.24 b	51.34 ± 0.55 a	24.43 ± 0.22 a	67.45 ± 0.19 c
Época	Lluvia	20.6 ± 0.18 a	49.3 ± 0.48 b	24.45 ± 0.14 a	68.24 ± 0.14 a
	Seca	19.76 ± 0.22 b	51.69 ± 0.52 a	23.73 ± 0.17 b	67.8 ± 0.17 b
Valor P	Accesión	<.0001	0.7354	<.0001	<.0001
	Edad de rebrote	0.0016	0.0022	0.0001	<.0001
	Accesión × edad de rebrote	0.4288	0.9824	0.9262	0.5014
	Época	0.0314	0.0013	0.0226	0.1065
	Accesión × época	0.0006	0.0628	0.2724	0.0001
	Edad de rebrote × época	0.0022	0.0001	<.0001	<.0001
	Accesión × edad de rebrote × época	0.4331	0.8351	0.7977	0.4354

PC=Proteína cruda; FDN=Fibra en detergente neutro; FDA=Fibra en detergente ácido; DIVMS=Digestibilidad *in vitro* de la materia seca. Los valores con la misma letra no presentan diferencias significativas entre medias (P>0.05).

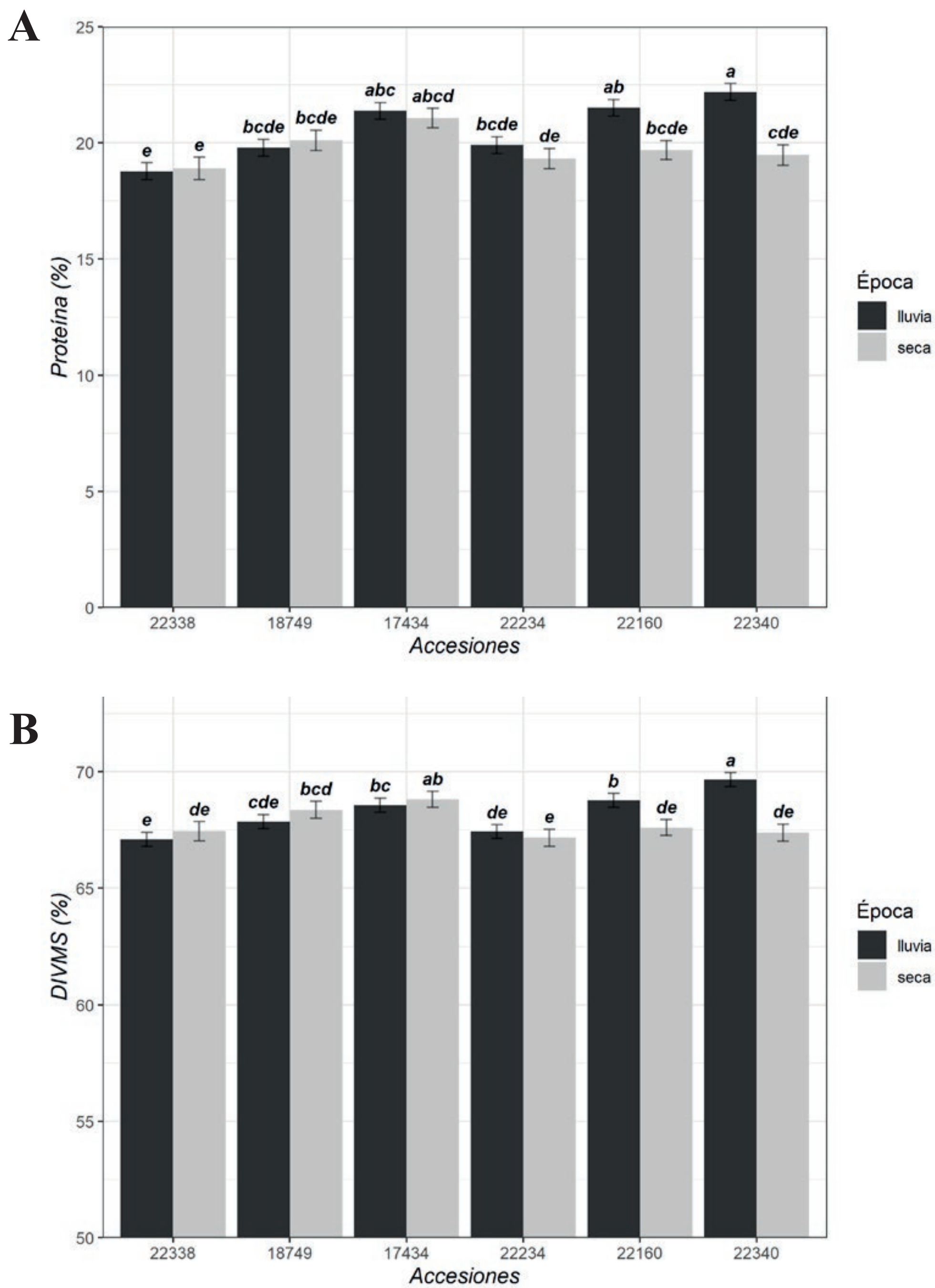

Figura 3. Efecto de la interacción accesión por época en el porcentaje de proteína (A) y digestibilidad in vitro de la materia seca (B) para seis genotipos de *A. pintoi* evaluados en la subregión del Nordeste de Antioquia, Colombia. Los valores con la misma letra no presentan diferencias significativas entre medias (P>0.05).

Discusión

El rendimiento de forraje sobresaliente obtenido para la accesión CIAT 22160, el cual no difirió del obtenido con la accesión CIAT 17434 de amplia difusión, coincide con lo reportado por Rincón et al. (2020), quienes realizaron evaluaciones similares en la región de la Orinoquia (Villavicencio - Colombia), donde seleccionaron esta accesión como promisoria, y la misma fue liberada como cultivar comercial con el nombre de Centauro. Del mismo modo, Pizarro et al. (1997), trabajando en el Cerrado brasileño, reportaron que la accesión CIAT 22160 presentó una alta producción de materia seca, aunque con rendimientos inferiores a los obtenidos en el presente trabajo (1,800 kg/MS/ha).

En cuanto a la altura y cobertura, en otros estudios (Pizarro et al. 1997; Rincón et al. 2020) también se ha reportado que la accesión CIAT 22160 presentó una mayor altura (20 cm) y una cobertura similar a la registrada en el presente estudio. La mayor cobertura observada en las accesiones CIAT 17434 y 22160, así como su estabilidad en ambas épocas, es una característica de gran importancia porque le permite manifestar una buena capacidad de competencia con arvenses y prevenir la erosión del suelo (Andrade et al. 2016; Carvalho y Quesenberry 2009; Assis et al. 2018; Orduz-Rodríguez et al. 2011; Rincón et al. 2020). Es por esas características que se considera al *A. pintoi* una especie que puede integrarse en diferentes sistemas agrícolas y forestales, como es el caso de asocios con plátano (Musa AAB) (Ramos et al. 2011), café (Rose et al. 2019) y maíz (Sumiahadi et al. 2019).

Los diámetros de tallo obtenidos para las diferentes accesiones fueron inferiores a los reportados por Carvalho y Quesenberry (2009), trabajando con 34 accesiones de maní forrajero, quienes encontraron para esta característica un valor promedio de 2.95 mm, y un rango de 2 a 7 mm. En el mismo trabajo, para el ancho de hoja se encontró valores promedio ligeramente superiores a los del presente estudio (1.51 vs. 1.48 cm, respectivamente), pero inferiores para el largo de hoja (2.49 vs. 2.55 cm, respectivamente). Estas características morfológicas son de interés en programas de de selecciòn de *A. pintoi* donde uno de los objetivos es aumentar la producción de biomasa (Carvalho y Quesenberry 2009); dado que la mayor longitud y ancho de hoja se relaciona con una mayor área foliar, y eventualmente una mayor capacidad potencial para capturar la radiación (Lopes de Sá et al. 2015), lo que debe traducirse en mayor producción de biomasa forrajera.

Los contenidos promedio de PC y DIVMS reportados en el presente estudio, fueron superiores a los encontrados por Fernandes et al. (2017) en 10 accesiones de *A. pintoi* evaluadas en Planaltina, Brasil (16.6% y 58.5%, respectivamente), aunque similares en el contenido de FDA (24.1%). En el caso específico de las accesiones CIAT 17434 y 22160, Sébastien et al. (2013) trabajando en dos regiones consideradas como húmeda y subhúmeda, con diferencias en precipitación (1,197 y 909 mm), temperatura (26 °C y 27 °C) y propiedades químicas del suelo (pH: 5.90 y 6.35; N: 0.04 y 0.08%, P: 3 y 6 mg/kg, K: 0.4 y 0.5 cmol(+)/kg), han reportado menor concentración de proteína cruda (entre 17.77 y 17.89% y 18.03% – 18.61%, para las accesiones CIAT 17434 y 22160, respectivamente) que la observada con las mismas accesiones en este estudio. Las diferencias en la concentración de proteína cruda no solo responden a las características genéticas de las accesiones, sino que pueden estar también influenciadas por las condiciones edafoclimáticas de las zonas de estudio, principalmente relacionadas con el contenido de nitrógeno (N) presente en el suelo (Fernandes et al. 2017). Otro aspecto importante para considerar es que algunas de las acciones (CIAT 22338, 18749, 17434 y 22234) tendieron a mostrar pocas diferencias en el contenido de proteína y digestibilidad debidas a la época del año; lo cual es muy crítico en el caso de la mayoría de las gramíneas nativas (Salamanca-Carreño et al. 2022) o introducidas (Carvajal-Tapia et al. 2021). Esto les da un valor especial a estas accesiones de *Arachis pintoi* cuando crecen en asocio con gramíneas.

El hábito de crecimiento rastrero y la calidad nutricional de la especie *A. pintoi* es muy atractiva para asociarla con gramíneas e incorporarla en las praderas de pastoreo, por el aporte que hace a la dieta de los bovinos, además, de otros beneficios como la cobertura del suelo anteriormente citada, pero también la fijación de nitrógeno (Sotelo-Cabrera et al. 2017). También se ha demostrado que el número de estolones y el crecimiento decumbente favorecen la persistencia de la leguminosa (Castillo-Gallegos 2003; Ascencio-Rojas et al. 2005), lo que permite aplicarle una defoliación frecuente y severa, sin que ello resulte en pérdida de su productividad (Sinclair et al. 2007).

Conclusiones

Los resultados agronómicos confirmaron la variabilidad existente entre las accesiones de *Arachis pintoi* evaluadas, destacándose algunas de ellas por sus atributos de interés zootécnico como son la producción de biomasa forrajera y su calidad nutricional, por lo cual constituyen un recurso forrajero de interés para ser incorporado en los sistemas de producción ganadera.

La producción, atributos morfológicos y de calidad nutricional de la accesión CIAT 22160 permite perfilar a esta como promisoria para zonas de ladera en el Nordeste de Antioquia (Colombia); sin embargo, amerita continuar las evaluaciones en fincas de productores, midiendo la respuesta animal.

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Research Paper

Protected urea as a nitrogen source for Mulato II grass: impacts on forage production, feed value and composition

Urea protegida como fuente de nitrógeno para el pasto Mulato II: impactos en la producción de forraje, el valor nutritivo y la composición

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Abstract

The growing demand for high-yielding forage cultivars with drought tolerance, broad environmental adaptation and sustained feed quality has stimulated the development of new *Urochloa* (syn. *Brachiaria*) genotypes, such as Mulato II. Efficient nitrogen (N) fertilization strategies are essential to optimize their productivity and nutritional value. This study aimed to evaluate the effects of N fertilization, using conventional and protected urea at 0, 50, 100 and 150 kg N/ha on green mass production (GMP), dry matter production (DMP), leaf:stem ratio (LSR), nutritional value, apparent nitrogen recovery (ANR), apparent nitrogen conversion efficiency (ANCE), and crude protein yield per hectare (CP/ha) of Mulato II. The experiment followed a completely randomized 4 × 2 factorial design. The results showed that the N source significantly affected GMP, DMP, neutral detergent fiber (NDF) during the second growth period, and ANCE. Increasing N rates led to higher GMP, DMP and CP concentration, while decreasing ANCE. Fertilization with protected urea improved ANCE and reduced NDF concentration, indicating greater efficiency in nitrogen utilization. These findings support the strategic use of protected urea at moderate N rates to enhance forage productivity and nitrogen use efficiency in Mulato II.

Keywords: biomass production, fiber concentration, nitrogen conversion, nitrogen fertilization, nitrogen recovery.

Resumen

La creciente demanda de cultivares de forraje de alto rendimiento con tolerancia a la sequía, amplia adaptación ambiental y calidad sostenida del valor nutritivo ha estimulado el desarrollo de nuevos genotipos de *Urochloa* (sin. *Brachiaria*), como Mulato II. Las estrategias eficientes de fertilización nitrogenada (N) son esenciales para optimizar su productividad y valor nutricional. Este estudio tuvo como objetivo evaluar los efectos de la fertilización con N, utilizando urea convencional y protegida a 0, 50, 100 y 150 kg N/ha en la producción de de biomasa fresca (GMP), de materia seca (DMP), relación hoja:tallo (LSR), valor nutricional, recuperación aparente de nitrógeno (ANR), eficiencia aparente de conversión de nitrógeno (ANCE) y rendimiento de proteína cruda por hectárea (PC/ha) del pasto Mulato II. El experimento siguió un diseño factorial 4 × 2 completamente aleatorizado. Los resultados mostraron que la fuente

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de N afectó significativamente GMP, DMP, fibra detergente neutro (FDN) durante el segundo período de crecimiento y ANCE. El aumento de las dosis de N resultó en una mayor GMP, DMP y contenido de PC, a la vez que disminuyó la ANCE. La fertilización con urea protegida mejoró la ANCE y redujo la concentración de FDN, lo que indica una mayor eficiencia en la utilización del nitrógeno. Estos hallazgos respaldan el uso estratégico de urea protegida con dosis moderadas de N para mejorar la productividad del forraje y la eficiencia en el uso del nitrógeno en Mulato II.

Palabras clave: Concentración de fibra, eficiencia de conversión de nitrógeno, fertilización nitrogenada, producción de biomasa, recuperación de nitrógeno.

Introduction

In central Brazil, particularly in regions with Oxisol soils, pasture degradation remains a major constraint to sustainable livestock production. This degradation is largely driven by the inherent low fertility of these soils, combined with inadequate fertilization practices and improper pasture management (Dupas et al. 2016; Galindo et al. 2017). Strategies to enhance forage productivity are therefore essential to support more profitable and sustainable livestock systems in these regions.

Grasses of the genus *Urochloa* have been widely adopted across tropical regions owing to their adaptability to diverse soil types and climatic conditions, especially in areas of low to medium soil fertility. These grasses also provide flexible grazing management and competitive forage yields, making them preferred for improving pasture productivity under challenging conditions (Hunegnaw et al. 2022; Dupas et al. 2016). Among the newer genotypes, *Urochloa* hybrid 'Mulato II' (Mulato II), formerly marketed as Convert HD364 in Brazil, has gained prominence. Although this hybrid shows promising agronomic characteristics, including tolerance to drought and high productivity, its responses to nitrogen fertilization are still not fully understood. Comprehensive research is needed to study forage yield potential, morphological traits and nutritional quality under nitrogen fertilization.

According to Liebig's Law of the Minimum (van der Ploeg et al. 1999), plant growth is constrained by the scarcest essential nutrient. In tropical pastures, nitrogen (N) is typically the most limiting nutrient for forage production and quality, especially in highly weathered soils such as Oxisols (Delevatti et al. 2019; Dupas et al. 2016; Galindo et al. 2017) and for *Urochloa* hybrids (Pereira et al. 2021). Adequate N supply is crucial for promoting pasture recovery, enhancing forage productivity, and supporting sustainable animal production. N plays a key role in plant metabolism and directly influences tillering, leaf expansion and protein synthesis. However, due to its mobility and susceptibility to losses via leaching, volatilization and denitrification, its efficient use is a major challenge in pasture-based systems (Dupas et al. 2016). In tropical soils, N levels are often below the plant's requirement. In addition, N source and amount can influence N absorption and the production and feed value of grasses. Among the N sources available, urea is commonly used. However, variations in the form and speed of release of N in fertilizers can affect its use by the plant (Espindula et al. 2021; Ransom et al. 2020). Therefore, optimizing N use is a key factor to enhance sustainability of pasture-based systems. The development and use of enhanced-efficiency N fertilizers, such as protected urea, aim to reduce losses and improve N use efficiency.

Mulato II was selected for this study due to its widespread adoption in tropical forage systems, particularly in Brazil. Despite the potential benefits of N fertilization, limited studies have explored their effects on Mulato II under tropical conditions in Brazil. Existing research with other tropical grasses such as *Urochloa brizantha* and *Megathyrsus maximus* suggests positive effects of N fertilization on dry matter yield and forage quality (Dupas et al. 2016; Galindo et al. 2017), reinforcing the need to evaluate these effects in Mulato II.

This study evaluated the forage production, feed value and N recovery efficiency of Mulato II under N fertilization using prilled urea (conventional) and polymer-coated urea (protected urea). We hypothesized that the use of protected urea would enhance N recovery and improve both forage productivity and nutritional quality compared to conventional urea.

Materials and Methods

Experiment location

The experiment was carried out at the facilities of the Animal Science Department of the Veterinary School of the Federal University of Goiás, Goiânia city, Goiás State (16°36' S, 49°16' W; 727 masl). The soil in the experimental area is classified as dystrophic Red Latosol (Santos et al. 2018). Soil samples were collected before the establishment of the experimental plots at a depth of 0 to 20 cm for chemical and physical soil characterization (Table 1).

Table 1. Experimental area soil physical and chemical properties.

Soil parameter	Units	Data
pH	$CaCl_2$	5.0
S	mg/kg	13
P[1]		2
P[2]		5
K		120
K	cmol/kg	0.31
Ca		1.7
Mg		0.7
H+Al		2.2
Al		0.0
CEC		5.0
Clay	%	45
Silt		19
Sand		36
Base saturation		56
Al saturation		0
Organic matter		2.7
Ca/CEC		34
Mg/CEC		14
K/CEC		6

P[1]=Mehlich-1 (Mehlich 1 phosphorus extraction); P[2]=Ion-exchange resin extraction ("resin" method) as described by Medeiros et al. (2021).

According to the Köppen classification (Dubreuil et al. 2018), the climate of the region is Aw (hot and semi-humid, with well-defined seasons, with the dry season from May to October and rainfall between November and April) with a minimum temperature of 13 ºC and maximum of 32 ºC throughout the year. Climatic data for the experimental period from December 2016 to June 2017 were obtained from the Evaporimetric Station of Goiânia, located at the School of Agronomy and Food Engineering at the Federal University of Goiás, located 1 km away from the experimental area.

Experimental design and treatments

A completely randomized factorial experimental design was used with 4 N treatments (0, 50, 100 and 150 kg N/ha), 2 N sources (conventional and protected urea) and 3 replications, totaling 24 experimental plots.

Polymer coated urea protection technology was used and urea granules were coated with additive layers of Kimcoat N polymers by Kimberlit. The additives present in Kimcoat N protect the urea from the main losses that occur in the fertilization process (NH_3 volatilization, nitrification and denitrification) and allow a greater N presence in the form of ammonium in the soil (Roberto 2007).

Planting and management

Soil preparation was carried out using a disc harrow followed by a levelling harrow prior to planting. Experimental plots of 2 × 3 m separated by paths of 0.5 m wide were established in December 2015 and Mulato II seeds were sown manually at a rate of 12 kg of viable pure seeds (VPS)/ha. During the establishment phase, phosphorus was applied at a rate of 61.1 kg P/ha (140 kg P_2O_5/ha from single superphosphate), along with 50 kg FTE BR12/ha, a slow-release micronutrient fertilizer. This formulation provides essential micronutrients including boron (B), copper (Cu), manganese (Mn), and zinc (Zn) in balanced proportions, based on technical recommendations for tropical pastures on Oxisols (Martha Júnior et al. 2007).

The 50 kg/ha application was selected to supply adequate levels of these nutrients for optimal early plant development, particularly in soils known to be deficient in micronutrients due to low natural fertility. No liming was required, as soil pH and base saturation were within suitable ranges for *Urochloa* cultivation.

Plots were maintained by mechanical cutting at an average height of 35 cm during the establishment phase. Forage canopy height was measured using a graduated stick and an acetate sheet, which was slid along the stick to the height of the leaf horizon plane without disturbing the canopy surface following the method of Pequeno et al. (2014).

Plots were cut to 15 cm height at the start of the experiment on December 5, 2016, and the treatments of 0, 50, 100 and 150 kg N/ha were applied. The higher treatments of 100 and 150 kg N/ha were divided to 2 applications in an attempt to reduce nutrient losses (Martha Júnior et al. 2007) with the second application applied on February 25, 2017.

Forage harvest using intermittent defoliation regimes based on forage canopy height with pre- and post-harvest heights of 0.35 and 0.15 m, respectively, was done using a brush cutter. The 0.50 m from the edges of each plot were excluded to avoid border effects. The determination of the forage harvest time was based on the forage canopy height, which did not allow establishing specific cutting dates. Evaluations were carried out in Period I (summer), from December 2016 to February 2017 and Period II (autumn) from March to June 2017. For the treatment using conventional urea, the average cutting days were 93, 66, 60 and 70 days and, for the treatment using protected urea, were 80, 62, 55 and 52 days for the 0, 50, 100 and 150 kg N/ha respectively. Forage harvested was expressed proportionally to a full standard cut (1.00), where a value of 1.00 represents the total harvested biomass during the period, 0.33 indicates that only 33% of the biomass (compared to a full cut) was harvested and 1.33 means that the amount harvested was 133% of the biomass observed in a standard single cut. In Period I, using conventional urea, 1 full cut (1.00) was performed for the treatments of 0, 50, and 100 kg N/ha, and 1.33 for the 150 kg N/ha treatment. In Period II, 1 cut (1.00) was carried out for all N levels. For the protected urea treatment, in Period I, only 0.33 of the standard biomass was harvested for the control (0 kg/ha), and a full cut (1.00) was performed for the other N levels. In Period II, a full cut was made for levels of 0 and 50 kg N/ha, and 1.33 for 100 and 150 kg N/ha.

Forage accumulation and morphological composition

A forage sample was taken in each plot at each harvest to quantify the accumulated forage using metal quadrats measuring 0.5 m^2 (0.5 × 1 m), with feet at 0.15 m cutting height. Fresh material was cut and weighed in the field and a subsample of approximately 500 g was taken for nutritional analysis. The subsample was weighed, dried in a forced air circulation oven at 55 ºC for 72 h and then weighed to calculate the sample dry weight. Average accumulation rates were calculated for each regrowth interval. The forage accumulation of each regrowth was considered as the forage mass harvested above the residue height. The dry matter production was calculated as the sum of forage accumulated above the residue in all harvests during the experiment.

The morphological samples of forage collected (accumulated forage) were subsampled and manually separated into their morphological components (leaves, stem and/or pseudostem and dead material). For this experiment, the pseudostem was defined as the lower portion of the shoot formed by the overlapping sheaths of the leaf bases, which gives the appearance of a stem but does not show true internodal elongation. This structure is typical in grasses such as *Urochloa* spp., where the pseudostem contributes significantly to the plant's vertical growth and supports the emerging leaves. Subsamples of each component were weighed and dried in a forced air circulation oven at 55 ºC for 72 h. These data were used to determine the percentage of each component in the forage mass, leaf:stem ratio and leaf area index from each quadrat. Average values were calculated for each plot.

Forage nutritional quality

The subsamples collected from the accumulated forage and dried in an oven at 55 °C for 72 hours were ground in a Wiley mill with a 1 mm sieve, and later analyzed for dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), mineral matter (MM), hemicellulose (HEM) and lignin (LIG), according to the methodology described by AOAC (2019).

Conversion efficiency, apparent nitrogen recovery and crude protein production per hectare

The method of Carvalho and Saraiva (1987) was used to calculate the apparent N conversion efficiency (ANCE) and the percentage apparent N recovery (ANR), using the formulas:

ANCE=kg of DM produced/kg of applied N

%ANR=100 × [(Nfert - Ncontrol)/Napplied)].

where:
Nfert is the total N absorbed in the fertilized plot (kg/ha);
Ncontrol is the total N absorbed in the unfertilized (control) plot (kg/ha); and
Napplied is the amount of applied N (kg/ha).

Statistical analysis

The statistical model used was:

$$Y_{jk}=\mu+D_j+F_k+(DF)_{jk}+e_{jk},$$

where:
Y_{jk} are the values observed in the variables;
μ is the mean of the characteristic;
D_j is the effect of the ith N amount;
F_k is the effect of the jth N source;
$(DF)_{jk}$ is the interaction effect of the ith amount with the jth N source; and
e_{jk} is the associated experimental error.

The evaluated characteristics were submitted to analysis of variance and the means were compared by the Tukey test at 5% probability. If there was interaction, the data were adjusted using a regression equation. The analyses were carried out using R statistical software (R Core Team 2023).

Results

There was no effect of the interaction between N amounts and source (P>0.05) for green biomass production (GMP), dry matter production (DMP) and leaf:stem ratio (LSR) (Table 2).

There was also no significant effect (P>0.05) of amount of N on these variables, with the exception of GMP, with a linear effect observed. The increase in N resulted in an increase of 84.6% in GMP, from 22,576 kg/ha at 0 to 41,683 kg/ha at 150 kg N/ha. Linear regression of GMP as a function of N treatments is represented by the equation y=23,656.33+126.89x. The N source influenced (P<0.05) the GMP and DMP and fertilization with conventional urea resulted in lower biomass production (dry and green) than fertilization with protected urea. Leaf:stem ratio was not affected by N source or amount.

Table 2. Mean values of green biomass production, dry matter production and leaf:stem ratio of Mulato II under levels and sources of nitrogen fertilizer.

Treatments	Green biomass production (kg/ha)	Dry matter production (kg/ha)	Leaf:stem ratio
Amount N (kg/ha)			
0	22,576b	6,739	3.93
50	31,153ab	8,990	3.31
100	37,280a	9,618	3.69
150	41,683a	9,676	3.29
N Sources			
Common Urea	29,607b	7,935b	3.57
Protected Urea	36,739a	9,570a	3.54
P value			
N amount	0.005	0.065	0.153
N Sources	0.048	0.05	0.893
Amount × Sources	0.50	0.64	0.70
C.V. (%)	24.60	22.57	15.21

Averages followed by different lowercase letters in the columns differ from each other at a 5% probability level according to the Tukey test.

The average nutritional composition of the forage was grouped into summer (period I) and autumn (period II). No interaction (P>0.05) was observed between N treatment and source for any of the nutritional response variables evaluated in Mulato II (DM, MM, CP, NDF, ADF and HEM) in any of the periods (Table 3). In both periods, there was an effect (P<0.05) of the N amount only for DM and CP concentration. A positive linear effect was observed (P<0.05) for CP concentration, represented by the equation y=5.07+0.041x and y=3.02+2.04x and determination coefficient (R^2) of 0.67 and 0.69 for period I and II, respectively. The N source had no significant effect (P>0.05) on any of the nutritional variables analyzed during the summer period and affected only NDF (P<0.05) in the autumn period.

Table 3. Average dry matter (DM), mineral matter (MM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and hemicellulose (HEM) of Mulato II grass under levels and sources of nitrogen (N) in summer (period I) and autumn (period II).

Period	Treatment	DM %	MM %	CP %	NDF %	ADF %	HEM %
Period I - Summer	Amount N (kg/ha)						
	0	28.70a	8.23	5.07b	55.34	27.37	27.97
	50	27.34ab	7.66	7.10b	52.26	27.67	24.59
	100	24.47ab	7.21	9.14ab	56.44	29.23	27.21
	150	20.81b	8.08	11.18a	58.98	27.04	22.93
	N Sources						
	Common Urea	25.29	7.9	10.75	54.16	28.30	25.85
	Protected Urea	24.71	7.7	8.57	52.85	27.35	25.50
	P value						
	N amount	0.05	0.26	0.05	0.10	0.11	0.14
	N Sources	0.53	0.60	0.15	0.49	0.15	0.82
	Amount × Sources	0.64	0.87	0.88	0.42	0.15	0.30
	C.V. (%)	8.85	11.85	6.51	8.67	5.60	15.41
Period II - Autumn	Amount N (kg/ha)						
	0	28.04a	8.26	5.13c	57.67	29.69	27.97
	50	27.71ab	8.08	6.95bc	57.96	31.03	26.93
	100	22.75b	7.84	9.22ab	59.07	29.40	28.56
	150	22.98b	7.48	11.16a	56.06	29.50	26.55
	N Sources						
	Common Urea	25.79	7.71	8.50	58.99a	30.62	28.08
	Protected Urea	24.95	8.13	7.73	56.39b	29.20	26.92
	P value						
	N amount	0.01	0.13	0.001	0.29	0.43	0.20
	N Sources	0.52	0.08	0.29	0.02	0.08	0.11
	Amount × Sources	0.57	0.06	0.43	0.48	0.84	0.88
	C.V. (%)	12.26	7.14	6.28	4.57	6.34	5.8

Means followed by the same lowercase letter in the same row and uppercase in the column do not differ (P>0.05) by Tukey's test at 5% probability.

Lignin levels did not differ with the treatments and there was no interaction between amounts and sources. A significant difference was observed for dead material (Table 4), where amounts of 0 and 50 kg N/ha showed lower losses.

For ANR, no interaction between N sources and amount was observed, and there was also no difference in ANR for N sources, however there was a difference (P<0.05) for the amount of 150 kg N/ha (Table 5). The ANR values showed a linear response to N amount.

ANCE showed no interaction between N source and amounts but differed (P<0.05) between N rates and sources evaluated (Table 5). The regression for ANCE used the equation y= 58.73-0.36x, demonstrating decreasing linear behavior. CP/ha did not show interaction between the sources and amounts of N and between evaluated sources but presented interaction for the amounts of N (P<0.05), showing the highest value observed for 150 kg N/ha.

Table 4. Mean values of dead material and lignin content determined for Mulato II for amounts and sources of nitrogen (N).

Treatments	Dead material (kg/ha)	Lignin (%)
Amount N (kg/ha)		
0	430b	7.398
50	520b	6.982
100	810a	7.320
150	970a	7.345
N Sources		
Common Urea	830	7.257
Protected Urea	430	7.625
P value		
N amount	0.027	0.925
N Sources	0.137	0.985
Amount × Sources	0.316	0.127

Means followed by the same lowercase letter in the same column do not differ from each other (P>0.05) by the Tukey test at 5% probability.

Table 5. Average values of apparent nitrogen recovery (ANR), apparent nitrogen conversion efficiency (ANCE) and crude protein/hectare (CP/ha) from Mulato II under amounts and sources of nitrogen (N).

Treatments	ANR (%)	ANCE (kg DM)	CP/ha (kg/ha)
Amount N (kg/ha)			
0	-0.15b	-	165.27b
50	5.44b	42.64a	247.68b
100	12.09b	19.14b	318.52b
150	29.56a	6.43b	762.34a
N Sources			
Common Urea	14.32	16.28b	401.58
Protected Urea	9.15	29.71a	345.32
P value			
N amount	0.001	0.001	0.001
N Sources	0.154	0.026	0.479
Amount × Sources	0.591	0.268	0.624
C.V. (%)	72.15	44.89	45.80

Means followed by the same lowercase letter in the same column do not differ from each other (P>0.05) by the Tukey test at 5% probability.

Discussion

Green mass production, dry matter and leaf:stem ratio

Previous research has shown that the response of tropical grass pastures to N fertilization increases up to amounts of 180 kg N/ha/growth cycle and, on average, the N conversion efficiency (dry matter of forage/kg of N) decreases from 120 kg/ha/growth cycle (Martha Júnior et al. 2007). In the present experiment, the amounts used in each cycle were lower with a maximum of 75 kg N ha/cycle, supplying a total of 150 kg N/ha divided into 2 applications, and a positive response was seen in GMP and not DMP. The increase in GMP observed in the present experiment is likely associated with the positive effects of N on tillering, plant growth rate, senescence and pasture structure (Faria et al. 2018; Lee et al. 2017), which stimulate carbon accumulation, the main constituent of plant tissue synthesized during photosynthesis and predominantly stored in leaves (Gastal et al. 1992). Additionally, N is a structural component of amino acids, proteins, nucleic acids, hormones, and chlorophyll (Paśmionka et al. 2021; Rütting et al. 2018). N deficiency can lead to reduced tillering and increased dormancy of buds (Souza et al. 2021a). In previous studies with *Urochloa* hybrids, GMP reached up to 30 t/ha when 200 kg/ha of N was applied to *Urochloa brizantha* (Teixeira et al. 2018). The GMP values in this experiment are consistent with those reported in the literature.

The average DMP recorded in this study was 8,756 kg/ha, compared with pastures of Mulato II managed under continuous stocking at 0.40 m height, reporting 13,400 kg DM/ha/year with 250 kg N/ha and 7,940 kg/ha using 50 kg N/ha (Silva et al. 2016). Other studies report DMP values of 10,630 and 10,090 kg/ha for 0.40 and 0.50 m cutting heights over 90–120 days (Marques et al. 2017). Despite being lower, the results in this study exceeded those obtained by Alves (2016), who recorded 3,543 kg/ha with 80 kg N/ha under similar conditions. The absence of significant effects of N on DMP may be associated with a lower dry matter concentration noted by Cantarella et al. (2007), who observed decreased DM content with increasing N levels. This may be due to the stimulation of leaf growth, which has higher water content and is more digestible (Faria et al. 2019).

The reduced GMP and DMP observed with conventional urea can be attributed to its faster release and higher potential for N losses. In contrast, protected urea resulted in a 24% increase in GMP, likely due to its controlled release mechanism, which minimizes leaching, volatilization, and denitrification (Dias 2016). Typically, pasture response to N fertilization follows a linear trend; as N increases, production increases (Martha Junior et al. 2007; Teixeira et al. 2018). However, environmental stressors such as high temperatures and water deficit, as observed during parts of this experiment (October 2016 and January 2017), may increase N loss. Souza et al. (2021b) found that water stress negatively impacted the growth of several *Urochloa* genotypes, especially with application of N above 50–60 kg N/ha/cycle. Such responses may also be influenced by the type and frequency of N application (Carvalho et al. 2018; Faria et al. 2018).

Although no significant differences were detected in leaf:stem ratio, the values recorded are considered satisfactory because maintaining a high leaf:stem ratio is desirable with leaves providing more digestible nutrients (Oliveira et al. 2016). Accordingly, maximizing the leaf fraction in forage can improve digestibility and overall nutritional quality (Faria et al. 2019).

Feed value

The highest average dry matter (DM) contents were observed in the control treatment, which may be explained by the longer regrowth interval (80 days), resulting in plants at a more advanced stage of maturity at harvest. As N application increased, the regrowth interval was reduced to 55 days, which led to plants with higher water content and lower DM content. Additionally, GMP increased with higher N treatments. A similar trend was observed by Teixeira et al. (2018) for *Urochloa brizantha* 'Marandu' as moisture content decreased with maturation (Duarte 2012).

The lack of significant differences in mineral matter (MM) content among treatments may be associated with the chemical characteristics of the soil, which likely provided sufficient mineral availability. The MM values obtained (7.14 to 8.26%) are within the range reported in the literature (3.8 to 11.86% in dry matter) for fertilized tropical grasses (Fernandes and Coalho 2018; Silva et al. 2018).

N fertilization resulted in a linear increase in crude protein (CP) in Mulato II. The highest CP (11.18 and 11.16%) was observed using 150 kg N/ha in periods I and II, respectively. This increase reflects greater N availability and uptake by the plant. Marques et al. (2017) also reported a positive relationship between N and CP content in Mulato II corroborating the present findings.

NDF levels affect intake and rates of passage in the digestive tract of ruminants, while ADF is associated with digestibility (Van Soest 1994). NDF levels in tropical grasses may be above 70% (Marques et al. 2017) but in this study, NDF for the amounts and sources of N tested were below the 60% limiting consumption (Van Soest 1994), indicating that Mulato II provides adequate amounts of NDF for ruminal function and fiber supply for cattle without compromising consumption. In period II (autumn), lower NDF was observed when fertilized with protected urea compared to conventional urea. This response is related to the plant structure, mainly the leaf:stem ratio because the accelerated growth of the plant due to the application of N promoted a greater proportion of plant stem, increasing the levels of NDF. The amount of indigestible fiber should be 30% or less to favor increased consumption of DM by the animal (Mertens 1997). Thus, the values obtained in Mulato II are satisfactory for use in ruminant feeding, regardless of the amount or source of N used for fertilization during forage production.

Although differences in climatic conditions, soil and fertilization can lead to differences in hemicellulose contents, NDF and ADF, there were no differences with amount and source of N in Mulato II in this experiment. The observed values are within the range reported in the literature for tropical grasses (Guerra et al. 2019). Lignin levels were expected to decrease with increasing N (Maranhão et al. 2009). However, this decrease was not observed in the present study, which can be attributed to the lack of difference in other fibrous components, which were below those reported by Maranhão et al. (2009) when evaluating the cultivars *Urochloa brizantha* and *U. decumbens* under N fertilization. The results obtained also agree with those of Cantarino (2017), who reported no effect of N amount on lignin levels for *Urochloa ruziziensis.*

Lower senescence-related losses and accumulation of dead material were recorded at 0 and 50 kg N/ha, probably due to slower plant growth under reduced N availability. In contrast, higher levels of N resulted in greater growth rates and increased senescence, leading to a higher proportion of dead material in those treatments.

Apparent nitrogen recovery, nitrogen conversion efficiency and crude protein production per hectare

N recovery when applied via topdressing showed no difference between the sources of urea with 150 kg N/ha showing the highest N recovery, close to 30%. This does not mean that the applied N was totally lost, because it can be leached or suffer a denitrification process, or immobilization and volatilization due to its high solubility (Austin et al. 2013). Only a part of the applied mineral N can be absorbed by the plants with between 40% and 60% routinely absorbed (Marques et al. 2017).

For tropical pastures, the average efficiency of N use in forage conversion is 30 kg DM/kg N, with a range of 5 to 80 kg DM/kg N (Martha Júnior et al. 2007). The values observed in the present study were within the range reported in the literature where the highest rates of conversion efficiency in tropical grasses was observed at 150 kg N/ha, but was not found in this research.

A decrease in ANCE was observed as N increased, with mean values of 42.64, 19.14 and 6.43 kg DM/ kg N, for 50, 100 and 150 kg N/ha respectively. This result can be attributed to the soil chemical composition of the experimental area, which had a residue of soil fertility from a history of approximately 13 years of cultivation of corn and sorghum crops intended for silage production. Primavesi et al. (2004) evaluated ANCE in coastcross pastures, using urea and ammonium nitrate at 0, 25, 50, 100 and 200 kg N/ha application after cuts performed every 24 days at 10 cm above ground in the rainy season. They reported mean values of conversion efficiency of 25.3, 27.5, 20.9 and 13.2 kg DM/kg N with application of 25, 50, 100 and 200 kg N/ha, respectively. The higher ANCE observed in treatments with protected urea can be attributed to the slower release of the nutrient compared to conventional urea, which can lead to increased losses or inefficiency in the recovery of applied N. The slow release of protected urea can lead to higher conversion efficiency by forage plants, due to lower losses by leaching, volatilization and denitrification (Chagas et al. 2017; Dias 2016).

N fertilization positively improved CP/ha with application of 150 kg N/ha producing 762 kg CP/ha, compared to the control which produced 165 kg CP/ha, showing the great advantage of using N fertilization for pastures. An increasing response in CP/ha was seen with increased N. This can be explained by the greater number of evaluation cuts in the plots where the highest amounts of 150 kg N/ha were applied, with the leaf:stem ratio of 3.29, because of the higher nutrient concentration in the leaves. This is desirable in pasture management because, in addition to increasing forage dry matter, a higher leaf:stem ratio is beneficial since leaves are the main source of nutrients for ruminants. The aim is that the highest proportion of roughage in the animal diet is provided by leaves instead of stems and dead material (Oliveira et al. 2016).

Conclusions

The increase in N provided greater GMP accumulation with protected urea providing greater biomass production. The feed value of Mulato II was not affected by amount and source of N in the 2 evaluation periods (summer and autumn), except for DMP, which was higher with low amounts of N, and CP, which increased with increasing amount of N. The use of protected urea resulted in lower levels of NDF in period II (autumn). Although ANCE was reduced with increasing N, ANR/ha and CP/ha showed linear increases as a function of N fertilization. Fertilization with protected urea resulted in greater ANCE, reflecting the slower release of N from this source.

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Research Paper

Herbicide sensitivity of desmanthus (*Desmanthus virgatus*) at different stages of development

*Sensibilidad a herbicidas del frijolillo (*Desmanthus virgatus*) en diferentes etapas de desarrollo*

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Abstract

Desmanthus (*Desmanthus* spp.) is a native, naturalised or sown legume in many tropical and subtropical areas, including Australia where its potential use as a companion legume is extending to more southern latitudes. Desmanthus pastures are commonly sown into former cropping paddocks which have a significant weed burden. In these situations, weeds can be an issue during the establishment phase as well as in established desmanthus pastures. Three field experiments were conducted in northern New South Wales to assess the sensitivity of *D. virgatus* 'Marc' to herbicides at different stages of pasture development. At sowing, imazethapyr [0.41 kg active ingredient (a.i./ha)] and trifluralin (0.85 kg a.i./ha) were suitable for pre-emergent use. In a 9-week-old seedling pasture, bromoxynil (0.14–0.56 kg a.i./ha) and flumetsulam (0.02–0.08 kg a.i./ha) caused little plant damage and are suitable for use, while 2,4-D amine (0.54–2.16 kg a.i./ha) and MCPA (0.49–1.95 kg a.i./ha) caused extensive damage, reducing herbage production and delaying flowering. In a 10-month-old established pasture, bromoxynil (0.14–0.56 kg a.i./ha), imazethapyr (0.04–0.14 kg a.i./ha) and terbuthylazine (0.44–1.75 kg a.i./ha) caused minor short-term plant damage. Isoxaflutole (0.04–0.15 kg a.i./ha) resulted in temporary plant foliage bleaching and reduced production, without on-going effects following cutting. Established plants of desmanthus were defoliated by paraquat (0.2–0.8 kg a.i./ha) but regrew without phytotoxic effects. All these herbicides could be used on desmanthus plants. In established desmanthus pastures 2,4-DB (0.35–1.4 kg a.i./ha) caused significant damage but not plant death. There were no ongoing effects of the herbicide on plant productivity following cutting.

Keywords: Fluroxypyr, phytotoxicity, pyroxasulfone, S-metolachlor, yield.

Resumen

El Frijolillo (*Desmanthus* spp.) es una leguminosa nativa, naturalizada o sembrada en muchas áreas tropicales y subtropicales, incluida Australia, donde su uso potencial como leguminosa acompañante se está extendiendo a latitudes más meridionales. El frijolillo se siembra comúnmente en antiguos terrenos de cultivo que tienen una carga significativa de malezas. En estas situaciones, las malezas pueden ser un problema durante la fase de establecimiento, así como en en praderas de frijolillo establecidas. Se llevaron a cabo tres experimentos de campo en el norte de Nueva Gales del Sur para evaluar la sensibilidad de *D. virgatus* 'Marc' a los herbicidas en diferentes etapas de desarrollo de la pastura. En la siembra, el imazetapir [0.41 kg de ingrediente activo (i.a./ha)] y la trifluralina (0.85 kg i.a./ha) fueron adecuados para uso como preemergente. A las 9 semanas, el bromoxinil (0.14–0.56 kg i.a./ha) y el flumetsulam (0.02–0.08 kg i.a./ha) causaron poco daño a las plantas y son adecuados para su uso, mientras que la 2,4-D amina (0.54–2.16 kg i.a./ha) y el MCPA (0.49–1.95 kg i.a./ha) causaron daños fuertes, reduciendo la producción de

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forraje y retrasando la floración. En una pastura de 10 meses de edad, el bromoxinil (0.14–0.56 kg i.a./ha), el imazetapir (0.04–0.14 kg i.a./ha) y la terbutilazina (0.44–1.75 kg i.a./ha) causaron daños menores a corto plazo. El isoxaflutol (0.04–0.15 kg i.a./ha) provocó un blanqueamiento temporal del follaje y una reducción de la producción, sin efectos persistentes tras el corte. Las plantas establecidas de frijolillo fueron defoliadas por paraquat (0.2–0.8 kg i.a./ha), pero rebrotaron sin efectos fitotóxicos. Todos estos herbicidas pueden utilizarse en plantas de frijolillo. En pasturas establecidas de frijolillo, el 2,4-DB (0.35–1.4 kg i.a./ha) causó daños significativos, pero no la muerte de las plantas. No se observaron efectos persistentes del herbicida en la productividad de las plantas en cortes posteriores.

Palabras clave: Fluroxypyr, fitotoxicidad, pyroxasulfone, S-metolachlor, rendimiento.

Introduction

Desmanthus (*Desmanthus* spp.) is a tropical forage legume with multiple species native to the Americas and/or Caribbean which has naturalised in many tropical and subtropical environments (Burt 1993; Lazier and Ahmad 2016; Cook et al. 2020). In Australia, *D. leptophyllus* Kunth is naturalised in the northern parts of the country (Cook et al. 2020), with cultivars of several species available and suitable as a companion legume in grass pastures and rangelands (Gardiner 2016). Desmanthus is predominantly found on soils with neutral to alkaline pH with textures ranging from loams and heavy clays to gravel and sands (Cook et al. 2020). In Australia, desmanthus is sown at latitudes north of approximately -28.5° (Cook et al. 2020). Additionally, over the last decade, this legume demonstrated potential in mixtures with sown tropical perennial grasses in field experiments in northern inland New South Wales (NSW), at latitudes of -30.7°, south of those previously tested in Australia (Boschma et al. 2021a, 2021b).

Desmanthus has been commercially available in Australia for several decades, initially with the release of 'Jaribu' in the 1990s. It was a blend of 3 cultivars consisting of *D. virgatus* (L.) Willd. 'Marc', *D. leptophyllus* Kunth 'Bayamo' and *D. pubescens* B.L. Turner 'Uman'. 'Marc' was the only persistent cultivar in the mix (Pengelly and Conway 2000) and is still available today, along with several other cultivars. Information on establishment and management is required for successful adoption of new species into grazing systems. This information includes preferred soil types, suitable companion species and herbicide options to control weeds.

When sowing new pastures, it is recommended to conduct weed control for several years prior to sowing (Harris et al. 2014). However, the commercial reality is that this preparation time is often circumvented, and herbicide options are sought to control weeds during the establishment phase. Weeds can provide significant competition with desmanthus, especially in establishing stands, reducing vigour and productivity (Cox 1998; Cox and Harrington 2005). Weeds can also reduce productivity of established pastures. The range of weeds varies greatly with location and soil type, including annual summer-growing grasses and broadleaf species.

Several studies have been conducted in Australia to test the tolerance of desmanthus to a range of herbicides (Cox 1998; Cox and Harrington 2005), however none of the herbicides tested are registered for use with desmanthus. Our paper reports 3 field experiments conducted with the objective to quantify the sensitivity of *D. virgatus* to a range of herbicides not previously tested for use with desmanthus, applied at 3 developmental stages: pre-emergent, seedling (9-week-old) and established pasture (10-month-old). Sensitivity was assessed using measures of plant density, herbage production and phytotoxicity to increase knowledge of the sensitivity of desmanthus to a broader range of herbicides and provide data to increase confidence for their use. In Australia, the findings and previously published reports will be used as evidence for an Australian Pesticides and Veterinary Medicines Authority (APVMA) permit application for commercial use of suitable herbicides in desmanthus pastures/seed crops.

Materials and Methods

Three experiments were conducted at the Tamworth Agricultural Institute (-30.1445° 150.9677°, 400 masl, 649 mm annual average rainfall) on a brown Chromosol soil (pH $CaCl_2$ (0–10 cm) 6.7; Isbell 2021). *Desmanthus virgatus* 'Marc' was used in the experiments conducted at 3 different stages of pasture development: Pre-pasture emergence, seedling pasture (<3 months old) and established pasture (>9 months old).

In each experiment, mechanically scarified seeds of desmanthus were sown at 4 kg/ha (germinable) at 1 cm depth with a narrow tyned cone seeder in 6 rows, each row 0.25 m apart. The plots were 2 m wide and at least 3 m long and each experiment was arranged in a randomised complete block design with 4 replicates. Four rates of each herbicide, nil (0), half (0.5x), standard (1x) and twice (2x) the standard rate for legume pastures, were applied using a battery operated backpack sprayer (Selecta 15 L model KN14-2, silvan.com.au) with a 1 m hand-held boom. The half and standard rates, and sometimes the double rate were within the registered label application rate for other pasture legumes or related species. The nil treatments were sprayed with water. Most herbicides tested were registered for use on other pasture legumes (trifluralin, imazethapyr, bromoxynil, 2,4-DB) or local evidence suggested they may be suitable (2,4-D amine, MCPA, paraquat), however, several were purely for experimental testing (fluroxypyr, S-metolachlor, pyroxasulfone). Rainfall (mm) figures from the Bureau of Meteorology (Station 55325, 1993–2023) were collected (Figure 1).

Experiment 1 – Pre-pasture emergence

Desmanthus was sown on 23 February 2016. Four herbicides were tested at 4 application rates (Table 1). Trifluralin was applied 5 days prior to sowing and incorporated to approximately 5 cm; the other 3 herbicides were applied 4 days after desmanthus was sown. The experiment was irrigated with 74 mm over a 7-day period after the herbicide treatments had been applied to assist legume establishment. Seedling density (plants/m^2) was assessed 3 weeks after sowing by counting the number of plants in 9 lengths of 0.3 m row (total 2.7 m of row) and converting to plants/m^2.

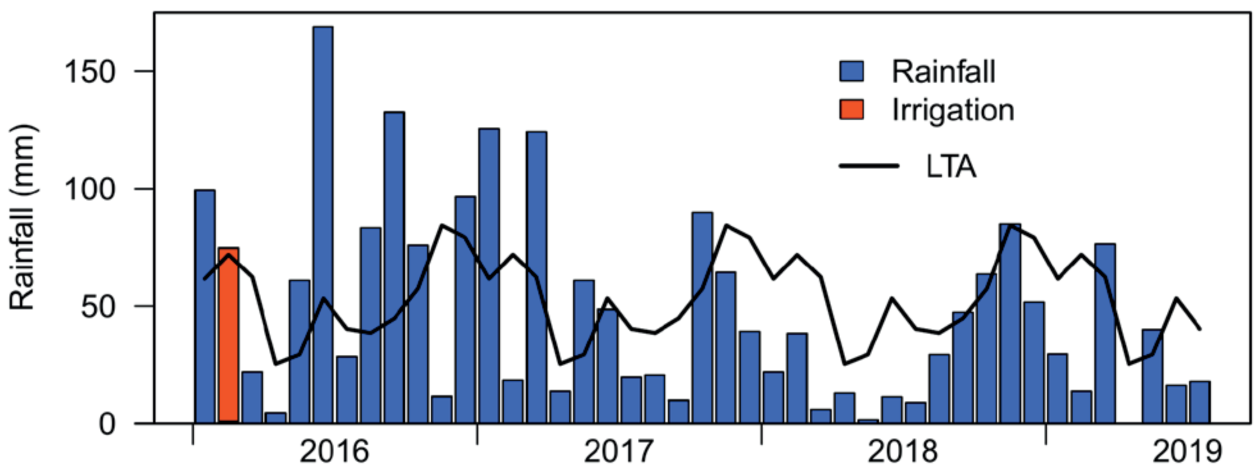

Figure 1. Actual and long-term average rainfall (mm) recorded from Bureau of Meteorology (Station 55325, 1993–2023). Irrigation applied is shown in red. LTA=Long-term average rainfall. The experiments were conducted February–November 2016 (experiment 1), November 2017–March 2018 (experiment 3) and February–June 2019 (experiment 2).

Table 1. Herbicides, rates, details of application and chemical group in the pre-pasture emergent experiment (experiment 1).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)			Water volume applied (L/ha)	Application details	Chemical group[1]
	0.5x	1x	2x			
Trifluralin	0.41	0.82	1.63	135	Applied pre-sowing and incorporated (18.2.16)	3
Imazethapyr	0.04	0.07	0.14	148	Applied post-sowing (29.2.16)	2
S-metolachlor	0.72	1.44	2.88	148	Applied post-sowing (29.2.16)	15
Pyroxasulfone	0.05	0.10	0.20	148	Applied post-sowing (29.2.16)[2]	15

[1]Chemical group is based on the herbicide mode of action (www.croplife.org.au)
[2]Recommended practice is application pre-sowing with incorporation by sowing using knife points with press wheels or narrow points and harrows (Anon. undated)

Seedling herbage production (kg DM/ha) was assessed on 29 March 2016, 5 weeks after sowing to estimate seedling vigour. On 10 May 2016, prior to the first frost when the pasture was 11 weeks old, desmanthus herbage production was assessed a second time. The experiment was mown to 10 cm during winter when the plants were defoliated by frost. Spring regrowth was assessed on 17 November 2016.

All herbage production assessments were conducted using a calibrated visual estimate similar to that reported in Boschma et al. (2011). Each plot was divided into 3 equal strata, and total herbage production scored on a continuous scale 0–5 (where 0=nil, 5=highest) and proportion (%) of desmanthus assessed in each strata by a single operator. Fifteen quadrats (0.4 × 0.4 m) were selected representing the range in total production and proportion of desmanthus present in the experiment. The calibration quadrats were cut to 1 cm above the soil surface and herbage sorted into desmanthus and other plants. The material was dried in a dehydrator at 80 °C for 48 hr. Total production scores were converted to dry matter (kg DM/ha) and actual percentage using linear and quadratic regressions ($R^2 \geq 0.83$) to determine the herbage production of desmanthus.

Experiment 2 – Seedling pasture

Desmanthus was sown in December 2018. Five herbicides at 4 rates (162 L water/ha) were applied to the 9-week-old pasture on 7 February 2019 (Table 2). Phytotoxicity was assessed weekly for 4 weeks following treatment application using a plant damage score of 0–10 (Table 3). Herbage production was assessed on 1 April 2019, 8 weeks after application (WAA) and prior to first frost using the method described for experiment 1. Phenological development of desmanthus plants was assessed every 6–11 days (total 8 times) over the period 7 March–29 April 2019 using the scoring system where 0=vegetative, 1=reproductive (buds present), 2=flowering, and 3=seed set (pods present). In June 2019 once frosts had commenced and plant growth ceased, the percentages of pods that had matured (either contained brown seed or pod had dehisced) were recorded.

Table 2. Herbicides, the chemical group and application rates greater than zero applied to seedling desmanthus (experiment 2).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)			Chemical group[1]
	0.5x	1x	2x	
2,4-D amine	0.54	1.08	2.16	4
MCPA	0.49	0.98	1.95	4
Flumetsulam[2]	0.02	0.04	0.08	2
Fluroxypyr	0.01	0.02	0.40	4
Bromoxynil	0.14	0.28	0.56	6

[1]Chemical group is based on the herbicide mode of action (www.croplife.org.au)

[2]Applied with paraffinic oil (0.29 L a.i./100 L water) and alkoxylated alcohol non-ionic surfactant (0.12 L a.i./100 L water)

Table 3. Phytotoxicity scores to rate sown plant (crop) damage up to 4 weeks after herbicide application (modified from Vanhala et al. 2004). Damage symptoms included plant injury, necrosis and reduced growth.

Score	Criteria
0	No crop reduction or injury
1	Slight discolouration or stunting
2	Some discolouration or stunting
3	Slight crop damage
4	More pronounced crop damage
5	Moderate crop damage
6	Moderately high crop damage
7	More pronounced crop damage
8	Heavy crop damage
9	Heavy crop damage with potential plant losses
10	Potential total crop death

Experiment 3 – Established pasture

Six herbicides were applied to 10-month-old desmanthus 'Marc' on 16 November 2017 (Table 4). Plant damage was assessed 1, 2 and 4 weeks after treatment application using the phytotoxicity score described in Table 3. The extent of brown out (percentage of plant leaf that was desiccated) was assessed on the plots applied with paraquat. Herbage production was assessed on 3 occasions: 15 December 2017, 1 February and 8 March 2018 (4, 11 and 16 WAA, respectively). The plots were mown after each assessment to 10 cm with a flail mower and the herbage removed from the experimental area. Production was assessed using the visual assessment method described in experiment 1.

Data analyses

Seedling counts, phytotoxicity scores, pod maturity and herbage production data were analysed by analysis of variance (AOV) with herbicide, rate of herbicide (0, 0.5x, 1x, and 2x recommended rate) and their interaction were explanatory factors and replicate a blocking factor. All analyses were conducted using R (R Core Team 2023). Herbage production data assessed in experiment 1 on 10 May and 17 November 2016 were square root transformed to meet the assumption of homogeneity of variance. For all variables, differences between means were determined using the least significant difference (LSD) at P=0.05.

Plants in all plots had pods present by the final phenological development assessment which was quantitatively summarised by calculating the area under a curve (AUC) (Simko and Piepho 2012) where plants with earlier flowering and pod development had a higher AUC. The AUCs were calculated, analysed and LSD determined as above.

Table 4. Herbicides, the chemical group and application rates greater than zero, applied to established desmanthus (experiment 3).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)			Chemical group[1]
	0.5x	1x	2x	
Paraquat	0.20	0.40	0.80	22
Isoxaflutole	0.04	0.08	0.15	27
2,4-DB	0.35	0.70	1.40	4
Terbuthylazine	0.44	0.88	1.75	6
Imazethapyr	0.04	0.07	0.14	2
Bromoxynil	0.14	0.28	0.56	6

[1]Chemical group is based on the herbicide mode of action (www.croplife.org.au)

Results

Experiment 1 – Pre-pasture emergence

There was no effect of imazethapyr applied pre-emergent on desmanthus seedling plant densities assessed 3 weeks after sowing (Figure 2). Trifluralin had no effect on seedling density at the half rate, however density declined at the standard and double rates, with plant densities at the double rate 45% of the control (P<0.05). Plant density was significantly reduced at all rates of both S-metolachlor and pyroxasulfone compared to the control. At the double rate of pyroxasulfone, plant density was 5% of the control (P<0.05).

Seedling herbage production assessed 6 weeks after sowing reflected significant damage (P<0.05) by all herbicides (Table 5a). Imazethapyr and trifluralin resulted in the least effect on seedling growth while pyroxasulfone had the greatest effect. S-metolachlor damage was intermediate. There was no interaction with herbicide rate, with seedling herbage production declining with increasing herbicide rate for all herbicides (P<0.05).

The effect of the herbicides was still evident on plant production assessed at the end of the growing season with significant main effects and herbicide-rate interaction (Table 5b). Herbicides ranked from least to greatest effect on desmanthus plants were trifluralin<imazethapyr <S-metolachlor and pyroxasulfone (P<0.05). Damage increased with increasing rate of active ingredient (main effect, P<0.05), but there was no effect of 0.5 rates of trifluralin and imazethapyr (P<0.05).

The effects of the pre-emergent herbicides were still evident the following growing season (November 2016, 8 months after application), especially those sprayed with S-metolachlor and pyroxasulfone (Table 5c). At standard rates of these 2 herbicides, desmanthus production was about 25% of the control, although at half application rates production was approximately 80% and similar to the majority of the controls. In contrast, the productivity of desmanthus sprayed with imazethapyr and trifluralin at standard rates was 70–75% of the control (P<0.05).

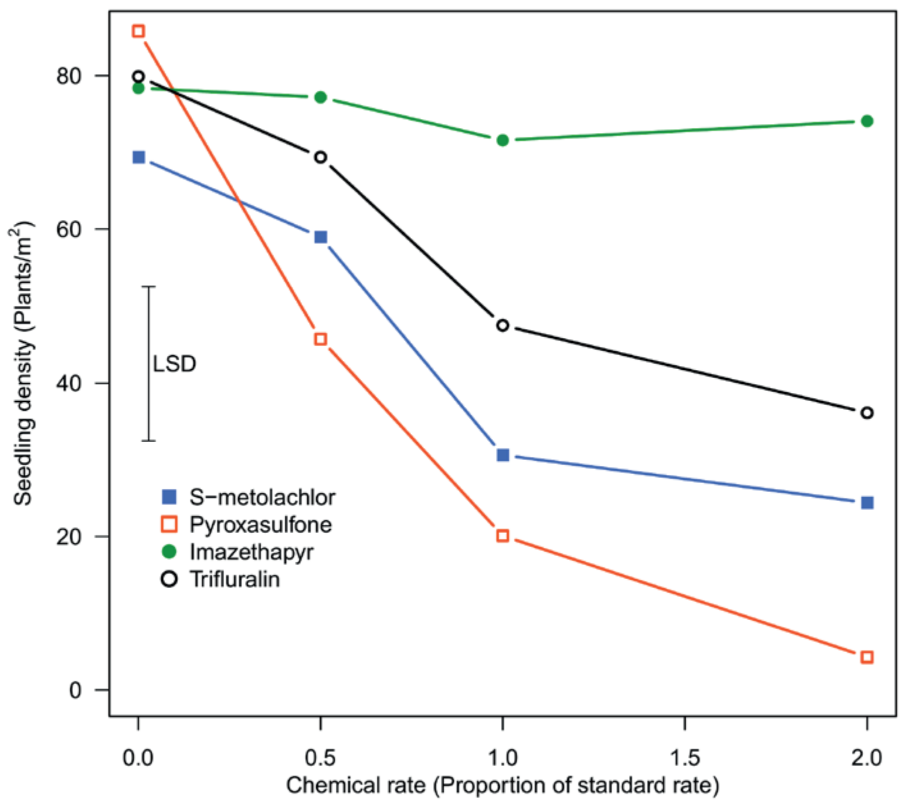

Figure 2. Seedling density (plants/m^2) of desmanthus 3 weeks after sowing and treatment with pre-emergent herbicide. LSD (P=0.05) is shown.

Table 5. Herbage production (kg DM/ha) of desmanthus on (a) 29 March 2016, (b) 10 May 2016 and (c) 17 November 2016 sprayed pre-emergent with herbicides at 4 rates (0, 0.5x, 1x and 2x).

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)				Average
	0	0.5x	1x	2x	
(a) 29 March 2016					
S-metolachlor	53.6	30.4	18.0	14.3	29.1B
Pyroxasulfone	56.5	25.5	17.5	4.4	26.0C
Imazethapyr	50.7	46.2	33.8	18.3	37.3A
Trifluralin	59.4	45.0	38.1	25.5	42.0A
Average	55.1A	36.8B	26.9C	15.6D	
(b) 10 May 2016[1]					
S-metolachlor	1,957a	916cd	280e	47fg	602C
Pyroxasulfone	2,049a	1,227bc	231e	2g	589C
Imazethapyr	1,616ab	1,499ab	978cd	197ef	965B
Trifluralin	1,848a	1,684ab	978cd	613d	1,211A
Average	1,864A	1,315B	548C	139D	
(c) 17 November 2016[1]					
S-metolachlor	2,144abc	1,788bcd	571f	32g	872B
Pyroxasulfone	2,374a	1,750cd	549f	10g	858B
Imazethapyr	2,146abc	2,067abcd	1,615d	678f	1,560A
Trifluralin	2,209ab	2,137abc	1,609d	1,123e	1,740A
Average	2,217A	1,932A	1,018B	292B	

[1]Herbage production values were back transformed. Values with the same lowercase letter within an assessment date are not significantly different (herbicide × rate interaction, P=0.05). Within each assessment, average herbicide and rate values with the same uppercase letter are not significantly different (main effect, P=0.05).

Experiment 2 – Seedling pasture

Significant damage (P<0.05) to desmanthus seedlings resulted following application of MCPA, 2,4-D amine and fluroxypyr (Figure 3). The damage caused by fluroxypyr was severe (phytotoxicity score >8) and most seedlings died. Seedlings sprayed with 2,4-D amine and MCPA showed moderately high to heavy damage at all rates 1 WAA (phytotoxicity score>5) with phytotoxicity scores still >6 at the standard and double rates 4 WAA (P<0.05). Seedlings sprayed with the half rate of both herbicides recovered over the 4 weeks following application, but damage (phytotoxicity score ~3) was significantly greater than the control 4 WAA (P<0.05).

Bromoxynil and flumetsulam caused only slight distortion to the plant growing points (phytotoxicity scores ≤3) of desmanthus seedlings. Damage caused by the double rate of bromoxynil was initially greater than the control (P<0.05) but receded to be minor (phytotoxicity scores=2) 4 WAA and not significantly different to the control. At the initial assessment (1 WAA), flumetsulam at all rates caused some damage to the seedling desmanthus (average phytotoxicity scores=2.7, P<0.05), however the plants recovered with damage assessed to be minor compared to the control by 4 WAA at all applied rates, except the standard rate.

Herbage production in April (8 WAA) showed the contrasting effect of the herbicides on desmanthus seedling growth. MCPA and 2,4-D amine had the greatest effect (P<0.05), especially at the standard and double rates (productivity 25–50% of the control). In contrast, flumetsulam had no effect and bromoxynil a moderate effect (66% of the control) on herbage production (Figure 4).

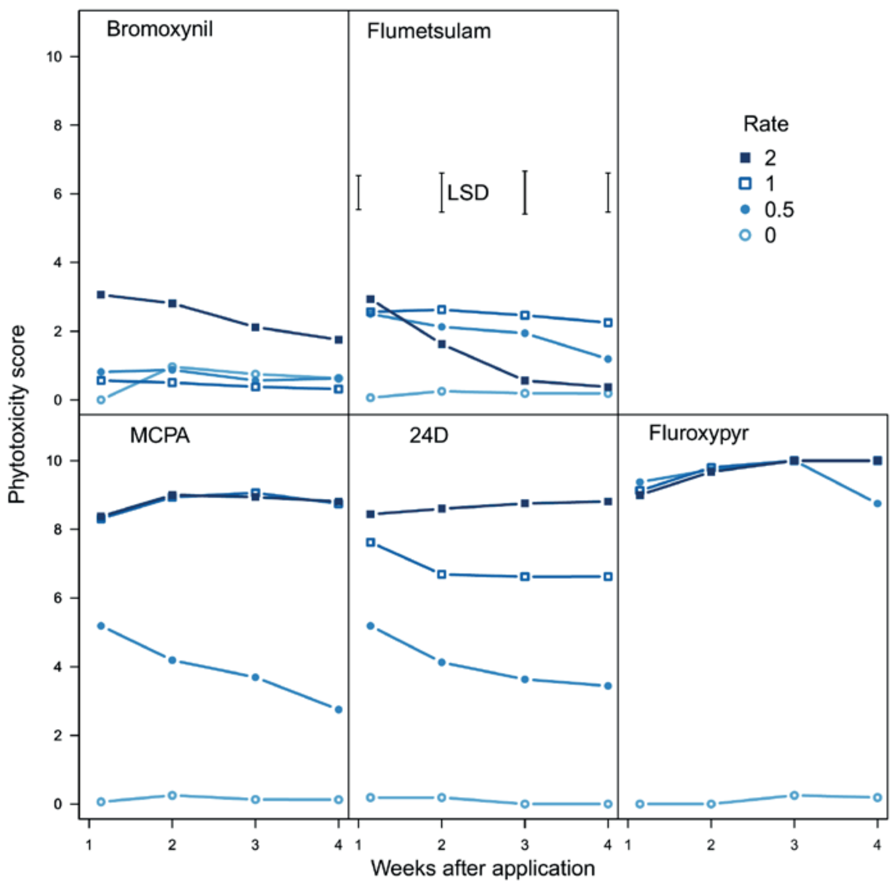

Figure 3. Phytotoxicity score to assess desmanthus plant damage over 4-week period following treatment with (a) bromoxynil, (b) flumetsulam, (c) MCPA, (d) 2,4-D amine, (e) fluroxypyr, at 4 rates (details in Table 2). Score 0=nil damage and score 10=plant death. LSD for comparison within an assessment date of each herbicide are shown (P=0.05).

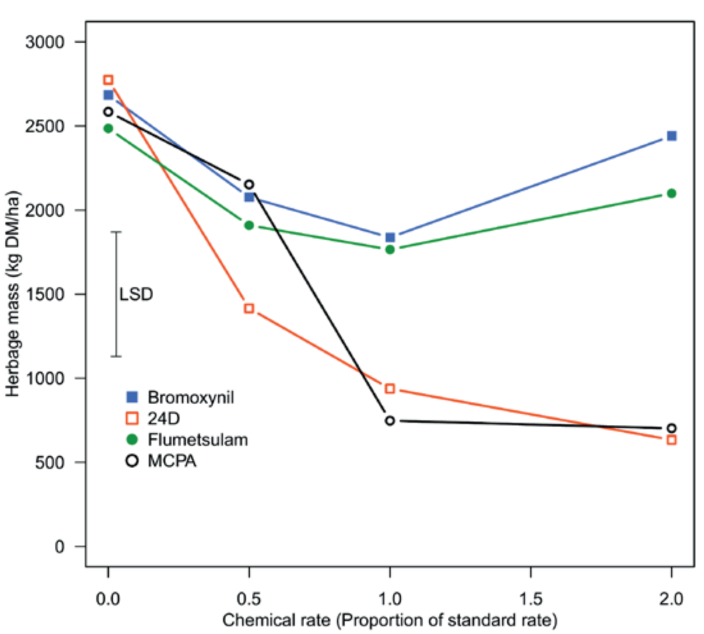

Figure 4. Herbage production (kg DM/ha) of establishing desmanthus, 8 weeks after application of 4 herbicides. Fluroxypyr was not included in the analysis because all plants had died. LSD is shown (P=0.05).

Both MCPA and 2,4-D amine delayed flowering (smaller area under a curve) of the establishing desmanthus plants (Table 6). This was particularly evident at the standard and double rates (P<0.05). Bromoxynil had nil to slight effect on flowering at all rates tested while flumetsulam was intermediate (P<0.05).

The proportion of seed pods that had matured at the end of the growing season was highly variable. Plants sprayed with flumetsulam had the highest proportion of mature pods (66%), similar to bromoxynil and MCPA (51–56%), while plants sprayed with 2,4-D amine had the lowest proportion (35%) (P<0.05). There was no effect of any herbicide rate, except for the double rate of 2,4-D amine where plants had a lower proportion of mature pods than the control and half rate (P<0.05).

Experiment 3 – Established pasture

The greatest plant damage to mature desmanthus plants during the 4 weeks following herbicide application was inflicted by 2,4-DB, isoxaflutole and paraquat (Figure 5).

2,4-DB resulted in significant damage (P<0.05) to mature plants of desmanthus with plant stems twisting and growing points distorted. Damage was significant at all rates applied compared to the control 1 WAA (phytotoxicity scores average 7 compared to 0.5 for control), and damage generally increased over the 4 weeks phototoxicity was assessed (P<0.05). At the final phytotoxicity assessment (4 WAA), plants sprayed with all rates of 2,4-DB still showed significant damage (P<0.05) with a phytotoxicity score >7 (Figure 5).

Plant damage resulting from all rates of isoxaflutole 1 WAA was moderate (phytotoxicity score 5–6) compared to the control (P<0.05). Over the following weeks as plants continued to grow, the extent of foliage bleaching due to the herbicide declined, except for the double rate which resulted in maximum damage 2 WAA (phytotoxicity score 6.6) (Figure 4). By 4 WAA, plants sprayed with the half rate of isoxaflutole had fully recovered and those sprayed with the standard rate showed only slight damage.

No physical damage to desmanthus plants was incurred due to imazethapyr, bromoxynil or terbuthylazine at the half and standard rates (phytotoxicity scores <1). There was slight growth retardation at the double rate 1–2 WAA (P<0.05) and the plants had recovered within 4 WAA (Figure 5).

Paraquat had the fastest and most significant effect of the herbicides tested on desmanthus plants with phytotoxicity scores of 8–9.5 at all rates compared to the control 1 WAA. By 2 WAA, plants were recovering and phytotoxicity scores fell as the plants produced new leaf. Peak brownout caused by paraquat application ranged from 91–98% and occurred 1 WAA at the standard and double rates. Brownout was slower for the 0.5 rate, peaking 2 WAA. Plants regrew quickly with no phytotoxic effects of the herbicide evident 4 WAA (Figure 5).

Herbage production assessed 4 weeks after treatments were applied reflected the phytotoxicity assessment (Figure 6) with all rates of 2,4-DB and paraquat reducing herbage production compared to the control by an average 38 and 26%, respectively (P<0.05). There was no effect of bromoxynil, imazethapyr and terbuthylazine on desmanthus production. Isoxaflutole reduced herbage production at the standard and double rates by 9 and 21% respectively (P<0.05).

There was no effect of any of the herbicides on desmanthus regrowth after cutting, indicating no long-lasting effects of the herbicides applied. Herbage production assessed 11 and 16 weeks after treatment application averaged 5,560±126 kg DM/ha (standard error) and 1,854±42 kg DM/ha, respectively.

Table 6. Time to flowering reported as an area under the curve for 4 herbicides applied at 4 rates (0, 0.5x, 1x and 2x). Fluroxypyr was not included in the analysis because all plants had died.

Herbicide	Rate of active ingredient in application rates (kg a.i./ha)				Average
	0	0.5x	1x	2x	
Bromoxynil	2.8a	2.7a	2.3bc	2.8a	2.7A
2,4-D	2.9a	2.1cd	1.9de	1.6e	2.1C
Flumetsulam	2.8a	2.3bcd	2.1cd	2.3bcd	2.4B
MCPA	2.8a	2.5ab	2.1cd	2.0d	2.3B
Average	2.8A	2.4B	2.1C	1.4C	

Values with the same lowercase letter are not significantly different (herbicide × rate interaction, P=0.05). Average herbicide and rate values with the same uppercase letter are not significantly different (main effect, P=0.05).

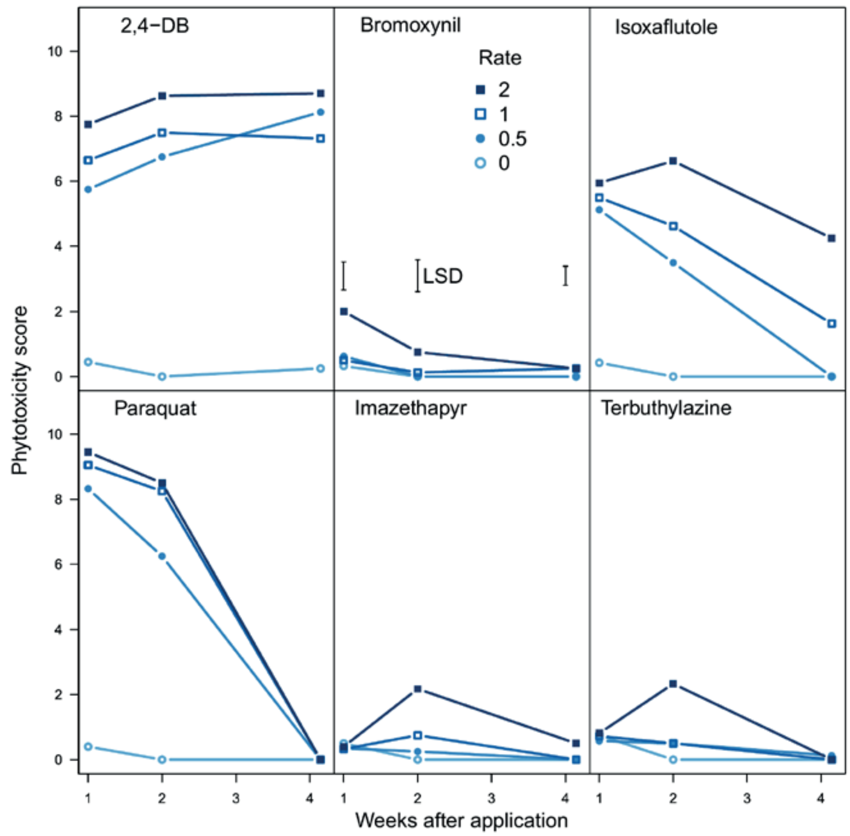

Figure 5. Phytotoxicity score to assess desmanthus plant damage following treatment with (a) 2,4-DB, (b) bromoxynil, (c) isoxaflutole, (d) paraquat, (e) imazethapyr and (f) terbuthylazine at 4 rates (details in Table 3). Score 0=nil damage and score 10=plant death. LSDs for comparison within an assessment date of each herbicide are shown (P=0.05).

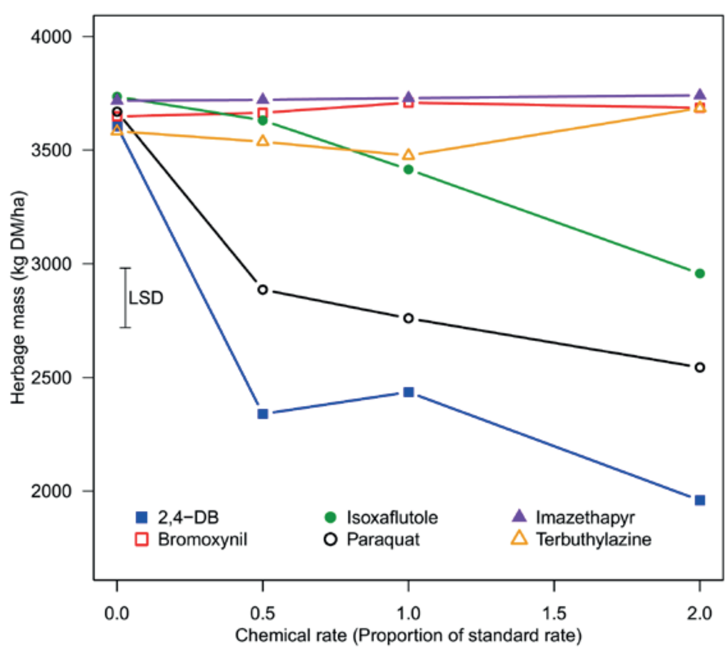

Figure 6. Desmanthus herbage production (kg DM/ha) in December 2017, 4 weeks after application of 6 herbicides at 4 rates.

Discussion

These experiments have identified a range of herbicides that can be used to control weeds in desmanthus pastures without damage to the forage. The objective of the study was not to quantify the extent that weeds can be controlled but determine the sensitivity of desmanthus to the herbicides. Currently, each of the herbicides tested is registered for control of a range of weeds in Australia.

Pre-emergent desmanthus

The negative effect of both trifluralin and imazethapyr at the standard rate is in contrast to findings of Cox and Harrington (2005), who reported no effect of either pre-emergent herbicide on desmanthus 'Marc' emergence and/or productivity. This difference could be associated with the drier environmental conditions experienced during this experiment. In the 2 months following emergence, about 27 mm rainfall was received (about 60 mm less than the long-term average) while the Cox and Harrington (2005) studies were conducted in pots or in the field with irrigation. Greater plant damage caused by herbicides was reported in lower rainfall situations in other crops, including *D. bicornutus* (Grichar and Ocumpaugh 2007). Grichar and Ocumpaugh (2007) associated the greater damage they recorded with longer persistence of herbicides in the soil due to reduced microbial activity following suboptimal soil temperature and moisture conditions (Goetz et al. 1990; Ahmad et al. 2003; Reedich et al. 2017).

Collectively, these results and those of Cox and Harrington (2005) suggest that trifluralin and imazethapyr can be applied pre-emergence to desmanthus pastures. Trifluralin can be applied at rates of 0.4 and up to 0.8 kg a.i./ha and imazethapyr at 0.04 and up to 0.07 kg a.i./ha. During conditions that are unfavourable for pasture establishment, herbicides applied at the maximum rates may inhibit establishment and subsequent productivity.

In Australia, trifluralin is currently registered for control of weeds during establishment of several temperate pasture legumes at 0.58–0.82 kg a.i./ha and imazethapyr at 0.05–0.10 kg a.i./ha. Additionally, imazethapyr is registered as a pre-emergent crop herbicide for the tropical legume centrosema (*Centrosema pascuorum*) 'Cavalcade' in the Northern Territory at 0.05–0.10 kg a.i./ha (Moore and Moore 2024).

Pyroxasulfone is recommended to be applied then incorporated by sowing within 3 days of application using either knife points and press wheels or narrow points and harrows (Anon. undated). Sowing using these techniques moves herbicide treated soil from the sown seed. We did not apply the herbicide using this method which would explain the poor establishment of desmanthus observed.

S-metolachlor is registered as a pre-emergent herbicide for control of toad rush (*Juncus bufonius* L.) in several temperate pasture legumes and grasses in Australia. The registered rates are low with 0.19–0.24 kg a.i./ha (Moore and Moore 2024) and insufficient to control the majority of weeds common in establishing pastures. Development of seed safeners such as oxabetrinil and metcamifen which protect sorghum [*Sorghum bicolor* (L.) Moench] from the phytotoxic effects of metolachlor allow higher rates of S-metolachlor to be applied (Rosinger 2014). Extension of this technology to pasture and other crop species would provide significant advantages for agricultural systems.

Seedling desmanthus

Flumetsulam and bromoxynil caused little effect on seedling desmanthus plants when they were applied at rates of 0.02–0.08 and 0.14–0.28 kg a.i./ha respectively. On desmanthus seedlings younger than in this research, Cox and Harrington (2005) reported greater damage caused by flumetsulam, but less damage by bromoxynil. We concur that these herbicides can be used in seedling stands of desmanthus. Application of these herbicides also resulted in increased herbage production post-application at the rates below and above the standard. This stimulatory response when associated with subtoxic concentrations of herbicide is called hormesis and is considered an adaptive response of stressed plants (Belz and Duke 2014; Vargas-Hernandez et al. 2017). Hormesis has been reported in oats (*Avena sativa* L.) in response to bromoxynil application (Wiedman and Appleby 1972).

Flumetsulam is registered in Australia for the control of broadleaf weeds in a range of temperate legumes at 0.02–0.04 kg a.i./ha with similar results to findings for desmanthus (Moore and Moore 2024). Also, only minor damage was observed when seedlings were sprayed with 0.08 kg a.i./ha (double rate) with only a slight delay in flowering, but no effect on seed pod maturity. Bromoxynil is registered for control of broadleaf weeds in pastures or cereals undersown with several temperate legumes at 0.14–0.56 kg a.i./ha (Moore and Moore 2024).

MCPA and 2,4-D amine, and especially fluroxypyr caused significant damage to seedling desmanthus at all rates applied, with application of fluroxypyr resulting in significant plant death. Fluroxypyr is registered for control of broadleaf weeds in lucerne (*Medicago sativa* L.) pastures although clovers (*Trifolium* sp.) are susceptible (Moore and Moore 2024). Similarly, Cox and Harrington (2005) reported extensive damage to 2-week-old desmanthus seedlings by MCPA and 2,4-D amine. We recommend that these herbicides should not be used on seedling desmanthus pastures.

Established desmanthus

Bromoxynil, imazethapyr and terbuthylazine caused minor damage and isoxaflutole moderately high damage to established plants at all rates applied, with plants recovering within 4 weeks of application with no productivity losses. Bromoxynil is registered for control of broadleaf weeds in a range of temperate legume pastures at 0.14–0.56 kg a.i./ha; rates similar to those used in this study (Moore and Moore 2024). Also, imazethapyr is registered for use in established lucerne (*Medicago sativa* L.) and serradella (*Ornithopus* sp.) pastures at 0.05–0.10 kg/ha; a slightly narrower and lower range than found suitable for desmanthus (Moore and Moore 2024). Terbuthylazine is registered to control grass and some broadleaf weeds in established lucerne at rates lower than found suitable for desmanthus in this study (0.75–1.05 compared with 0.44–1.75 kg a.i./ha) (Moore and Moore 2024).

Paraquat caused rapid and significant brown out of desmanthus plants although subsequent regrowth was healthy and there was no ongoing effect of the herbicide. Paraquat is registered for control of grass and broadleaf weeds in lucerne at 0.3–0.6 kg a.i./ha (Moore and Moore 2024); a narrower and lower range than found suitable for desmanthus in the study.

2,4-DB caused significant distortion of stems and the growing points of desmanthus plants at all the rates applied. Herbage production 4 WAA reflected this damage, however, once the damaged material was removed, the plants regrew normally with no further effects on plant development or productivity. This study indicates that 2,4-DB could be an option in established desmanthus pastures at application rates up to 1.4 kg a.i./ha. However, further testing is recommended to understand the effect of stress, including moisture stress and competition in mixtures, on plant response and recovery. Label recommendations of 2,4-DB for control of broadleaf weeds in temperate legume pastures are 0.5–1.6 kg a.i./ha, although the critical comments highlight that crop sensitivity can vary with species, variety and season of application (Moore and Moore 2024).

Herbicide sensitivity of other Desmanthus species

These studies used ‘Marc’ because it was a commercial and readily available cultivar at the time experiment 1 was conducted. Currently, more cultivars are available in Australia from several other species. The greatest number of cultivars are of *D. virgatus* (‘Marc’, ‘Ray’, ‘JCU 2’, ‘JCU 3’, ‘JCU 5’, ‘JCU 8’) with cultivars available of *D. bicornutus* (‘JCU 4’, ‘JCU 6’), D. leptophyllus (‘JCU 1’, ‘JCU 7’) and *D. pernambucanus* (‘JCU 9’) as well. Further testing of these species, and potentially cultivars, is required to ensure their tolerance to the herbicides identified in this study is similar to ‘Marc’. This will be particularly important where multiple desmanthus species are sown as a mixture, such as cultivar ‘Progardes’ which is a blend of multiple species and cultivars (Gardiner 2016).

Conclusions

This research identified herbicides suitable for use with desmanthus to control broadleaf weeds in desmanthus pastures at different stages of development. Imazethapyr (0.41 kg a.i./ha) and trifluralin (0.85 kg a.i./ha) supported good establishment when used as pre-emergent. In seedling pastures, bromoxynil (0.14–0.56 kg a.i./ha) and flumetsulam (0.02–0.08 kg a.i./ha) caused little damage. In established pastures, bromoxynil (0.14–0.56 kg a.i./ha), imazethapyr (0.04–0.14 kg a.i./ha), terbuthylazine (0.44–1.75 kg a.i./ha) and isoxaflutole (0.04–0.15 kg a.i./ha) caused minor and temporary damage only. Additionally, established plants of desmanthus regrew well after application of paraquat (0.2–0.8 kg a.i./ha). There may be an opportunity to use 2,4-DB (0.35–1.4 kg a.i./ha) in established pastures in some situations, for example, to salvage a desmanthus pasture.

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Research Paper

The use of ethephon for improving shoot development of buds from different positions of BRS Capiaçú elephant grass culms

El uso del etefón para mejorar el desarrollo de brotes en diferentes posiciones del culmo de pasto elefante Capiaçú

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Abstract

Use of ethephon on buds from different positions on the culm of BRS Capiaçú elephant grass was evaluated to improve development of shoots during planting. The experiment compared buds originating from the apex and base of the BRS Capiaçú culm without ethephon application, cut culms with buds immersed for 1 min in ethephon solution (0.650 L ethephon/ha) and application of 150 L ethephon/ha directly on the bud on the standing culm. The position of the bud in the culm and the application of ethephon positively influenced the development and gaseous exchange of BRS Capiaçú. Buds immersed for 1 min in ephethon showed better development, CO_2 assimilation rate (A), transpiration (E) and stomatal conductance. Plants growing from buds from the base of the culm produced more leaves, with higher biomass and higher transpiration, It is recommended to use buds from the base of the BRS Capiaçú culm for propagation when using ethephon.

Keywords: *Cenchrus purpureus* (Schumach.) Morrone, forage, phytohormone, stomatal conductance, transpiration.

Resumen

Se evaluó el uso de etefón en diferentes posiciones en el culmo de pasto elefante BRS Capiaçú para mejorar el desarrollo de los brotes durante la fase de establecimiento. El experimento comparó brotes originados del ápice y la base del culmo BRS Capiaçú sin aplicación de etefón, porciones de tallo cortadas con brotes sumergidos durante 1 min en solución de etefón (0.650 L de etefón/ha) y la aplicación de 150 L de etefón/ha directamente en el brote en el culmo en pie. La posición del brote en el culmo y la aplicación de etefón influyeron positivamente en el desarrollo y el intercambio gaseoso de BRS Capiaçú. Los brotes sumergidos durante 1 min en etefón mostraron mejor desarrollo, tasa de asimilación de CO_2 (A), transpiración (E) y conductancia estomática. Las plantas que crecen a partir de yemas de la base del culmo produjeron más hojas, con mayor biomasa y mayor transpiración. Se recomienda utilizar yemas de la base del culmo de BRS Capiaçú para la propagación cuando se utiliza etefón.

Palabras clave: *Cenchrus purpureus* (Schumach.) Morrone, conductancia estomática, fitohormona, forraje, transpiración.

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Introduction

The elephant grass (*Cenchrus purpureus* (Schumach.) Morrone) cultivar 'BRS Capiaçú' (BRS Capiaçú) stands out from other elephant grass cultivars for its resistance to damping off, ease of mechanical harvesting and erect and dense clumps. It is a tall cultivar, reaching up to 4 m height in favorable conditions, planted from vegetative cuttings that produce plants with a high number of tillers from the axillary and basal buds. It has high regrowth rates that support up to 4 cuts during the year and it is widely recommended and adopted in Brazil. Unlike other pasture grasses, it needs to be replanted every 3 years to sustain high productivity (Lisboa et al. 2019a).

BRS Capiaçú can be used to produce good quality silage or as fresh chopped green feed for livestock (Pereira et al. 2016). This forage produces more dry matter at a lower cost than corn and sugarcane, and its silage is a cheaper alternative for pasture supplementation in the dry season (Gonçalves et al. 2022; Alves et al. 2022). Bud selection is an important decision at planting because the position of the bud in the culm can influence sprouting, due to the lower amount of lignin in tissues (Kalanzi and Mwanja 2023; Santos et al. 2023) and higher amount of auxins that control cell elongation (Taiz et al. 2017). The first sprouting of the culms occurs when soil moisture and temperature conditions allow the meristems in buds to initiate enzymatic and hormonal metabolism (Lisboa et al. 2019a). Exogenous application of phytohormones can support more uniform plant development and a greater number of tillers in the formation of clumps (Chang and Williams 2010).

The use of the phytohormone Ethephon, which releases ethylene, can improve production. The exogenous application of ethylene can promote better expansion of the aerial part of plants in the early stages of crop development. Ethylene is a gaseous hormone that is naturally synthesized in plants and acts in cell expansion, flowering and fruit maturation (Chang 2016; Chang and Williams 2010; Taiz et al. 2017). Ethylene was observed to promote greater tillering in the initial phase of development of sugarcane (Lisboa et al. 2019b) when investigating the responses of exogenously applied ethylene to sugarcane buds.

The root system can be influenced by ethylene, promoting greater root growth with increased nutrient and water uptake, so plants can withstand a longer period of water stress (Chen et al. 2021). Phytoregulators can also cause internal changes in tissues and physiology, promoting better response in gas exchange parameters, including internal carbon concentration of the substomatal chamber, stomatal conductance, and leaf transpiration (Pan Rui et al. 2022). Photosynthesis requires a high carbon dioxide (CO_2) concentration in the mesophyll cells. Exogenously applied ethylene can promote partial stomatal closure, which can reduce stomatal conductance and transpiration and increase the internal concentration of CO_2, making the photosynthetic process more efficient (Marin and Nassif 2013).

Farmers are seeking increased tillering in forages during the formation of clumps at the time of planting or after grazing to support greater dry mass production/area and greater tolerance to abiotic stresses. The exogenous application of ethephon for increased tillering is a possible strategy for better establishment of elephant grass.

Sugar degradation occurs naturally in cellular metabolism to obtain the chemical energy (adenosine triphosphate) (Taiz et al. 2017). When the ethephon molecule enters the cell, in the slightly alkaline cellular environment, it promotes the decomposition into ethylene, phosphate, and chloride ions (Zhang Wei and Wen Chi-Kuang 2010). The presence of ethylene within the cell stimulates the storage of these free sugars (sucrose and glucose-6-phosphate) as starch. When the grass seedlings are removed from ethylene, this starch is converted back into sugars, which are then consumed during the lateral bud sprouting process, increasing tillering in the early stages of forage development.

The objective of this work was to evaluate the use of ethephon in buds originating from different positions on the BRS Capiaçú culm on CO_2 assimilation rate/area (A), transpiration (E), stomatal conductance (gs), internal concentration of CO_2 in the substomatal chamber (ci), efficient use of water (EUW), stomatal density (DEM), stomatal functionality (FUNE), length of the aerial shoot (APL), number of fully expanded leaves (NL) and dry mass of the aerial shoot and roots (DMAP and RDM).

Materials and Methods

The experiment was carried out in August 2023 at the Faculty of Agricultural Sciences at the State University of São Paulo (UNESP), Dracena, São Paulo (21°29’10.24″ S, 51°31‘41.29″ W; 411 masl).

The experimental design was a completely randomized 2 × 3 factorial scheme with 4 replications. The first factor tested was apex and base location of the bud on the BRS Capiaçú culm, and the second factor was ethephon application levels (no application, buds immersed for 1 min in an ethephon solution at a concentration of 0.650 L/ha and application with ethephon solution at a concentration of 0.650 L/ha directly on the bud on the standing culm using a volume of 150 L/ha, giving a total of 6 treatments.

The 10 L capacity pots were filled with 0–0.3 m soil classified as Hypoferric Red Latosol (Santos et al. 2013) (Table 1).

The soil was fertilized following the requirements of the BRS Capiaçú crop according to van Raij et al. (1996). A 5 cm culm fragment with 1 bud from each treatment was planted at a depth of 5 cm, 1 in each pot. The pots were placed in a greenhouse covered with light-diffusing plastic film and 70% black shade screen on the sides. During the experiment, the average maximum daily temperature was 28.5 °C and the minimum was 17.2 °C, and the relative humidity varied between 70–80%. All pots were irrigated until they reached field capacity and weed removal was carried out as needed.

The first fully expanded fresh leaf was selected from the apex of each plantlet from shoots from the apex and base of the culm for gas exchange analysis using the Infra-Red Gas Analyzer (IRGA), ADC BioScientific Ltd, model LC-Pro) with 1,200 µmol/m^2/s of photosynthetically active radiation (PAR) provided by LED lamps. After stabilization of leaf gas exchange, the following parameters were determined: CO_2 assimilation rate expressed per area (A expressed as µmol CO_2/m^2/s); transpiration (E expressed as mmol H_2O/m^2/s); stomatal conductance (gs expressed as mol H_2O/m^2/s) and internal concentration of CO_2 in the substomatal chamber (ci expressed as µmol/mol) with 380 ppm of CO_2 and chamber temperature of 28 °C. For the determination of efficient use of water (EUW) the following formula was applied:

$$EUW = \frac{A}{E}$$

where:
EUW=efficient use of water;
A=CO_2 assimilation rate; and
E=transpiration.

On the same leaf, an abaxial epidermal impression was taken using cyanoacrylate ester (Segatto et al. 2004) to determine DEM and FUNE according to Castro et al. (2009).

After 30 days, plant height (PH), leaf length and leaf width were measured in mm with a graduated ruler. Leaf number (NL) was counted and leaf area (LA) was determined by multiplying leaf length and width. The correction factor [LA = (leaf length × leaf width) × 0.75], was applied according to Simões et al. (2017). To determine dry mass aerial part (DMAP), the green matter was cut close to soil level and root dry mass (RDM) was determined after washing the soil from the roots with running water. The fresh samples were dried in an oven with air circulation at a constant temperature of 65 °C until constant weight.

Statistical analysis

For statistical evaluation, the variables were submitted to normality tests using the Shapiro-Wilk test, followed by analysis of variance using the F test ($P<0.05$). Means were compared using the Tukey test at 5% probability (Banzatto and Kronka 2013). A Pearson correlation and principal component analysis (PCA) was performed using the R Studio statistical program (R Core Team 2019).

Table 1. Soil chemical attributes.

pH	OM	P	K	Ca	Mg	H+Al	Al	SB	CEC	V%	m%
$CaCl_2$	g/dm^3	mg/dm^3	mmolc/dm^3								
4.0	4.0	1.0	0.3	6.0	2.0	33	13	8.0	41	20	61

SB=Sum of the bases; V%=Base saturation; m%=Aluminium saturation.

Results

A significant difference was observed for mode of application of ethephon on A, where immersion of the buds in the solution resulted in an increase of 24% (Table 2).

A showed a significant correlation with E, gs and EUW, and also with DMAP and NL (Figure 1), with a significant linear regression (Figure 2).

Buds from the base of the BRS Capiaçú culm had approximately 17% higher transpiration than the buds from the apex and use of ethephon increased transpiration by approximately 19% (Table 2). Buds from the apex without ethephon were negatively correlated with the traits measured, while the buds at the base of the culm and the treatments with ethephon were positively correlated to the traits measured (Figure 3).

Table 2. Mean values of CO_2 assimilation rate (A–µmol $CO_2/m^2/s$); transpiration (E–mmol $H_2O/m^2/s$); stomatal conductance (gs–mol $H_2O/m^2/s$), internal CO_2 concentration in the substomatal chamber (ci–µmol/mol) and efficient use of water (EUW) of BRS Capiaçú shoots.

Position	A	E	gs	ci	EUW
Apex	11.70a	1.41b	0.073a	188.67a	8.27a
Base	13.15a	1.71a	0.084a	174.56a	7.50a
LSD	2.26	0.17	0.012	26.33	1.00
P-value	0.1928ns	0.0024**	0.1001ns	0.2754ns	0.1268ns
Application					
Absence	11.28b	1.44b	0.069b	172.95a	7.72a
Immersion	14.78a	1.77a	0.092a	169.61a	8.44a
On the bud	11.21b	1.48b	0.074ab	202.29a	7.50a
LSD	3.37	0.26	0.018	39.18	1.49
P-value	0.0216*	0.0081**	0.0143*	0.0913ns	0.2660ns
P-value P x A	0.1494ns	0.5289ns	0.1828ns	0.4280ns	0.3732ns
CV%	21.25	13.06	18.55	16.90	14.82
OM	12.42	1.56	0.079	181.62	7.88

OM=overall mean; CV=Coefficient of variation; LSD=Least significant difference; **=significant at 1% probability level (P<0.01); *=significant at 5% probability level (P<0.05). Means followed by the same letter are not statistically different.

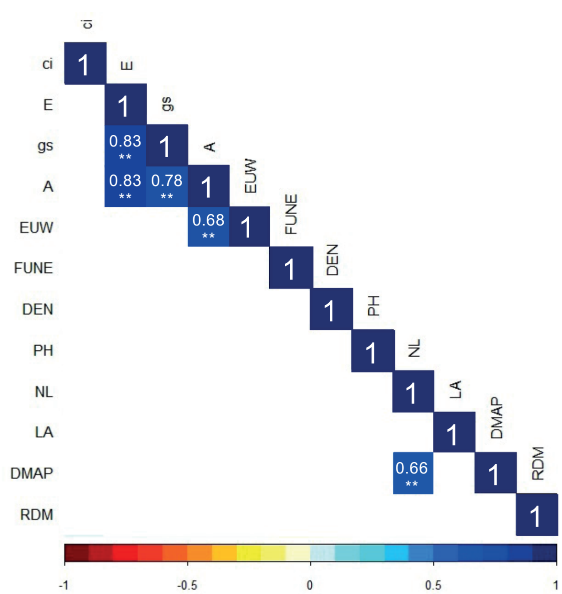

Figure 1. Significant Pearson's correlation among BRS Capiaçú shoot variables.

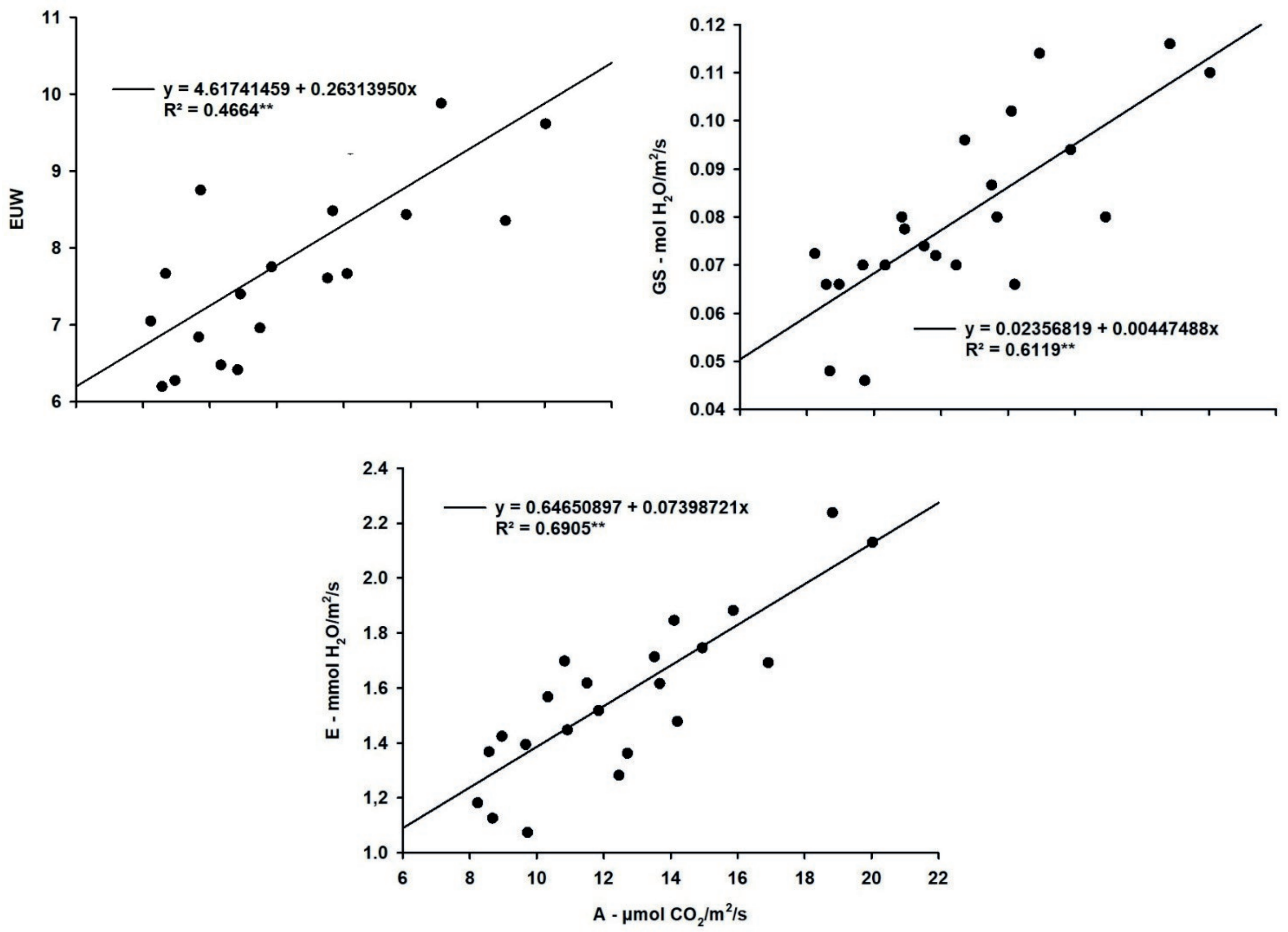

Figure 2. Significant linear regression between CO_2 assimilation rate (A) with transpiration (E); stomatal conductance (gs) and efficient use of water (EUW) of BRS Capiaçú shoots.

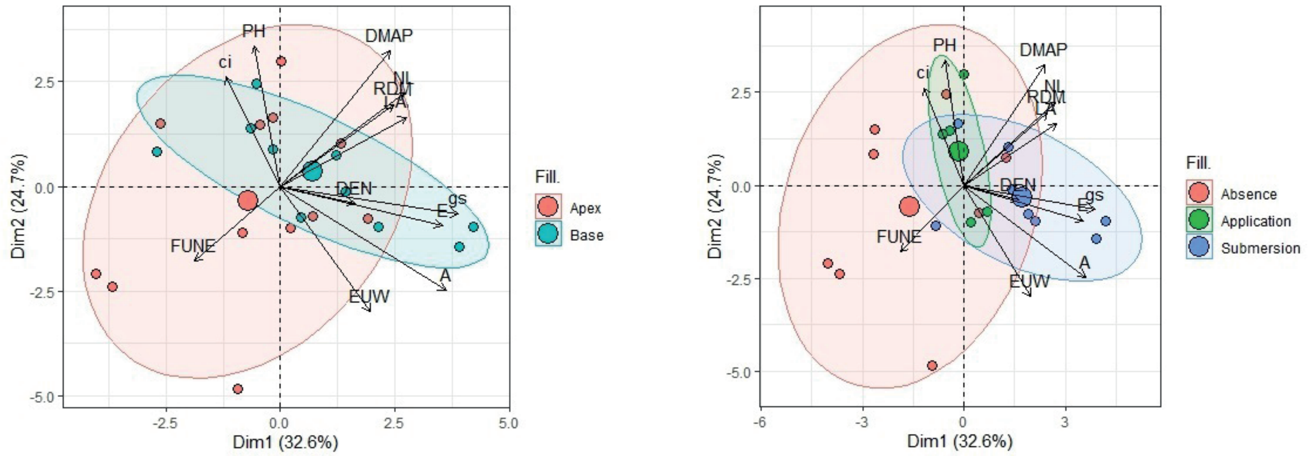

Figure 3. Biplot graph of analysis of significant principal components of BRS Capiaçú, showing the correlations between the positions of the buds in the culm and the ethephon application methods.

A significant difference was found for application of ethephon on gs, where conductance increased by 25% when ethephon was used (Table 2). Stomatal conductance was correlated with leaf transpiration (Figure 4).

No statistical differences were observed for ci, UEA (Table 2), stomatal density and stomatal functionality in BRS Capiaçú (Table 3).

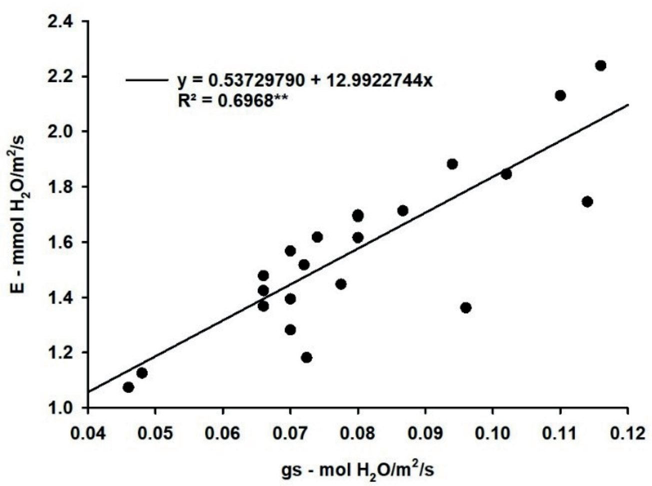

Figure 4. Linear regressions between stomatal conductance (gs) with transpiration (E) of BRS Capiaçú shoots.

No statistical difference was found for PH from buds in different positions in the culm and application of ethephon. NL was statistically different with shoots from buds from the base of the culm showing 14% more leaves than shoots from apex buds. Treatment with ethephon resulted in 33.23% more leaves (Table 4).

Table 3. Mean values of stomatal density (DEN–number of stomata/mm^2) and stomatal functionality (FUNE) of BRS Capiaçú shoots.

Position	DEN	FUNE
Apex	60.96a	1.60a
Base	64.03a	1.53a
LSD	9.05	0.21
p-value	0.4866ns	0.5147ns
Application		
Absence	57.55a	1.62a
Immersion	62.85a	1.52a
On the bud	67.09a	1.55a
LSD	13.46	0.31
P-value	0.2219ns	0.6950ns
P-value P x A	0.1516ns	0.0947ns
CV%	16.88	15.68
OM	62.50	1.56

OM=Overall mean; CV=Coefficient of variation; LSD=Least significant difference; **=significant at the 1% probability level (P<0.01); *=significant at 5% probability level (P<0.05). Means followed by the same letter in the row are not statistically different.

Table 4. Mean values of plant height (PH), leaf number (NL), leaf area (LA), dry mass of the aerial part (DMAP) and root dry mass (RDM) of BRS Capiaçú shoots.

Position	PH (cm)	NL	LA (cm2)	DMAP (g)	RDM (g)
Apex	77.00a	28.91b	547.57a	5.39b	2.85a
Base	80.08a	33.75a	529.64a	7.34a	3.28a
MSD	6.45	4.29	116.01	0.92	0.85
p-value	0.3290ns	0.0294*	0.7492ns	0.0003**	0.3112ns
Application					
Absence	80.87a	23.87b	389.68b	5.52b	2.17b
Immersion	75.25a	35.75a	635.19a	6.63ab	3.93a
On the bud	79.50a	34.37a	590.95a	6.96a	3.10ab
MSD	9.60	6.38	172.60	1.37	1.26
P-value	0.3201ns	0.0003**	0.0043**	0.0380*	0.0088**
P-value P x A	0.3201ns	0.1829ns	0.2775ns	0.0046**	0.0079**
CV%	9.58	15.96	25.11	16.87	32.40
OM	78.54	31.33	538.60	6.37	3.07

OM=overall mean; CV=Coefficient of variation; MSD=Minimum Significant Difference. **=significant at the level of 1% of probability (P<0.01); *=significant at 5% probability level (P<0.05). Means followed by the same letter are not statistically different.

A significant effect was found for mode of application of ethephon on leaf area (LA), where the immersion of the bud in the solution provided a greater leaf area of approximately 39% in the shoot than those from buds without ethephon (Table 4). Ethephon treatment resulted in more and larger eaves, supporting photosynthetic rate and carbon dioxide assimilation (Table 2) which was reflected in the correlation with the increase in the dry mass of the plant (Figure 1).

There was a positive correlation between number of leaves and dry mass of the aerial part of the shoot (Figure 5).

Ethephon increased dry matter with buds from the base of the culm treated with ethephon producing approximately 56% more dry matter than the buds at the apex without ethephon (Table 5).

Visual differences in shoot development were noticeable after treatment with ethephon (Figure 6).

A significant interaction was observed between root dry mass and ethephon treatment (Table 4), where the shoots from buds at the base of the culm immersed in ethephon solution, showed 77% higher root mass when compared to shoots from buds at the apex without ethephon (Table 6).

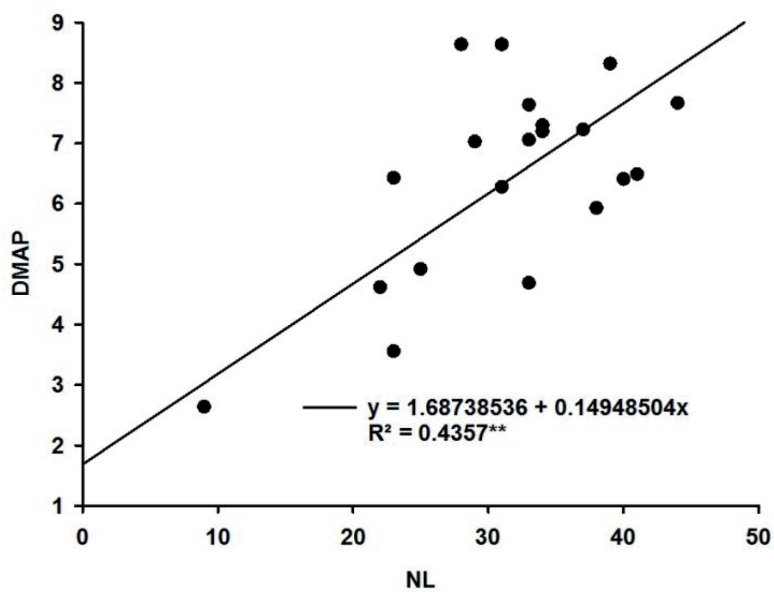

Figure 5. Significant linear regressions between number of leaves (NL) and dry mass of the aerial part (DMAP) of BRS Capiaçú shoots.

Table 5. Average values (g) of the interaction among bud position on the culm and ephethon treatment on dry mass of the aerial part (DMAP) of BRS Capiaçú shoots.

	Absence	Immersion	On the bud
Apex	3.35bB	6.20aA	6.62aA
Base	7.05aA	7.68aA	7.30aA
	MSDCol: 1.59	MSDLin: 1.94	

Means followed by the same lowercase letter in the column do not differ statistically. Means followed by the same capital letter in the row do not differ statistically. MSD=Minimum Significant Difference.

Table 6. Average values (g) of the interaction among bud position on the culm and ephethon treatment on root dry mass (RDM) from BRS Capiaçú shoots.

	Absence	Immersion	On the bud
Apex	0.95bB	3.78aA	3.55aA
Base	3.40aA	4.07aA	2.66aA
	MSDCol: 1.47	MSDLin: 1.79	

Means followed by the same lowercase letter in the column do not differ statistically. Means followed by the same capital letter in the row do not differ statistically. MSD=Minimum Significant Difference.

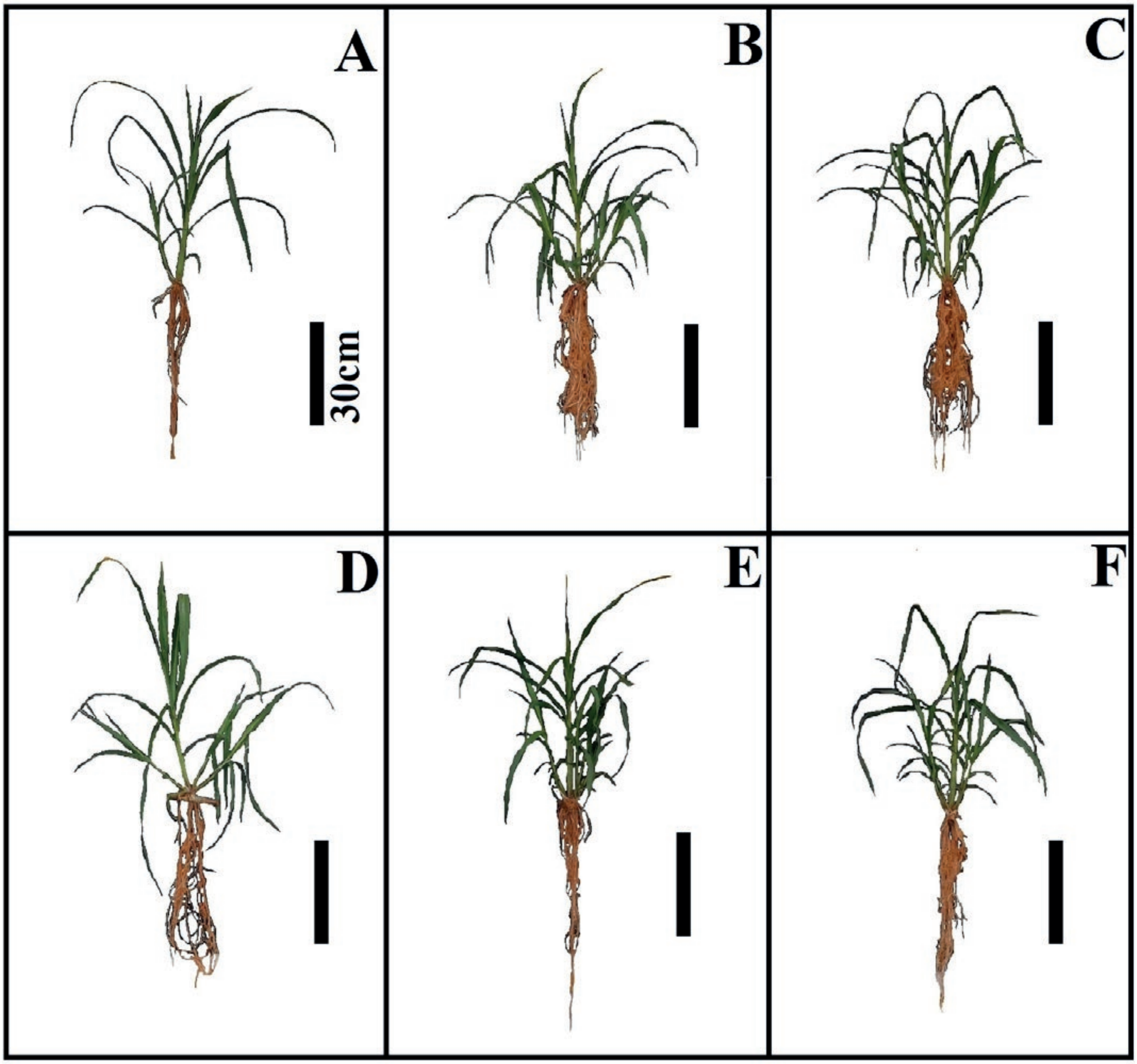

Figure 6. BRS Capiaçú shoots after planting the shoots with buds originating from different positions on the culm and with ethephon application after 30 days growth. A=Bud from the apex of the culm without ethephon; B=Bud from the apex of the culm immersed in ethephon for 1 min; C=Bud from the apex of the culm with application on the culm; D=Bud from the base of the culm without ethephon; E=Bud from the base of the culm immersed in ethephon for 1 min; F= Bud from the base of the culm with application on the culm.

Discussion

This research demonstrates that ethephon can be used to increase shoot development from buds in BRS Capiaçú. Ethephon is low cost, easy to apply and can be applied to buds through soaking or buds on culms on the mother plants or buds on culms in the planting furrow.

The use of a phytoregulator may be reflected in CO_2 assimilation rates, particularly when it releases ethylene during degradation and metabolism, because ethylene acts directly on the stomatal opening and closing mechanisms and guarantees greater gas exchange (Gao Yang et al. 2022; Yao Guang-Qian et al. 2020).

Buds from the base of the culm usually have a higher concentration of sucrose while buds from the apex of the culm have a higher concentration of glucose, therefore implying a greater expenditure of energy for the reduction of sucrose into glucose in buds from the base of the culm, which may have been reflected in transpiration by the leaves (Aude 1993).

Treatment method also affected the results, possibly because the immersion of the buds in the solution may have provided a greater contact surface with ethephon, which was reflected in increased release of ethylene in the bud and increased foliar transpiration in BRS Capiaçú (Lisboa et al. 2019a; Pérez-Pérez et al. 2020).

The stomatal conductance (gs) results confirm that after the degradation of ethephon and ethylene release, ethylene started to influence the stomatal opening, and provided greater stomatal conductance (Lisboa et al. 2019b; Yao Guang-Qian et al. 2020). The concentration of abscisic acid and ethylene hormones within the xylem vessels are the factors that most influence stomatal opening and closing (Pérez-Pérez et al. 2020).

Differences for plant height (PH) can be explained by ethylene supporting better development of size and number of leaves, producing similar results to the higher number of leaves observed when ethephon was applied exogenously in sugarcane (Lisboa et al. 2019b). The increase in the ethylene concentration in the leaves also accelerates its senescence (Peerzada and Iqbal 2021). Further work is needed to determine the appropriate concentrations of ephethon to increase plant growth without causing senescence in BRS Capiaçú.

Increased growth with application of ephethon in buds at the base of the culm in BRS Capiaçú was not expected because buds at the base of the culm have higher amounts of lignin (Li Quing et al. 2022). Increased lignin and availability of glucose for respiration in the buds at the base of the culm may make them slower at sprouting. Ethylene may help the process of degradation of sucrose into glucose (Accácio et al. 2021) and subsequent development of the aerial part. Translocation of nutrients inside the plant supports shoot and root development in the initial phase (Schenato et al. 2007). Nutrient availability can be increased through better root development, allowing access to nutrients at a greater soil depth and increased water absorption. This may explain why buds from the base of the culm showed increased root growth with application of ethephon.

Conclusions

The position of the buds on the culm and the application of ethephon on buds positively influenced gaseous exchange via stomata and shoot and root growth. Buds immersed for 1 min in a solution of 0.650 L ethephon/ha showed a higher, CO_2 assimilation rate, transpiration and stomatal conductance. Based on these results, it is recommended to use buds originating from the base of the BRS Capiaçú culm treated with ephethon for the propagation of the crop.

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(Note of the editors: All hyperlinks were verified 17 September 2025).

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