Agronomía Mesoamericana

UNIVERSIDAD DE COSTA RICA

Technical note

Volumen 37: Artículo nc8qa216, 2026
e-ISSN 2215-3608, https://doi.org/10.15517/nc8qa216

Establishment of new drought-tolerant varieties of *Cenchrus purpureus*[*]

Establecimiento de nuevas variedades de *Cenchrus purpureus* tolerantes a la sequía

Jorge Valentín Wright-Ramírez[1], *José Leonardo Ledea-Rodríguez*[2], *Dalibia Díaz-Fonseca*[1], *Rafael Herrera-García*[3], *Ramón Crucito Arias-Pérez*[1], *José Alfredo Guevara-Franco*[2]

[*] Reception: October 22, 2025. Acceptance: March 16, 2026. This work was part of project "Rehabilitation of pastoral systems in eastern Cuba" led by Instituto de Investigaciones Agropecuarias "Jorge Dimitrov" de Cuba.
[1] Instituto de Investigaciones Agropecuarias "Jorge Dimitrov". Gaveta Postal 2140, Bayamo, Granma, Cuba. wright.jv2020@gmail.com (https://orcid.org/0009-0006-8113-1601); dalibiadiasfonseca@gmail.com (https://orcid.org/0009-0000-3726-5262); rarias@dimitrov.cu (https://orcid.org/0009-0002-0192-4830).
[2] Universidad Autónoma de Baja California Sur, Departamento Académico de Ciencia Animal y Conservación del Hábitat. BLVD Forjadores, Colonia Universitario, CP: 23080, La Paz, B.C.S. México. j.ledea@uabcs.mx (corresponding author, https://orcid.org/0000-0001-5195-1496); jguevara@uabcs.mx (https://orcid.org/0000-0002-1552-8217).
[3] Instituto de Ciencia Animal. Apartado 24, San José de Las Lajas, Mayabeque, Cuba. rherrera@ica.co.cu (https://orcid.org/0000-0003-1424-6311).

Abstract

Introduction. Drought can reduce grain production by up to 50 % and drastically reduce the biomass of pastures and forages used for animal feed. **Objective.** To evaluate the establishment of ten new varieties of *Cenchrus purpureus* that are tolerant to drought under conditions of intense seasonal drought in Cauto Valley, Cuba. **Materials and methods**. The present study used a randomized block design with four replicates to evaluate ten new varieties of *Cenchrus purpureus* (CT-600, CT-601, CT-602, CT-603, CT-604, CT-605, CT-606, CT-607, CT-608 and CT-609) on Fluvisol soil in an area of intense seasonal drought in Cuba, from November 2019 to May 2020. The variety CT-115 was used as a control. At the time of sprouting, soil moisture, plant height, leaf area, biomass yield, and leaf-to-stem ratio were monitored and calculated. **Results.** During the first 12 days after planting, varieties CT-608, CT-607, CT-609, CT-600, CT-115, and CT-603 showed a higher percentage of sprouting ($p \leq 0.05$), a response maintained at 19 days. The varieties CT-603 and CT-608 reached the highest sprouting capacity, exceeding 60 % in 29 days, followed by CT-600 and CT-609 with more than 50 %, and then CT-607 with 44 % ($p \leq 0.05$). The remaining varieties, including the control, exhibited slower sprouting, with values ranging from 20 to 40 % by that period. **Conclusions.** At the establishment cut, no significant differences were found between varieties in height, growth, leaf area, and dry matter (DM) yield; however, biomass structure indicators varied, with only CT-604 surpassing the control in leaf-to-stem ratio (2.1 vs. 1.5) and leaf percentage (67.4 vs. 57.8 %). The new varieties demonstrated the capacity to establish under the conditions evaluated.

Keywords: *Pennisetum purpureum*, drought, grasses, forage production.

Resumen

Introducción. La sequía puede reducir la producción de granos hasta en un 50 % y disminuir drásticamente la producción de biomasa de pastos y forrajes. **Objetivo.** Evaluar el establecimiento de diez nuevas variedades de *Cenchrus purpureus* tolerantes a la sequía en condiciones de sequía estacional intensa en el Valle del Cauto, Cuba. **Materiales y métodos.** El presente estudio utilizó un diseño de bloques aleatorios, con cuatro repeticiones, para evaluar diez nuevas variedades de *Cenchrus purpureus* (CT-600, CT-601, CT-602, CT-603, CT-604, CT-605, CT-606, CT-607, CT-608 y CT-609) en suelo Fluvisol e intensa sequía estacional en Cuba, de noviembre de 2019 a mayo de 2020. La variedad CT-115 se utilizó como control. En el momento de la germinación de las variedades, se monitoreó la humedad del suelo, altura de las plantas, área foliar, rendimiento de biomasa y relación hoja/tallo. **Resultados.** Durante los primeros 19 días después de la siembra, las variedades CT-608, CT-607, CT-609, CT-600, CT-115 y CT-603 mostraron un mayor porcentaje de germinación ($p \leq 0{,}05$). Las variedades CT-603 y CT-608 a los 29 días superaron la capacidad de germinación del control en 60 % ($p \leq 0{,}05$). **Conclusiones.** En el momento del corte de establecimiento, no se encontraron diferencias significativas entre las variedades en cuanto a altura, crecimiento, área foliar y rendimiento de materia seca (MS); sin embargo, los indicadores de la estructura de la biomasa variaron, y solo la CT-604 superó al control en la relación hoja-tallo (2,1/1,5) y en el porcentaje de hojas (67,4 frente a 57,8 %). Las nuevas variedades demostraron su capacidad de establecerse en las condiciones evaluadas.

Palabras clave: *Pennisetum purpureum,* sequía, pastos, rendimiento.

Introduction

Drought can reduce grain production by up to 50 % (Asati et al., 2022; Upadhyaya et al., 2012) and drastically reduce biomass production of pastures and forages used for animal feed. It involves molecular mechanisms on the part of the plant with morphological manifestations that include but are not limited to reduction of the states (water potential or relative water content), turgor pressure (Purbajanti et al., 2020) and, reduction of leaf expansion as the first response of plants to drought stress (Perera et al., 2019). The above generally affects biomass production, which is the main objective of grass and forage cultivation..

In recent years, drought periods have increased worldwide, and a decrease in rainfall volume has been observed (Cruz et al., 2025). Rainy periods have shifted or become shorter (Allan, 2012), negatively affecting biomass capacity accumulation and grain production. Researchers from the agricultural and livestock sectors around the world focus their efforts on producing food in the context of climate change and a combination of abiotic stresses (Liu et al., 2022), accentuated in arid and/or seasonally dry regions, the latter condition being present as a characteristic feature in the tropical region.

Some plant species tolerate a wide threshold of available soil moisture. That is the case of *Sorghum bicolor* L. Moench and *Pennisetum glaucum* L. (Cruz et al., 2025), the latter being a relative of Napier Grass (*Cenchrus purpureus* (Schumach) Morrone syn. (formerly *Pennisetum purpureum*) (Chemisquy et al., 2010; Mogotsi et al., 2020), native to sub-Saharan Africa. Due to its ecological plasticity, it has been distributed in regions with partially humid climates, such as Australia, Asia, South America, Mesoamerica, and tropical Caribbean islands (Muktar et al., 2023; Singh et al., 2013), because of its biomass production benefits, it became popular for feeding dairy cows first. Then, its use in feeding other animal species became common. Its productive and quality history continues to this day.

This variety has been widely used as animal feed in Cuba since 1980, although there are no records of its introduction (Herrera et al., 1995). The seasonality of rainfall in Cuba leads to food scarcity due to water scarcity, hurting cattle production systems. Considering the above, a *C. purpureus* improvement program was created based

ISSN 2215-3608 https://doi.org/10.15517/nc8qa216

on physical and chemical mutagens under *in vitro* conditions to obtain clones tolerant to drought and mixed stress situations (drought and salinity) (Herrera et al., 2003). These clones maintained genetic stability, allowing them to be identified as varieties (Herrera, 2009). Although they have been extensively studied in the western region of Cuba, the eastern region, especially in the Cauto Valley (which occupies 4.5 thousand km^2), has not been studied. The Cauto Valley region is known for its livestock activity (approximately 90%) (Ponce Palma et al., 2020), its hydrological (Sánchez-Sánchez et al., 2013), and geological features (Gonzalez, 1916).

These characteristics vary from those described for the western part of the country (Álvarez, 2017). In the Cauto Valley, studies on the establishment and forage valuation of the new varieties obtained by tissue culture have not yet been carried out. For this reason, the objective of the present study was to evaluate the establishment of ten new varieties of *C. purpureus* that are tolerant to drought under conditions of intense seasonal drought in Cauto Valley, Cuba.

Materials and methods

The research was conducted on Fluvisol soil at the Pasture and Forage Experimental Station of the Jorge Dimitrov Agricultural Research Institute in Granma, Cuba, from November 2019 to May 2020. This site constitutes a representative ecosystem of the Cauto Valley. The air temperature ranged from 24.2 ºC during the dry season (November–April) to 27.7 ºC during the rainy season (May–October), reaching maximum values of 28.6 ºC and 32.8 ºC, respectively. Annual rainfall fluctuated between 630 and 1500 mm, with periods of intense drought during the dry season, accounting for 7.0 to 11.9 % of the total.

Treatments and design

Eleven treatments were evaluated in a randomized block design with four replicates. Experimental units consisted of 4 x 5-meter plots. The treatments included 10 new varieties of *Cenchrus purpureus* (CT-600, CT-601, CT-602, CT-603, CT-604, CT-605, CT-606, CT-607, CT-608, CT-609) obtained by tissue culture from the apical cone of the *C. purpureus* Cuba CT-115 variety, selected for its drought tolerance and as a control.

Procedure

Planting was done with a row spacing of 1 m and a planting density of 2.5 t ha^{-1} of cuttings. The number of buds planted per plot was standardized, and the sprouting percentage was quantified through direct observation and counting. Plant height was measured biweekly, from the base to the apical cone, to determine growth and the total number of green leaves. The yield based on the grass response was measured by cutting at the end of the growth spurt, with a decline in daily growth rate after 154 days. To obtain the green biomass yield, the edge effect (50 cm) was excluded, and the total fresh weight of the plot was measured.

To determine the leaf-to-stem ratio, a 200 g subsample of green biomass was placed in a forced-air circulation oven until it reached constant weight. The dry matter was estimated through an arithmetic relationship between the green and dry weight of the components. The leaf area was determined by using a planimeter after sampling two plants per plot. The soil moisture was determined gravimetrically at 8, 12, 16, 20, and 22 weeks after planting. Soil samples from five random points per plot were taken at two depths: 0-20 cm and 20-40 cm (Table 1).

ISSN 2215-3608 https://doi.org/10.15517/nc8qa216

Table 1. Soil moisture (%) in the experimental plots. Estación Experimental de Pastos y Forrajes del Instituto de Investigaciones Agropecuarias "Jorge Dimitrov". Cuba, 2020.

Cuadro 1. Humedad del suelo (%) en las parcelas experimentales. Estación Experimental de Pastos y Forrajes del Instituto de Investigaciones Agropecuarias "Jorge Dimitrov". Cuba, 2020.

Week	Depth (cm)	
	0 - 20	**20 - 40**
8	13.3	13.1
12	11.3	11.9
16	10.3	9.9
20	9.0	9.1
22	14.3	15.6
General mean	11.7	11.9
±SE	0.3	

±SE: Standard error. /±SE: Error estándar.

Statistical analysis

Statistical analysis was performed using STATISTICA version 10.0 (StatSoft, 2011). Data normality was assessed using the Kolmogorov-Smirnov test, and homogeneity of variance using Bartlett's test. Each variable was analyzed using analysis of variance (ANOVA). Means were compared using the Newman-Keuls test (StatSoft, 2011). The application of the mathematical model of the design controlled for the effect of variety, as shown in equation 1.

$$Y_i = \mu + V_i + \beta_j + e_i \qquad (1)$$

Where: Y_{ij} = response variable, μ = constant common to all observations, T_i = effect of the *i*-the treatment (varieties) ($i = 1,\ldots,11$), β_j = effect of the *j*-the block ($j = 1,\ldots,4$), e_{ij} = random error ~ N (0, σ2e).

To explore the relationship between early establishment vigor and final agronomic performance, a Pearson correlation analysis was performed. The correlation coefficients (*r*) were calculated between the sprouting percentage at 29 days after planting (as an indicator of early vigor) and the main agronomic variables evaluated at the establishment cut (154 days after planting), including plant height, dry matter yield, leaf-to-stem ratio, and leaf area per plant. Correlation significance was tested at $p < 0.05$.

Results

During the first 12 days after sowing, the varieties CT-608, CT-607, CT-609, CT-115, and CT-603 showed, in that order, the highest sprouting percentages ($p \leq 0.05$), a behavior that was maintained until 19 days, when the CT-600 variety was added to the highest performing group. At day 29, varieties CT-603 and CT-608 reached the highest sprouting levels, exceeding 60 %, followed by CT-600 and CT-609, with values above 50 %, and CT-607, with 44 % ($p \leq 0.05$). In contrast, the remaining varieties, including the control (CT-115), showed slower sprouting, with percentages between 20% and 40% for the same period (Figure 1).

ISSN 2215-3608 https://doi.org/10.15517/nc8qa216

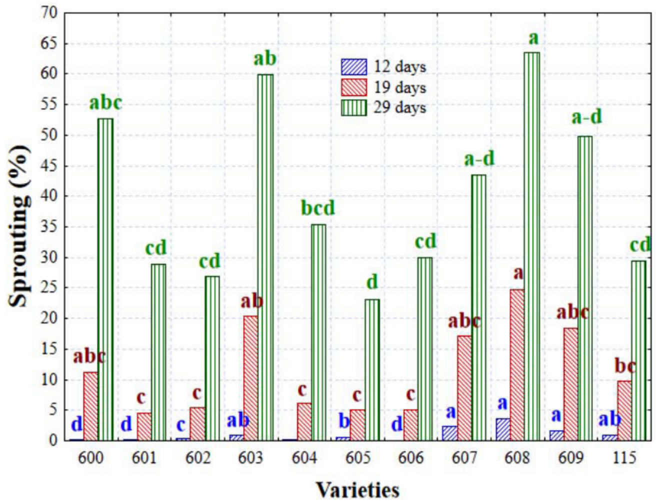

Figure 1. Variation in the sprouting percentage of the varieties. Pasture and Forage Experimental Station of the Jorge Dimitrov Agricultural Research Institute, Cuba. 2020.

[a,b,c,d] Different letters within each age indicate differences for $p < 0.05$ according to Newman-Keuls

Figura 1. Variación en el porcentaje de germinación en nuevas variedades. Estación Experimental de Pastos y Forrajes del Instituto de Investigaciones Agropecuarias "Jorge Dimitrov". Cuba 2020.

[a,b,c,d] Letras diferentes en una misma columna indican diferencias según Newman-Keuls (Statsoft, 2011) para $p \leq 0,05$.

The response of the evaluated varieties to the establishment cut is present in Table 2. No significant differences were observed among varieties in plant height, average daily growth, leaf area, and dry matter (DM) yield ($p \geq$

Table 2. Agronomic variable's behavior at the establishment cut (154 days). Estación Experimental de Pastos y Forrajes del Instituto de Investigaciones Agropecuarias "Jorge Dimitrov". Cuba, 2020.

Cuadro 2. Comportamiento de las variables agronómicas en el corte de establecimiento (154 días). Estación Experimental de Pastos y Forrajes del Instituto de Investigaciones Agropecuarias "Jorge Dimitrov". Cuba, 2020.

Variety	Cutting height (cm)	Mean growth (cm day^{-1})	Leaf area		Yield (t ha^{-1} DM)	Leaf/stem ratio	% leaves
			Per leaf (cm^2)	Per plant (m^2)			
CT-600	89.7	0.56	97.5	0.10	9.0	1.9^{ab}	65.7^{ab}
CT-601	98.6	0.61	83.7	0.08	9.5	1.8^{ab}	64.5^{ab}
CT-602	91.2	0.57	85.3	0.08	9.0	1.5^{b}	59.2^{ab}
CT-603	83.3	0.52	133.5	0.36	9.2	1.8^{ab}	64.6^{ab}
CT-604	87.2	0.54	87.4	0.07	8.5	2.1^{a}	67.4^{a}
CT-605	74.2	0.46	154.8	0.17	10.9	2.0^{ab}	66.2^{ab}
CT-606	57.3	0.36	72.0	0.06	3.7	1.8^{ab}	64.1^{ab}
CT-607	70.4	0.44	62.6	0.05	10.5	1.8^{ab}	63.4^{ab}
CT-608	99.4	0.62	130.0	0.13	8.0	1.9^{ab}	64.8^{ab}
CT-609	79.6	0.49	123.7	0.12	7.7	1.7^{ab}	62.6^{ab}
CT-115	99.4	0.62	106.0	0.11	8.0	1.5^{b}	57.8^{b}
±SE	0.5	0.03	0.14	0.005	0.1	0.01	0.08

[a,b] Different letters in the columns indicate differences according to Newman-Keuls (StatSoft 2011) for $p < 0.05$. DM: Dry matter. ±SE: Standard error. / [a,b] Letras diferentes en una misma columna indican diferencias según Newman-Keuls (Statsoft, 2011) para $p \leq 0,05$. MS: Materia seca. ±EE: Error estándar.

ISSN 2215-3608 https://doi.org/10.15517/nc8qa216

0.05), indicating a uniform agronomic response after 154 days of growth under intense seasonal drought conditions and without irrigation.

Biomass indicators showed significant differences in structure and distribution. The CT-604 variety outperformed the control (CT-115) in leaf-to-stem ratio (2.1 vs. 1.5) and leaf percentage (67.4 % vs. 57.8 %) ($p \leq 0.05$). The other varieties showed no significant differences ($p \geq 0.05$), except in CT-602, which presented a leaf-to-stem ratio statistically similar to that of the control ($p \geq 0.05$). To date, there is no information available on the performance of these new varieties during the establishment phase under intense seasonal drought conditions. These results constitute the first documented report in a dryland livestock production system.

To further investigate the relationship between early establishment vigor and final agronomic performance, a Pearson correlation analysis was performed between sprouting percentage at 29 days (Figure 1) and the variables evaluated at the establishment cut at 154 days (Table 2). The results (Table 3) showed a positive but low and non-significant ($p > 0.05$) correlation with final plant height ($r = 0.32$) and dry matter yield ($r = 0.28$). The correlation with leaf-to-stem ratio was practically null ($r = -0.05$). These findings suggest that, under the intense seasonal drought conditions of this study, early sprouting vigor is not a reliable predictor of final yield or biomass structural quality in *C. purpureus*.

Table 3. Pearson correlation coefficients (*r*) between sprouting percentage at 29 days and agronomic variables at the establishment cut (154 days).

Cuadro 3. Coeficientes de correlación de Pearson (*r*) entre el porcentaje de brotación a los 29 días y las variables agronómicas al corte de establecimiento (154 días).

Variable (154 days)	Correlation with sprouting at 29 days (*r*)	*p*-value
Plant height (cm)	0.32	0.18
Dry matter yield (t ha^{-1})	0.28	0.24
Leaf-to-stem ratio	–0.05	0.84
Leaf area per plant (m^2)	0.21	0.39

Discussion

Sprouting studies conducted in western Cuba with these new varieties show similarities to their parent, CT-115, whose germination is characterized by a gradual, prolonged pattern extending beyond 28 days (Herrera et al., 1995). In this study, the fact that between 30 and 65 % of the planted buds sprouted after 29 days suggests an adequate establishment capacity under seasonal drought conditions, considering that soil moisture did not exceed 13.2 %, a value lower than the wilting coefficient desired for this type of soil (Hernández-Jiménez et al., **2015**). The plant height values indicated a short stature, which may be related to abiotic stress, particularly water deficit. Water deficit affects plant growth rate due to cellular dehydration and altered metabolism (Zhang et al., 2018), aspects that are subject to high variability, as manifested in controlled experimental conditions, when developed under production conditions, or in open fields (Mustamu et al., 2023), as was the case in the present study.

However, the parent of the new varieties (CT-115) is short and ideal for grazing (Gudiño-Escandón et al., 2025; Retureta-González et al., 2019). In the present study, no differences ($p \geq 0.05$) were observed in the height of CT-115 concerning the new varieties, suggesting that, due to their genetic origin, they could be showing this trait. Thus, the low-height response could not necessarily be linked to an effect of intense seasonal drought.

ISSN 2215-3608 https://doi.org/10.15517/nc8qa216

The higher percentage of leaves in some of the new varieties, compared to the control, indicates a favorable structural response and positive implications for the production of quality biomass in water-constrained regions. The number of leaves is primarily affected as a physiological compensation mechanism when the plant is under water stress, since both the morphology of this organ and its number constitute an important portal for water exchange with the environment, for the development of vital aspects such as gas exchange, water balance, and photosynthesis (Azcón-Bieto & Talón, 2013). Therefore, under seasonal drought conditions, the plants' ability to respond by producing more leaves than stems suggests potential uses in animal feed.

This behavior coincides with that reported by Mengistu et al. (2022), who highlights the role of leaves as indicators of tolerance to water stress in forage crops. A higher proportion of functional leaf tissue can favor digestibility and nutritional forage value, representing an advantage in livestock systems located in arid areas or with irregular rainfall.

In addition to favorable leaf production of the new varieties, the productive results based on dry matter yield were also encouraging. In studies involving the parent cultivar (*Cenchrus purpureus* [Schumach] Morrone cv. Cuba CT-115). Productivity and yield responses are closely related to soil and climate characteristics of the experimental or production sites.

Under conditions of the Mexican dry tropics, to evaluated several cultivars of *C. purpureus*, some of them, such as CT-169, also obtained through genetic improvement programs, and observed productive responses that ranged between 1.4-1.8 t ha^{-1} DM (Villanueva-Avalos et al., 2022), while in the Veracruz region, Mexico in a warm humid climate, yields of up to 18 t ha^{-1} DM were reported (Reyes et al., 2018). In Honduras, during rainfall regimes of 1419 mm year^{-1} obtained yields of 2.25 t ha^{-1} DM at 90 days (Medrano-Escobar et al., 2024), Although structurally they did not differ from the rest of the varieties ($p \geq 0.05$), these results suggest that CT-604 could express relevant differences in biomass quality, as demonstrated in previous studies (Ray-Ramírez et al., 2018). This finding justifies its subsequent evaluation under nutritional analysis and digestibility schemes, to validate its potential in animal feed in rainfed areas.

The lack of a significant correlation between early sprouting and final dry matter yield ($r = 0.28$, $p > 0.05$) is a key finding of this study. This result indicates that, while rapid emergence is desirable for soil cover and weed competition, it does not determine the productive potential of the variety under prolonged water stress. Recent studies in wheat support this observation; Lan et al. (2022) found no significant correlation between early root and shoot vigor and demonstrated that traits responsible for early drought tolerance (such as root biomass) differ from those conferring tolerance to late drought stress (such as grain weight and leaf area).

It is possible that varieties with slower sprouting, such as CT-604, possess physiological mechanisms (e.g., a deeper root system or greater water-use efficiency) that allow them to match or even surpass the growth of fast-sprouting varieties when stress intensifies in later stages. Additionally, Vukasovic et al. (2022) identified that early vigor in wheat is governed by specific genetic loci (such as QTLs on chromosomes 2D, 1B, and 5A) that are not necessarily associated with final yield, reinforcing the idea that these are genetically dissociable traits. This result underscores the importance of comprehensive evaluations covering the entire establishment phase, rather than relying solely on initial indicators.

Conclusions

This study concluded that the new *Cenchrus purpureus* varieties evaluated established adequately in Fluvisol soils during the dry season and that early sprouting was not related to final dry matter yield. The results confirmed that, of the ten varieties studied, CT-604 showed the greatest potential during the establishment phase, based on a higher number of leaves and a better leaf-to-stem ratio. This suggests its suitability for forage systems in arid zones and areas with intense drought in the Cauto Valley.

ISSN 2215-3608 https://doi.org/10.15517/nc8qa216

Acknowledgement

To the technicians at the Pasture and Forage Experimental Station of the Jorge Dimitrov Agricultural Research Institute for their support in establishing the project, cultural activities, and measurements taken. To the Ministerio de Ciencia, Tecnología y Medio Ambiente de Cuba (CITMA), Ministerio de la Agricultura de Cuba (MINAG), and Ministerio de Educación Superior de Cuba (MES) for the funding provided through the project "Rehabilitation of pastoral systems in eastern Cuba," which was awarded through a call for proposals by the Jorge Dimitrov Agricultural Research Institute (IIA, acronyms in spanish), Granma, Cuba; executed by the IIA's Experimental Station for Pastures and Forages.

Interests conflict

The authors declare that there are no conflicts of interest.

References

Allan, R. P. (2012). Regime dependent changes in global precipitation. *Climate Dynamics*, *39*(3), 827-840. https://doi.org/10.1007/s00382-011-1134-x

Álvarez, A. (2017). Spatial distribution of three tropical pasture species in Cuba from the analysis of soil indicators and of the present and future climate. *Cuban Journal of Agricultural Science*, *50*(4), 683. https://www.cjascience.com/index.php/CJAS/article/view/671

Asati, R., Tripathi, M. K., Tiwari, S., Yadav, R. K., & Tripathi, N. (2022). Molecular Breeding and Drought Tolerance in Chickpea. In *Life*, *12*(11), Article 1846. https://doi.org/10.3390/life12111846

Azcón-Bieto, J., & Talón, M. (2013). *Fundamentos de fisiología vegetal* (J. Azcón-Bieto & M. Talón, Eds.; Univ. de Barcelona). https://bit.ly/4so5OVf

Chemisquy, M. A., Giussani, L. M., Scataglini, M. A., Kellogg, E. A., & Morrone, O. (2010). Phylogenetic studies favour the unification of Pennisetum, Cenchrus and Odontelytrum (Poaceae): A combined nuclear, plastid and morphological analysis, and nomenclatural combinations in Cenchrus. *Annals of Botany*, *106*(1), 107-130. https://doi.org/10.1093/aob/mcq090

Cruz, A., Saini, D. K., Aviles, D., Norris, A., & Jagadish, S. V. K. (2025). Sorghum and pearl millet as sustainable alternative forage options for water limited environments: Opportunities and challenges. In N. M. Kirkham., S. C. Murray (Eds.), *Advances in Agronomy* (pp. 137-192). Academic Press. https://doi.org/10.1016/bs.agron.2024.08.001

Gonzalez, A. de J. (1916). *Geología y suelos de Cuba en relación a la ganadería* (1st ed.). Universidad Estatal de Míchigan.

Gudiño-Escandón, R. S., García-Barradas, M. del R., Córtes-Villagómez, J. A., & Vega-Murillo, V. E. (2025). Impacto de la ganadería bovina sustentable y amigable con la biodiversidad para una alimentación saludable. Estudios de caso en trópico mexicano. *Brazilian Journal of Animal and Environmental Research*, *8*(1), Article e78160. https://doi.org/10.34188/bjaerv8n1-123

Hernández-Jiménez, A., Pérez-Jiménez, J. M., Bosch-Infante, D., & Speck, N. C. (2019). La clasificación de suelos de Cuba: énfasis en la versión de 2015. *Cultivos Tropicales*, *40*(1), Article 15. https://ediciones.inca.edu.cu/index.php/ediciones/article/view/1504

Herrera, R. S. (2009). Mejoramiento de *Pennisetum purpureum* en Cuba. *Revista Cubana de Ciencia Agrícola*, *43*(4): 345-349. https://biblat.unam.mx/hevila/Revistacubanadecienciaagricola/2009/vol43/no4/2.pdf

Herrera, R. S., Chaplé, Z., Cruz, A. M., Romero, A., & García, M. (2003). Obtención de plántulas de *Pennisetum purpureum*, resistentes a la sequía y a la salinidad. Nota técnica. *Revista Cubana de Ciencia Agrícola*, *37*(2), 189-191. https://www.redalyc.org/articulo.oa?id=193018061015

Herrera, R., Martínez, R., Cruz, R., Tuero, R., García, M., Guisado, I., & Dorta, N. (1995). Producción de biomasa con hierba elefante (*Pennisetum purpureum*) y caña de azúcar (*Saccharum officinarum*) para la ganadería tropical. II. Carbohidratos solubles y estructurales. *Revista Cubana de Ciencia Agrícola*, *29*(2), 245-252. https://biblat.unam.mx/es/revista/revista-cubana-de-ciencia-agricola/articulo/produccion-de-biomasa-con-hierba-elefante-pennisetum-purpureum-y-cana-de-azucar-saccharum-officinarum-para-la-ganaderia-tropical-ii-carbohidratos-solubles-y-estructurales

Lan, Y., Chawade, A., Kuktaite, R., & Johansson, E. (2022). Climate change impact on wheat performance-effects on vigour, plant traits and yield from early and late drought stress in diverse lines. *International Journal of Molecular Sciences*, *23*(6), Article 3333. https://doi.org/10.3390/ijms23063333

Liu, Y., Atieno, M., Cardoso, J. A., Yang, H., Xu, B., Dong, R., Yan, L., Huang, C., Huan, H., Yu, D., Douxchamps, S., & Liu, G. (2022). Mining and utilization of salinity tolerant legumes in tropical coastal agroecosystems: An overview. *Grass Research*, *2*, Article 10. https://doi.org/10.48130/GR-2022-0010

Medrano-Escobar, A., Martínez-Banegas, C., Martínez-Aguilar, Y., Verdecia-Acosta, D., & Herrera, R. (2024). Nutritive quality of *Cenchrus purpureus* (Schumach.) Morrone cv. Cuba CT-115 under edaphoclimatic conditions of Zamorano, Honduras. *Cuban Journal of Agricultural Science*, *58*, 1-10. https://cu-id.com/1996/v58e03

Mengistu, G., Aleme, M., Bogale, A., Tulu, D., Faji, M., Terefe, G., & Mohammed, K. (2022). Dry matter yield and nutritive quality of alfalfa (*Medicago sativa* L.) cultivars grown in sub-humid areas in Ethiopia. *Cogent Food & Agriculture*, *8*(1), Article 852. https://doi.org/10.1080/23311932.2022.2154854

Mogotsi, K., Koobonye, M., Galesekwe, K., & Odubeng, M. (2020). Adoption of Napier Grass [*Cenchrus purpureus* (Schumach.) Morrone] among Livestock Farmers in Botswana: Challenges and Future Prospects. *Journal of Agriculture and Ecology Research International*, *21*(8), 16-28. https://doi.org/10.9734/jaeri/2020/v21i830158

Muktar, M. S., Bizuneh, T., Anderson, W., Assefa, Y., Negawo, A. T., Teshome, A., Habte, E., Muchugi, A., Feyissa, T., & Jones, C. S. (2023). Analysis of global Napier grass (*Cenchrus purpureus*) collections reveals high genetic diversity among genotypes with some redundancy between collections. *Scientific Reports*, *13*(1), Article 14509. https://doi.org/10.1038/s41598-023-41583-7

Mustamu, N. E., Tampubolon, K., Alridiwirsah, Basyuni, M., AL-Taey, D. K. A., Jawad Kadhim AL Janabi, H., & Mehdizadeh, M. (2023). Drought stress induced by polyethylene glycol (PEG) in local maize at the early seedling stage. *Heliyon*, *9*(9), Article e20209. https://doi.org/10.1016/j.heliyon.2023.e20209

Perera, R. S., Cullen, B. R., & Eckard, R. J. (2019). Growth and physiological responses of temperate pasture species to consecutive heat and drought stresses. *Plants*, *8*(7), Article 227. https://doi.org/10.3390/plants8070227

Ponce Palma, I., La O Arias, M., Nahed Toral, J., & Guevara Hernández, F. (2020). Social Learning by Small Ruminant Farmers in Granma, Cuba. In M. Arce Ibarra, M. R. Parra Vázquez, E. Bello Baltazar, L. Gomes de Araujo (Eds.) *Socio-Environmental Regimes and Local Visions: Transdisciplinary Experiences in Latin America* (pp. 271-290). Springer, Cham. https://doi.org/10.1007/978-3-030-49767-5_14

Purbajanti, E. D., Kusmiyati, F., & Fushkah, E. (2020). Water use efficiency and nutrient uptake of rice under soil water stress condition. *Journal Pertanian Tropik*, *7*(1), 72-81. https://doi.org/10.32734/jpt.v7i1.3732

Ray-Ramírez, Jorge Valentín; Almaguer, Rafael F; Ledea-Rodríguez J. L; Benítez-Jímenez Diocles Guillermo; Arias-Pérez, Ramón Crucito; Rosell, G. (2018). Evaluation of varieties of *Cenchrus purpureus* tolerant to drought under pre-montain conditions. *Cuban Journal of Agricultural Science*, *52*(1), 75-85. https://www.cjascience.com/index.php/CJAS/article/view/781/791

Retureta-González, C., Padilla-Corrales, R., Martínez-Zubiaur, R., Vega-Murillo, V., Gudiño-Escandon, R., & Montero-Lagunes, M. (2019). Efecto del riego sobre la calidad, desarrollo y producción de biomasa a dos edades de corte en *Cenchrus purpureus* vc. CT-115 para la región central del estado de Veracruz. *Avances En La Investigación Agropecuaria*, *23*(1), 41-47. https://www.redalyc.org/articulo.oa?id=83759628004

Reyes, C. S., Enríquez, Q. J. F., Hernández, G. A., Esqueda, E. V. A., & Gutiérrez, A. D. A. (2018). Rendimiento de seis cultivares de *Cenchrus purpureus* (Schumach.) Morrone con potencial para producción de bioetanol. *Agroproductividad*, *11*(5), 56-61. https://ageconsearch.umn.edu/record/352905/?v=pdf

Sánchez-Sánchez, Y., Fernádez, C. de M., & Rochenel, S. (2013). Caracterización hidrológica del Valle del Cauto, Cuba. *Minería y Geología*, *29*(2), 16-34. https://www.redalyc.org/pdf/2235/223528710002.pdf

Singh, B. P., Singh, H. P., & Obeng, E. (2013). Elephantgrass. In B. P. Singh (Ed.), *Biofuel Crops: Production, Physiology and Genetics* (1st ed., pp. 271-291). Fort Valley State University Fort Valley, Georgia. USA. http://doi.org/10.1079/9781845938857.0000

Upadhyaya, H. D., Kashiwagi, J., Varshney, R. K., Gaur, P. M., Saxena, K. B., Krishnamurthy, L., Gowda, C. L. L., Pundir, R. P. S., Chaturvedi, S. K., Basu, P. S., & Singh, I. P. (2012). Phenotyping chickpeas and pigeonpeas for adaptation to drought. *Frontiers in Physiology*, *3*, Article 179. https://doi.org/10.3389/fphys.2012.00179

Villanueva-Avalos, J. F., Vázquez-González, A., & Quero-Carrillo, A. R. (2022). Atributos agronómicos y producción de forraje en ecotipos de *Cenchrus purpureus* en condiciones de trópico subhúmedo. *Revista Mexicana de Ciencias Agrícolas*, *27*(13), 1-9. https://doi.org/10.29312/remexca.v13i27.3147

Vukasovic, S., Alahmad, S., Christopher, J., Snowdon, R. J., Stahl, A., & Hickey, L. T. (2022). Dissecting the genetics of early vigour to design drought-adapted wheat. *Frontiers in Plant Science*, 12, Article 754439. https://doi.org/10.3389/fpls.2021.754439

Zhang, R., Schellenberg, M. P., Han, G., Wang, H., & Li, J. (2018). Drought weakens the positive effects of defoliation on native rhizomatous grasses but enhances the drought-tolerance traits of native caespitose grasses. *Ecology and Evolution*, *8*(23), 12126-12139. https://doi.org/10.1002/ece3.4671