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Drought tolerance indices in the evaluation of tropical forage plants

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ABSTRACT

This study aimed to evaluate the performance of *Urochloa brizantha* cultivars under conditions with and without water restriction using drought tolerance indices as tools to identify genotypes tolerant to water deficit. The experiment was conducted in a greenhouse using a completely randomized design in a 4×2 factorial scheme, consisting of four cultivars (Marandu, MG4, MG13 Braúna and MG5 Vitória) and two water availability levels (50% and 100% of field capacity), with six replications. Each experimental unit consisted of a plastic pot with drainage holes (8.0 dm^3 capacity) containing two plants. The following variables were evaluated: plant height, number of tillers, total number of leaves, cumulative leaf length, leaf elongation rate and total dry mass yield, measured 35 days after the beginning of the treatments. The tolerance indices used were: i) Percentage Reduction (%R); ii) Stress Susceptibility Index (SSI); and iii) Stress Tolerance Index (STI). The STI proved to be the most suitable index for identifying *U. brizantha* cultivars with better simultaneous performance under both water deficit and optimal water conditions. The MG4 and MG13 Braúna cultivars show superior overall performance compared to MG5 Vitória and Marandu under both conditions. The Marandu cultivar exhibited greater tolerance to water stress for structural traits.

Keywords: Biomass production, Morphogenetic traits, *Urochloa brizantha*, Water stress.

Índices de tolerância à seca na avaliação de forrageiras tropicais

RESUMO

Objetivou-se avaliar o desempenho de cultivares de *Urochloa brizantha*, em ambientes com e sem restrição hídrica, utilizando índices de tolerância para identificação de genótipos tolerantes ao déficit hídrico. O experimento foi conduzido em casa de vegetação, seguindo o delineamento inteiramente casualizado, com arranjo fatorial 4×2, sendo quatro cultivares (Marandu, MG4, MG13 Braúna e MG5 Vitória), duas condições de disponibilidade hídrica (50% e 100% da capacidade de campo) e seis repetições. A parcela foi constituída por um vaso plástico, com furos, com capacidade para 8,0 dm^3, contendo duas plantas. Foram avaliadas as variáveis altura de planta, número de perfilhos, número total de folhas, comprimento laminar acumulado, taxa de alongamento foliar e produção de massa seca, no 35º dia após o início da aplicação dos tratamentos. Os índices de tolerância utilizados foram: i) Porcentagem de Redução (%R); ii) Índice de Susceptibilidade ao estresse (ISS); e iii) Índice de Tolerância ao Estresse (ITS). O ITS é mais adequado para identificação de cultivares de *U. brizantha* com melhor desempenho simultâneo em ambientes com e sem restrição hídrica. As cultivares MG4 e MG13 Braúna apresentam melhor desempenho geral quando comparada à MG5 Vitória e Marandu, em ambas as condições hídricas. A cultivar Marandu expressa tolerância ao estresse hídrico para características estruturais.

Palavras-chave: Características morfogênicas, Produção de biomassa, *Urochloa brizantha*, Estresse hídrico.

1. Introduction

Animal production in tropical and subtropical regions relies heavily on the availability and quality of pastures. However, pasture productivity is frequently constrained by irregular rainfall patterns and prolonged drought periods, particularly in semiarid regions due to seasonal water deficits (Kroth et al., 2015; Awalla et al., 2023). Water is one of the most critical resources for proper plant functioning and growth and, at the same time, represents the most limiting abiotic factor (Araújo Júnior et al., 2019; Awalla et al., 2023). In northeastern Brazil, water deficit is one of the major constraints limiting agricultural productivity (Silva et al., 2018), causing significant adverse effects on crop production (Silva et al., 2024).

Water deficit can be defined as an imbalance between soil water availability and evapotranspiration demand, resulting in plant water stress. From a physiological perspective, water stress affects plant metabolism by inducing stomatal closure, reducing the photosynthetic rate and decreasing Relative Water Content (RWC) in plant tissues, which may ultimately lead to membrane damage (Silva et al., 2018; Araújo Júnior et al., 2019). Moreover, it induces morphological and productive changes that culminate in growth inhibition, reduced leaf area, marked decline in leaf elongation rate and, consequently, lower biomass production (total, shoot, root, stem and leaf dry matter) (Bonfim-Silva et al., 2011; Pezzopane et al., 2015; Silva et al., 2018; Araújo Júnior et al., 2019).

Understanding forage performance under water deficit is essential for assessing the effects of drought on forage production (Araújo Júnior et al., 2019). The impact of water stress is further intensified by soil characteristics, particularly in Quartzarenic Neosols (Sales et al., 2010). These soils are characterized by low natural fertility (Oliveira et al., 2017) and poor water-holding capacity due to their predominantly sandy texture (Sales et al., 2010; Carvalho et al., 2015). Consequently, the low water retention capacity of the surface soil layer reduces water availability to plant roots, thereby increasing the severity of water stress in forage plants during drought periods (Carvalho et al., 2015).

To mitigate the adverse effects of water deficit, one promising strategy is the selection of cultivars with greater drought tolerance and higher water-use efficiency (Pezzopane et al., 2015). Drought tolerance is an essential trait for pasture establishment in semiarid environments, and grasses of the genus *Urochloa* possess adaptive mechanisms, including the development of deep root systems and osmotic adjustment, which contribute to maintaining tissue hydration and preserving cell membrane integrity under water-limited conditions (Silva et al., 2018). Within the species *Urochloa brizantha*, genotypic variation in performance under water deficit has been reported (Pezzopane et al., 2015; Cheruiyot et al., 2018), enabling the identification, selection and recommendation of genotypes better adapted to drought-prone environments.

When evaluating genotype performance under abiotic stress conditions, drought tolerance indices have proven to be effective tools for ranking and identifying more resilient and stable genotypes (Awalla et al., 2023). These indices simultaneously assess plant performance under both stressed and non-stressed conditions, allowing the identification of genotypes with greater yield stability (Fernandez, 1992; Batista et al., 2019). Several authors have recommended the combined use of multiple indices to minimize bias and improve the accuracy of genotype selection (Majidi et al., 2016; Awalla et al., 2023; Silva et al., 2024). Biomass yield under stressed and non-stressed environments is one of the variables commonly used to calculate drought tolerance indices (Lapuimakuni et al., 2018; Batista et al., 2019). Likewise, morphological and growth traits, such as total dry matter, root dry matter, leaf area and leaf elongation rate, have also been recognized as reliable indicators of drought tolerance (Pezzopane et al., 2015).

Despite the recognized importance of *U. brizantha* and the high susceptibility of sandy soils to drought, particularly in the Brazilian semiarid region, studies evaluating the performance of cultivars of this species under water-restricted conditions remain limited. Therefore, the present study aimed to evaluate the performance of *U. brizantha* cultivars under both adequate and restricted water availability using drought tolerance indices as a tool to identify genotypes tolerant to water deficit.

2. Material and Methods

The experiment was conducted in a greenhouse covered with low-density polyethylene film and equipped with masonry benches and anti-aphid screens on the Experimental Farm of the Federal University of Western Bahia (UFOB), located in the municipality of Barra, Bahia State, Brazil (11°04′56″ S, 43°11′09″ W; approximately 409 m above sea level). According to the Köppen–Geiger climate classification (Beck et al., 2018), the region has a BSh (hot semiarid) climate, with mean annual temperature of 25.7 °C and average annual precipitation of 649 mm. Air temperature and relative humidity inside the greenhouse were monitored daily throughout the experimental period (September to December 2021) using a digital thermo-hygrometer. During the study, minimum and maximum temperatures ranged from 30.5 to 38.0 °C, while relative humidity ranged from 10.0 to 34.5%.

The genotypes evaluated were the *Urochloa brizantha* (Stapf) R.D. Webster cultivars Marandu, MG4, MG13 Braúna and MG5 Vitória (syn. Toledo – 02/06/00 or Xaraés – 11/09/01), selected because they are widely used for establishing rainfed pastures in extensive grazing systems. Seeds were obtained from the seed bank maintained by UFOB in Barra, Bahia, through a partnership with Matsuda. The experiment was arranged in a completely randomized design with treatments distributed in a 4 × 2 factorial scheme, consisting of four cultivars and two water regimes, with six replications, totaling 48 experimental units.

Each experimental unit consisted of a perforated plastic pot with a capacity of 8.0 dm^3 containing two plants. The pots were filled with soil collected from the experimental area of the Experimental Farm, classified as a Quartzarenic Neosols with a loamy sand texture, containing 11% clay, 2.5% silt and 86.5% sand. According to the soil chemical analysis, liming was unnecessary. Establishment fertilization consisted of 56 mg dm^{-3} of single superphosphate (18% P_2O_5) and 23 mg dm^{-3} of urea (45% N). Two topdressing fertilizations were subsequently applied, each consisting of 50 mg dm^{-3} of NPK fertilizer (20-00-20) and 23 mg dm^{-3} of urea (45% N).

Ten seeds were sown per pot. When seedlings reached the four fully expanded leaf stage, thinning was performed, leaving five plants per pot. Three weeks after sowing, topdressing fertilization with nitrogen and potassium was applied, followed by a second thinning, leaving two plants per pot. Forty-one days after sowing, all plants were uniformly clipped to 5 cm above the soil surface, and the second topdressing fertilization was applied.

Until the uniformity cut, all experimental units were irrigated manually once daily using a graduated beaker to restore the soil to its maximum water-holding capacity. This capacity was determined by gradually adding water to pots containing dry soil until water began to percolate through the bottom of the pot. After drainage had ceased, the pots were weighed and these values were compared with the weight of the pots containing dry soil. Subsequently, daily irrigation volumes were determined by replacing the amount of water lost through evapotranspiration, estimated from the daily difference between the current pot weight and that recorded on the previous day.

Ten days after the uniformity cut, the water regime treatments were initiated. Plots assigned to the treatments without water deficit (control) continued to be irrigated with a volume of water sufficient to raise soil moisture to 100% of maximum water-holding capacity, whereas plots receiving the water-deficit treatments were supplied with only 50% of that amount. Irrigation volumes were determined daily by weighing the pots and calculating the difference between the current and previous day's pot weights.

Data collection was performed 35 days after the onset of the water treatments. Measurements were obtained from both plants in each pot, and the arithmetic mean was calculated; therefore, all values are expressed on a per-plant basis. The structural and morphogenetic variables evaluated were: i) Plant Height (PH, cm), measured from the soil surface to the curvature of the tallest leaf; ii) Total Number of Leaves (TNL), determined as the sum of all leaves (live, senescent, fully expanded and expanding); iii) Cumulative Leaf Length (CLL, cm), calculated as the sum of the lengths of all expanded leaves measured from the ligule to the leaf apex; iv) Number of Tillers (NT), obtained by counting all tillers per plant; and v) Leaf Elongation Rate (LER, cm $plant^{-1}$ day^{-1}), calculated by dividing accumulated leaf blade length by the regrowth period. Total Dry Mass Yield (TDMY, g) was used as the productive variable. After harvesting at ground level, plant samples were placed in paper bags and dried in a forced-air oven at 55–60 °C for 72 h to determine dry matter according to the INCT-CA G-0001/1 method described by Detmann et al. (2012).

Based on the obtained data, the following drought tolerance indices were calculated: i) Percentage Reduction (%R), according to Wardlaw et al. (1989), using the equation: $\%R = (1 - Yc/Ys) \times 100$; ii) Stress Susceptibility Index (SSI), proposed by Fischer and Maurer (1978), calculated as: $SSI = (1 - Yc/Ys)/(1 - Ymc/Yms)$; and iii) Stress Tolerance Index (STI), proposed by Fernandez (1992), calculated as: $STI = (Ys/Yms) \times (Yc/Ymc) \times (Ymc/Yms)$. For each evaluated trait, Yc represents the mean performance of each cultivar under water stress, Ys represents the mean performance of each cultivar under non-stress conditions, Ymc is the overall mean of all cultivars under water stress, and Yms is the overall mean of all cultivars under non-stress conditions.

Additionally, the mean performance of each cultivar for each variable evaluated was plotted on four-quadrant scatter plots constructed on Cartesian coordinates. The y-axis represented performance under water-stress conditions, whereas the x-axis represented performance without water stress conditions. The intersection of the axes corresponded to the overall mean of the four cultivars under stressed and non-stressed conditions for each evaluated variable.

3. Results and Discussion

The Percentage Reduction Index (%R) described by Wardlaw et al. (1989) quantifies the ability of genotypes to maintain their yield potential under stress conditions relative to non-stress conditions. Therefore, lower %R values indicate cultivars with greater stress tolerance.

Based on the %R values presented in Table 1, the cultivar Marandu exhibited lower reduction indices than the other cultivars for plant height, number of tillers, total number of leaves, cumulative leaf length and leaf elongation rate. These findings suggest greater morphological stability of this cultivar under water deficit conditions. However, Marandu showed the second highest reduction in total dry matter yield. For this trait, the cultivar MG4 exhibited virtually no reduction when performance under contrasting environmental conditions was compared, whereas MG 13 Braúna showed approximately half the reduction observed for Marandu and MG5 Vitória. These results indicate that, although Marandu is able to maintain the performance potential of several yield-related morphological components under water deficit, this stability is not reflected to the same extent in total dry mass yield.

Table 1. Percentage Reduction Index (%R) values for four *Urochloa brizantha* cultivars grown with and without water deficit conditions for Plant height (PH), Number of Tillers (NT), Total Number of Leaves (TNL), Cumulative Leaf Length (CLL), Leaf Elongation Rate (LER) and Total Dry Mass Yield (TDMY).

Cultivar	PH	NT	TNL	CLL	LER	TDMY
Marandu	9.35	0.00	1.84	0.27	1.80	22.35
MG4	31.42	15.22	18.38	15.45	18.38	0.78
MG13 Braúna	27.46	23.70	18.39	12.34	18.39	11.63
MG5 Vitória	24.29	10.59	9.76	15.89	9.76	26.67

The Fischer and Maurer (1978) Stress Susceptibility Index (SSI) is a dimensionless index and, similarly to the Percentage Reduction Index (%R), lower SSI values indicate greater drought tolerance. In other words, the index expresses the magnitude of the effects of drought on cultivar performance, thereby providing a more efficient means of identifying genotypes with superior performance under water-limited conditions. Based on the SSI values presented in Table 2, the cultivar Marandu exhibited greater efficiency and drought tolerance for the morphological traits plant height, number of tillers, total number of leaves, cumulative leaf blade length and leaf elongation rate. However, when the productive trait total dry matter yield (TDMY) was considered, the cultivar MG4 showed greater drought tolerance. Comparing the ranking of cultivars based on %R (Table 1) and ISS (Table 2) for each of the variables analyzed, it is evident that the cultivar rankings were similar, demonstrating that these indices can yield comparable results.

Table 2. Stress Susceptibility Index (SSI) values for four *Urochloa brizantha* cultivars grown with and without water deficit conditions for Plant Height (PH), Number of Tillers (NT), Total Number of Leaves (TNL), Cumulative Leaf Length (CLL), Leaf Elongation Rate (LER) and Total Dry Mass Yield (TDMY).

Cultivar	PH	NT	TNL	CLL	CLL	TDMY
Marandu	0.37	0.00	0.13	0.02	0.13	1.47
MG4	1.26	1.02	1.26	1.26	1.26	0.05
MG13 Braúna	1.10	1.59	1.26	1.01	1.26	0.76
MG5 Vitória	0.97	0.71	0.67	1.29	0.67	1.75

Regarding drought susceptibility, Awalla et al. (2023) also reported that the cultivar Xaraés (syn. MG5 Vitória) was classified as drought-susceptible, similarly to Marandu, indicating that water deficit significantly affects its productivity. Under severe drought conditions, however, Xaraés was previously reported to exhibit greater drought tolerance than BRS Piatã, based on biomass production (Pezzopane et al., 2015). Nevertheless, the more recent study employing drought tolerance indices (Awalla et al., 2023) classified Xaraés as less drought-tolerant than BRS Piatã.

These findings demonstrate that the stability of structural traits is not necessarily associated with higher productivity, since different physiological mechanisms may influence plant performance under stress conditions (Pandey et al., 2017). This behavior is consistent with that reported for tropical grasses subjected to water deficit, in which reduced soil water availability constrains key physiological processes required for plant growth (Pezzopane et al., 2015; Awalla et al., 2023).

Recent studies have shown that *Urochloa* cultivars may exhibit distinct adaptive strategies in response to water deficit. Some genotypes maintain greater morphological stability, whereas others display a greater capacity to sustain physiological activity and biomass production under drought conditions (Awalla et al., 2023; Zuffo et al., 2022). Water limitation reduces cell turgor and induces stomatal closure, resulting in decreased photosynthetic rate and carbon assimilation (Silva et al., 2018). Consequently, leaf expansion and tiller emergence are reduced, ultimately compromising biomass production (Araújo Júnior et al., 2019).

According to Blum (2017), osmotic adjustment is an important mechanism enabling plants to cope with water deficit by maintaining cell turgor pressure despite reduced water availability. This process allows plants to decrease their internal osmotic potential through the accumulation of compatible solutes, thereby facilitating water uptake from the soil while preserving essential cellular functions, including growth and organelle protection, during drought periods. Another important adaptive mechanism is stomatal regulation, which minimizes excessive water loss through transpiration. According to Tardieu et al. (2018), stomatal closure accounts for a rapid physiological response that stabilizes plant water potential in relation to fluctuations in evaporative demand and soil water content. Wang and Xu (2026) further described the role of abscisic acid (ABA) in activating chloride channels in guard cells, triggering stomatal closure and consequently reducing transpiration. Together, these mechanisms enable plants to conserve water and maintain water balance, thereby enhancing survival under drought conditions.

According to Fernandez (1992), some drought tolerance indices, such as the Stress Susceptibility Index (SSI), are effective for identifying stress-tolerant genotypes with low yield potential; however, they are unable to distinguish genotypes that simultaneously exhibit high yield potential and drought tolerance. To overcome this limitation, Fernandez (1992) proposed the Stress Tolerance Index (STI), which enables the identification of genotypes with superior performance under both non-stress and stress conditions. Higher STI values indicate greater drought tolerance combined with higher yield potential.

Application of the STI to the *Urochloa brizantha* cultivars revealed that MG13 Braúna achieved the highest index values for plant height, number of tillers, total number of leaves, cumulative leaf blade length and leaf elongation rate. For total dry matter yield, MG13 Braúna was surpassed only by MG4 and MG5 Vitória, although the STI values among these cultivars were very similar. In contrast, Marandu exhibited substantially lower STI values than the remaining cultivars for all evaluated traits. Since the STI identifies genotypes that combine superior performance under optimal growing conditions with drought tolerance, these results indicate that MG4, MG5 Vitória and particularly MG13 Braúna are better adapted to environments with adequate water availability while also exhibiting greater tolerance to water deficit than does Marandu.

Table 3. Stress Tolerance Index (STI) values for four *Urochloa brizantha* cultivars grown with and without water deficit conditions for Plant Height (PH), Number of Tillers (NT), Total Number of Leaves (TNL), Cumulative Leaf Length (CLL), Leaf Elongation Rate (LER) and Total Dry Mass Yield (TDMY).

Cultivar	PH	NT	TNL	CLL	LER	TDMY
Marandu	0.34	0.38	0.29	0.32	0.29	0.37
MG4	0.81	0.84	0.90	0.82	0.90	1.09
MG13 Braúna	1.14	1.63	2.31	1.84	2.31	0.97
MG5 Vitória	0.83	0.76	0.47	0.83	0.47	1.09

In a study conducted by Cheruiyot et al. (2018) evaluating *Urochloa brizantha* accessions in Kenya, the cultivar MG4 exhibited reduced forage biomass yield under water deficit conditions compared with irrigated conditions, indicating low drought tolerance. The authors classified MG4 as drought-susceptible regarding forage dry matter production and plant height, suggesting that this cultivar is not well suited for regions experiencing prolonged drought.

Regarding post-stress recovery, Kroth et al. (2015) reported that the cultivar Marandu achieved the greatest shoot dry matter accumulation during the recovery period following the re-establishment of irrigation, indicating an efficient capacity to recover after drought stress. From a physiological perspective, Marandu exhibited a higher root elongation rate under water deficit conditions, which may represent an adaptive mechanism for accessing water from deeper soil layers (Silva et al., 2018).

Figure 1 presents the average performance of each cultivar for each variable in environments with and without stress. Exploratory analysis of the two-dimensional plots shows that MG13 Braúna is consistently positioned in the upper-right quadrant for all evaluated traits, whereas Marandu is consistently located in the lower-left quadrant. The cultivars MG4 and MG5 Vitória are also positioned in the upper-right quadrant for total dry matter yield, although their positions vary for the remaining traits.

Because the intersection of the two axes corresponds to the overall mean performance of the four cultivars in each environment, a cultivar positioned in the upper-right quadrant exhibits above-average performance under both with and without stress conditions. Conversely, a cultivar located in the lower-left quadrant performs below the overall mean in both environments. Therefore, MG13 Braúna demonstrated superior performance relative to the overall mean under both optimal growing conditions and water deficit for all traits evaluated. A similar pattern was observed for MG4 and MG5 Vitória, specifically for total dry matter yield. In contrast, Marandu consistently exhibited below-average performance under both optimal and water-limited conditions for all evaluated traits.

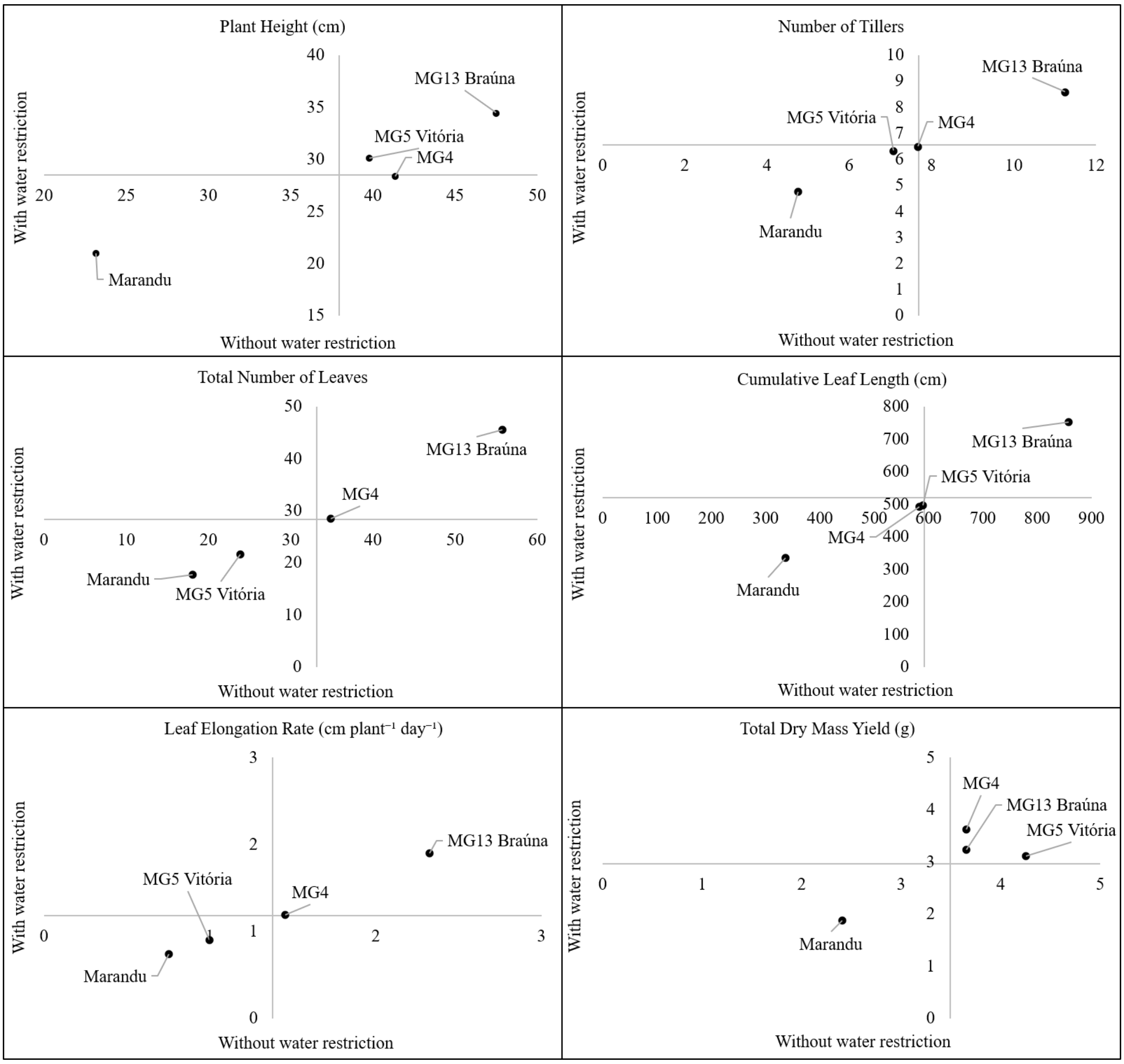

Figure 1. Mean performance of the *Urochloa brizantha* cultivars Marandu, MG4, MG5 Vitória and MG13 Braúna for Plant Height, Number of Tillers, Total Number of Leaves, Cumulative Leaf Length, Leaf Elongation Rate and Total Dry Mass Yield when cultivated with and without water deficit.

The results obtained in the present study highlight the importance of selecting the most appropriate drought tolerance index according to the intended breeding objective or agronomic application. As demonstrated, the Percentage Reduction Index (%R) and the Stress Susceptibility Index (SSI) identify Marandu as the most desirable genotype for selection, whereas the Stress Tolerance Index (STI) identifies MG13 Braúna, followed by MG4 and MG5 Vitória, as the superior genotypes.

Stress tolerance can be defined as the ability of an individual to maintain its performance under adverse environmental conditions and may vary among species, among cultivars within the same species, among phenological stages of a given cultivar and among different plant organs or tissues. Examination of the Marandu cultivar, identified by the %R and SSI as drought-tolerant, shows (Table 1) that water deficit caused little or no change in plant height, number of tillers, total number of leaves, cumulative leaf blade length or leaf appearance rate. In contrast, total dry matter yield was substantially reduced. These findings indicate that, for plant height, number of tillers, total number of leaves, cumulative leaf blade length and leaf appearance rate, Marandu exhibits a greater degree of drought tolerance than do the other evaluated cultivars.

Beloni et al. (2018) reported considerable variability among *Urochloa* cultivars in their responses to water deficit. These authors observed that cultivars such as Marandu and BRS Paiaguás exhibited greater survival capacity associated with higher biomass production and deeper root systems, demonstrating that root architecture is a key component of drought adaptation in these tropical grasses. In addition, osmotic adjustment, as described by Turner (2018), may contribute to plant productivity under water-limited conditions by enhancing the capacity of the root system to extract water from the soil while maintaining essential physiological processes, including leaf expansion and photosynthesis, during drought stress. Together, these physiological strategies enable certain cultivars to maintain higher growth rates and greater drought resistance, particularly under severe water deficit.

Nevertheless, drought tolerance alone is insufficient if a genotype does not also exhibit high productive performance. As shown in Table 1, Marandu presented a lower %R for total dry matter yield than MG5 Vitória, indicating greater drought tolerance according to this index. However, comparison of the mean dry matter production of these cultivars under water deficit conditions (Figure 1) revealed that MG5 Vitória produced 3.12 g plant^{-1}, whereas Marandu produced only 1.87 g plant^{-1}.

To identify not only drought-tolerant genotypes but also those capable of maintaining high productivity, Fernandez (1992) proposed the Stress Tolerance Index (STI). Notably, Marandu, which exhibited the lowest STI values (Table 3), performed below the overall mean for all evaluated traits in both growing environments (Figure 1). Conversely, MG13 Braúna and MG4, which consistently exhibited the most favorable STI values, showed above-average performance under both environments for all traits evaluated (MG13 Braúna) or performance close to the overall mean (MG4).

Overall, drought tolerance indices constitute valuable tools for identifying and selecting genotypes possessing adaptive mechanisms and resilience to water deficit. These indices facilitate decision-making in breeding programs by identifying sources of drought tolerance genes for one or more traits, as well as supporting the selection of cultivars best suited to regions subject to prolonged drought (Lapuimakuni et al., 2018; Zuffo et al., 2022). One of the main advantages of these indices is their ability to discriminate among genotypes under water deficit conditions by ranking and classifying them according to their performance (Batista et al., 2019; Zuffo et al., 2022) and the specific objectives of the researcher. Furthermore, the use of these indices enables the exploitation of genetic variability for drought tolerance within a species, thereby supporting the selection of genotypes with greater yield stability across contrasting environments (Lapuimakuni et al., 2018).

It should be emphasized that the data and subsequent interpretations presented in this study were obtained from pot experiments conducted under controlled environmental conditions. Therefore, validation through more robust field experiments under conditions representative of diverse pasture production environments is required.

4. Conclusions

Under the conditions evaluated, the cultivars MG4 and MG13 Braúna exhibited superior overall performance compared with MG5 Vitória and Marandu, both under adequate water availability and under water deficit conditions. Marandu demonstrated greater stability for structural traits, indicating a higher degree of drought tolerance. The Stress Tolerance Index (STI) proved to be the most effective index for identifying Urochloa brizantha cultivars combining greater yield potential with superior adaptability under both with and without water deficit conditions.

Authors' Contribution

Laura Marina de Oliveira Castro carried out the field experiment, collected and processed data, and wrote the manuscript. Ueslei Figueiredo de Lima assisted with field data collection and sample processing. Adérico Júnior Badaró Pimentel collaborated in the study planning and experimental design, conducted the statistical analysis, and revised the manuscript. Janaina de Lima Silva coordinated the planning and execution of the study, data evaluation and revision of the manuscript.

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