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Yield Component Responses of the *Brachiaria brizantha* Forage Grass to Soil Water Availability in the Brazilian Cerrado

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Abstract: Brazil is one of the world's largest producers of beef cattle and dairy products, which requires high forage yield to attend grass-fed animals' demand. Among the grass species adopted in the forage production system in Brazil, the *Brachiaria* genus stands out. This genus comprises nearly 85% of all planted forage area. In general, forage production systems in Brazil are essentially rainfed, and thus susceptible to seasonal soil water stresses. Selecting the suitable *Brachiaria* cultivar for lands susceptible to periodic waterlogging and dry spells is crucial to enhance forage yield, and consequently, to reduce the environmental footprint of the livestock sector. In this research, we investigated the performance of three recent commercial *Brachiaria brizantha* cultivars (Piatã, BRS Paiaguás, and MG13 Braúna) extensively adopted in Brazil's grazing systems subjected to different ranges of soil water potential. For three cutting periods, yield related-variables (e.g., plant height, leaf area, dry biomass, and water use efficiency) were measured. Our results point to the existence of a low drought-resistant trait among cultivars, indicating the need for releasing better-adapted cultivars to cope with reduced soil water availability. All cultivars achieved higher performance at soil water pressure head between -15 kPa and -25 kPa; and in general, the cultivar. Piatã showed slightly superior results to most of the treatments.

Keywords: beef cattle; dehydration response; tropical forages

1. Introduction

Cattle ranching is one of the largest agricultural activities in Brazil [1]; where around 90% of the cattle herds are pasture-fed [2]. Both natural and planted pasture lands occupy roughly 200 Mha, primarily used to feed beef cattle [3]. In this system, the forage production is essentially rainfed, in which over 80% of the yield occurs during the rainy season, thus the forage production is highly susceptible to seasonal water stress due to either waterlogging or drought [4–6]. Sustainable pasture management is a key element in the enhancement of productivity and reduction of the conversion of natural forests into grasslands, and consequently, the decrease of the environmental footprint of the livestock sector [7]. Although most of the improvements are driven towards the development of new inputs (e.g., seeds, fertilizers, and machinery adoption), the selection of adequate forage cultivars based on their water demand according to the local water availability patterns seems a safe path to improve productivity and manage water consumption by grasslands.

In order to sustain the Brazilian cattle ranching activity growth expected for this decade [3,8], planted grassland currently corresponds to nearly 120 Mha (60% of the total area). It is worth noting that 85% of these planted pasture lands are comprised of *Brachiaria* spp., a tropical forage grass that has been largely used by the Brazilian cattle ranchers since the 1950s [2,9]. In general, the *Brachiaria* genus is distributed throughout the entire tropical zone, showing high biomass yield potential for both grazing and ensiling [10–12].

Regarding the Cerrado biome (Brazilian savannah), the last agricultural frontier of the country, 60 Mha is used as grazing land, with 51 Mha cropped with *Brachiaria* genus [6,13]. In general, for this large producer region of beef and dairy products, there is limited information on selecting the suitable *Brachiaria* cultivar for lands susceptible to periodic waterlogging and dry spells. Thus, in order to allow correct cultivar selection, it is necessary to know the yield response of the regional forage cultivars to the natural conditions of water stress. In this study, we investigated the performance of three important commercial *B. brizantha* cultivars extensively adopted in grazing systems in the Cerrado region subjected to different ranges of soil water potential (from complete saturation to moderate drought). Given the varied range of habitats in which this grass forage grows, we hypothesized that under similar conditions of water stress, some cultivars may outperform their counterparts in terms of plant growth variables, and consequently biomass yield. The experiment was carried out in a greenhouse to allow controlled water management and the measurement of phenotypic variables related to grass biomass yield. The general aim of our research is to generate information to support future field experiments under larger ranges of soil water availability, and thus, to assist cattle ranchers in the selection of the best *B. brizantha* cultivars for the establishment of grazing systems.

2. Materials and Methods

The Brazilian Research Agricultural Corporation (EMBRAPA) released the *Brachiaria brizantha* cultivars Piatã and BRS Paiaguás, while the Matsuda Group launched the cultivar MG13 Braúna. These cultivars are largely adopted in grazing fields in the Brazilian Cerrado due to their recognized nutritional value, and their claimed biomass yield during dry seasons. The general adaptation characteristics and yield patterns of these cultivars obey the rule of increasing pasture and animal productivity. These features are based on the well-documented biomass yield and pasture quality achieved by the *Brachiaria* genus in tropical savannahs [2,5,14,15].

2.1. Experimental Design and General Soil Properties

A greenhouse experiment was conducted at the Federal University of Mato Grosso campus in Rondonópolis, Brazil (16° 28' S, 50° 34' W; 248 m above sea level). The Köppen climate type is Aw—tropical zone with dry winter [16]. Throughout the experiment, the greenhouse presented an average relative humidity and air temperature of 61% and 26.4 °C, respectively.

For the purpose of this research, we selected a coarse-textured soil classified as Fluvisol according to the IUSS Working Group WRB [17], which is prone to waterlogging during the rainy season and drought during the dry season. This soil group occupies large areas in the Cerrado biome and is usually located at and nearby river flood plains. Consequently, this soil group is generally used for forage production (grazing) due to the risks related to yield failures that it offers to cash crops (e.g., soybean, maize, and cotton), which are more resource-demanding.

Disturbed soil samples were collected from the top soil layer (0–0.2 m), and then passed through a 4 mm sieve for the composition of the experimental units. Additional soil samples passed through a 2 mm sieve for natural chemical status and particle-size distribution analysis, Table 1.

Table 1. Soil chemical and particle size distribution analysis for the sampled soil.

pH	CaCl ₂	P	K	S	Ca	Mg	Al	H + Al	C.E.C.	O.M.	V	m	
		mg·dm ⁻³				cmol _c ·dm ⁻³			g·kg ⁻¹		%		
5.3		20.4	47	2	4.3	0.8	0.0	2.7	7.9	21.0	65.9	0.0	
Zn	Mn	Cu				Fe			B	Clay	Silt	Sand	
		mg·dm ⁻³							g·kg ⁻¹				
10.5		68.0	0.8				93			0.13	145	150	705
P = phosphorus, K = potassium, S = sulfur, Ca = calcium, Mg = magnesium, Al = aluminum, C.E.C = cation exchange capacity, O.M. = organic matter, V = base saturation, m = aluminum saturation, Zn = zinc, Mn = manganese, Cu = copper, Fe = iron, and B = boron.													

Nitrogen, phosphorus, and potassium were supplied according to the demand required by the *Brachiaria* spp. The following nutrient doses were applied for all plants: 200 mg·dm⁻³ of nitrogen, 150 mg·dm⁻³ of phosphorus applied in unique dose at sowing, and 100 mg·dm⁻³ of potassium. The used mineral sources were urea, single superphosphate, and potassium chloride, respectively. The sieved soil and the single superphosphate were mixed together, and this homogenized material was used to fill 72 pots of 5 L each (5 kg of soil material for each pot). The potassium chloride and urea were diluted in water and applied at the beginning of the experiment and as restitution minerals throughout the crop cycles (growth and regrowth) for all treatments. A randomized block design (with four replicates) was used for this experiment, adopting a factorial scheme 3 × 6 (three *Brachiaria* cultivars: MG13 Braúna, BRS Paiaguás, and Piatã; and six values of soil water pressure heads: 0, −10, −20, −30, −40, and −50 kPa), totaling 72 pots, where each pot was considered as an experimental unit.

The soil water retention curve $h(\theta)$, the analytical relationship between soil water content (θ) and the soil water pressure head (h), were obtained using a different set of pots with similar volumetric capacity. Water-filled tensiometers were installed in those pots (four replicas) with previously saturated soil. The soil water content was monitored by recording the weight change over time while the soil water pressure head was measured twice a day. The gravimetric water content was then converted to volumetric unit using the relation between bulk soil density and water density. The lowest value of pressure head recorded by the tensiometers was −61 kPa, therefore, the soil water retention curve ranged from soil saturation to this lower bound of −61 kPa. The soil water retention curve was described by the analytical θ - h function defined by [18], Equation (1), which was fitted to the obtained data-pairs (θ - h) minimizing the sum of squared errors using the RETC software [19]:

$$\Theta = [1 + |ah|^n]^{(1/n)-1} \quad (1)$$

where $\Theta = (\theta - \theta_r) / (\theta_s - \theta_r)$ is the effective saturation, θ (m³ m⁻³) is the water content, h (kPa) is the pressure head, θ_r is the residual water content, θ_s is the saturated water content, and α (kPa⁻¹), and n are shape parameters. Figure 1 shows the fitted soil water retention curve of the soil material after accommodation in the pots. The high values of parameters α and n confirm the expected hydraulic characteristic for a coarse-textured soil. It also shows that under the lowest applied pressure head during the experiment (−50 kPa) the used soil material still holds water content over 20%.

Figure 1. Soil water retention curve according to the Van Genuchten (VG) model [18] of the soil material after accommodation in the experimental units, together with its respective fitted parameters of Equation (1).

2.2. Cultivars Sowing and Plant Establishment

Approximately 50 seeds were sowed in each experimental unit (pot); four days after emergence (DAE), the seedlings were thinned out, leaving five vigorous plants in each experimental unit. At the 10th DAE, when plants were uniform and around 10 cm height, the soil water pressure head treatments were applied (0, −10, −20, −30, −40, and −50 kPa). The pressure head measurements were recorded twice a day (early in the morning and by the end of the afternoon) during the entire experimental period (90 day); after the readings, the water inside the tensiometer tubes was replenished. A thin 1 cm water depth over the soil surface simulated the flooded condition treatment throughout the experiment, whereas the negative h values simulated the moderate dehydration stress.

2.3. Response Variables

Thirty days after starting the treatments (40 DAE), plants were clipped at 5 cm above pot surface level to stimulate regrowth; this protocol was repeated twice throughout the experiment with the same time interval between cuts (30 day), totaling 90 days of experiment. At each cut, the following variables were measured: plant height (cm); leaf area ($\text{cm}^2 \cdot \text{pot}^{-1}$); actual bulk leaf succulence ($\text{g} \cdot \text{cm}^{-2}$; for the first and third cuts); aboveground dry biomass ($\text{g} \cdot \text{pot}^{-1}$); water use efficiency ($\text{kg} \cdot \text{m}^{-3}$; for the second cut); and root dry biomass ($\text{g} \cdot \text{pot}^{-1}$, measured only once at the end of the experiment).

Plant height was considered as the vertical distance from the pot soil surface to the curvature point of the last expanded leaf. The leaf area (LA) measurements were performed using a LI 3100 area meter (LI-COR Bio-Science). Regarding the dry biomass measurements, the fresh material was packed in proper paper bags and allowed to dry in a forced-air ventilation oven at 65 °C.

The following relation was used to obtain the actual bulk leaf succulence ($LS, \text{g} \cdot \text{cm}^{-2}$), an indicative of pasture palatability:

$$LS = \frac{FLB - DLB}{LA} \quad (2)$$

where FLB is the fresh harvested leaves, and DLB is the dry leaf biomass.

The agricultural water use efficiency (WUE) is the ratio between the amount (e.g., biomass) of agricultural yield per a volume (or value) of water used for achieving this production. The most common units for expressing water use efficiency are $\text{kg} \cdot \text{m}^{-3}$ or $\text{ton} \cdot \text{m}^{-3}$, i.e., the mass of agricultural yield per volume of water used [20,21]. Expressing WUE in $\text{kg} \cdot \text{m}^{-3}$, we calculated it by the ratio between aboveground dry biomass yield (kg) of each pot (PY) and the amount of water consumed by the crop (ET) during the growth period:

$$WUE = \frac{PY}{ET} \quad (3)$$

With controlled water depth applied on pots with sealed bottom, no runoff or deep percolation occurred, and water use was strictly due to evaporation and transpiration processes. Thus, the daily water volume applied in each pot in order to maintain the pressure head values constant for each treatment throughout the experiment, was assumed as a proxy of evapotranspiration (ET) rate.

2.4. Statistical Analysis

The response variables were analyzed by one-way ANOVA to explore significant differences ($p < 0.05$) among the three *Brachiaria brizantha* cultivars subjected to the water pressure head treatments. In case of significant interaction between the evaluated factors (cultivars and soil water pressure heads), the respective response variable was subjected to regression analysis for each cultivar as a function of the quantitative factor (soil water pressure head) at $p < 0.05$.

3. Results and Discussion

3.1. Plant Height

Both sources of variation (cultivars and soil water pressure heads— h) affected plant height. However, interaction effect between h treatments and plant height was observed only for the second cut (Table 2 and Figure 2). The cultivar Piatã obtained the highest values for the three cuts at all h values, followed by the BRS Paiaguás for the first and third cuts, while for the second cut, the cultivar MG13 Braúna outperformed the BRS Paiaguás at h values -30 kPa and -40 kPa.

Table 2. Effect of soil water pressure head on plant height (*Brachiaria brizantha* cultivars) for the three cutting periods.

Plant Height ¹ (cm)						
Cultivar	First Cut (40 day after emergence (DAE))					
Braúna	46.1 c $\pm$ 8.1					
Paiaguás	53.0 b $\pm$ 10.7					
Piatã	61.0 a $\pm$ 10.1					
Cultivar	Second cut (70 DAE)					
	Soil water pressure head (kPa)					
	0	−10	−20	−30	−40	−50
Braúna	49.8 b $\pm$ 6.3	68.9 b $\pm$ 2.9	69.0 b $\pm$ 3.0	66.3 b $\pm$ 5.7	59.0 a $\pm$ 5.5	39.2 a $\pm$ 5.6
Paiaguás	59.2 b $\pm$ 5.0	82.0 a $\pm$ 6.6	78.6 ab $\pm$ 7.0	59.2 b $\pm$ 10.8	56.9 a $\pm$ 5.7	40.6 a $\pm$ 8.7
Piatã	78.4 a $\pm$ 7.8	92.8 a $\pm$ 4.3	84.0 a $\pm$ 10.0	86.2 a $\pm$ 5.6	67.9 a $\pm$ 9.2	48.6 a $\pm$ 6.7
Cultivar	Third cut (100 DAE)					
Braúna	46.9 c $\pm$ 14.0					
Paiaguás	48.1 b $\pm$ 16.2					
Piatã	54.6 a $\pm$ 16.8					

¹ $\pm$ standard deviation of the four replicas. Cultivars means followed by the same letters under the same treatment (pressure head) and cuts do not differ from each other statistically according to the Tukey's test at $p < 0.05$.

Figure 2 shows the quadratic-shaped regression models fitted between soil water pressure head and plant height data for all evaluated scenarios. In general, the highest values were observed for h ranging from -10 kPa to -20 kPa. Comparing the observed plant heights in this optimum h range to those from wetter and drier soil conditions, reductions of up to 36% and 60% occurred, respectively, indicating that plant height of the studied *B. brizantha* cultivars is susceptible to both waterlogging and moderate dehydration stress, though dehydration stress seems to be a more severe constraint. Some research indicates that height alteration of plants exposed to waterlogging stress may be related to morphological plant responses to reduced soil air-filled porosity [22], which may trigger stem elongation as an attempt to increase access to, and diffusion of, O_2 [23].

Figure 2. Regression models relating soil water pressure head to plant height of *Brachiaria brizantha* cultivars for the three cutting periods (40, 70, and 100 DAE (days after emergence)). Error bars correspond to the standard deviation of the four replicas.

3.2. Leaf Area

The applied pressure head treatments significantly affected ($p < 0.05$) the leaf area (LA) at the first and second cuts (Table 3 and Figure 3). For the first cut, at and near soil saturation, the cultivars BRS Paiaguás and Piatã obtained the highest LA values. For drier soil conditions ($h = -40$ and $h = -50$ kPa) the observed numerical differences among cultivars were not statistically significant. Regarding the second cut, at soil saturation the cultivar Piatã obtained the highest LA value, whereas at -30 kPa the cultivar BRS Paiaguás obtained the lowest LA. For all other pressure head values, the differences were not significant ($p > 0.05$).

According to Figure 3, the optimum soil pressure head range for leaf area development was from -15 to -25 kPa. Regarding the first cut, similar LA reduction was observed for both stresses (water excess and moderate dehydration). On the other hand, for the second and third cuts the dehydration stress was more limiting to LA than water excess. According to Guenni et al. [5], among the most common *Brachiaria* species, only *B. brizantha* showed reduced LA when subjected to severe dehydration stress. The final leaf size depends on cells division and expansion, and it has been shown that dehydration stress affects leaf area by reducing cell number and size [24].

Table 3. Effect of soil water pressure head on leaf area (*Brachiaria brizantha* cultivars) for the three cutting periods.

Cultivar	Leaf Area ¹ (cm ² .pot ⁻¹)					
	First cut (40 DAE)					
	Soil water pressure head— <i>h</i> (kPa)					
	0	−10	−20	−30	−40	−50
Braúna	609 b ± 157	2329 b ± 58	1982 b ± 125	1826 a ± 65	1267 a ± 308	939 a ± 29
Paiguás	948 ab ± 160	3190 a ± 220	2892 a ± 204	1620 a ± 390	1632 a ± 295	1020 a ± 150
Piatã	1241 a ± 121	2910 a ± 362	2336 b ± 281	2254 b ± 269	1553 a ± 250	1138 a ± 222
Cultivar	Second cut (70 DAE)					
	Soil water pressure head— <i>h</i> (kPa)					
	0	−10	−20	−30	−40	−50
Braúna	1581 b ± 404	4222 a ± 165	3826 a ± 313	3427 a ± 339	1960 a ± 474	999 a ± 398
Paiguás	1403 b ± 405	4194 a ± 700	4042 a ± 650	1632 b ± 575	1930 a ± 316	690 a ± 299
Piatã	2750 a ± 442	4235 a ± 600	3241 a ± 318	3162 a ± 593	1930 a ± 417	1005 a ± 423
Cultivar	Third cut (100 DAE)					
Braúna	2150 a ± 1412					
Paiguás	1752 a ± 1476					
Piatã	2211 a ± 1344					

¹ ± standard deviation of the four replicas. Cultivars means followed by the same letters under the same treatment (pressure head) and cuts do not differ from each other statistically according to the Tukey's test at $p < 0.05$.

Figure 3. Regression models relating soil water pressure head to leaf area of *Brachiaria brizantha* cultivars for the three cutting periods (40, 70, and 100 DAE). Error bars correspond to the standard deviation of the four replicas.

3.3. Bulk Leaf Succulence

For this variable, cultivar was the main source of variation, with Piatã and BRS Paiaguás obtaining higher succulence degree than that of the cultivar MG13 Braúna at both cut periods (Table 4). No interaction effect was detected between the h treatments and the cultivar. In general, the cultivars that developed higher leaf area presented higher succulence degree as well. Actual leaf succulence degree is a proxy of adequate cell turgor, which is a well-known property that promotes plant growth at cell and organ levels [24–26]. The higher succulence degree observed for the cultivars Piatã and BRS Paiaguás was in agreement with plant height measurements, where these two cultivars obtained superior plant height values for most of the pressure head treatments, which may have been stimulated by higher cell turgor. A general regression model was fitted to the pooled data from all three cultivars of each evaluated cutting period. For the first cut, a quadratic regression model showed that higher leaf succulence occurs between the pressure head range -20 kPa and -30 kPa; on the other hand, a highly linear regression model fitted to the data from the third cut, showing a reduction trend of leaf succulence degree as the soil became drier (Figure 4).

Figure 4. Regression models relating soil water pressure head to bulk leaf succulence of *Brachiaria brizantha* cultivars for the first and third cutting periods (40 and 70 DAE). Error bars correspond to the standard deviation of the four replicas.

Table 4. Effect of soil water pressure head on leaf succulence (*Brachiaria brizantha* cultivars) for the first and third cutting periods.

Bulk Leaf Succulence ¹ (g·cm ⁻²)	
Cultivar	First cut (40 DAE)
Braúna	0.013 b ± 0.001
Paiguás	0.017 a ± 0.003
Piatã	0.017 a ± 0.002
Cultivar	Third cut (100 DAE)
Braúna	0.015 b ± 0.002
Paiguás	0.017 ab ± 0.001
Piatã	0.020 a ± 0.003

¹ ± standard deviation of the four replicas. Cultivars means followed by the same letters under the same treatment (pressure head) and cuts do not differ from each other statistically according to the Tukey's test at $p < 0.05$.

3.4. Aboveground Dry Biomass

So far, we have discussed parameters related to plant growth (phenotypic traits), and consequently to biomass yield. On the other hand, aboveground dry biomass is likely the most interesting variable regarding the potential yield of pasture species, for either grazing or ensiling purposes [11]. Although, from a nutritional standpoint, biomass yield alone is insufficient to assess the value of a cultivar regarding ruminants' growth performance. In this sense, additional studies are needed to assess the nutritional aspects of these cultivars while subjected to varying soil water availability. According to our statistical analysis, in general, the cultivar Piatã obtained slightly higher aboveground dry biomass yield than its counterparts to most of the evaluated scenarios. Rare exceptions occurred at $h < -20$ kPa, where the cultivar Piatã was outperformed by its counterparts (Table 5 and Figure 5).

Table 5. Effect of soil water pressure head on aboveground dry biomass (*Brachiaria brizantha* cultivars) for the three cutting periods.

Aboveground Dry Biomass ¹ (g)						
Cultivar	First cut (40 DAE)					
	Soil water pressure head— h (kPa)					
	0	−10	−20	−30	−40	−50
Braúna	2.5 a ± 0.4	8.8 b ± 1.1	1.5 b ± 0.5	8.0 a ± 1.3	6.2 a ± 2.1	4.0 b ± 1.7
Paiguás	3.8 a ± 1.1	12.7 a ± 2.1	7.4 a ± 2.1	8.2 a ± 2.1	5.8 b ± 2.1	4.5 a ± 1.1
Piatã	3.7 a ± 1.2	12.0 a ± 0.8	7.4 a ± 0.8	8.2 a ± 1.6	5.8 b ± 1.7	3.5 b ± 0.9
Cultivar	Second cut (70 DAE)					
	Soil water pressure head— h (kPa)					
	0	−10	−20	−30	−40	−50
Braúna	8.2 b ± 2.9	27.9 a ± 2.4	22.9 ab ± 2.4	20.8 a ± 2.5	12.3 a ± 4.3	6.0 a ± 2.2
Paiguás	8.1 b ± 2.6	24.8 a ± 6.4	27.5 a ± 5.0	9.8 b ± 2.1	12.1 a ± 2.1	5.0 a ± 2.5
Piatã	21.5 a ± 3.1	27.5 a ± 7.0	19.8 b ± 2.6	20.3 a ± 3.5	12.8 a ± 1.9	7.7 a ± 2.7
Cultivar		Third cut (100 DAE)				
Braúna		18.4 ab ± 14.1				
Paiguás		15.0 b ± 13.7				
Piatã		18.9 a ± 12.4				

¹ ± standard deviation of the four replicas. Cultivars' means followed by the same letters under the same treatment (pressure head) and cuts do not differ from each other statistically according to the Tukey's test at $p < 0.05$.

Figure 5. Cultivars of *Brachiaria brizantha*, MG13 Braúna, BRS Paiaguás, and Piatã at soil water pressure head $|h|$ 0, 10, 20, 30, 40, and 50 kPa on the 30th day after the first cut (70 DAE).

Interaction effects between h treatments and cultivars were observed for the first and second cuts only, where quadratic regression models show that the pressure head value close to -20 kPa gave the highest yields of aboveground dry biomass (Figure 6), while at higher or lower pressure head the aboveground biomass yield was constrained. This result indicates that both cultivars lack the trait to cope with waterlogging and moderate dehydration stresses. Guenni et al. [5] investigating dehydration stress on *Brachiaria* species found that *B. brizantha* is among the most susceptible ones, showing the earliest dehydration stress onset, and consequently, the largest yield reduction. Meirelles et al. [6] showed that established and grazed *B. brizantha* pasture responds rapidly to the first water pulse of the rainy season, increasing live phytomass from 30 (end of dry season) to $100 \text{ g} \cdot \text{m}^{-2}$ (after the first rainfall events).

Given the high water demand by the *B. brizantha*, as shown in our results and elsewhere [5,6,10], it is expected that these three analyzed cultivars have the potential to shape the soil water balance components of large areas (e.g., reduce water infiltration while transpiration rates are increased, thus, depleting soil water content).

3.5. Root Dry Biomass

Root dry biomass (which was measured at the third cut) did not differ between cultivars and neither was any interaction effect of soil pressure heads over cultivars detected. Although the highest observed root dry biomass was at $h = -10$ kPa, it is worth noting that under soil saturation root dry biomass was higher than that at $h < -30$ kPa (Figure 7).

Figure 6. Regression models relating soil water pressure head to aboveground dry biomass of *Brachiaria brizantha* cultivars for the three cutting periods (40, 70, and 100 DAE). Error bars correspond to the standard deviation of the four replicas.

Figure 7. Regression models relating soil water pressure head to root dry biomass of *Brachiaria brizantha* cultivars for the third cutting period (100 DAE).

Root biomass is directly related to root length density, an important property in root water uptake processes [27]. However, sole use of total root biomass quantity may produce biased information regarding root water uptake efficiency, which depends on not only biomass (root presence) but mostly on root activity. When comparing the results of aboveground dry biomass of the third cut to that of root dry biomass at this same cut, one can see that at $h = -40$ and -50 kPa root biomass was almost double that of the aboveground biomass. A similar result was observed at soil saturation. The highest ratio (0.8) between above and belowground dry biomass was recorded at $h = -20$ kPa, and the lowest

(0.25) at $h = -50$ kPa, indicating that under dehydration stress the evaluated *B. brizantha* cultivars invested more resources on root biomass than aboveground biomass (Figure 8), which is likely an attempt to increase root water access. Nonetheless, as discussed in Guenni et al. [5], in some cases low shoot/root biomass ratio is poorly correlated to root water uptake efficiency.

Figure 8. Root development of *Brachiaria brizantha* cultivars (MG13 Braúna, BRS Paiaguás, and Piatã) at soil water pressure head $|h|$ 0, 10, and 50 kPa on the 100 DAE (third cut).

The relation between root density and water uptake efficiency can be even more complex at heterogeneous field scale, where soil hydraulic properties (water retention and hydraulic conductivity) play a paramount role in the soil water flow towards roots. Based on soil physics processes, water flow in the vadose zone is a passive response to hydraulic gradients developed between the bulk soil and the root surface. Consequently, larger root biomass (a proxy of root density) drives water flow at potential rates under small pressure head gradients, since the sum of all flux densities from individual roots is sufficient to supply the potential atmospheric demands, and thus postpone the onset of drought stress. On the other hand, under restricted root development, larger hydraulic gradients are necessary in order to attain flux densities compatible to atmospheric demand [28,29]. The hydraulic gradients developed in the vadose zone are also highly influenced by the unsaturated hydraulic conductivity $K(h)$, where depending on the soil hydraulic properties, a larger hydraulic gradient may be necessary to compensate small drops on $K(h)$ [30].

3.6. Water Use Efficiency

In the following we present the results regarding water use efficiency (WUE) calculated at the second cutting period (70 DAE), Table 6 and Figure 9. The detected interaction effect of h treatments on WUE shows that the Piatã cultivar obtained the most regular averages for all pressure head treatments, while the other cultivars exhibited larger oscillation, especially the BRS Paiaguás. The Piatã cultivar obtained its highest WUE value at soil saturation, which is in agreement with the aboveground dry biomass presented in Figure 6 for the second cut, whereas the other cultivars attained their highest WUE at h ranging from -10 to -20 kPa. Guenni et al. [10] showed instantaneous photosynthetic water use efficiency to be constant and similar for several *Brachiaria* species subjected to dehydration stress treatments.

Controlled greenhouse experiments permit higher WUE value attainment than field conditions for allowing precise water replenishment (reducing evaporation losses), maintaining soil water potential closer to the desired range. Accordingly, other studies investigating the WUE of planted and natural pasture species have reported lower WUE values than those reported in Table 6. Snyman [31] reported a WUE average of $0.78 \text{ kg}\cdot\text{m}^{-3}$ for six dryland planted pasture species. White and Snow [32] simulated WUE for different irrigation scenarios, climate, and soil types, with results ranging from $1\text{--}3 \text{ kg}\cdot\text{m}^{-3}$. As an example of how soil water availability can strongly control WUE, Moot et al. [33] found WUE ranging from below $1 \text{ kg}\cdot\text{m}^{-3}$ to $4 \text{ kg}\cdot\text{m}^{-3}$ for different combinations of pasture species and soil types with very different water availability patterns throughout the year.

As discussed in Molden et al. [34] and Bodner et al. [35], the knowledge of the most adequate soil water content range for plant growth is essential for the optimization of growth factor resources (e.g., water, nutrients, light) of either rainfed or irrigated crops, which are responsible for controlling the phenotypic expression of crops.

Table 6. Effect of soil water pressure head on water use efficiency (*Brachiaria brizantha* cultivars) for the second cutting period.

Cultivars	Water Use Efficiency ¹ ($\text{kg}\cdot\text{m}^{-3}$)					
	Second cut (70 DAE)					
	Soil water pressure head— h (kPa)					
	0	10	20	30	40	50
Braúna	$2.19 \text{ b} \pm 0.7$	$6.10 \text{ a} \pm 0.4$	$5.55 \text{ a} \pm 0.6$	$5.25 \text{ a} \pm 0.1$	$4.08 \text{ a} \pm 1.2$	$3.47 \text{ a} \pm 1.3$
Paiaguás	$2.03 \text{ b} \pm 0.6$	$5.50 \text{ b} \pm 1.0$	$5.19 \text{ a} \pm 0.6$	$3.26 \text{ b} \pm 0.5$	$3.61 \text{ a} \pm 0.6$	$2.70 \text{ a} \pm 1.4$
Piatã	$5.63 \text{ a} \pm 0.9$	$5.55 \text{ a} \pm 1.1$	$5.00 \text{ a} \pm 0.5$	$4.98 \text{ a} \pm 0.7$	$4.02 \text{ a} \pm 0.7$	$3.62 \text{ a} \pm 1.4$

¹ $\pm$ standard deviation of the four replicas. Cultivars means followed by the same letters under the same treatment (pressure head) and cuts do not differ from each other statistically according to the Tukey's test at $p < 0.05$.

Figure 9. Regression models relating soil water pressure head to water use efficiency of *Brachiaria brizantha* cultivars for the second cutting period (70 DAE). Error bars correspond to the standard deviation of the four replicas.

4. Conclusions

The main findings of our research on evaluating different *Brachiaria brizantha* cultivars regarding their phenotypic traits and yield aspects, allow us to conclude that:

1. The low drought-resistant trait observed for all evaluated *Brachiaria brizantha* cultivars, grown on Fluvisol, indicates the need for releasing of better-adapted cultivars to cope with scenarios of reduced soil water availability typical of drought-prone regions.
2. Regarding the phenotypic traits response, the cultivar Piatã, followed closely by the cultivar BRS Paiaguás, showed superior results to most of the evaluated scenarios.
3. The evaluated *Brachiaria brizantha* cultivars grown in a coarse-textured soil achieved higher performance at soil water pressure heads (h) within the range -15 kPa and -25 kPa; however, given the high dependence of soil water availability on soil hydraulic properties, other soil types should be tested in experiments under natural field conditions.

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