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Adaptation and indication of forage crops for agricultural production in sandy soils in western Bahia State, Brazil

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ABSTRACT. The diversity of soils and climate in Brazil imposes the need to evaluate the adaptation of fodder species to soil and climate conditions to guide producers and technicians in choosing the best alternatives for their region. The objective of this study was to evaluate and identify fodder cultivars for pasture and soil cover with tolerance to drought and high production in the sandy soils of southern Bahia, Brazil. The performance of 29 commercial cultivars of perennial and annual tropical forage species was evaluated in six cuts in 2019 and 2020. The green and dry mass yield per cut and the daily dry matter accumulation rate were evaluated considering the periods of water surplus and deficit and the drought tolerance index for each cultivar was estimated. Grass and legume cultivars showed differences in establishment, yield in the water surplus, and in the re-establishment after the water deficit. Based on the values of the drought tolerance index and in the dry mass daily yields before and after the water deficit, the cultivars adapted and indicated for regional continuous grazing were Xaraés, Marandu, Massai, Tanzânia, Paiaguás, and Zuri, in that order. The grasses *B. ruziziensis* and *B. decumbens* were indicated for use as cover plants after the harvest due to their high capacity of establishment and short-term production. The annual and perennial legume plants were also indicated for cover, and the combination of cultivars and their potential for straw in direct planting or use in integrated systems still need to be validated.

Keywords: grasses; legume; tropical fodder; drought tolerance; sandy soils.

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Introduction

Brazil is a country with an agricultural vocation, an activity that accounts for 22% of the national GDP (Gross Domestic Product). The relative area of anthropized land in Brazil is approximately 30% where cultivated pastures account for 13%, native pastures for 8%, and the rest for agriculture and urbanization (Empresa Brasileira de Pesquisa Agropecuária [Embrapa], 2018). In recent years, the global agricultural activities have been challenged to adopt environmentally friendly production strategies to reduce the opening of new unexplored areas and thus reduce the impact of climate change (Schultze-Kraft et al., 2018). Therefore, the challenge faced by both agriculture and beef cattle production is to produce more in order to meet the increase in domestic demand and exportation, both of which are economically important, and to accomplish all this without expanding the cultivated area already in use in the country, seeking sustainability.

The diversity of climate and soils in the Cerrado Biome implies extensive research in the application of sustainable land use strategies (Gomes et al., 2019). The combination of economically viable agricultural production and the protection of fragile sandy soils is very challenging, especially in the Cerrado region of western Bahia, which has been intensely anthropized since the 1980s and where there are sandy soils with low annual rainfall (Donagemma et al., 2016).

The first finding in the diagnosis of the farms in the region was that two or more annual harvests are not feasible without the use of irrigation (Santos et al., 2018). The second was that in exclusively agricultural farms, the land remains uncovered after the harvest and, at most, weeds or voluntary plants from the previous harvest grow. The third was that in cattle-raising farms, fodder emptiness during the dry season is quite intense, which requires the use of supplementation, feedlot, or semi-confinement, which may also lead to overgrazing, which results in the pastures degradation.

The knowledge of production models that incorporate the principles of a conservationist agriculture, such as the integrated systems of agriculture-livestock and direct planting (Donagemma et al., 2016; Flynn, Ribera, Calil, & Valdes, 2018), are of public domain and are essential for the sustainability and increase of agricultural and livestock production in these regions. The use of these systems has made it economically feasible to carry out more than one annual harvest in the rural areas, preventing fodder shortages in livestock, as well as bringing numerous other economic and environmental benefits in the medium and long term (Bungenstab, Almeida, Laura, Balbino, & Ferreira, 2019).

In this context, in the Brazilian sandy and fragile soils, pastures and forage plants used in integrated systems or just as soil cover in the critical inter-harvest period, are critical for erosion and soil temperature control. These plants increase the organic matter levels in the soil by stabilizing the structure and reducing soil losses due to leaching (Vilela et al., 2011; Gomes et al., 2019). Specifically for livestock, the daily growth rate of some forages and their adoption in new production systems may extend the grazing period at the beginning of the drought in the region, reducing the demand for supplementation, and increasing the efficiency of the activity.

The local diagnosis (Santos et al., 2018) pointed to the need to identify the best fodder crops with soil cover ability after the harvest of crops (grains and fibers) and those with potential to extend livestock production in the dry season. The definition of cultivars for this region in a non-random way, based on the results of technical-scientific studies, is essential, since this is a primary component that can result in the success or failure of the proposal and use of any of the integrated systems in the short and long term.

Therefore, this research aimed to evaluate grasses, legume, and a tropical cruciferous plant, with commercial seeds easily available and commonly used in the Brazilian forage cultivation, regarding the capacity of adaptation and growth/establishment after planting, as well as to evaluate its production potential in the annual water deficit period in the western region of Bahia State, Brazil.

Material and methods

The experiment with 29 forage cultivars was started in November 2018, with the sowing (except for *Cynodon* spp. cv. Tifton 85, which was planted through cuttings) in 5 x 5 m plots with 1.5 m between them, in a random block design with four repetitions. The experiment was carried out at the Santa Luzia Farm, which is part of the Trijunção Farm, located in the region of Cocos and Jaborandi, Bahia State, Brazil. The soil of the experimental area was classified as Red-Yellow argissolic dystrophic latosol, with a sand to loam texture (Santos et al., 2019), with the following characteristics (layer of 0-20 cm): pH in water = 6.07; Al = 0.01; Ca = 0.91; Mg = 0.36; H + Al = 0.87; T = 2.17 ($\text{cmol}_c\ \text{dm}^{-3}$); P-Mehlich 1 = 2.1; K = 14.3 (mg dm^{-3}); V = 59.5 (%); clay content = 12.6(%); organic matter = 0.67 (dag kg^{-1}). The climate of the region is classified as Aw, Tropical Seasonal dry winter according to the Köppen classification. The historical series of water capacity in the soil from 1998 to 2017 was presented by Albuquerque, Guimarães, Viana, Albuquerque Filho, and Santos (2020). The ten-day-scale climatological water balance, rainfall, and average temperature in the period of this experiment is showed in Figure 1.

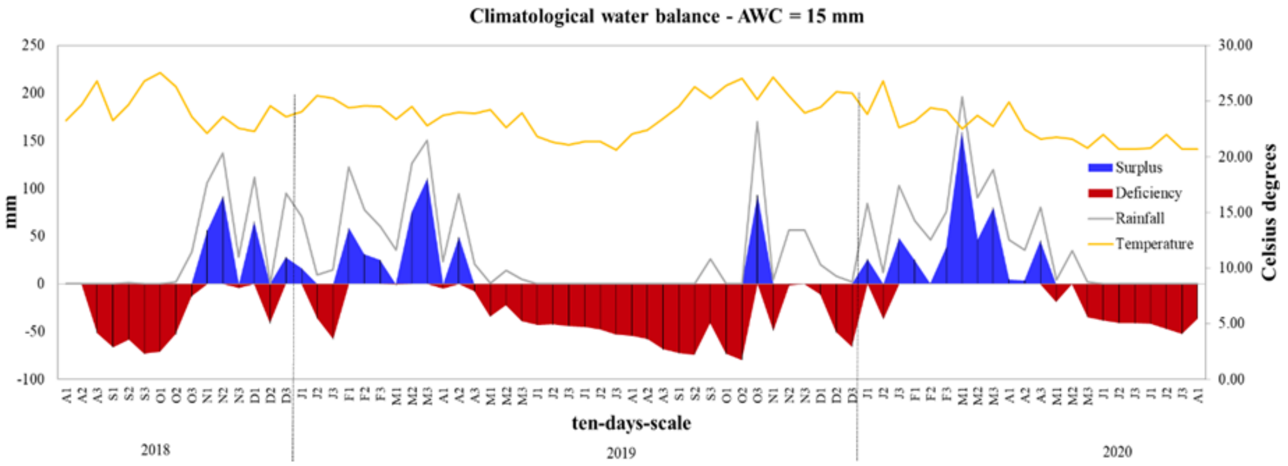

Figure 1. Climatologic water balance for available water capacity (AWC = 15 mm), rainfall (mm) and average temperature (°C) of each ten-day-scale, quantified during the forage evaluation period and the months of cutting, from August 2018 to August 2020, at the Santa Luzia Farm, Bahia State, Brazil.

The species and cultivars sown in November 2018 were the grasses *Cenchrus ciliares* (buffel grass); *Brachiaria brizantha* (syn. *Urochloa brizantha*) cv. Xaraés; *B. brizantha* cv. BRS Paiaguás; *B. brizantha* cv. BRS Piatã; *B. brizantha* cv. Marandu; *Brachiaria* spp. cv. BRS Ipyporã; *B. decumbens* (syn. *Urochloa decumbens*) cv. Basilisk; *B. ruziziensis* (syn. *Urochloa ruziziensis*) cv. Common; *Panicum maximum* (syn. *Megathyrsus maximus*) cv. BRS Zuri; *P. maximum* cv. Mombaça; *P. maximum* cv. Tanzânia; *P. maximum* cv. BRS Tamani; *P. maximum* cv. Massai; *P. maximum* cv. BRS Quênia; *Cynodon* spp. cv. Tifton 85; *Cynodon* spp. cv. Bermudagrass; *Andropogon gayanus*; *Avena strigosa* (black oat). Furthermore, the cruciferous *Raphanus sativus* (turnip) and the legumes *Calopogonium muconoides* (calopogonium); *Macrotyloma axillare* cv. Java; *Crotalaria ochroleuca*; *C. juncea*; *C. breviflora*; *C. spectabilis*; *Cajanus cajan* cv. Caqui; *Cajanus cajan* cv. Mandarim; *Stylosanthes capitata* + *S. macrocephala* cv. Campo Grande were also planted in the same period. In December 2019, the legume *Stylosanthes guianensis* cv. Bela was sown.

In the preparation of the area 2.5 t ha^{-1} of dolomitic limestone (PRNT 76%) was applied three months prior to planting and in the month before planting the area received 290 kg ha^{-1} of Monoammonium phosphate (MAP) and 100 kg ha^{-1} of KCl and micronutrients, according to the results of soil analysis and recommendation of Sousa and Lobato (2004). The nitrogen fertilization consisted in the application of 35 kg ha^{-1} of N after each cut, in the form of urea.

The six cuts of the fodder were performed in the following dates: i) Cut 1 in January 2019; ii) Cut 2 in March 2019; iii) Cut 3 in July 2019; iv) Cut 4 in December 2019; v) Cut 5 in February 2020; and vi) Cut 6 in June 2020.

The amount of rainfall between the seeding and the first cut was 233 mm for an interval of 77 days; between the first and the second cut, 437 mm, in 58 days; from the second to the third cut, 308 mm, in 103 days; from the third to the fourth cut, 332 mm, in 157 days; from the fourth to the fifth cut, 332 mm, in 74 days; and from the fifth to the sixth cut, 683 mm, in 106 days. Cut 2 was entirely discarded by fungal contamination of the samples during storage. Since in these two years of evaluation the rainfall was concentrated in the spring, summer and, to a lesser extent, autumn seasons, only Cut 4 can be considered as a drought cut, in which forages produced biomass during the annual water deficit period in the region, with about 2.11 mm average daily rainfall.

The forage grass plots were cut in an internal area of 4 m^2 at a height of 15 cm from the ground, leaving borders of one meter, which was later cut and the material discarded. The green samples of the plots were weighed in the field and a sub-sampling of approximately 300 g was performed, which was again weighed and placed to dry in an oven at 65°C, until constant weight, for the determination of dry mass and calculation of yield converted into tons per hectare (t ha^{-1}).

In contrast to grasses cuts, when making each of the cuts of the perennial and semi-perennial fodder legume *Cajanus cajan* cvs. Mandarim and Caqui, *Calopogonium muconoides* (calopogonium), *Macrotyloma axillare* cv. Java, and *Stylosanthes capitata* + *S. macrocephala* cv. Campo Grande, only one square meter on the diagonal of the plot (1 m^2) was cut. The processing of the cut samples was later identical to that of the grasses, as described above. This difference between the legume cuttings from those of the grasses occurred for two reasons. First due to the lack of knowledge about the regrowth capacity of these legume cultivars in the region and their cutting height. The second because of poor knowledge about their survival capacity, yield in the dry period of the region, and regrowth capacity in the new water surplus period. Thus, the green and dry mass yield of each cut of these legumes considers the accumulation of fodder between the date of planting and the date of a given cut. For example, the green mass of the third cut corresponds to the material that remained in the plot, growing, from planting to the realization of this cut.

Based on this information, the dry mass yield (DMY) was estimated and converted to tons per hectare. The percentage of dry mass (por DM) was estimated by dividing dry mass by green mass and multiplying by 100. The daily dry mass accumulation (DM daily) of each cut was estimated by dividing the dry mass by the interval of days between cuts and then converting the result to daily kilograms per hectare. The DMY variable of all cuts was added in order to result in the total dry mass yield in the period, and also DMY was estimated separately for the wet (Cuts 1, 3, 5, and 6) and dry (Cut 4) periods. The Drought Stress Index (DSI) and the Daily Drought Tolerance Index (DSI daily) were also estimated, dividing the mean (or daily mean) dry mass yield in the period of water deficit by the mean (or daily mean) value obtained in the period of water surplus, expressed as a percentage according to Cheruiyot, Midega, Van den Berg, Pickett, and Khan (2018).

It was necessary to reseed *Panicum maximum* cv. Quênia, cv. Tamani and Mombaça, because the seeds did not germinate well in the first seeding. The same occurred with *Cenchrus* spp., but it was not replanted. Thus, their production was estimated from the new seeding and their respective cuts after replanting were considered in the analysis. The cultivars *Cynodon* spp. cv. Tifton-85 and *Andropogon gayanus* did not produce enough to make the first cuts, so the cutting was only started when the plants reached adequate development. The annual fodder crops were not re-seeded in 2019 and, therefore, their evaluations were carried out in only one or until the fourth cut, depending on the duration of their life cycle and the dehiscence of the seeds, such as *Crotalaria juncea*.

Considering the above information and that not all cultivars were evaluated in multiple cuts or were concurrent during the whole experimentation period, the analysis of variance and tests of means of the treatments for the variables were performed for each cut separately. Analysis of variance was also performed for the perennial forages repeated measures according Resende (2002). The coefficient of cultivar repeatability was estimated for DMY based on cuts 1, 3, 5, and 6 (water surplus) excluding cut 4 (water deficit) not repeated. So, repeatability was estimated based on:

$$\hat{\rho} = \frac{\hat{\sigma}_p^2}{\hat{\sigma}_p^2 + \hat{\sigma}_{et}^2}$$

in which $\hat{\sigma}_p^2$ and $\hat{\sigma}_{et}^2$ are the estimated permanent variance among cultivars and the estimated environmental temporary variance, respectively. The permanent phenotypic value of cultivars was predicted as:

$$\widehat{PV}p = \mu + \beta_p(\mu_i - \mu)$$

$$\beta_p = \frac{\hat{\sigma}_p^2}{\hat{\sigma}_p^2 + \hat{\sigma}_{et}^2/m};$$

in which m is the number of cuts estimated by the harmonic mean of cultivars cuts; μ is the general mean of all cuts and μ_i is the mean of cultivar *i* in multiple cuts. The accuracy was estimated as:

$$(\beta_p)^{1/2}.$$

The previous analyses and Pearson's correlation and Principal Component Analysis (PCA) were performed using the R Project for Statistical Computing software (R Core Team, 2020).

Results and discussion

The results of the analysis of variance univariate for total dry mass yield and perennial cultivars repeated measures are presented in Table 1. A significant treatment effect was found for all treatments and no significance was recorded for blocks (not showed), revealing an entirely randomized design. The experimental coefficients of variation were high (CVe > 30%) in the analyses of the DMY, Cuts 1, 3, 4, and 6. However, this did not affect the significant statistical difference of treatments evaluated in each cut.

Table 1. Analysis of variance of the total dry mass (DMY), in t ha^{-1}, between cultivars, for each cut made in 2019 and 2020 and Drought Tolerance Index (DSI), and analysis of variance for DMY in perennial cultivars in multiple cuts (DMY-RM).

	DMY					DSI	DMY-RM
	Cut 1	Cut 3	Cut 4	Cut 5	Cut 6		
Source of variation	MS	MS	MS	MS	MS	MS	MS
Cuts	-	-	-	-	-	-	136.0**
Treatment	40.7**	40.1**	55.4**	91.1**	43.0**	727.7**	47.6**
Residue	10.3	16.7	7.8	8.4	7.3	306.2	17.9
CVe (%)	83.3	36.2	63.7	25.4	32.2	31.1	45.9

MS: mean square; CVe: experiment coefficient of variation; ** significant at 5% probability level according to the test-F.

The results of DMY means of treatments for the cuts 1 and 4 are presented in Figure 2, as well as DMY phenotypic value for the perennial forages and their Drought Tolerance Index (DSI). The results of cuts 1 and 4 were quite revealing when the forages were considered separately according to their classification by species and cultivar. In Cut 1, *B. ruziziensis*, *B. decumbens* cv. Basilisk, and *Panicum maximum* cv. Zuri displayed excellent establishment speed, and production capacity, which reached a dry mass yield above 8 t ha^{-1} in 77 days. Under severe drought conditions perennial forage grass cultivars presented a significant reduction in dry mass yield (Figure 2 - Cut 4), although they regrew and increased their productivity in the next period of water surplus (data not showed).

Among the legumes/cruciferous *C. spectabilis* and the forage turnip performed well, with dry mass accumulation above 2.5 t ha^{-1} in 77 days (Figure 2 – Cut 1). *Stylosanthes* spp. cv. Campo-Grande and the cultivars of *Cajanus cajan* (Mandarim and Caqui) presented slower establishment; however, at Cut 4 their accumulated dry mass yield surpass statistically from the grass yield (Figure 2 – Cut 4). This last result should be interpreted with caution, since these legumes were not in competition with grasses on the same plot, a situation that would probably reduce their production if grown together (Boddey, Casagrande, Homem, & Alves, 2020). *Stylosanthes guianensis* cv. Bela produced more than 10 t of dry mass per hectare between sowing in December/2019 and the first cut in June/2020. *Stylosanthes* spp. cv. Campo Grande did not regrow after Cut 5, and the only legume that remained alive until Cut 6 were the two pigeonpea cultivars and *Stylosanthes* cv. Bela. Cut 4 was considered a cut made after water deficit and it presented the high yield of total dry mass of the cv. Mandarim. However, even not separated in its botanical components (leaf, stem, dead material), Mandarim had few leaves at that time and its dry mass yield was due, mainly, to the weight of the stems.

The estimated DMY coefficient of cultivar repeatability was equal to 0.33, considered of low magnitude, and the accuracy was equal to 0.79, considered of moderate magnitude (Resende, 2002). Low magnitude repeatability in this case is due to the high magnitude of temporary environmental variance which means, in fact, an opportunity for multipurpose cultivar selection in this sandy environment. This parameter allowed the prediction of perennial species and cultivars permanent phenotypic value for DMY, per perennial cultivar per cut (Figure 2 – PVp – DMY). So, the expected future performance or probable ability of production/yield of cultivars evaluated in that sandy soils have been ranked.

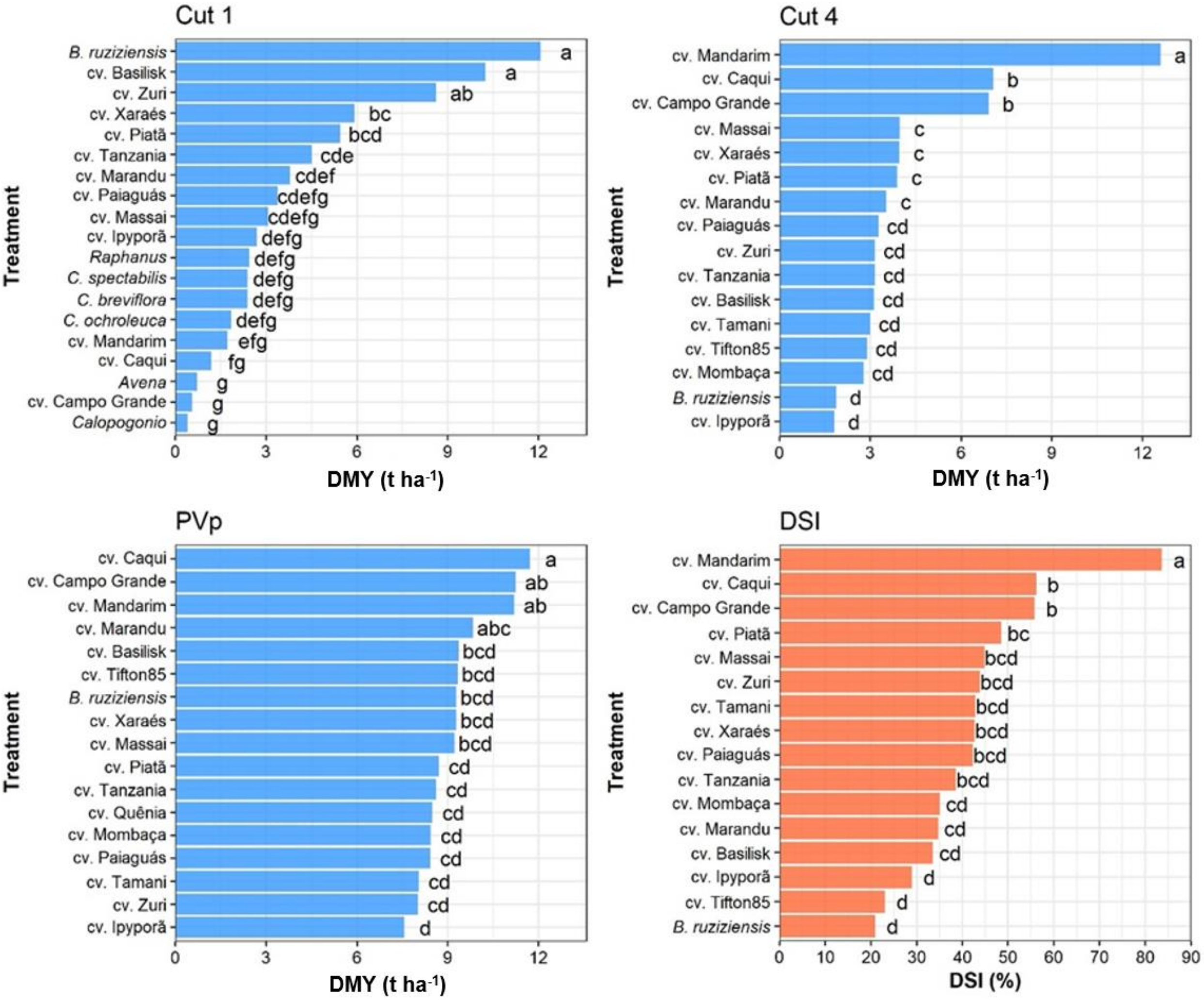

Figure 2. Average total dry mass yield, in t ha^{-1}, for the cuts 1 and 4; DMY predicted phenotypic permanent value (PVp) for perennial cultivars for cuts performed in water surplus and Drought Tolerance Index (DSI, % - last graph) of perennial cultivars evaluated in five cuts at Santa Luzia Farm, Bahia State, Brazil. Different letters in the graphs indicate significant differences by LSD test, $p < 0.05$.

When considering the Drought Tolerance Index (Figure 2 - DSI), a difference between cultivars of *Brachiaria* was observed. DSI of Piatã (48%), Paiaguás (42%), and Xaraés (43%) were higher than those for cultivars Marandu (34%), Basilisk (33%), Ipyporã (28%), and *B. ruziziensis* (20%). *P. maximum* cultivars presented similar magnitudes of DSI, except the cv. Mombaça (35%). Chereuiyot et al. (2020), who did not evaluate the cultivars of *Panicum* in their work and neither some of the *Brachiaria* cultivars here analyzed, also reported the higher tolerance to severe drought by the Xaraés and Piatã cultivars. These authors observed a low DSI in the Mulato I, Mulato II, and Cayman cultivars, all resulting from interspecific hybridization in which one of the genitors was a tetraploid *B. ruziziensis*. A low DSI was evidenced in the present work for cv. Ipyporã, which is also an interspecific hybrid resulting from the crossing of *B. brizantha* and *B. ruziziensis* (Valle et al., 2017). The DSI data of the other species/cultivars absent in Figure 2 - DSI were not estimated either because they are annual or because they were not submitted to Cut 4. Among the legumes, *Cajanus cajan* cv. Mandarim (84%), cv. Caqui (56%), and *Stylosanthes* spp. cv. Campo Grande (56%) stood out in the DSI. The drought tolerance of the species of these genera of legume was well known, as reported by Sinha et al. (2020).

Table 2 shows the average daily dry mass yield (DMY daily) for the perennial grass/legume cultivars in the different cuts. Consistent evidence is that the DMY daily during the period preceding Cut 4 was the lowest for all legume forages except for cv. Mandarim (mean of 73.95 kg ha^{-1} day).

Table 2. Estimated daily dry mass yield for the period between the cuts of the fodder crop cultivars, at the Santa Luzia Farm, Bahia State, Brazil.

	Cut 1	Cut 3	Cut 4	Cut 5	Cut 6
cv. Caqui	15.36 *c*	132 *abc*	45 *b*	314 *a*	168 *a*
cv. Mandarim	22.31 *c*	168 *a*	112 *a*	195 *b*	153 *a*
cv. Campo Grande	-	101.55 *cd*	44 *bc*	357 *a*	-
cv. Basilisk	133.05 *a*	111 *abcd*	20 *bcd*	153 *bcdef*	45 *c*
B. ruziziensis	156.69 *a*	76 *cd*	12 *d*	159 *bcd*	54 *bc*
cv. Xaraés	76.69 *b*	97 *cd*	25 *bcd*	180 *bc*	76 *bc*
cv. Marandu	34.81 *bc*	162 *ab*	23 *bcd*	133 *cdefg*	70 *bc*
cv. Piatã	58.47 *bc*	109 *bcd*	25 *bcd*	155 *bcde*	60 *bc*
cv. Massai	18.05 *c*	102 *cd*	25 *bcd*	140 *cdefg*	80 *b*
cv. Tanzania	42.86 *bc*	101 *cd*	20 *bcd*	123 *defg*	76 *b*
cv. Paiaguás	33.54 *bc*	113 *abcd*	21 *bcd*	105 *defg*	73 *bc*
cv. Tifton85	-	85 *cd*	18 *cd*	160 *bcd*	72 *bc*
cv. Zuri	59.03 *bc*	90 *cd*	20 *bcd*	100 *g*	61 *bc*
cv. Ipyporã	30.94 *bc*	98 *cd*	12 *d*	95 *g*	63 *bc*
cv. Mombaça	-	107 *bcd*	18 *cd*	104 *efg*	56 *bc*
cv. Tamani	-	63 *d*	19 *bcd*	103 *fg*	73 *bc*
cv. Quênia	-	-	-	94 *g*	91 *b*

Treatments with the same letter in the same column are not significantly different by LSD test. Symbol - means treatment was not evaluated in the cut.

The selection for adaptation represents a key factor in the identification of those forages for cultivation in the soil and climate conditions found in the target region, both for use in pastures and for use as cover plants in agriculture, aiming at direct planting in the next harvest. Regardless of the main use, the question of drought tolerance is central to the selection for adaptation in the western region of Bahia, especially considering that the regional rainfall period is usually restricted from five to six months in each year and that all species and cultivars tested in this experiment showed some growth in those edaphoclimatic conditions.

Drought tolerance in plants can be defined as the ability to endure and grow, throughout the period of low water supply (Chereuiyot et al., 2020). Therefore, besides the variables evaluated in a previous work (Santos et al., 2019), this study estimated the drought stress index (DSI), both for total (DSI Total) and daily dry mass yield (DSI daily), since the production data were evaluated after the period of intense water deficit. In this period, the average daily rainfall was less than 2 mm. Together with these two indexes, this study analyzed all the characteristics of green and dry mass yield per cut, as well as their daily production and the percentage of dry mass in the periods of water surplus and deficit. The phenotypic correlations between these characteristics allowed the identification of those with high correlation and significance and to define which would be used in the PCA.

The correlations (with significance) between variables used in the PCA are presented in Table 3. The higher correlations were found between total dry mass yield of the six cuts (DMY total) and total dry mass yield in the water surplus period (DMY wet), equal to 0.99; and between the DSI and the daily DSI, equal to 0.96. The correlations between the daily dry mass yield (DMY daily) among all cuts was significant only after Cut 3, and even so, reinforcing that repeatability magnitude does not enable us to predict with high accuracy the production of a cultivar in subsequent cuts.

Table 3. Phenotypic correlations for total dry mass yield (DMY total), in the period of water surplus (DMY wet) and water deficit (DMY dry), in t ha^{-1}; percentage of dry mass in the water surplus and deficit period (per DM wet and per DM dry, respectively); daily dry mass accumulation in Cuts 1, 3, 4, 5, and 6 (DMY daily), in kg ha^{-1} day; and the Drought Tolerance Index (DSI and DSI daily), in percentage.

	DMY total	DMY wet	DMY dry	perDMY dry	perDMY wet	DMY1 daily	DMY3 daily	DMY4 daily	DMY5 daily	DMY6 daily	DSI
DMYwet	0.99										
DMYdry	0.81	0.72									
perDMY dry	0.88	0.84	0.84								
perDMY wet	0.27	0.28	0.17	0.31							
DMY1 daily	0.28	0.34	0.01	0.12	0.03						
DMY3 daily	0.54	0.59	0.23	0.56	0.29	0.43					
DMY4 daily	0.74	0.68	0.82	0.86	0.26	0.19	0.61				
DMY5 daily	0.32	0.38	0.00	0.33	0.20	0.33	0.60	0.36			
DMY6 daily	0.20	0.24	-0.02	0.25	0.21	0.06	0.53	0.34	0.47		
DSI	0.79	0.70	0.96	0.90	0.23	0.01	0.36	0.89	0.12	0.10	
DSIdaily	0.69	0.59	0.98	0.98	0.16	-0.06	0.16	0.82	-0.03	-0.02	0.96

Correlations underlined are significant at $p < 0.05$ by Student´s *t*-test.

The PCA result is presented in Figure 3. The first two components explained approximately 69% of the variation among the evaluated cultivars. It is interesting to observe that most of the perennial forage grasses were grouped apart from the other perennial legume cultivars according to the daily dry mass in the cuts from the water surplus period. The perennial legumes cv. Mandarim, cv. Campo Grande, and cv. Caqui, were differentiated from all the others by the tolerance to drought, represented by the variables dry mass percentage and dry mass yield (DMY dry) in the period of water deficit (por DM dry), DSI, DSI daily, and daily dry mass yield in Cut 4 (DMY4 daily).

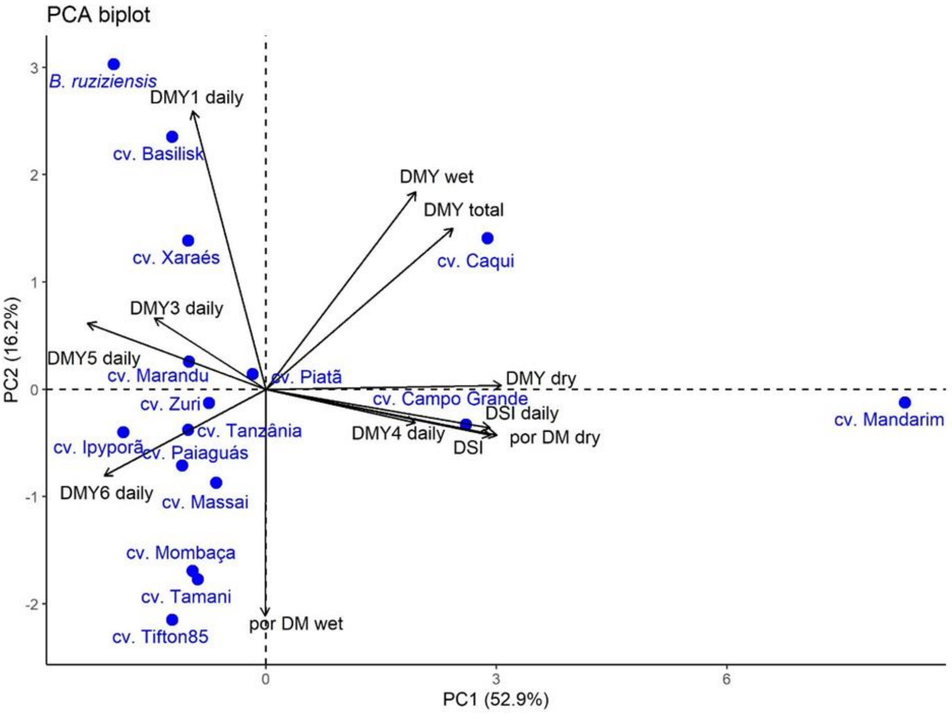

Figure 3. Biplot of the Principal Component Analysis of the standardized characteristics associated with dry mass yield of 23 Grasses and legumes forage crops, evaluated for their adaptability to the climatic conditions of Southern Western Bahia, Brazil, in five cuts, in 2019 and 2020. Contribution in percentage to the differences between the cultivars in the PC1 (52.9%) and PC2 (16.2%) components, on the x and y axes, respectively.

Regarding the water stress condition, pointed out by the arrows on the second upper and lower quadrant (Figure 3), the cv. Piatã is the closest to the most tolerant legumes. This result should be interpreted with caveats since the dry mass yield of cv. Piatã in the period of water deficit (3.97 t ha^{-1}) was less than half of the average production in the water surplus period (8.4 t ha^{-1}). Moreover, its recovery capacity and average production after the water shortage (Cuts 5 and 6) is only 13% higher than the average of Cuts 1 and 3. In contrast, based on the average of Cuts 5 and 6, Xaraés and Massai produced 34.6 and 58.8% more, respectively, than the average of Cuts 1 and 3. This indicated the immense capacity of recovery of the latter two after the water stress. Furthermore, cvs. Mandarim and Caqui produced 60 and 91% more, respectively, in the same condition described above and showed different recovery capacities after hydric stress. That is, cv. Caqui presented lower DSI than cv. Mandarim, but showed a higher capacity of recovery after the water stress (Figures 2 – DSI and 3).

The drought tolerance in plants can be expressed in many ways, such as escape (short cycle), presence of deep and dense roots, higher tolerance to heat, reduced stomatal conductance, compensatory growth, presence of reserve tissues, among others (Meena & Kaur, 2019). In the present work, endurance was defined as the survival, reproduction, and productive capacities throughout the evaluation period. Based on all the results presented, the cultivars evaluated in the region can be classified in several ways, one of which will be explained in the following division, whose components are not exclusive: i) species/cultivars of rapid establishment after sowing: cv. Basilisk, *B. ruziziensis*, forage turnip, and *Crotalarias*; ii) species/cultivars with higher tolerance to water deficit: cv. Piatã, cv. Xaraés, cv. Mandarim, and cv. Campo Grande; iii) species/cultivars that recover and continue the high production after the water deficit: cv. Xaraés, cv. Tifton85, cv. Massai, cv. Piatã, *B. ruziziensis*, cv. Marandu, cv. Tanzania and cv. Caqui; iv) species/cultivars of slower establishment, but of high and continuous productivity after this initial phase, without considering the period of hydric stress: cv. Marandu, cv. Xaraés, cv. Massai, cv. Piatã, cv. Tifton-85, and cv. Basilisk.

Annual cycle species strategically promote an escape from the dry period, especially those of extremely short cycle, such as forage turnip, black oat, and *C. breviflora*, analyzed in this research. They showed rapid initial growth, bloomed, produced seeds, and became senescent before the start of the annual water deficit period. In addition, these species can be classified as those that require low-input to develop, but at the same time return low-output biomass. They are thus considered to be efficient in adaptation (survival and investment in reproduction) since they limit their development to the most favorable period of the year. Therefore, their contribution to land cover is only temporary.

In addition, perennial grasses, and semi-perennial fodder legumes (*Stylosanthes* spp. and *Cajanus cajan*) presented an adaptive response to drought different from those of the annual species. They presented growth and production defined as median input and output and can be considered plants with a highly adaptive efficiency, since they invest in accumulation of reserves in roots or in the base of the plant to survive and reproduce more often over time, usually for two or more years (Meena & Kaur, 2019). Thus, these plants showed continuous growth without water deficits, but tolerated periods of drought because they preserved living growth points and, certainly, because they had energy reserves at their roots, which were mobilized when conditions became favorable for growth again (Cuts 5 and 6). This adaptive response was evidenced in some species and tested cultivars, in grasses with higher biomass production in more than one cut, and in semi-perennial legumes that, despite presenting a slower growth, were kept alive after the period of water deficit.

Decision-making and indication of forage cultivars for grazing

In the decision-making about the indication of forage grass cultivars to attend the livestock in the region, cvs. Xaraés, Marandu, Massai, Tanzânia, Paiaguás, and Zuri are the best options, in that order. The cv. Paiaguás also presented potential for production in the period, preceding the water deficit, and its use to postpone supplementation and, in addition, for deferral and using pasture as supplementation in the dry season. The cultivars of *Panicum maximum*, Massai, Tanzânia, and Zuri, are interesting for use in the region, including the fact that cv. Massai is relatively easier to manage in relation to cv. Mombaça, also that *Panicum* cultivars have better nutritional quality than the *Brachiaria* cultivars (Jank, Barrios, Valle, Simeão, & Alves, 2014). Cv. Quênia needs to be evaluated longer in the region to estimate its DSI.

The most indicated legumes for pasture were those semi-perennials. The two pigeonpea and the two *Stylosanthes* cultivars meet this requirement since, besides fixing nitrogen, they have a high protein and tannin content. This meets the demand to increase the production per area and per animal, besides promoting the increase of the carbon stock in the soil and the reduction of greenhouse gas emissions by animals (Bues et al., 2013).

Even though this study provided much information, the extension of this study should consider new experiments with these forages under pasture, properly managing them to define the rotation of animals in the paddocks, the support capacity in different seasons and under trampling, and carrying out adjustments of grazing intensity. The results of green and dry mass yield, for example, can be different when compared to the yield and growth under cut or grazing, or if they are in consortium or not (Grace et al., 2019).

Regardless of the indication of forage adapted for pasture, in a region that has medium to low and poorly distributed rainfall and low fodder production in the dry period, some options to meet the needs of livestock during the water deficit must be permanent (Finch et al., 2016).

Decision-making and indication of fodder cultivars for soil cover adapted to the sandy soils of Bahia

In the decision-making process of choosing forage crops as cover plants for the inter-harvest period, which protect the soil during the period of water deficit, promote the accumulation of carbon and organic mass, and form a quality straw for direct planting in the next harvest, the objective is to evaluate the potential of combining species/cultivars. This approach assumes that plots with a greater diversity of species usually have greater temporal stability and will probably contribute more to the increase of the organic mass content in sandy soil. Temporal stability is based on the "security" hypothesis of Cleland et al. (2013), in which differential responses among species to environmental changes enable functional compensation as species are grown and die, and thus there is a maintenance of the cover, improvement of surface moisture, and potential contribution to surface fertility as decomposition of the species that perished takes place. This is the rationale behind the species combination theory for use as cover plants.

This work assessed the dry mass yield of all forages under experimentation but not the C:N ratio after sampling. Sousa et al. (2019) evaluated some of the forages studied in this work and showed that *B. ruziziensis*, *C. juncea*, and *C. cajan* were those with the highest C:N ratio and highest dry mass yield. Thus, they considered these species as those with the highest potential for cover, either in single planting or in consortium with other forages.

Based on the aforementioned, the choice of forage candidates for cover plants differs from the choice of species for grazing purposes since those cultivars need to be able to establish themselves quickly in the area and adequately cover the soil in the short term, because the interval between the harvest and the beginning of the water deficit period is short. Survival and high yield in the medium and long term are not as important for cover plants. In this aspect, the decision should prioritize those species/cultivars that established and produced greater dry mass before Cut 3.

In this way, hypothetically, the indication of cover plants focuses on the grasses cv. Basilisk and *B. ruziziensis*, which were the ones with the highest establishment and production speed after sowing. The fact that these two species are susceptible to spittlebugs (such as *Notozulia entreriana* and *Deois flavopicta*) should be considered in terms of risk before planting in areas of high infestation. Regarding the legumes/cruciferous, the indications are for those with higher establishment speed, higher dry mass yield, and resistance/ability of controlling the regional soil nematodes. Thus, from this group, the forage turnip meets the first requirement; the *Crotalaria* spp. meet the first and the last; the *Stylosanthes* spp. meet the second and the last; and pigeonpea meets the second requirement.

The indication of forage for grazing purposes pointed to the use of cultivars only for pasture, but not for other potential uses, such as integrated crop-livestock systems. In this system, the agricultural and forage crops are cultivated simultaneously and, after harvesting the crop, the pasture is already grown and can be used longer during the water deficit. Another possibility, untested, was the sowing of pasture after the harvest of the summer crop. In this case, the growth and development phases of tropical forage grass can be altered, therefore not inducing flowering in the first year. Once the proper rainfall conditions are in place at the end of the water surplus period, the fodder might present a higher nutritional quality during the water deficit period and thus supply the nutritional needs of the animals during the period called "fodder emptiness", that is, low pasture and animal production during the water deficit period. This possibility needs to be evaluated, including its economic viability.

Two other issues also emerged when considering the choices of species/cultivars as cover plants. The first refers to the fact that the sowing of the experiment herein presented was carried out in the period of water surplus, with overlapping of the time in which the agricultural crops were sown. In this case, the production capacity of these species is unknown if sown in the final third of the water surplus period in the region. That is, if sowing is carried out between the end of February and the beginning of March, would there be time for adequate establishment/production of dry mass, cover, and reduced degradation of the dry straw before the next period of water surplus for direct planting of the crop? This question needs to be addressed experimentally in future works.

The second issue refers to the acceptance or refutation of the hypothesis that plants of faster establishment and growth resulting from experimentation on plots, and their combinations of legumes/cruciferous/Gramineae species are capable of forming the best straw mulch for direct planting (Sousa et al., 2019). Therefore, one of the extensions of this work is to include, in future experiments, some treatments with species mixtures that do not meet the initial hypothesis, i.e., species of slower establishment, with greater tolerance to drought, higher C:N ratio, and other possible combinations. According to the scientific method, this should be the most indicated strategy and it is the one that should be adopted in the validation and indication of species and cultivars for the region in order to cover the soil in the period of water deficit.

Conclusion

The cultivars adapted and indicated for regional continuous pasture were Xaraés, Marandu, Massai, Tanzânia, Paiaguás, and Zuri, in this order. However, neither one attended to the complete fodder needs in the period of annual water deficit in the western region of Bahia State, Brazil. The grasses *B. ruziziensis* and *B. decumbens* were indicated for use as cover plants after the harvest due to their high capacity of establishment and short-term production.

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