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Research Paper

Effect of irrigation on biomass production and components of dallis grass (*Paspalum dilatatum*) and Bahia grass (*P. notatum*) in Uruguay

Efecto del riego sobre la producción de biomasa y componentes del pasto dallis (Paspalum dilatatum) *y pasto Bahía* (P. notatum) *en Uruguay*

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Abstract

Use of irrigation in forage production systems based on perennial C4 grasses has been limited because of inconsistent responses of biomass production to water. The effects of three different levels of irrigation on growth of *Paspalum notatum* (Bahia grass) and *P. dilatatum* (dallis grass) over two consecutive growing seasons were studied. The phenological state of the plants was inferred by the proportion of lamina and non-lamina components. While irrigation failed to increase annual dry matter yield of forage, phenological composition of forage was affected by irrigation with both species showing changes in distribution of dry matter accumulation among different above-ground plant parts. Future research on these species should study the effects of moisture deficit on phenology to better understand the effects of irrigation.

Keywords: Growth rate, phenology, tropical forage, water management, warm-season grasses.

Resumen

El uso de riego en sistemas de producción de forraje basados en gramíneas perennes C4 se ha visto limitado debido a las respuestas erráticas de la producción de biomasa a la irrigación. Se estudió el efecto de tres niveles diferentes de riego sobre *Paspalum notatum* y *P. dilatatum* durante dos temporadas de crecimiento consecutivas. El estado fenológico de las plantas se infirió por la proporción de componentes lámina y no lámina. Los resultados mostraron que la composición fenológica del forraje se vio afectada por el riego, aunque no resultó en un aumento en el rendimiento anual, ambas especies mostraron cambios en la distribución de la acumulación de materia seca entre las diferentes partes aéreas de la planta. Futuras investigaciones sobre estas especies deberían estudiar el efecto del déficit de humedad sobre la fenología, para comprender mejor los efectos del riego.

Palabras clave: Especies herbáceas tropicales, fenología, forraje, manejo del agua, tasa de crecimiento.

Introduction

Adoption of C4 grass species is an efficient alternative for producing feed for livestock (Biran et al. 1981) in regions like Argentina, southern Brazil, Uruguay, South Africa and New Zealand. Limitations to the use of highly productive C4 perennial grasses (Cunha et al. 2007), including difficulties in crop establishment and uncertainty in production associated with irregular weather conditions, have prevented wide adoption of perennial warm season grasses by commercial producers (McCormick et al. 2009). Appropriate species for these areas require high water use efficiency to produce high yield and should be adapted to the

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environment (Neal et al. 2011). The unpredictable nature of rainfall and evapotranspiration during the warm season limits potential growth rates (Giménez and Lanfranco 2012) and results in a high year-to-year variability in herbage production (Royo Pallarés et al. 2005) with many producers opting for C3 species with simpler management and higher resilience but lower productivity in such environments. The use of irrigation in forage production can be a potentially valuable strategy to reduce pasture seasonality (Giménez and García Petillo 2011). However, it is necessary to improve the understanding of why highly productive perennial species do not always respond to irrigation (Forde et al. 1976; Marais et al. 2006).

Water management is intended to overcome water deficits allowing pastures to achieve high growth rates and increase forage production and quality during critical periods (Beaty et al. 1974). Adjustments to the quantity and timing of irrigation are needed to achieve efficient water use, which involves maintaining soil moisture at levels sufficient for plants to reach their potential transpiration, while minimizing losses to the environment. Understanding root depth, minimum water content in the soil to avoid stress and the soil water holding capacity are important for determining irrigation frequency (Snyman 1994). Recently, a model to estimate water use efficiency was developed for bioenergy perennial grasses (Kiniry and Kim 2020). In many cases, effects of irrigation are not consistent and it may either increase production (Harris and Lazenby 1974) or even depress growth at high water volumes (Marais et al. 2006; Stone et al. 2012).

Bahia grass (*Paspalum notatum* Flüggé) and dallis grass (*Paspalum dilatatum* Poir.) produce early forage in spring and have a high level of adaptation to frost (Costa and Scheffer-Basso 2003). Both species show high variability in the summer, associated primarily with climate and its effects on the phenological stage of the plant (Pereira et al. 1978). Positive responses to irrigation in these species may be expected in areas with high levels of radiation and temperature and soils with non-limiting nitrogen availability (Stone et al. 2012). The irrigation regime modulates partitioning of photoassimilates by producing a larger and deeper root system under reduced irrigation (Jordan et al. 2003), which in turn affects the phenological responses of the plant. Dallis grass exhibits a considerable degree of phenological synchronization among tillers (González-Barrios et al. 2016), reflected in the proportions of lamina and non-lamina components. Increased growth rates of the whole plant during both vegetative and reproductive stages have been reported as a response to rainfall during the summer (Speranza 2017).

Both Bahia grass and dallis grass are adapted and productive species with potential to improve forage availability, reduce pasture variability over time and avoid negative impacts on the cool season component of the pasture mixture (Costa and Scheffer-Basso 2003; Tejera et al. 2015). Irrigation is expected to improve warm season forage production. Most published results for warm season grasses report only cumulative seasonal values for whole plants and responses of different plant components to different levels of water availability are more limited. The aim of this research was to evaluate the responses of different production components under cutting of two C4 grasses subjected to different levels of water availability.

Materials and Methods

Pasture treatments, management and measurements

The study was carried out at the Mario A. Cassinoni Experimental Station of the Facultad de Agronomía, Universidad de la República, in Paysandú, Uruguay (32°23' S, 58°02' W). The experiment was located on a mild slope on soils classified as Cambisols, with a composition of 35.1 % sand, 29.7 % silt and 35.2 % clay (Altaminino et al. 1976). Rainfall shows an isohygric pattern throughout the year; average annual rainfall is 1,238 mm and mean annual temperature is 18.4 ºC (Castaño et al. 2011). The experimental site had been planted previously with a mixture of *Dactylis glomerata* L. and *Medicago sativa* L. for 4 years. Plots were cleared and sown in February 2010 to dallis grass (*P. dilatatum* var. *dilatatum* Australian commercial seed) and Bahia grass (*P. notatum* var. *saurae* cultivar 'Pensacola') at a rate of 12 kg/ha. All plots were fertilized with 43.6 kg P/ha at seeding and received 5 applications per year of 50 kg N/ha, applied after each harvest during the experimental period.

The trial was established as a Randomized Complete Block Design with a split-plot treatment arrangement with 3 replications. The entire plot was irrigation level and sub-plots were the grasses (Bahia grass and dallis grass). Each individual experimental unit was 10 m^2. Treatments consisted of three levels of water availability: no irrigation (NIR), irrigation to 50 % of reference evapotranspiration (50 % ET0) and irrigation to 100 % of reference evapotranspiration (100 % ET0). Irrigation was applied with fixed sprinklers with a flow of 70 l/h during the night to avoid drift. The Penman-Monteith equation (Allen et al. 2006) was used to estimate evapotranspiration (ET), while values of temperature, humidity, radiation and wind speed were collected from an automatic weather station every 30 minutes. The time for irrigation was estimated by calculating water balance (Thornthwaite and Mather 1955), the desired level of soil moisture and intended ET for each treatment by providing differing numbers of irrigation events, applying 48 mm of water at each event. Data published by Jia et al. (2009) for Bahia grass were used to obtain the crop coefficient (kc) and applied to both species due to the lack of specific information for dallis grass and because no differences were expected between warm season grasses. Water balance was calculated (Thornthwaite and Mather 1955) showing the crop ET (ETC: potential without nutrition or disease limitations, kc=0.9). An approximation of ET (average kc=0.75) was used for the irrigation treatments to account for foliar recovery after harvests (Jia et al. 2009).

Samples were taken during the warm season from December 2010 to April 2011 (year 1) and November 2011 to April 2012 (year 2). Subperiods between harvests varied between 25 and 37 days to allow the pasture to reach a minimum height of 15 cm. Prior to the first evaluation, pastures were harvested at 5 cm stubble to homogenize the plots. Biomass was sampled from three 0.2 m × 0.5 m quadrats/plot cut to 5 cm stubble. Following sampling, remaining forage on each experimental unit was mowed to 5 cm stubble and removed. Samples were sorted into green lamina (lamina) and other components, including stems, inflorescences, dead material and leaf sheaths (pseudostem), in the laboratory, dried at 60 °C for 72 h and weighed. At the end of each experimental period, tiller density was determined using a 0.2 m × 0.5 m quadrat and tiller weight was measured by sampling 20 tillers/plot cut at ground level and dried at 60 °C until constant weight.

Statistical analysis

The response variables analyzed were total production, lamina and pseudostem production, tiller density and tiller weight by species. These variables were analyzed individually using ANOVA. By adjusting the split plot design per year for each subperiod and species, the accumulation rates of lamina and pseudostem were analyzed to determine the interaction between irrigation level and the corresponding subperiod effect. Cumulative yield for the 2 years or comparison between species was not considered. Data were analyzed using GLM and means were compared by a Tukey test using a P-value 0.05 significance level. Prior to analysis, model assumptions (normal distribution, independence of errors and homogeneity of variances) were validated. Subperiods (repeated measurements in time on GLM) were also studied by an autocorrelation matrix of the 1st order to improve model fitness. The model used was:

$$Y_{ijk} = \mu + \tau_i + \beta_j + \delta_{ij} + (\tau\beta)_{ij} + P_k + (\tau P)_{ik} + \xi_{ijk}$$

where:

Y is the response variable;

μ is the general experimental mean;

τ is the effect of ith treatment;

β_j is the effect of jth block;

δ_{ij} is the random effect associated with observation Y_{ij}. (error A);

$(\tau\beta)_{ij}$ is the effect of interaction between ith treatment and jth block;

P_k is effect of kth subperiod;

$(\tau P)_{ik}$ is the effect of interaction between ith treatment and kth subperiod; and

ξ_{ijk} is the random error associated with observation Y_{ijk}.

Statistical analysis was done using InfoStat (Di Rienzo et al. 2018).

Results

The analysis of rainfall and ET data by period shows potentially critical subperiods with lower rainfall and ET, as well as subperiods with a higher level of precipitation and lower ET (Figure 1). Subperiods 1 and 2 in 2010–2011 and 2011–2012 required more frequent irrigation to allow a greater ET rate in irrigated treatments associated with higher temperature (Figure 1). Comparing precipitation during the trial period with the historical trend (1980–2009) of average monthly precipitation (Castaño et al. 2011) (106 mm January, 125 mm February, 138 mm March, 159 mm April, 102 mm May, 68 mm June, 56 mm Jul, 55 mm August, 71 mm September, 121 mm October, 123 mm November, 113 mm December), the monthly distribution of rainfall was similar to the historical trends during both years under study and lower rainfall was observed only in the first half of the growing season (Figure 1).

Yields of lamina, pseudostem and lamina + pseudostem were not significantly different between irrigation treatments or species, except for Bahia grass in 2011–2012 with only the 50 % ET0 producing significantly higher yields than NIR, both for lamina +

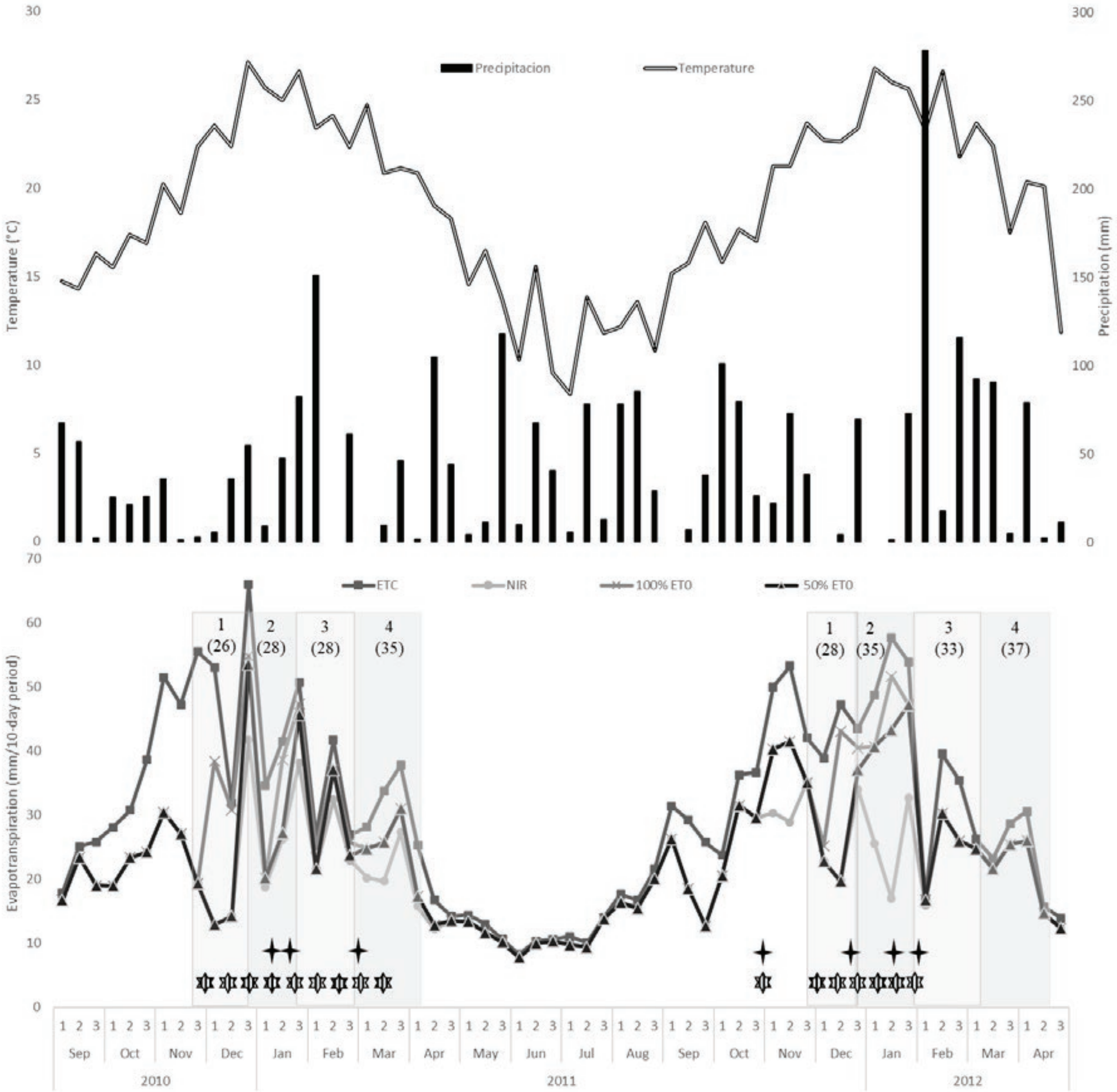

Figure 1. Precipitation, temperature, crop evapotranspiration (ETC) and actual evapotranspiration (ET) in the three irrigation treatments (100 % ET0, 50 % ET0 and NIR) from September 2010 until April 2012. 100 % ET0=irrigation to 100 % of evapotranspiration; 50 % ET0=irrigation to 50 % of evapotranspiration; NIR=no irrigation; ★=time of irrigation in 100 % ET0; ✦=time of irrigation in 50 % ET0. Four grey bands with numbers 1–4 and parenthesized values show subperiods 1–4 (length of regrowth periods following harvesting, days). Numbers 1, 2 and 3 above the months indicate the first, second and third 10-day periods (8 d in February and 11 d in October, December, January and March).

pseudostem and pseudostem (Table 1). For dallis grass, treatments were not significantly different in any season (Table 2). Both species were almost unresponsive to the irrigation treatments, showing a similar behavior in response to supplemental water. Production in 2011–2012 was much lower than in 2010–2011 due to a reduction in tiller population ($P<0.001$), but no significant differences ($P>0.05$) were found among treatments (Tables 1 and 2).

Production by subperiods showed significant differences in above-ground production for both species (Figures 2 and 3). For Bahia grass, differences in lamina production were detected among treatments in subperiod 2 in 2010–2011 (Figure 2). For dallis grass, differences in pseudostem production were detected for subperiod 2 in the first summer only (Figure 3). Irrigation increased production of both species ($P<0.01$) in periods of high ET and radiation when water deficits took place (subperiod 2; Figure 1). However, there was no response to irrigation treatments towards the end of the summer (Figures 2 and 3). Components of aboveground production showed significant differences in dallis grass for the pseudostem component in 2010–2011 and the lamina fraction in 2011–2012 (Figure 3). Alternation in growth rate was observed with an earlier significant increase in the pseudostem

Table 1. Yields of lamina + pseudostem, lamina, pseudostem and density and weight of tillers in *Paspalum notatum* (Bahia grass) under different irrigation treatments (100 % ET0=irrigation to 100 % of evapotranspiration; 50 % ET0=irrigation to 50 % of evapotranspiration; NIR=no irrigation) in 2010–2011 and 2011–2012.

Year	2010–2011			2011–2012		
Parameter/Treatment	100 % ET0	50 % ET0	NIR	100 % ET0	50 % ET0	NIR
Lamina + pseudostem (kg DM/ha)	9,653 ±390	9,253 ±662	8,402 ±251	4,968ab ±368	5,881a ±439	4,229b ±297
Lamina (kg DM/ha)	5,878 ±451	5,858 ±589	5,268 ±225	3,413 ±248	3,609 ±329	2,834 ±292
Pseudostem (kg DM/ha)	3,774 ±70	3,395 ±400	3,134 ±466	1,555ab ±188	2,236a ±234	1,395b ±51
Tiller density (number/m^2)	2,760 ±205	2,813 ±167	2,253 ±114	1,397 ±87	1,597 ±117	1,440 ±179
Tiller weight (g)	0.37 ±0.06	0.32 ±0.01	0.35 ±0.03	0.41 ±0.02	0.4 ±0.14	0.4 ±0.07

Values are mean ± s.e. Values with different letters within each variable and each year differ significantly ($P < 0.05$).

Table 2. Yields of lamina + pseudostem, lamina, pseudostem and density and weight of tillers in *Paspalum dilatatum* (dallis grass) under different irrigation treatments (100 % ET0=irrigation to 100 % of evapotranspiration; 50 % ET0=irrigation to 50 % of evapotranspiration; NIR=no irrigation) in 2010–2011 and 2011–2012.

Year	2010–2011			2011–2012		
Treatment	100 % ET0	50 % ET0	NIR	100 % ET0	50 % ET0	NIR
Lamina + pseudostem (kg DM/ha)	11,091 ±768	8,288 ±661	9,175 ±5,126	4,024 ±131	4,058 ±849	5,019 ±1,506
Lamina (kg DM/ha)	6,106 ±145	4,812 ±459	4,683 ±445	2,173 ±105	2,262 ±200	2,933 ±850
Pseudostem (kg DM/ha)	4,985 ±636	3,476 ±205	4,492 ±280	1,851 ±155	1,670 ±347	2,086 ±665
Tiller density (number/m^2)	2,720 ±144	2,813 ±127	2,613 ±127	743 ±140	990 ±201	1,020 ±140
Tiller weight (g)	0.33 ±0.06	0.32 ±0.05	1.08 ±0.73	0.62 ±0.06	0.48 ±0.17	0.62 ±0.06

Values are mean ± s.e.

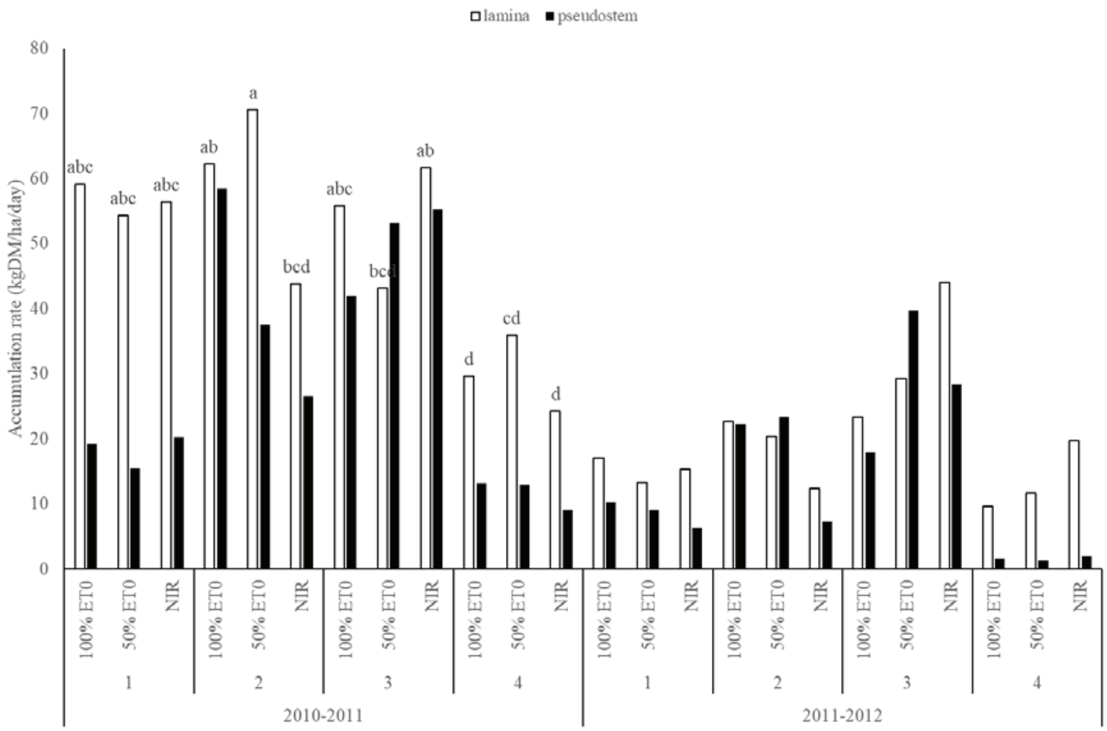

Figure 2. Rates of lamina and pseudostem accumulation in *Paspalum notatum* (Bahia grass) in irrigation treatments (100 % ET0=irrigation to 100 % of evapotranspiration; 50 % ET0=irrigation to 50 % of evapotranspiration; NIR=no irrigation) and regrowth periods (subperiods 1–4) in 2010–2011 and 2011–2012. Values with different letters within each component and year differ significantly ($P<0.05$).

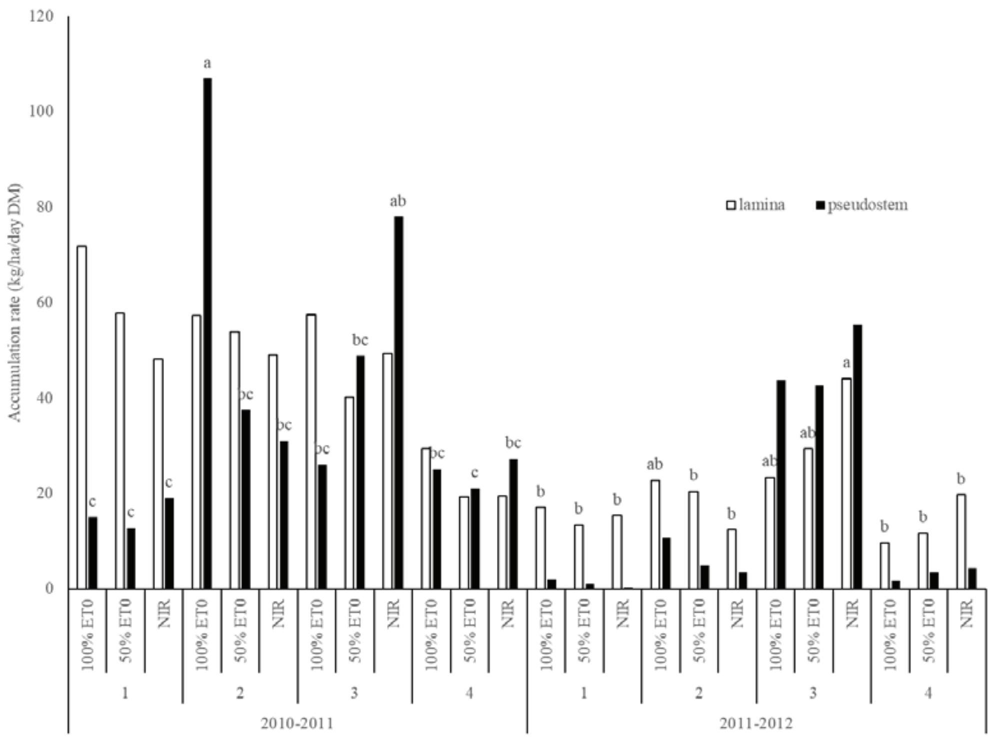

Figure 3. Rates of lamina and pseudostem accumulation in *Paspalum dilatatum* (dallis grass) in irrigation treatments (100 % ET0=irrigation to 100 % of evapotranspiration; 50 % ET0=irrigation to 50 % of evapotranspiration; NIR=no irrigation) and regrowth periods (subperiods 1–4) in 2010–2011 and 2011–2012. Values with different letters within each component and year differ significantly (P<0.05).

component for the 100 % ET0 (subperiod 2). For Bahia grass in 2010-2011, the lamina component was significantly lower than for 50 % ETO in subperiod 2 for NIR. The pseudostem component was not significantly reduced, with an amount proportional to the lamina accumulation rate, with increasing growth rate for NIR in subperiod 3.

Discussion

The addition of supplementary water did not produce a consistent and significant increase in forage production for the species studied. One of the possible reasons may be that both grasses are drought-tolerant and the distribution and volume of precipitation did not result in frequent or extended periods of moisture stress (Pezzopane et al. 2017). Total forage production of dallis grass was not affected by supplementary water at any time during the growing season, while the effects on Bahia grass were significant in the second growing season. The same absence of overall response has been reported before for several warm season perennials. Rodrigues et al. (2005) did not find a response when evaluating *Cynodon* sp. under 3 water management conditions in the Brazilian tropical zone and Forde et al. (1976) found no response in dallis grass during 2 summers with below-average precipitation under similar climatic conditions. Owensby et al. (1970) found no responses in forage production when comparing addition of nitrogen + moisture with nitrogen only to a number of warm season grasses in Manhattan, Kansas. Mislevy and Everett (1981) even reported a negative response to supplementary irrigation on warm season grasses and found that non-irrigated plants accumulated nutrients more efficiently. Bahia grass and dallis grass maintained effective nutrient and water uptake under low soil moisture through the development and penetration of roots into the soil (Ogata et al. 1985) , although Pezzopane et al. (2017) reported these species can exhibit different strategies of response and potential adaptation during water stress conditions.

One factor that is not always considered when measuring the response of perennial warm season grasses to irrigation is the phenological state of the plant when moisture stress occurs. A comparison between Bahia grass and *P. urvillei*, a member of the Dilatata group and a close relative of dallis grass (Vaio et al. 2019), showed that these species were very different in terms of phenological synchronization among tillers through the growing season. *P. urvillei* showed concentrated flowering earlier in the season (Lopes and Franke 2011) consistent with the curves reported for dallis grass (González-Barrios et al.

2016). Synchronization in the phenological stage of the tillers can be approximated by recording the development of lamina and non-lamina components (including pseudostem and inflorescence) because only tillers induced to the reproductive stage will elongate stems and internodes, for both dallis grass (Costa and Scheffer-Basso 2003) and Bahia grass (Beaty et al. 1968).

A considerable degree of phenological synchronicity among tillers is expected in dallis grass (González-Barrios et al. 2016). Plants of dallis grass clipped at different phenological stages can vary substantially in forage production and levels of reserves (Pereira et al. 1978). Under field conditions, the availability of moisture when the leaf/sheath ratio is low (reproductive stage) may not be translated into a higher growth rate, while for plants which received the same precipitation in a vegetative stage, production increased more than twofold in dallis grass (Speranza 2017). At least for some warm-season species which show several relatively synchronic reproductive phases during the growing season, the efficiency of using supplementary water for forage production may be highly dependent on the general phenological stage of the plants.

For Bahia grass, differences in yield among treatments affected both lamina and pseudostem in relatively similar ways. The peaks of pseudostem production observed in dallis grass were not found in Bahia grass (Adjei et al. 1992), which is explained by the different phenological behavior of the two species. Owing to differences in plant architecture (Lopes and Franke 2011), variations in the non-lamina components in Bahia grass cannot be attributed to flowering as in dallis grass. The most noteworthy result obtained with Bahia grass was the observed trend of intermediate irrigation levels outperforming higher irrigation, which deserves further study. Lack of response to different moisture levels in root development of Bahia grass has been also reported, although moderate deficits may even promote underground growth (Sinclair et al. 2011).

The data show that the phenological composition was affected by irrigation. However, it is necessary to understand how moisture deficit is related to the onset of each flowering cycle. Our results also suggest that there may be negative effects of the highest irrigation treatments. In the second growing season, when tiller densities were lower, subperiods were observed in which the addition of water at 100 % ET0 tended to depress growth rates for both species. In the case of Bahia grass, plots under intermediate levels of irrigation tended to outperform those at higher irrigation levels. This detrimental effect of higher irrigation levels has been observed before and has been attributed to leaching or changes in the use of nutrients (Mislevy and Everett 1981; Marais et al. 2006). These species have been shown to maintain effective nutrient and water uptake at low soil moisture levels through the development and penetration of roots in plants under water stress (Ogata et al. 1985), which may also explain the lack of response to higher irrigation. This trend should be specifically addressed in future research by specifically recording performance using intermediate levels of water replenishment.

Conclusions

This research confirmed that phenological composition of forage from Bahia grass and dallis grass was indeed affected by irrigation, although not directly reflected in an increase in annual dry matter yield. Instead, effects of irrigation depended on the species and were mostly observed during specific periods of the growth cycle. Forage production of Bahia grass and dallis grass during summer may not be as directly related to the availability of water as expected, even under significant moisture stress. Although different in growth habit and morphology, both species showed changes in the distribution of dry matter accumulation among the different aboveground structures in response to watering, not always resulting in an increase in yield. Further research to examine moisture deficit in these species should take into account plant phenology as well as the compensating mechanisms of each species and responses to intermediate levels of irrigation.

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(Note of the editors: All hyperlinks were verified 5 January 2023).

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