Controlled deficit irrigation on growth variables of *Pennisetum purpureum* x *Pennisetum typhoides*

Riego deficitario controlado en las variables de crecimiento del *Pennisetum purpureum* x *Pennisetum typhoides*

Irrigação deficitária controlada nas variáveis de crescimento do *Pennisetum purpureum* x *Pennisetum typhoides*

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Crop production

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Abstract

Currently, efficiency in water use in agriculture is being sought through techniques that allow for the reduction of the water footprint of crops. This is why the effect of controlled deficit irrigation on the growth variables of King Grass Morado (*Pennisetum purpureum* x *Pennisetum typhoides*) was evaluated in the canton of Chone, Ecuador. The treatments studied were: irrigation levels at 40, 60, 80, and 100 % of the crop evapotranspiration (ETc). The grass was sown in black polyethylene bags with a capacity of 10 kg of soil. A completely randomized experimental design with repeated measures over time was used, along with five replicates. The results obtained from the Friedman test showed significant differences ($p<0.0001$) due to the effects of the study factors: deficit irrigation and successive cuts of the grass on the net assimilation rate of the grass (TAN), growth rate (TC), relative growth rate (TCR), and leaf area index (IAF) did not occur in the same way for the interaction between them. When the irrigation sheet is applied at 80 % of ETc, the TC is better at 0.0002409 $g.(dm^2.d)^{-1}$, TCR is -0.00022 $g.g.d^{-1}$, and TAN is 0.0072065 $g.(dm^2.d)^{-1}$. The leaf area index performs best with the irrigation sheet at 100 % of ETc with 1.81. King Grass Morado can reduce its actual water requirement by up to 80 % without being affected in growth variables.

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Resumen

Actualmente se busca la eficiencia del uso del agua en la agricultura con técnicas que permitan reducir la huella hídrica de los cultivos, Es por ello que se evaluó el efecto del riego deficitario controlado en las variables de crecimiento del pasto King Grass Morado (*Pennisetum purpureum* x *Pennisetum typhoides*) en el cantón Chone, Ecuador. Los tratamientos en estudio fueron: lamina de riego al 40, 60, 80 y 100 % de la evapotranspiración del cultivo (ETc). El pasto se sembró en bolsas de polietileno color negra con capacidad de 10 kg de suelo. Se utilizó un diseño experimental completamente aleatorizado con medidas repetidas en el tiempo, y cinco repeticiones. Los resultados obtenidos en la prueba Friedman determinaron diferencias significativas ($p<0,0001$) por efecto de los factores de estudio: riego deficitario y cortes sucesivos del pasto en la tasa de asimilación neta del pasto (TAN), tasa de crecimiento (TC), tasa de crecimiento relativo (TCR) e índice de área foliar (IAF) no sucedió así para la interacción entre ellos. Cuando se aplica la lámina de riego al 80 % de la ETc es mejor la TC 0,0002409 $g.(dm^2.d)^{-1}$, TCR -0,00022 $g.g.d^{-1}$, TAN 0,0072065 $g.(dm^2.d)^{-1}$. El índice de área foliar tiene el mejor comportamiento con la lámina de riego al 100 % de la ETc con 1,81. El pasto King Grass Morado puede disminuir hasta el 80 % de su necesidad hídrica real y no verse afectado en las variables de crecimiento

Palabras clave: restricción hídrica, pasto de corte, variables fisiológicas.

Resumo

Atualmente, procura-se a eficiência do uso da água na agricultura com técnicas que permitam reduzir a pegada hídrica das culturas. Por isso, foi avaliado o efeito da irrigação deficitária controlada nas variáveis de crescimento do capim King Grass Morado (*Pennisetum purpureum* x *Pennisetum typhoides*) no cantão de Chone, Equador. Os tratamentos em estudo foram: lâmina de irrigação a 40, 60, 80 e 100 % da evapotranspiração da cultura (ETc). O capim foi semeado em sacos de polietileno de cor preta com capacidade para 10 kg de solo. Utilizou-se um desenho experimental completamente aleatorizado com medidas repetidas no tempo e cinco repetições. Os resultados obtidos no teste de Friedman determinaram diferenças significativas ($p<0,0001$) devido ao efeito dos fatores de estudo: rega deficitária e cortes sucessivos da relva na taxa de assimilação líquida da relva (TAN), taxa de crescimento (TC), taxa de crescimento relativo (TCR) e índice de área foliar (IAF), não acontecendo o mesmo para a interação entre eles. Quando se aplica a lâmina de rega a 80 % da ETc, a TC é melhor com 0,0002409 $g.(dm^2.d)^{-1}$, TCR -0,00022 $g.g.d^{-1}$, TAN 0,0072065 $g.(dm^2.d)^{-1}$. O índice de área foliar tem o melhor comportamento com a lâmina de rega a 100 % da ETc com 1,81. A relva King Grass Morado pode diminuir até 80 % da sua necessidade hídrica real e não ser afetada nas variáveis de crescimento.

Palavras-chave: restrição hídrica, corte de capim, variáveis fisiológicas.

Introduction

Latin America is an area where grasses are grown, especially in tropical climates. In Ecuador, the largest area of arable land is used for pasture. In Manabí and especially in the canton of Chone, livestock producers use Purple King Grass (*Pennisetum purpureum* x *Pennisetum typhoides*) as the main feed for their animals (ESPAC, 2022). In semi-arid environments, climate is the main responsible for seasonal variations in forage production, thus defining the seasonality of forage supply in two seasons, rainy and dry (Chavarría *et al*., 2017 and Maranhão *et al*., 2020).

Efficient water use in agriculture is a priority for sustainable food production. Irrigation compensates for crop water losses due to evapotranspiration, achieving a water balance for optimal production (López *et al*., 2018). To be more efficient in water use, controlled deficit irrigation (CDI) is a practice that partially reduces irrigation during periods of low sensitivity to water stress or when adverse effects on productivity are minimised (Tapia *et al*., 2021).

Irrigation is one of the most important agricultural techniques for pasture management, especially in more water-demanding grasses such as switchgrass. Deficit irrigation is an option to optimise water use in switchgrass production without affecting its growth and production. The physiological response of grasses to water stress to counteract it, then transforms into normal processes to survive and be able to produce according to the conditions present (Hajri *et al*., 2023). Several studies conducted on species of agricultural interest demonstrate the relationship between the physical-metabolic processes of plants (respiration, transpiration and photosynthesis) and production (Mastalerczuk and Borawska, 2021); but there is no research on the relationships between growth rates (Leaf Area Index, grass growth rate, relative growth rate, net assimilation rate) and water consumption of Purple King Grass.

The objective of this research was to evaluate the incidence of controlled deficit irrigation levels on the growth responses of Purple King Grass (*Pennisetum purpureum* x *Pennisetum typhoides*) in the canton of Chone, Ecuador.

Materials and Methods

Location of the study

The study was carried out at the experimental farm 'Campus Chone' of the Pontificia Universidad Católica del Ecuador-Sede Manabí (PUCEM), canton of Chone, province of Manabí, Ecuador, at 36 m above sea level. The climatic characteristics of the area were 986.3 $mm.yr^{-1}$ of precipitation; 90 % relative humidity; 25.62 °C average daily temperature and 1288.75 $mm.yr^{-1}$ evaporation (INAMHI, 2016). In addition, the edaphic parameters were, flat topography; pH 6.5 - 7.5; good drainage; with loam soil texture and electrical conductivity of 0.13 $dS.m^{-1}$.

Purple King Grass establishment and management

The grass was planted in black polyethylene bags with a capacity of 10 kg of soil, 35 cm diameter and surface area of 0.38 m^2 (Blanco *et al*., 2021). Twenty-five bags per treatment were used, for a total of 500 bags for the whole experiment. They were spaced 1 x 1 m apart. The establishment time was 60 days.

When the weed population exceeded 10 % infestation, manual control was carried out. *Spodoptera frugiperda* reached the threshold of economic damage (15 %) so Chlorpyrifos® was applied. The application rate was 2.5 $mL.L^{-1}$ of water.

Fertilisation was carried out according to the recommendations for the estimated grass yield (Hernández *et al*., 2021). This activity was carried out on the second day of cutting, applying fertilizer to the soil. Nitrogen was applied in the form of Urea 434.78 $kg.ha^{-1}$. In addition, to obtain the estimated production, a foliar fertilizer based on micronutrients (Mg, B, Cu, Fe, Mn, Mo, Zn) was applied at a dose of 10 $g.L^{-1}$ of water.

A uniformity cut was made prior to the beginning of the research and consisted of cutting all the grass of the experimental units at ground level. This activity was carried out in June, when the dry season begins on the Ecuadorian coast.

Irrigation

The water used for irrigation came from a surface stream (pipe) that originates in the upper part of the PUCEM farm. A water analysis was carried out. The results obtained for the different physical-chemical parameters and the USDA classification (Rodríguez *et al*., 2022) indicate that the water used is of good quality and suitable for irrigation (C2S1).

Irrigation scheduling for purple king grass

To elaborate the daily irrigation schedule, ETo was determined by the Penman Monteith FAO method (Chavarría *et al*., 2020), crop evapotranspiration (ETc) under standard conditions (Chavarría *et al*., 2017). The Kc obtained for Purple King Grass at the study site, for the dry period were: 1.01, 1.20 and 1.53 which were recorded every 15 days, during the grass recovery period. The irrigation lamina varied considering the treatments under study. The applied water was dosed with graduated plastic test tubes. In addition, tensiometers were placed to monitor soil moisture status.

Treatments under study

It consisted of applying different deficit irrigation rates in a controlled way, during grass growth in each experimental unit: (L1) Application of 40 % of the ETc. (L2) Application of 60 % of the ETc. (L3) Application of 80 % of the ETc. (L4) Application of 100 % of the ETc.

Study variables

Net assimilation rate (NAR), expressed in $g.cm^{-2}$ of leaf area. day^{-1}

The formula for the calculation of physiological growth parameters according to Di Benedetto and Tognetti (2016) was used:

$$NAR = \left(\frac{DW2 - DW1}{LA2 - LA}\right)\left(\frac{\log LA2 - \log LA1}{T2 - T1}\right)$$

Where: DW1 = Initial dry weight, DW2 = Dry weight t, LA1 = Initial leaf area, LA2 = Leaf area t, Log: Neperian logarithm, T1 = Day 0 (uniformity cut) and T2 = Days after cut t.

Grass growth rate (GGR), expressed in $g.cm^{-2}$ of $soil.day^{-1}$

The formula for the calculation of physiological growth parameters according to Di Benedetto and Tognetti (2016) was used:

$$GR = \left(\frac{(DW2 - DW1)}{SA(T2 - T1)}\right)$$

Where: PS1 = Initial dry weight, PS2 = Dry weight t, T1 = Day 0 (uniformity cut), T2 = Days after cut t. and SA: Area of soil occupied by the plant.

Relative growth rate (RGR), expressed in $g.g^{-1}.day^{-1}$

The formula for the calculation of physiological growth parameters according to Di Benedetto and Tognetti (2016) was used:

$$RGR = \left(\frac{(LogDW2 - LogDW1)}{(T2 - T1)}\right)$$

Where: DW1 = Dry weight of sample 1, DW2 = Dry weight of sample 2, Log: Neperian logarithm, T1 = Day zero of uniformity cut and T2 = Days after uniformity cut.

Leaf area index (LAI)

The total leaf area of the selected plants in the sampled useful area was determined by photographing the leaves with a flatbed scanner and analysing them with the free software ImageJ version 1.46 (Rasband, 2007). The following formula was used: LAI= leaf area / soil area.

Experimental design and statistical analysis of results

A completely randomised design (CRD) was used. Sampling used 4 plants which were located in the middle of each treatment. There were 5 replicates for the treatments under study. Cuttings were made at 45, 90, 135 and 180 days to obtain data. The analysis of results was by repeated measures over time, and a predictive model of the interaction of the treatments is presented for each variable evaluated. As the growth variables did not follow a normal distribution, they were evaluated using Friedman's non-parametric analysis. The statistical package used to process the data was InfoStat (Di Rienzo *et al*., 2020).

Results and discussion

Net assimilation rate of grass (NAR)

According to Friedman's non-parametric analysis, there were significant differences ($p<0.0001$) due to the effect of the study factors: deficit irrigation and successive cuts of grass; this was not the case for the interaction between them. According to the mean tests, the highest value was recorded with the 80 %ETc lamina, while the lowest value was for the 40 %ETc lamina. As for the cutting factor, the highest NAR value was obtained at 45 days, while the lowest NAR was at 180 days (table 1).

Table 1. Net assimilation rate of Pennisetum purpureum x Pennisetum typhoides by effect of controlled deficit irrigation (%ETc) and successive cuttings.

%ETc	Net assimilation rate of grass ($g.dm^{-2}.d^{-1}$)	Cuts	Net assimilation rate of grass ($g.dm^{-2}.d^{-1}$)
40	-0.034366[d]	45 days	0.043651[a]
60	0.0031326[b]	90 days	-0.013829[b]
80	0.0072065[a]	135 days	-0.022922[c]
100	0.0009842[c]	180 days	-0.049132[d]

[a,b,c,d]Different letters for each mean indicate statistical differences ($p<0.01$).

For each irrigation treatment, a quadratic equation was generated (figure 1) that estimated TAN as a function of days after cutting ($p<0.01$), with a coefficient of determination (R^2) ranging from 0.86 to 0.99.

The most restrictive deficit irrigation treatment (40 % ETc) obtained the lowest NAR value, to the point that it was negative (figure 1), due to the minimum assimilation of photoassimilates for the growth processes, and this behaviour can be interpreted as an activation of the response processes to the water deficit. NAR decreased progressively from the first (45 days) to the last cutting (180 days), the reasons for this reduction in photosynthetic rate with the cuts could be the elimination of leaf biomass, less meristematic activity and growth of new leaves after successive cuts, the depletion of reserves (carbohydrates, nutrients) at the base of the plant and roots necessary to generate new growth after each cut.

According to Hajri *et al.* (2023) this occurs because controlled deficit irrigation generates water stress in plants, which prioritise the photorespiration mechanism and accelerates leaf senescence (ageing).

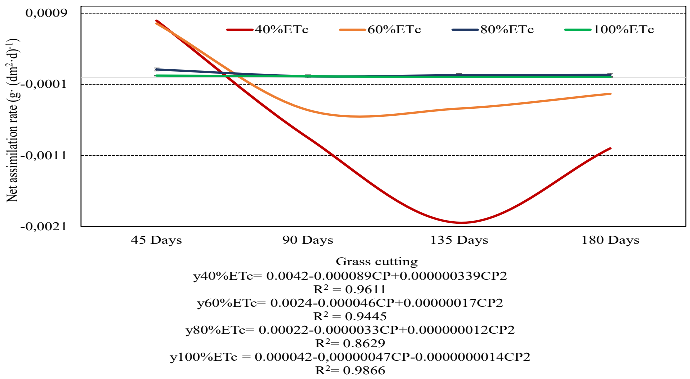

Figure 1. Net assimilation rate of *Pennisetum purpureum* x *Pennisetum typhoide* due to the effect of controlled deficit irrigation (%ETc) and successive cuts.

In this regard, Fariaszewska *et al*. (2020), Mastalerczuk and Borawska (2021) and Ghafar *et al*. (2021) indicated that drought stress triggered changes in plant physiological and biochemical responses, including photosynthesis, water relations, antioxidant defence and osmotic adjustment. Likewise, water deficits suspend grassland growth and decrease biomass yields (Velasco *et al*. 2018). Zhang *et al*. (2022) described morphological and biochemical changes as strategies to cope with water stress in tropical grasses. On the other hand, De Oliveira *et al*. (2024) highlighted that understanding the mechanisms that allow adaptation and tolerance to water stress in tropical grasses can help to improve their management and the selection of superior genotypes. Finally, in the ecological context it may affect the direction of plant tolerance to soil water deficiencies (Garcia and Eubanks, 2019).

Grass growth rate (GGR)

Friedman's non-parametric analysis detected significant differences ($p<0.0001$) in the effect of deficit irrigation and successive cuts on the GGR variable. The GGR was higher with the 80 %ETc and 100 %ETc mist, and did not differ statistically from each other; the lowest value was for the 40 %ETc mist, but it did not differ from 60 %ETc (table 2). As for the successive cuts factor, it was similar to NAR; at 45 days the highest value of GGR was obtained, decreasing progressively until 180 days, being this last cut the one that showed the lowest value of the variable.

Table 2. Grass growth rate of *Pennisetum purpureum* x *Pennisetum typhoides* by the effect of controlled deficit irrigation (%ETc) and successive cuttings.

%ETc	Grass growth rate (g. dm⁻².d⁻¹)	Cuts of the grass	Grass growth rate (g. dm⁻².d⁻¹)
40	0.0000709[c]	45 days	0.0009727[a]
60	0.0000793[bc]	90 days	-0.0001002[b]
80	0.0002409[a]	135 days	-0.0001025[c]
100	0.0002424[a]	180 days	-0.0001365[d]

[a,b,c,d]Different letters for each mean indicate statistical differences ($p<0.01$).

For each irrigation treatment, a quadratic equation was generated (figure 2) that estimated the expected GGR as a function of days after cutting ($p<0.01$), with a coefficient of determination (R^2) ranging from 0.89 to 0.94.

The negative GGRs can be influenced by various conditions of the experiment, including the effect of the bags in which the plants were planted. However, the discrepancy in growth rates between treatments can be explained by the availability of water and the periodicity or timing of grass clippings.

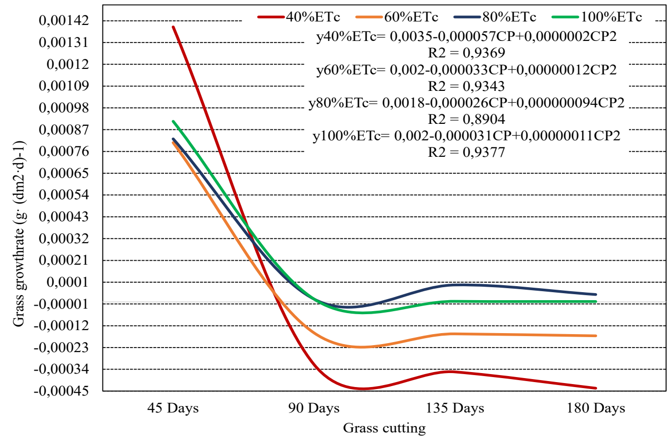

Figure 2. Grass growth rate of *Pennisetum purpureum* x *Pennisetum typhoide* due to the effect of controlled deficit irrigation (%ETc) and successive cuts.

These conditions suggest that plants may have allocated more resources to recovery after cutting, to the detriment of vegetative growth. These results coincide with Retureta *et al*. (2019) who state that, particularly in grasses, water availability (rainfall or irrigation) plays an important role in growth, since its deficit reduces photosynthesis, absorption and transport of nutrients, which is expressed as reduced plant growth and development.

Under field conditions, at 3,000 masl, with a warm temperate climate, average temperature of 13 °C.yr⁻¹ and 700 mm of precipitation, under these conditions Prudencio *et al*. (2020) found that Cameroon grass showed higher growth rates (196.51 kg.ha⁻¹.day⁻¹) than Maralfalfa (179.32 kg.ha⁻¹.day⁻¹) and King grass (179.58 kg.ha⁻¹.day⁻¹), which was influenced by the higher dry biomass content achieved. However, Cortes and Olarte (2018) reported rates of 66.67 kg dry biomass.ha⁻¹.day⁻¹ of purple King Grass harvested at 60 days.

Relative growth rate (RGR)

According to Friedman's non-parametric analysis for RGR, significant differences ($p<0.0001$) were generated due to the effect of deficit irrigation and successive cuts of the grass. It presented its highest value with the 100 %ETc lamina; the lowest value corresponded to the 40 %ETc lamina. With respect to the successive cuts factor, the highest value was obtained at 90 days and the lowest at 45 days (table 3).

For each irrigation treatment, a quadratic equation was generated (figure 3) that estimated the expected RGR as a function of days after cutting ($p<0.01$), with a coefficient of determination (R^2) ranging from 0.78 to 0.99.

Under extreme water deficit conditions (40 % and 60 %ETc), the photosynthetic rate decreases and interrupts carbohydrate metabolism and sucrose level in the leaves, resulting in a decreased growth rate. This, of course, represents a net loss of biomass, results that coincide with Di Benedetto and Tognetti (2016) and León *et al*. (2021) where they indicate that this measure is ideal in physiological studies aimed at understanding the factors that regulate the net partitioning of photoassimilates to the different organs of agronomic interest. In this sense, Starks *et al*. (2019), when the plant is shorter, the spatial configuration of the tillers is different, characterised by fewer stems of reduced thickness and the crop also has fewer leaves and, therefore, lower yields; this is a physiological response of adaptation of plants to conditions that are not optimal for their growth.

Table 3. Relative growth rate of *Pennisetum purpureum* x *Pennisetum typhoides* by effect of controlled deficit irrigation (%ETc) and successive cuttings.

%ETc	Relative growth rate ($g.g^{-1}.d^{-1}$)	Cuts	Relative growth rate ($g.g^{-1}.d^{-1}$)
40	-0.00923[d]	45 days	-0.00891[d]
60	-0.00911[c]	90 days	-0.00227[a]
80	-0.00022[b]	135 days	-0.00299[b]
100	-0.00003[a]	180 days	-0.00441[c]

a,b,c,d Different letters for each mean indicate statistical differences ($p<0.01$).

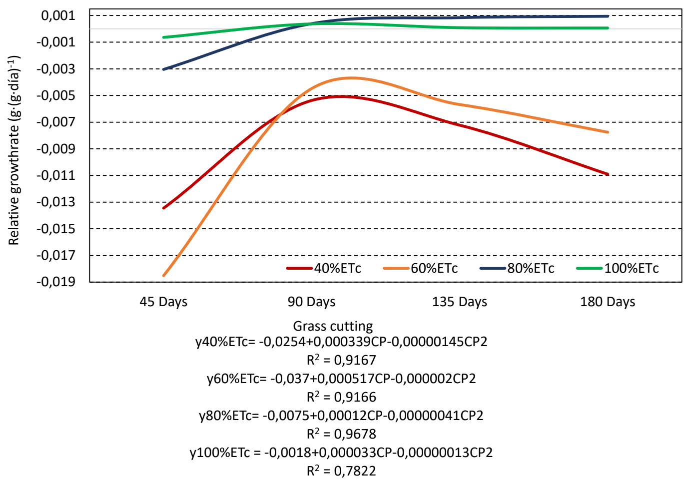

Figure 3. Relative growth rate of *Pennisetum purpureum* x *Pennisetum typhoides* due to the effect of controlled deficit irrigation (%ETc) and successive cuts.

Álvarez (2019) has pointed out that morphogenic characteristics are modified by environmental conditions, such as temperature, light intensity, water availability, amount of nutrients, periodicity and intensity of defoliation and the effects of grazing. Finally, Herrera (2020) states that grass species respond particularly and specifically to climatic elements (precipitation and temperature); the same grass variety responded differently (growth and production) in both seasons of the year (rainy and low rainfall periods).

Leaf area index (LAI)

Friedman's non-parametric analysis determined significant differences ($p<0.0001$) derived from the effect of deficit irrigation and successive grass cuts. The highest LAI occurred at 100 %ETc and the lowest at 40 %ETc. LAI was highest at 45 days and lowest at 180 days (table 4).

Table 4. Leaf area index of *Pennisetum purpureum* x *Pennisetum typhoides* by the effect of controlled deficit irrigation (%ETc) and successive cuttings.

%ETc	Leaf area index	Cuts	Leaf area index
40	0.46[d]	45 days	1.17[a]
60	0.76[c]	90 days	1.09[b]
80	1.22[b]	135 days	1.02[c]
100	1.81[a]	180 days	0.96[d]

[a,b,c,d] Different letters for each mean indicate statistical differences ($p<0.01$).

For each irrigation treatment (figure 4) a quadratic equation was generated that estimated the expected LAI as a function of days after cutting ($p<0.01$), with a coefficient of determination (R^2) ranging from 0.84 to 0.99.

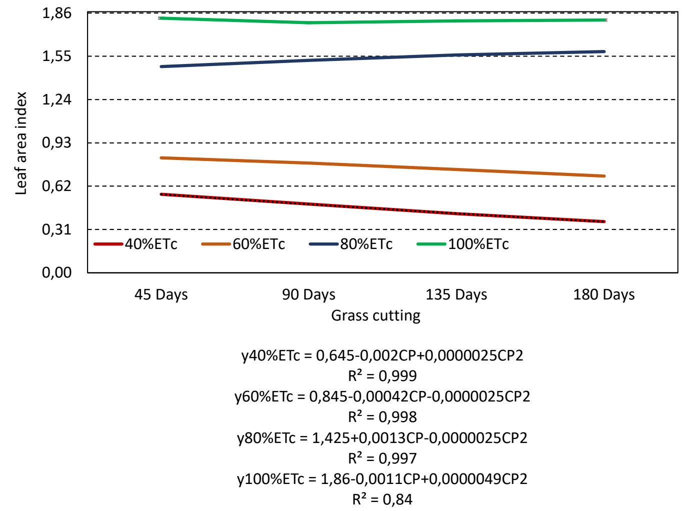

Figure 4. Leaf area index of *Pennisetum purpureum* x *Pennisetum typhoides* due to the effect of controlled deficit irrigation (ETc) and successive cuts.

At low irrigation levels (40 and 60 % ETc) the grass showed low water availability stress as more time elapsed since cutting. It is possible that the grass responds to stress by allocating more resources/energy to root growth in search of water, rather than producing more leaf tissue. On the other hand, with 80 and 100 %ETc there is enough water available to sustain leaf expansion, as reserves and photosynthetic capacity are restored after cutting, coinciding with Maranhão *et al*. (2018) where they indicate that, in plants, water is essential for morphological and physiological differentiation, so its absence can have repercussions on their growth and survival.

Under water stress conditions, stomata close to avoid transpiration losses, causing a decrease in the photosynthetic rate (Sosa *et al*., 2017). The main abiotic factors that determine transpiration rate in plants are: ambient temperature, relative humidity, solar radiation, wind speed, temperature and soil water content (Mastalerczuk and Borawska, 2021). Also, Lopez *et al*. (2018) mention that, in mature trees of six tropical species they determined losses of 50 % of leaf area index resulting from the reduction of monthly water dosage by 44 %.

Conclusions

Growth of Purple King Grass was negatively affected by restricting irrigation to levels below 60 % of the plant's requirement. Good water availability (>80 % ETc) in the grass achieved the highest values of net assimilation rate, grass growth rate, relative growth rate and leaf area index.

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