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EVAPOTRANSPIRAÇÃO, COEFICIENTE DE CULTURA E CRESCIMENTO DE CANA-DE-AÇÚCAR PLANTADA POR MUDAS PRÉ-BROTADAS E POR TOLETES

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1 RESUMO

Atualmente, a cana-de-açúcar apresenta diversos modos de plantio, destacando-se o plantio por mudas pré-brotadas. Esse sistema necessita de novos estudos para a recomendação adequada das práticas agronômicas, como a irrigação. Objetivou-se nesse trabalho avaliar e comparar o consumo hídrico, o coeficiente de cultura e o crescimento inicial da cana-de-açúcar plantada por mudas pré-brotadas (MPB) e por toletes. Foram definidos quatro tratamentos: cana-de-açúcar plantada por MPB e por toletes, plantio de grama batatais e solo nu, todos mantidos em lisímetros de pesagem. A evapotranspiração de referência (ETo) foi medida em lisímetros com a cultura de referência (grama). A evapotranspiração da cultura (ETc) da cana-de-açúcar plantada por MPB e toletes foi estimada por meio do balanço hídrico do solo. A estimativa dos coeficientes de cultura (Kc) foi obtida pela razão entre a ETc dos lisímetros com cana e a ETo. A comparação das variáveis entre a cana-de-açúcar plantada por MPB e por toletes foi realizada por análise de regressão. O Kc da cana-de-açúcar plantada por toletes variou de 0,86 a 2,88 e do plantio por MPB de 1,12 a 3,10. A cana-de-açúcar plantada por MPB apresenta maior consumo hídrico, coeficiente de cultura e crescimento inicial do que quando plantada por toletes.

Palavras-chave: arduino, consumo hídrico, irrigação, Kc, lisímetro de pesagem.

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2 ABSTRACT

Currently, the sugarcane presents several types of planting, especially the planting by pre-sprouted seedlings. This system needs new studies for the adequate recommendation of agronomic practices, such as irrigation. We aimed in this work to evaluate and compare the water consumption, crop coefficient and initial growth of sugarcane planted by pre-sprouted seedlings (PSS) and stalks. Four treatments were defined, being sugarcane planted by PSS and by stalks, bahiagrass grass and bare soil, all kept in weighing lysimeters. The reference evapotranspiration (ETo) was measured in the grass lysimeters. The crop evapotranspiration (ETc) of sugarcane planted by PSS and stalks was estimated by the water balance in the soil. The estimation of the crop coefficients (Kc) was obtained from the ratio between ETc of lysimeters with sugarcane and ETo. Comparison of the variables between planted sugarcane by

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PSS and by stalks was performed by regression analysis. The Kc of the sugarcane planted by stalks ranged between 0.86 to 2.88 and planting by PSS from 1.12 to 3.10. The sugarcane planted by PSS presents higher water consumption, crop coefficient and initial growth than when planted by stalks.

Keywords: arduino, water consumption, irrigation, Kc, weighing lysimeter.

3 INTRODUCTION

Brazil is the world's largest sugarcane producer, with an estimated production of 647.6 million tons for the 2017/2018 harvest in a planted area of 8.84 million hectares (COMPANHIA NACIONAL DE ABASTECIMENTO, 2018). The average productivity of sugarcane in Brazil is 74 Mg ha-^{1}, which is considered low, since in irrigated production systems, the crop has a productivity above 150 Mg ha^{-1} (SÁNCHEZ-ROMÁN *et al*., 2015; ANDRADE JUNIOR *et al*., 2017). To increase the quality and productivity of sugarcane fields, new planting systems, such as planting with presprouted seedlings (MPB), have been developed in recent years; however, research is needed to evaluate the impacts of this new system on agricultural recommendations (LANDELL *et al*., 2012; COELHO *et al*., 2018).

Conventionally, sugarcane is planted by burying stalks in the soil. In this system, stalk consumption ranges from 14 to 20 Mg ha $^{-1}$ (LANDELL *et al*., 2012). To reduce bud consumption for crop cultivation, increase the multiplication rate, and obtain more uniform sugarcane fields, the MPB production system was implemented. MPB production consists of the formation of seedlings from buds contained in the nodes of the sugarcane stalks, called mini-rebolos, which are planted in tubes containing substrate. The use of this new technology in sugarcane planting reduces seedling costs, reducing them to 2 Mg ha-^{1} in this system (LANDELL *et al*., 2012).

Because it is a new planting system, research is needed to recommend agronomic practices for the MPB system. Studies on weeds (PAULA *et al*., 2018), fertilization (GÍRIO *et al*., 2015; GAZOLA, CIPOLA FILHO, JÚNIOR, 2017), and effects on sugarcane productivity (MORAES *et al*., 2018) have already been carried out to support agronomic practices in this new system. However, little is known about irrigation management for sugarcane planted with presprouted seedlings. Therefore, irrigation management in the MPB system is based on existing data from sugarcane fields conventionally planted with setts. This practice can lead to inadequate and inefficient water management, directly impacting the amount of water used in the crop, since sugarcane is the crop with the largest irrigated area in Brazil (AGÊNCIA NACIONAL DE ÁGUAS, 2017), and planting sugarcane via MPB requires irrigation for the seedlings to take root.

Since propagation in the MPB system is carried out using already sprouted plants, the initial water consumption and crop coefficient (Kc) are expected to be greater than those in plantations using setts since the initial growth of sugarcane propagated by MPB is greater than that when planted using setts (COELHO *et al*., 2018). The initial Kc of presprouted seedlings is numerically greater than that recommended for conventional plantations (LIBARDI *et al*., 2019). However, there is no comparison of the water consumption of sugarcane fields planted with setts and MPB maintained under the same conditions; thus, studies in this area are needed to validate this hypothesis.

Therefore, the hypotheses for this study are that (i) in the initial growth phase, the water consumption and crop coefficient of sugarcane planted with MPB are greater than those of sugarcane planted with setts and that (ii) the initial growth of the crop is greater when it is propagated with MPB. The objective of this study was to evaluate and compare the water consumption, crop coefficient, and initial growth of sugarcane planted with presprouted seedlings and setts.

4 MATERIALS AND METHODS

The experiment was carried out in a greenhouse located in the municipality of Jaboticabal (21°14'25” S, 48°17'10” W and an altitude of 582 m). According to the Koppen classification, the climate of the region is Aw (subtropical) (ALVARES *et al*., 2013).

This study defined four treatments: sugarcane planted with presprouted seedlings (MPB) and setts, plantations of potato grass (*Paspalum notatum*), and bare soil. Sugarcane seedlings, both setts and MPB, were purchased from the Agricultural Institute of Campinas, IAC, Sugarcane Center. The cultivar selected for the experiment was RB96-6928. In the MPB treatment, two seedlings were placed in each lysimeter, with only one remaining after establishment. In the sett treatment, four sugarcane seedlings were planted, with only one remaining after establishment.

The weighing lysimeters consisted of metal vessels measuring 0.30 m in diameter and 0.30 m deep. The vessel was placed under a load cell and then filled with soil to 2 cm below the rim. The soil volume in the vessel was 19.1 ^{dm3}. A bidim-type blanket was placed at the bottom of the vessel to prevent soil loss into the drainage system.

The soil used was sieved and placed in each lysimeter vessel. A flexible tube was installed at the bottom of the vessel for drainage when necessary. This tube was kept closed and opened only when the water was drained. The drainage water was quantified and stored for use in subsequent irrigations. This procedure was performed to prevent the loss of soluble salts present in the soil.

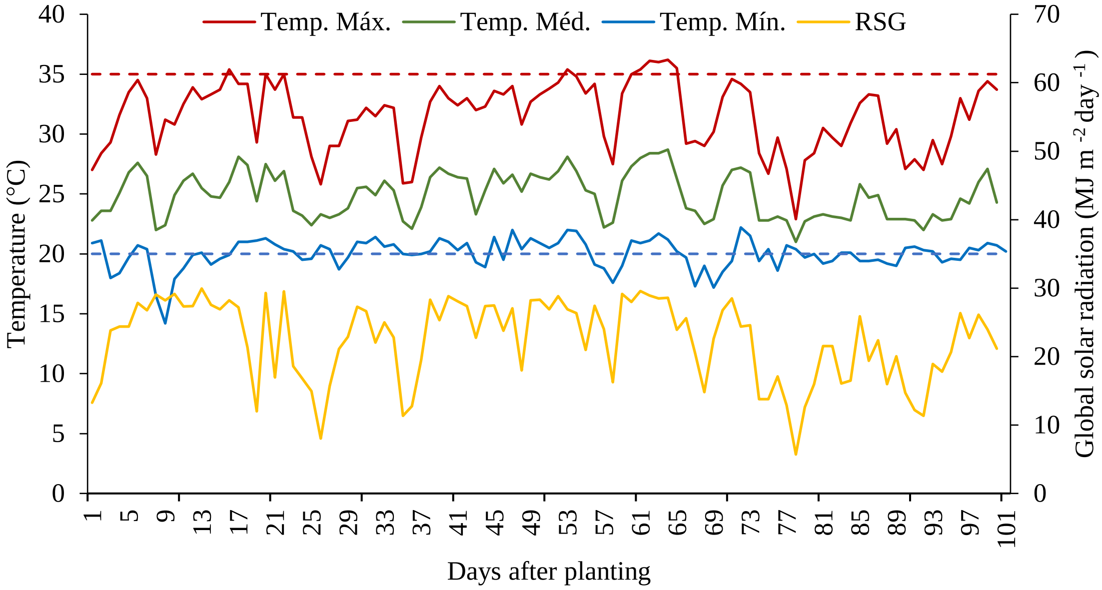
The Arduino platform, specifically the Arduino Nanoboard, was used to instrument the data acquisition, signal processing, and storage system (load cell). This platform enables rapid prototyping, as well as customization and adaptation of the sensor network to meet research needs.

The data acquisition and storage system was developed using modules: an 8 GB memory card (SD card), a DS3231 RTC (*real-time clock*) module, and a liquid crystal display integrated into the Arduino board. The load cell used in the lysimeter was a GL-100 (model from Alfa Instrumentos) for weighing up to 100 kg. The load cells were calibrated, and their hysteresis was also analyzed.

Using the data acquisition system, the field capacity point was determined, noting the gross weight of the system, which was considered the weight at field capacity.

The average maximum and minimum temperatures, as well as the average for the experimental period, were 31.5, 20.0, and 24.9 °C, respectively (Figure 1). The average daily radiation for the period was 22.4 MJ m $^{-2}$ day $^{-1}$. In some periods, the maximum and minimum temperatures were above and/or below the critical limit for sugarcane growth. The temperature considered ideal for good sugarcane development is in the range of 21--30 °C (MARIN *et al*., 2013).

Figure 1. Daily maximum, minimum and average temperatures and daily global solar radiation (GSR) during the experimental period.



Reference evapotranspiration (ETo) was measured in lysimeters with potato grass, which was the reference crop for this variable. The crop evapotranspiration (ETc) of sugarcane planted with MPB and setts was estimated via the soil water balance of each lysimeter, which was estimated via Equation 1. The time unit used to calculate storage variation was daily.

$$\Delta ARM = P + Irr - D - E - ETc \qquad (1)$$

where:
ΔARM = storage variation, mm;
P = precipitation, mm;
Irr = irrigation, mm;
D = drainage, mm;
E = evaporation, mm;
ETc = crop evapotranspiration, mm.

Considering that the variation in soil water storage is equal to zero, evapotranspiration was estimated via Equation 2.

$$ETc = P + Irr - D \qquad (2)$$

The estimate of crop coefficients (Kc) during the initial growth period of sugarcane planted with setts and MPB, up to 100 days after planting, was obtained by the ratio between the average ETc of the lysimeters and the ETo determined in the lysimeters with grass (Equation 3).

$$Kc = \frac{ETc}{ETo} \qquad (3)$$

where:
Kc = culture coefficient, dimensionless;
ETo = reference evapotranspiration, mm day $^{-1}$.

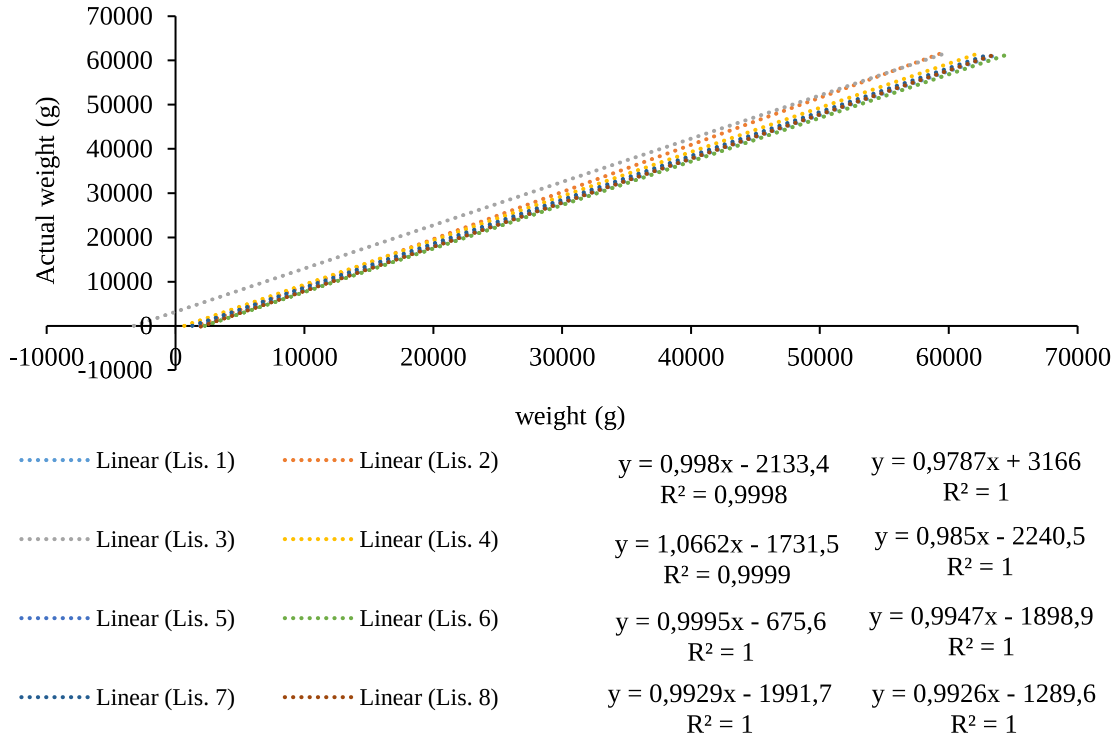
The daily Kc data for sugarcane planted with MPB and setts were subjected to regression analysis ($p < 0.05$). First-, second-, and third-degree regressions of the daily Kc value of sugarcane planted with MPB and setts were plotted as a function of time, with regression analysis being performed for the best-fitting model. The transpiration of grass and sugarcane planted with MPB and setts was calculated daily as the difference between the evapotranspiration of each treatment minus the water loss of the bare soil treatment (evaporation only).

The biometric evaluations performed on sugarcane included plant height, number of tillers, and stalk diameter. Height was measured from the soil surface to the highest point of the plant. The stalk diameter was standardized on the main sugarcane stalk via a caliper. The biometric attributes of sugarcane planted with MPB and setts were compared via regression analysis. The height, stalk diameter, and number of tillers were plotted against time, and first, second, and third-degree regressions were tested. The best-fitting equation for each case was subjected to regression analysis ($p < 0.05$).

5 RESULTS AND DISCUSSION

All load cells of the lysimeters were calibrated, which presented linear functions, demonstrating a high correlation between the mass read by the system and the real mass of the vessels ($R^2 > 0.99$) (Figure 2).

Figure 2. Dispersion of the masses read (g) by the Arduino nano board and the real masses of the lysimeters (g).

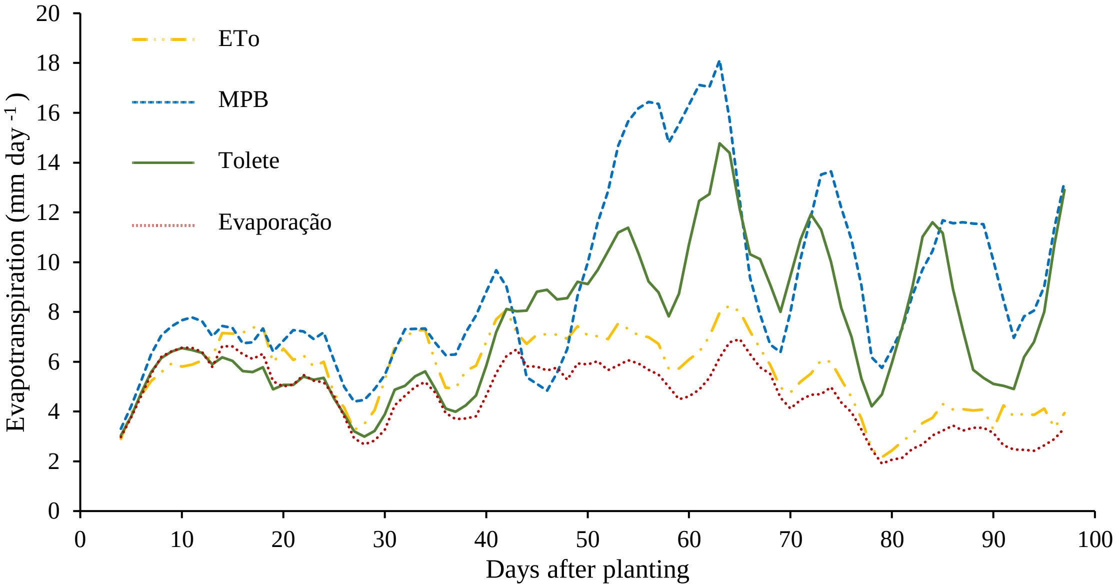


The coefficient of determination values demonstrated high accuracy in the lysimeter readings. On the Arduino platform, the calibration factors for lysimeters 1, 2, 3, 4, 5, 6, 7, and 8 were 42.200, 42.085, 39.840, 40.020, 39.210, 39.600, 38.290, and 40.150, respectively. Lysimeters 1 and 5 were maintained with potato grass, 2 and 6 with sugarcane under the MPB system, 3 and 7 with sugarcane by planting with setts, and 4 and 8 with bare soil.

During the experimental period, the accumulated soil water evaporation, reference evapotranspiration (ETo) and evapotranspiration (ETc) of sugarcane planted by the MPB and the evapotranspiration of sugarcane planted by setts were 448.8 mm, 539.9 mm, 887.2 mm and 732.1 mm, respectively. During the first 100 days of the sugarcane cycle, the water consumption of sugarcane planted with MPB was 21% greater than that of sugarcane planted with setts.

From 65 days after planting (Figure 3), sugarcane planted with setts began to experience daily evapotranspiration similar to that of sugarcane planted with MPB. These results indicate that the sugarcane crop coefficient in phase I of the vegetative cycle should be reviewed and adjusted if planting occurs as presprouted seedlings.

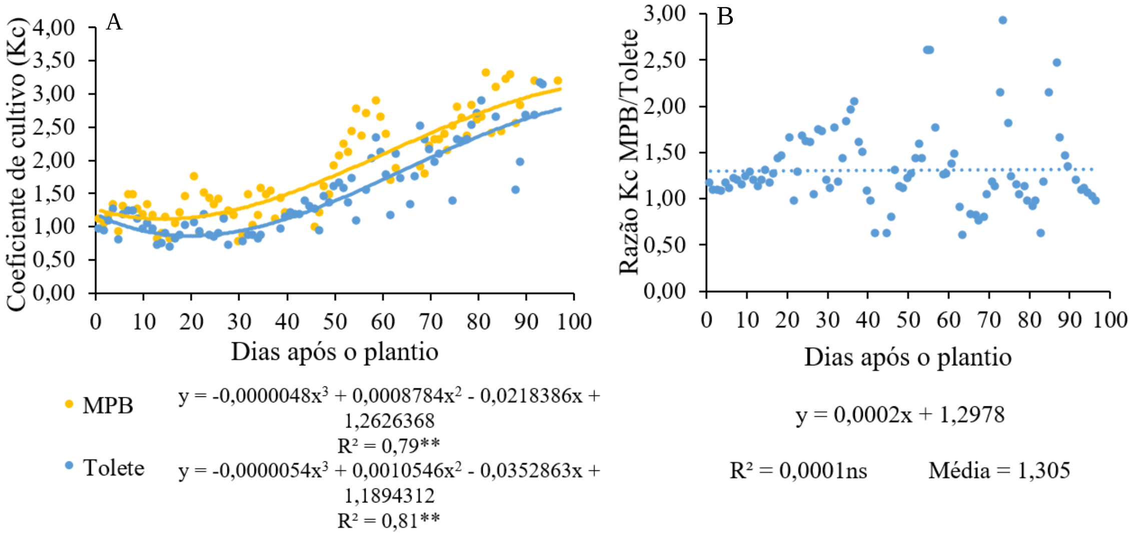
Figure 3. Daily data on evaporation, reference evapotranspiration (ETo) and evapotranspiration of sugarcane planted with presprouted seedlings (MPB) and with stems.



The average daily ETc of MPB plants was 9.1 mm day $^{-1,}$ and that of sett plants was 7.5 mm day $^{-1}$. The maximum peak ETc values of sugarcane planted with MPB and sett were 18 and 14 mm day $^{-1}$, respectively. The average soil water evaporation was 4.6 mm day $^{-1}$, which was observed in the lysimeters without cultivation. In the lysimeters cultivated with grass, the average measured evapotranspiration value was 5.5 mm day $^{-1}$.

The equation that best fit the crop coefficient variation of sugarcane planted with MPB and was set as a function of the crop cycle was the third-degree equation (Figure 4A). Both models were significant at the 1% probability level. During the experimental period, the Kc of sugarcane planted with MPB was greater than that of sugarcane planted with setts. For the MPB system, the Kc values ranged from 1.12--3.10, whereas for the setts, they ranged from 0.86--2.88. The calculation of the daily Kc ratio of sugarcane planted with MPB to sugarcane planted with setts revealed that a significant model to describe this variation was not obtained (Figure 4B). Thus, it was observed that, on average, the Kc of planting by MPB was 30.5% greater than the Kc of planting by setts throughout the analyzed period.

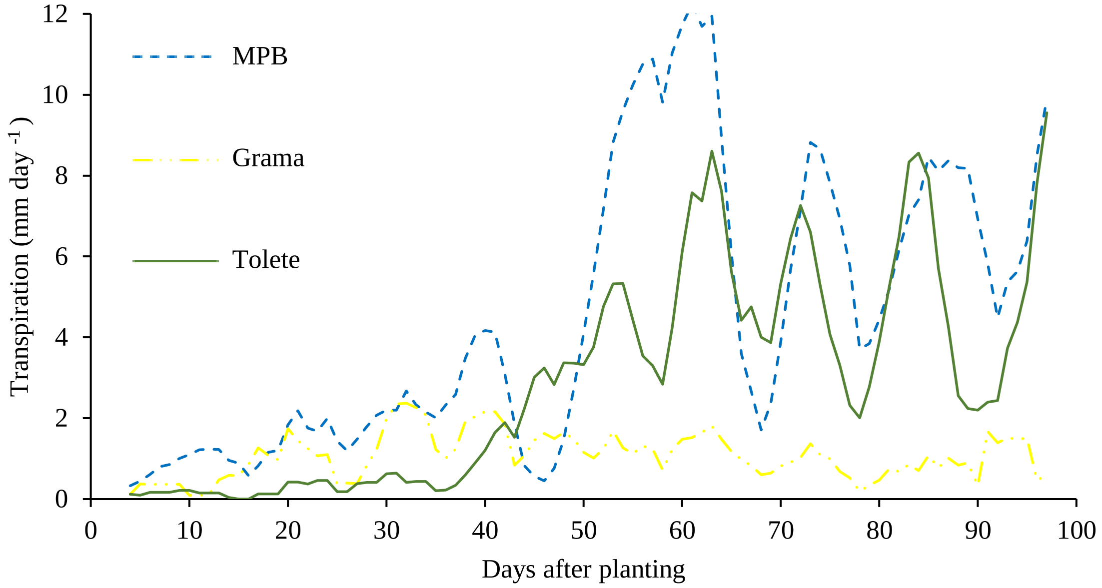
Figure 4. Daily variation in the crop coefficient as a function of time (A) for sugarcane planted with presprouted seedlings and by setts and daily variation in the crop coefficient ratio of sugarcane planted with MPB and by setts.



ns: not significant; **Significant at 1% probability.

With respect to daily transpiration, from the beginning of the experimental period, the sugarcane planted with MPB presented relevant transpiration values, which were greater than those of the grass after 48 DAP (Figure 5). During sett planting, transpiration was nearly zero until 20 DAP, with water loss prevailing only through soil evaporation. Only after 45 DAP did the sugarcane planted with setts transpire more than the batatais grass did. The accumulated water loss through transpiration of the sugarcane planted with MPB, setts, and batatais grass was 448.1 mm, 296.3 mm, and 103.2 mm, respectively. This indicates that transpiration was responsible for 50.5%, 40.5% and 19.1% of the total water loss during the experimental cycle for the MPB, stalk and potato grass systems, respectively.

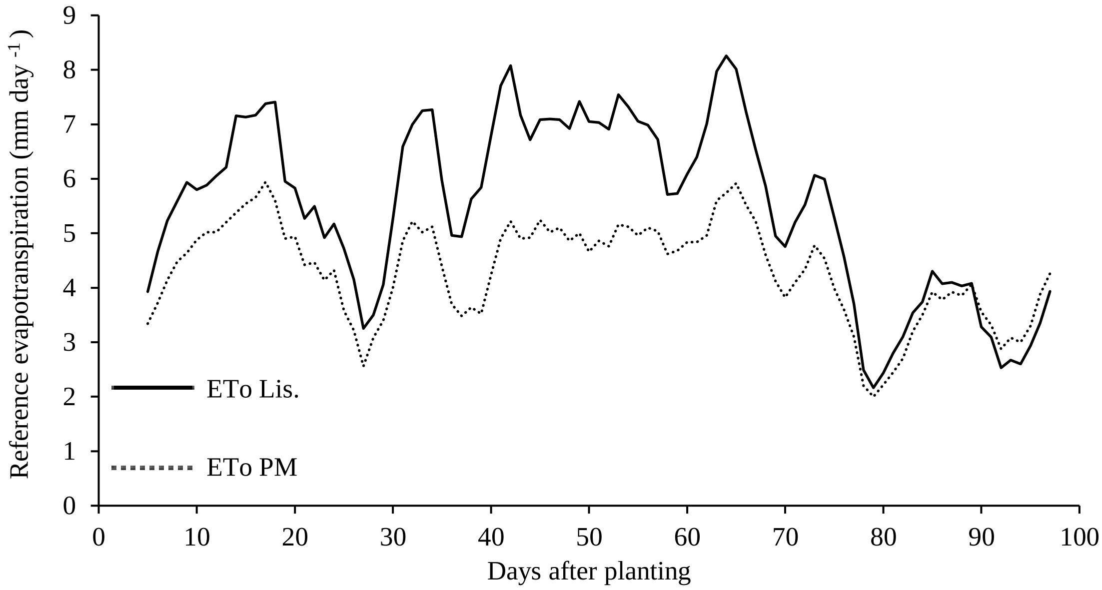
Figure 5. Daily transpiration of the treatments with sugarcane planted with presprouted seedlings and with setts and potato grass (ETo).



The high values of sugarcane evapotranspiration and crop coefficients can be explained by the fact that the experiment was carried out in a greenhouse.

The reference evapotranspiration (ETo) determined in the lysimeters was greater than the ETo estimated by the Penmann–Monteith equation of the meteorological station installed close to the site of the present study (Figure 6).

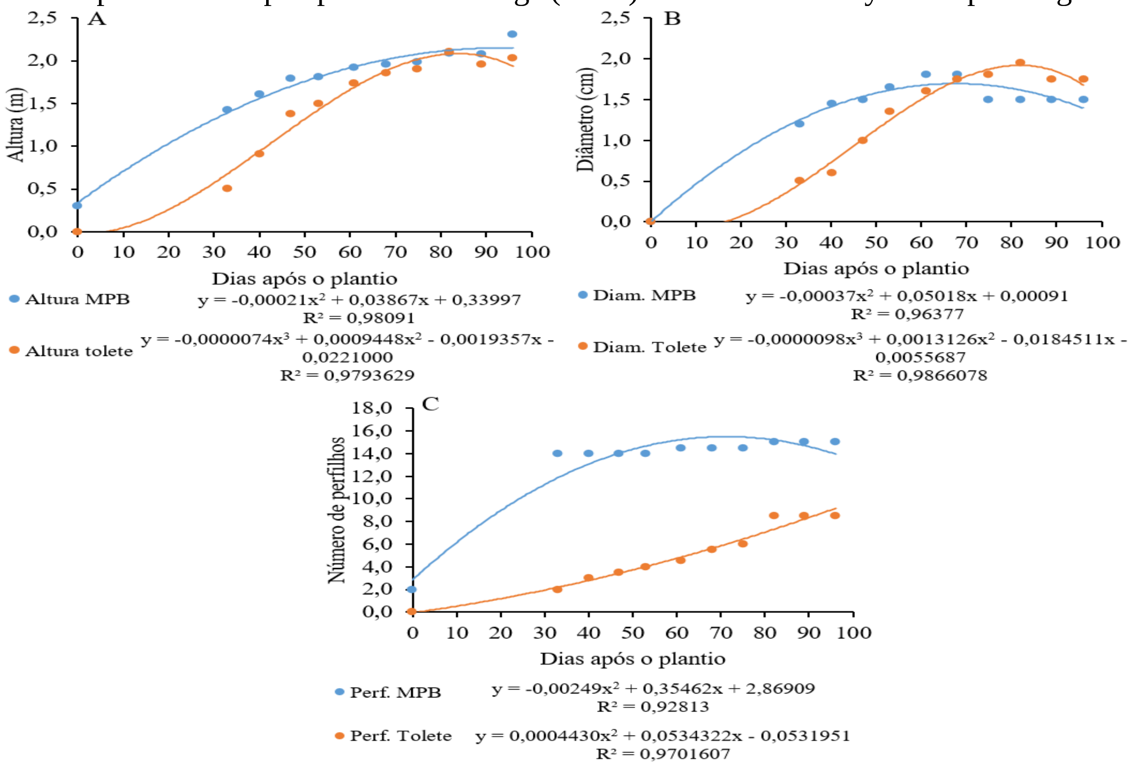
Figure 6. The daily reference evapotranspiration determined by lysimeters (ETo Lys.) and is calculated via the Penmann–Monteith equation (ETo PM).



The accumulated ETo up to 100 days of analysis was 539.9 mm in the weighing lysimeter and 416.4 mm in the value estimated by the Penmann–Monteith equation. The ETo estimated by the lysimeter was 29.7% higher than that estimated by the Penmann–Monteith model. This occurred because the temperature inside the greenhouse is higher than that in the open environment, which directly affects soil water loss and plant transpiration (ALLEN *et al*., 1998). Furthermore, the sugarcane was grown in pots with limited soil volume. Under these conditions, water loss through sugarcane evapotranspiration is greater than that through open-field cultivation, thus explaining the high evapotranspiration and Kc values. However, this does not prevent the comparison of water consumption and the crop coefficient of sugarcane propagated by MPB and by setts, since all the treatments were maintained under the same conditions. Thus, in a field experiment, the water consumption and initial Kc of sugarcane are expected to be greater when the crop is planted by MPB. Sharma *et al*. (2017) and Libardi *et al*. (2019), when experiments were conducted in greenhouses, the water consumption and Kc of plants were greater than those of plants with the same attributes determined in the field.

For plant height and stalk diameter, the best-fitting model for the MPB system was the cubic model, whereas for sett planting, it was the quadratic model (Figure 7). For the number of tillers, the best-fitting model was the quadratic model, regardless of the planting system. This finding demonstrates that the initial growth of sugarcane planted with setts is slower than the initial growth when the crop is planted with MPB. Since the seedlings are taken to plants already sprout, a cycle is anticipated in this system, which can last up to 100 days (COELHO *et al*., 2018).

Figure 7. Variation in plant height (A), stem diameter (B) and number of tillers (C) of sugarcane planted with presprouted seedlings (MPB) and set to 100 days after planting.



In sett planting, plant height and stalk diameter were similar between the systems only after 80 and 60 DAP, respectively. Before this period, the height and stalk diameter of sugarcane planted with MPB were greater than those of those planted with sett. The maximum height of sugarcane planted with MPB was 2.12 m at 92 DAP, whereas in sett planting, the crop reached a maximum height of 2.10 m at 84 DAP. For stalk diameter, the maximum value for the MPB system was 1.70 cm (68 DAP), and for sett planting, it was 1.90 cm (81 DAP).

The maximum number of tillers in the MPB planting system was 15.5, which was obtained at 71 DAP. In the case of sugarcane planting using setts, this maximum point was not possible. This confirms the early growth of the sugarcane cycle when the crop is planted with presprouted seedlings, since during the cycle, the crop reaches its maximum tillering, after which some tillers die until the number stabilizes.

The Kc values adopted for irrigation management of sugarcane in the field up to the first 100 days of the cycle are 0.50, 0.80, and 0.95 (DOORENBOS; KASSAM, 1994) (Table 1). These values are for plantings made with setts. Thus, according to the results of the present study, these values should be increased by 30% for plantations with MPB. That is, for sugarcane fields planted in the MPB system, the crop coefficient values up to 100 days of the cycle should be 0.65, 1.04, and 1.24. After this initial phase, the Kc values for sugarcane fields planted with MPB tend to be close to those of sugarcane fields planted with setts since sugarcane growth tends to be similar in both systems over time (Figure 7).

Table 1. Values of the crop coefficient (Kc) adopted for irrigation management of sugarcane planted in setts.

Cane age (days)	Phenological phase	Kc set*	Kc MPB
0 – 45	Planting at 0.25 coverage	0.50	0.65
45 – 75	From 0.25 to 0.50 coverage	0.80	1.04
75 – 95	From 0.50 to 0.75 coverage	0.95	1.24
95 – 150	From 0.75 to full coverage	1.10	
150 – 300	Maximum utilization	1.20	
300 – 350	Onset of senescence	0.90	
350 - 410	Maturation	0.65	

***Source:** Doorenbos and Kassam (1994).

Sugarcane planted with MPB has greater evapotranspiration because the seedling has already sprouted and been transported to the plant, which anticipates a phenological phase of the crop cycle (sprouting), advancing its growth cycle. Therefore, sugarcane propagated with MPB has a leaf area from planting, which explains the higher ETc values at the beginning of this stage, unlike sugarcane planted with setts, which only has significant ETc values 30 days after planting (Figure 5). Compared with setts, which have greater initial development in terms of height, number of tillers, and stalk diameter, MPB has advantages in terms of development (LANDELL *et al*., 2012).

However, sett planting results in larger stalk diameters at a certain point in the sugarcane cycle (Figure 7). Because MPB planting results in greater tillering, there is greater competition among tillers per environment, which leads to a decrease in stalk diameter in the MPB system. This occurs because the greater the number of plants per area is, the lower the availability of photosynthetic radiation for the lower leaves, generating shading and a reduction in the net photosynthetic rate per plant, resulting in the formation of smaller production units (SILVA, 2008).

Libardi *et al.* (2019) reported Kc values greater than 1.2 for sugarcane MPB production for three cultivars. Even though they were seedlings with small leaf areas and restricted root systems, the Kc values reported by the authors were higher than the maximum Kc values recommended for crop irrigation management in the field. For irrigation management of pepper crops in greenhouses, Sharma *et al*. (2017) reported crop evapotranspiration values above 10 mm day $^{-1}$ and Kc values greater than 1.6. These results confirm that there is greater water consumption for crops kept in greenhouses, as observed in the present study.

The higher water consumption of crops grown in pots in greenhouses is due to the higher average temperatures of this environment and the limited soil volume of the pots where the crops are maintained. Temperature directly affects water loss by crops, since the warmer the environment is, the greater the metabolic activity and water consumption of the crops.

However, even though these conditions are different from those found in the field, the results obtained in experiments carried out in greenhouses are often applicable to field crops (GAIHRE *et al*., 2014; HOLVOET *et al*., 2015). In the present study, sugarcane planted with setts and MPB were subjected to the same conditions. Therefore, it is expected that in the open field, the water consumption of MPB would be greater, with a proportion similar to that obtained in the present study in relation to planting with setts, allowing the extrapolation of the data obtained to sugarcane crops planted with MPB.

6 CONCLUSION

In the first 100 days of the cycle, sugarcane planted with presprouted seedlings had higher water consumption rates and crop coefficients than those planted with setts, with values that were 30% greater. The initial growth of sugarcane planted with presprouted seedlings was superior to that of sugarcane planted with setts.

7 ACKNOWLEDGMENTS

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