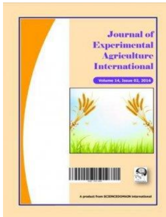

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Agronomical Performance of Sugarcane Varieties in Function of Different Irrigation Depths in Semi-arid Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author PBS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors IA, ELC and JBRS managed the analyses of the study and reviewed. Authors DTP, MFFT and HCSJ managed the literature searches and reviewed all drafts of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Irrigation is a major factor on sugarcane yield, especially on semi-arid regions. Genetic degenerated varieties, presenting low yield and quality, are still being planted on semi-arid regions. This study objective was to evaluate the agronomic performance of six sugarcane varieties, IAC86-2480, RB76-5418, RB83-5486, RB85-5536, SP80-1816 and SP80-1842, under different irrigation depths. Height, number of culms, culm`s diameter and yield were evaluated 11 months after planting. The experiment was conducted in Brazil, on the semi-arid region of Minas Gerais state, Jaíba city, at the experimental farm Mocambinho (FEMO). The experiment was designed on a randomized complete

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block design (RCBD), on a subdivided parcels scheme (6 x 5), being the six varieties used on the parcels and sub-parcels composed by five irrigation depths, with four repetitions. The varieties SP80-1842 and IAC86-2480 presented, on the highest irrigation depth, the highest height and number of culms, respectively. The varieties IAC86-2480 and RB83-5486 presented, on the lowest irrigation depth, the lowest results to culms diameter. The varieties SP80-1842 and SP80-1816 presented higher yields with 1351 mm depth. On a general manner, the varieties SP80-1842 and SP80-1816 presented the best agronomical performance, within the evaluated varieties, to semi-arid conditions. The 1351 mm depth presented the best results, regarding sugarcane production, on the studied conditions.

Keywords: Saccharum officinarum L.; development; hydric stress; yield.

1. INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is a crop of major agricultural importance, being the source of 80% of the 170.9 million tons of sugar produced in the world in 2017 [1]. Brazil figures among the main sugarcane producers, totaling 660 million tons, corresponding to 35 tons of sugar [2]. Furthermore, sugarcane can also be used in other relevant forms as, animal consumption forage, confectionery, alcoholic drinks and alcoholic fuels [3].

Water content on non-woody plants ranges from 80 to 90% of total biomass. Water is the central molecule of all plant physiological processes, being the main transport form of metabolites and nutrients [4]. The sugarcane plant presents four developmental stages (sprouting, tillering, vegetative growth and maturation). Hydric privation in the primary stages can limit vegetative growth and reduce yield [5]. Reduced expansion and development of leaves and further photosynthetic limitations are the main physiological causes associated to yield reduction [5,6,7].

In this manner, water availability can be considered a major cause of sugarcane yield fluctuation. Evaluating morphological variables of sugarcane under different irrigation levels is an important tool to investigate yield capacity and the irrigation effects on the crop [8]. On sugarcane breeding experiments, this tool can also be used, aiming on yield maximization.

Semi-arid regions, in general, presents low total precipitation and water availability. Thus, in those regions, irrigation is indispensable to farming practices [9]. The use of unimproved sugar-cane varieties, genetically degenerated and low yielding, is still common in many semi-arid regions of the world. Therefore, to introduce improved sugarcane varieties, on those regions, is of great importance to production viability.

In this context, this study's objective was to evaluate the agronomical characteristics of improved sugarcane varieties under different irrigation depths in semi-arid conditions.

2. MATERIALS AND METHODS

2.1 Location, Soil and Plant Material

The experiment was conducted in Brazil, on the semi-arid region of Minas Gerais State, Jaíba city, at the experimental farm Mocambinho (FEMO). Mocambinho is owned and managed by the EPAMIG institution. The coordinates of the experimental area were 15º 05' 34" latitude S and 43º 58' 44" longitude W. Mean temperature is 25.5°C (18.7°C minimum and 32.3°C maximum). Annual insolation is 2987 hours. Relative humidity 65.5%. Mean rainfall is approximately 800 mm annually, concentrated between October and March [10].

Previously to the experiment, soil samples were collected in the experiment area. The 0-20 and 20-40 cm profundities were used to texture and fertility analysis as recommended by Cantarutti et al. [11]. The soil was classified as dystrophic red latosol, presenting a medium texture (LVD) [12]. Following the fertility test results, fertilizing was perfomed according to Korndörfer et al. [13], consisting in applying, before planting, 150 kg.ha^{-1} of ammonium sulfate and 750 kg.ha^{-1} of single superphosphate. Liming and micronutrients correction were not performed following the fertility analysis. Pre-planting fertilizing was performed on the trenches.

Before planting, the soil was prepared, aiming to reduce compaction, by subsoiling, plowing and two processes of harrowing.

The six following sugarcane varieties were used, IAC86-2480, RB76-5418, RB83-5486, RB85-5536, SP80-1816 and SP80-1842. Seedlings were distributed on trenches, 25 to 30 cm depth, with 1.20 m within each other. Stalk selection criteria was 3 to 5 buds per stalk, resulting on 16 to 18 gems for each trench meter. Stalks were covered by a 5 to 10 cm soil layer.

Cover fertilizing was performed 90 days after planting (DAP), consisting of 150 kg.ha^{-1} of $(NH_4)_2SO_4$. During the crop cycle, the occurrence of pests and diseases was monitored and control was performed as necessary, following chemical and biological procedures recommended to the sugarcane crop [14]. Weed control was performed by chemical spaying, following weeds identification and procedures recommended to the sugarcane crop [xy].

2.2 Irrigation Treatments

To all varieties, five irrigation depths were employed, consisting of 271, 541, 811, 1081 and 1351 mm, corresponding to 25, 50, 75, 100 and 125% of the recommended depth, respectively. Irrigation was performed by line Source sprinkling, being one line of 11 nozzles, NAAN 5035 model, evenly spaced. Water was applied on decreasingly levels and perpendicular to the tubulation. Sprinklers height was proportional to plant growth and spaced 12 m from each other. Irrigation outflow was 3100 L.h$^{-1.}$

Irrigation management was perfomed using potential reference evapotranspiration (ETo), calculated according to the Hargreaves methodology (Equation 1), considered an alternative method when limited data is available [15]. To this calculation, precipitation data was collected on a meteorological station near the experimental area. Results of this equation presented the irrigation period to each treatment. Irrigation periods ranged from 1 to 3 days, according to irrigation management [16].

Equation 1. Potential reference evapotranspiration by Hargreaves methodology.

$$ETo = 0{,}0023 \times R_a \times (T + 17{,}8) \times (T_{\max} - T_{\min})^{0,5}$$

Being:

ETo= day mean evapotranspiration, mm.day^{-1}
T= day mean temperature, °C;
T_{max}= day max temperature, °C;
T_{min}= day minimum temperature, °C;
R_a= radiation on atmosphere top, mm.day^{-1}.

The water used for irrigation has a pH of 6,7, an electric conductivity of 320 µmho.cm^{-1}; and contained dissolved aluminum (0,09 mg.L^{-1}) and dissolved solids (180 mg.L^{-1}). An irrigation uniformity test was performed using collectors on the irrigation line, aiming to quantify effectively water outflow. Irrigation was interrupted 45 days before harvest. Harvest and measurements were performed when the plants were 11 months old.

2.3 Agronomical Evaluations

Agronomical evaluations were performed following the methods proposed by Gheller [17]. Plant height (m.plant^{-1}) was determined using a measuring tape, measuring from the base to the first leave intersection +1 to the sheath, apex and downwards. To quantify culms (ha^{-1}), all the culms on the three central lines present on 6 m, of all parcels, were counted. Culms diameter (mm.plant^{-1}) was determined using a digital caliper. Six culms were randomly collected on each parcel, and measurements took place on the central plant part. Yield was estimated using the data of culms diameter, plant height and culms number, following the methodology of Martins & Landell [18] (Equation 2).

Equation 2. Sugarcane estimated yield.

$$TCH = D^2 \times C \times H \times \left(\frac{0{,}007854}{E} \right)$$

Being:

TCH= sugarcane tons per hectare (t ha^{-1});
D= culms diameter (m);
C= number of culms by (m);
H= culms mean length;
E= spacing between trenches (m).

2.4 Experimental Design

The experiment was designed on a randomized complete block design (RCBD), on a subdivided parcels scheme (6 x 5), being the six varieties used on the parcels (IAC86-2480, RB76-5418, RB83-5486, RB85-5536, SP80-1816 and SP80-1842) and sub-parcels composed by five irrigation depths (271, 541, 811, 1081 e 1351 mm), with four repetitions. The total area presented 5000 m² (100 x 50 m).

The parcels were parallel to the irrigation lines. Sub-parcels presented 33,75 m² (7,5 x 4,5 m) and were composed of five 8 m lines. Externally to the parcels, 3 lines of sugarcane, RB73-9735 variety, were planted as turnrows (headlands).

2.5 Statistical Analysis

Data was statistically analyzed on bulk and means were compared by the Tukey test to varieties. To significant interactions, data unfolding was performed. To significant interactions identified by the F test ($P<0.05$), regression analysis was performed. The models used to explain the results were chosen regarding the significance of the equation parameters and determination coefficient value (R^2).

3. RESULTS AND DISCUSSION

To plant height and culms number, there were not significant interactions between varieties and irrigation depths. For all evaluated characteristics, it was observed significant effect of varieties and irrigation depths. The varieties IAC86-2480 and SP80-1842 presented the lowest and highest growth, respectively, compared to the rest of the varieties (Table 1).

Table 1. Plant height and number of culms of 6 sugarcane varieties, 11 months after planting

Varieties	Height ($m.plant^{-1}$)	Number of culms (ha^{-1})
IAC86-2480	2.201 d	99092 a
RB76-5418	2.921 bc	84092 ab
RB83-5486	2.780 c	64859 b
RB85-5536	2.895 c	82358 ab
SP80-1816	3.169 ab	75967 b
SP80-1842	3.276 a	82917 ab

**Means followed by the same letters not differ based on the Tukey Test, (P = 0.05)*

All the varieties presented mean height superior to 2.00 m (Table 1), similar to the results reported by Silva et al. [19], evaluating the variety SP83-5073 under different irrigation depths. Campos et al. [20] observed similar positive effects of irrigation on the height of several varieties, in a semi-arid region.

The variety IAC86-2480 was superior regarding the number of culms, with mean 99092 $culms.ha^{-1}$. According to Taupier & Rodrigues [21], this value is superior to the required number to maximum yield, 90000 culms ha^{-1}. This result differs on plant height, being the lowest value attributed to this variety (Table 1).

Significant differences were not observed between arieties RB76-5418, RB85-5536 and SP80-1842 regarding number of culms. The lowest value was observed in the variety RB83-5486, 64.859 culms ha^{-1} (Table 1).

A linear response was observed regarding the irrigation depth. The highest applied depth (1351 mm) provided heights superior to 3.00 m (Fig. 1A). This observation indicated a considerable relation between growth and soil humidity. According to Silva et al. [22], plant height is a major component to evaluate sugarcane yield potential and irrigation is a tool to full genetic potential expression. However, it is important to emphasize that excessive plant height can entail on plant bedding, leading to yield losses [23].

The number of culms and irrigation depths presented a crescent linear response. The highest number of culms was achieved with the highest irrigation depth 1351 mm (Fig. 1B). Differently from Silva et al. [19], a dependence between irrigation and number of culms to the variety SP83-5073, on similar conditions, was not observed. According to Singh et al. [24], the enhanced transport of water and nutrients provided by irrigation, and/or rainfall, has a direct effect on culm production and sugarcane water-use efficiency which was most probably the case of the present study.

To culm diameter and yield, there were significant interactions regarding variety and irrigation depth. All the varieties presented culms diameter values that can be considered medium (20 to 30 mm), regardless of the irrigation depth [25] (Table 2). Plant bedding can be considerably reduced with higher culms diameter values [26].

Significant differences were not observed in culms diameter between all varieties on the lowest irrigation depths (271 and 541 mm). Silva et al. [22] evaluated the initial growth of different sugarcane varieties, under different hydric schemes, and did not observed significant differences to this parameter. Significant differences were observed on the between the varieties on the 811, 1081 and 1351 mm irrigation depths.

The SP80-1816 variety presented the highest culm diameter values to the 811 mm, 1081 mm and 1351 mm depths. The variety RB83-5486 presented the lowest culm diameter on the 1351 mm depth (Table 2).

The varieties IAC86-2480 and RB83-5486 presented, in a general manner, similar behavior regarding culms diameter, with a reduction on this parameter in response to irrigation increase, comparable to results obtained by Carlos et al. [27] (Fig. 2).

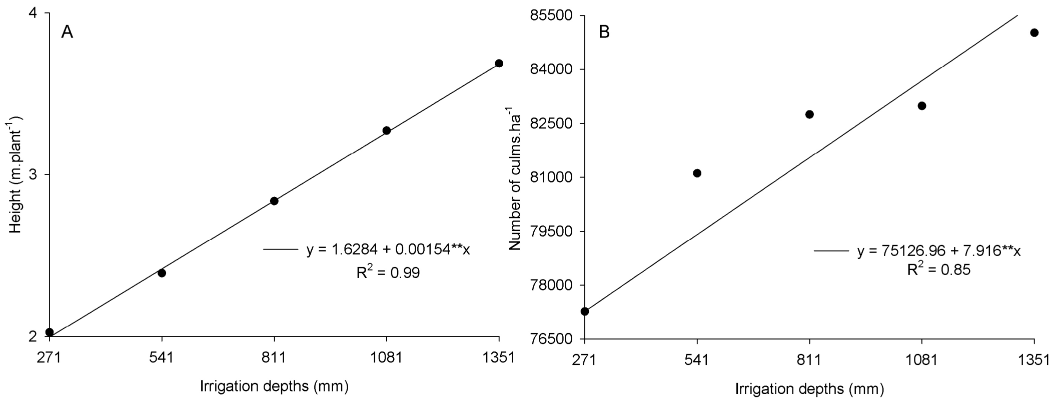

Fig. 1. Plant height (A) and number of culms (B) of sugarcane under five different irrigation depths, 11 months after planting

***Equations are significant on 1% probability (P<0.01)*

Table 2. Culms diameter (mm.plant^{-1}) of 6 sugarcane varieties under 5 irrigation depths, 11 months after planting

Varieties	Irrigation depths (mm.plant^{-1})									
	271		541		811		1081		1351	
IAC86-2480	26.08	a	25.86	a	24.39	b	24.16	ab	23.37	bc
RB76-5418	25.06	a	24.85	a	23.99	b	23.61	b	24.35	abc
RB83-5486	25.86	a	25.30	a	25.41	ab	24.42	ab	23.08	c
RB85-5536	25.56	a	24.21	a	25.70	ab	24.97	ab	25.35	ab
SP80-1816	24.98	a	26.07	a	26.82	a	25.78	a	25.85	a
SP80-1842	25.33	a	26.33	a	25.23	ab	25.37	ab	25.24	ab

**Means followed by the same letters not differ based on the Tukey Test, (P = 0.05).*

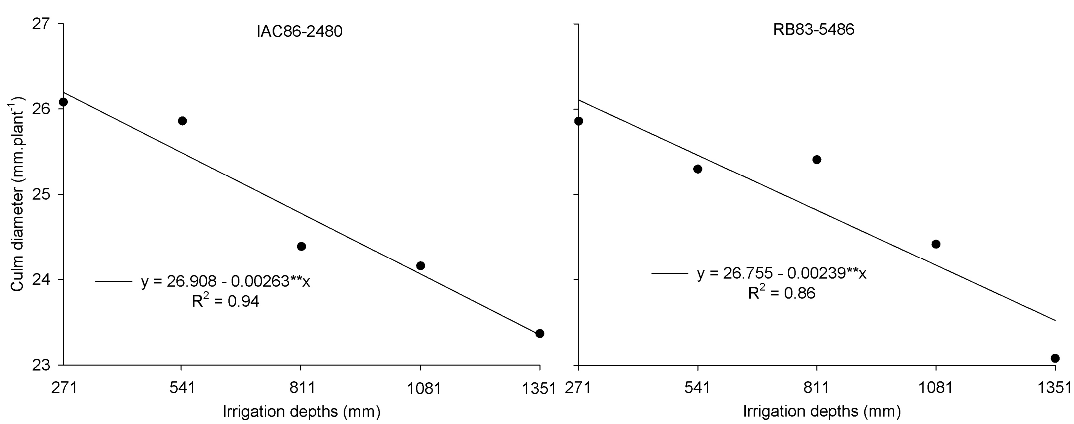

Fig. 2. Culm diameter of sugarcane under five different irrigation depths, 11 months after planting

*** Equations are significant by F test, 1% probability (P≤0.01)*

These results, however, differ from Silva et al. [19] and Oliveira et al. [28], who observed an increase on culm diameter in response to higher irrigation depths. This difference can be explained due to genetic characteristics, the occurrence of tillering, plant spacing, leaf area and environmental conditions [29].

According to Ferreira et al. [30], the most efficient sugarcane selection regarding yield is performed based on culms number and diameter. Similarly Silva et al. [31], report that tillering, jointly with plant height and culm diameter are evidences of yield potential. Cesnik & Miocque [25], however, assert that culm diameter is poorly influenced by environment, being an intrinsic genetic characteristic of each variety.

For the yield, in a general manner, the varieties presented similar behavior regarding irrigation depths, with highest yields at highest depths (1351 mm) and lowest yield at lowest depth (271 mm). Furthermore, significant differences were only observed between varieties starting with 541 mm (Table 3).

Significant differences on yield were not observed between the varieties 271 mm irrigation depth as well as at 1081 mm depth. At 1351 mm depth, the varieties SP80-1842, SP80-1816 and RB85-5536 presented the highest values, corresponding to 182.76, 173.66 and 173.42 t ha^{-1}, respectively. At the same irrigation depth, the RB83-5486 variety presented the lowest yield, 99.37 mm (Table 3).

The variety SP80-1842 presented the highest yields at all irrigation depths (Table 3). Therefore, this variety can be considered the highest producer among all the analyzed varieties in this region, regardless of the soil humidity conditions. This variety possesses characteristics that can enhance the responses to irrigation. They include rapid vegetative growth, adequate ratoon sprouting, high sucrose content, low isoporization and tolerance to diseases and pests are some of the characteristics [32].

Studying three sugarcane varieties on the first cultivation cycle, under similar conditions as this present study, Oliveira et al. [32] observed similar results. The observed yields were 197.7, 140.3 and 133.1 t ha^{-1} to the varieties RB72-454, RB85-5113 and RB85-5536 respectively.

A crescent linear behavior was observed to yield, on all varieties, with the best results to the highest irrigation depths (Fig. 3).

The results corroborate with Silva et al. [8], who observed that additional irrigation had a significant effect on sugarcane yield. Thus, in this study, an increase on yield was linearly correlated to an increase on water consumption.

The varieties IAC86-2480, RB76-5418, RB85-5536, SP80-1816 and SP80-1842 had similar behavior, presenting the highest yield with the 1351 mm depth. The variety RB83-5486 presented the highest yield with 1081 mm depth. High-yield is a genetic characteristic of determined varieties that, when associated with other factors such as soil and water availability throughout the cropping cycle, can enhance productivity, as observed on the varieties IAC86-2480, RB76-5418, RB85-5536, SP80-1816 and SP80-1842 (Fig. 3).

Oliveira et al. [33,34] evaluated different sugarcane varieties, in similar conditions, and observed that fertilization and irrigation suppression affects directly these attributes. However, Moraes et al. [35] reported that different soil preparing systems, as plowing, harrowing and liming, poorly affect the agronomic sugarcane characteristics, reinforcing the irrigation effects on the observed results.

Table 3. Yield of 6 sugarcane varieties under 5 irrigation depths, 11 months after planting

Varieties	Irrigation depths (mm)									
	271		541		811		1081		1351	
IAC86-2480	68,68	a	93,26	ab	98,52	bc	124,60	a	136,36	ab
RB76-5418	92,38	a	107,41	ab	101,73	abc	126,21	a	138,97	ab
RB83-5486	64,41	a	65,08	b	96,97	c	107,58	a	99,37	b
RB85-5536	77,57	a	91,86	ab	120,39	abc	143,14	a	173,42	a
SP80-1816	76,68	a	109,37	ab	146,71	ab	139,52	a	173,66	a
SP80-1842	97,15	a	129,74	a	149,85	a	143,27	a	182,76	a

**Means followed by the same letters not differ by the Tukey Test, 5% probability (P = 0.05)*

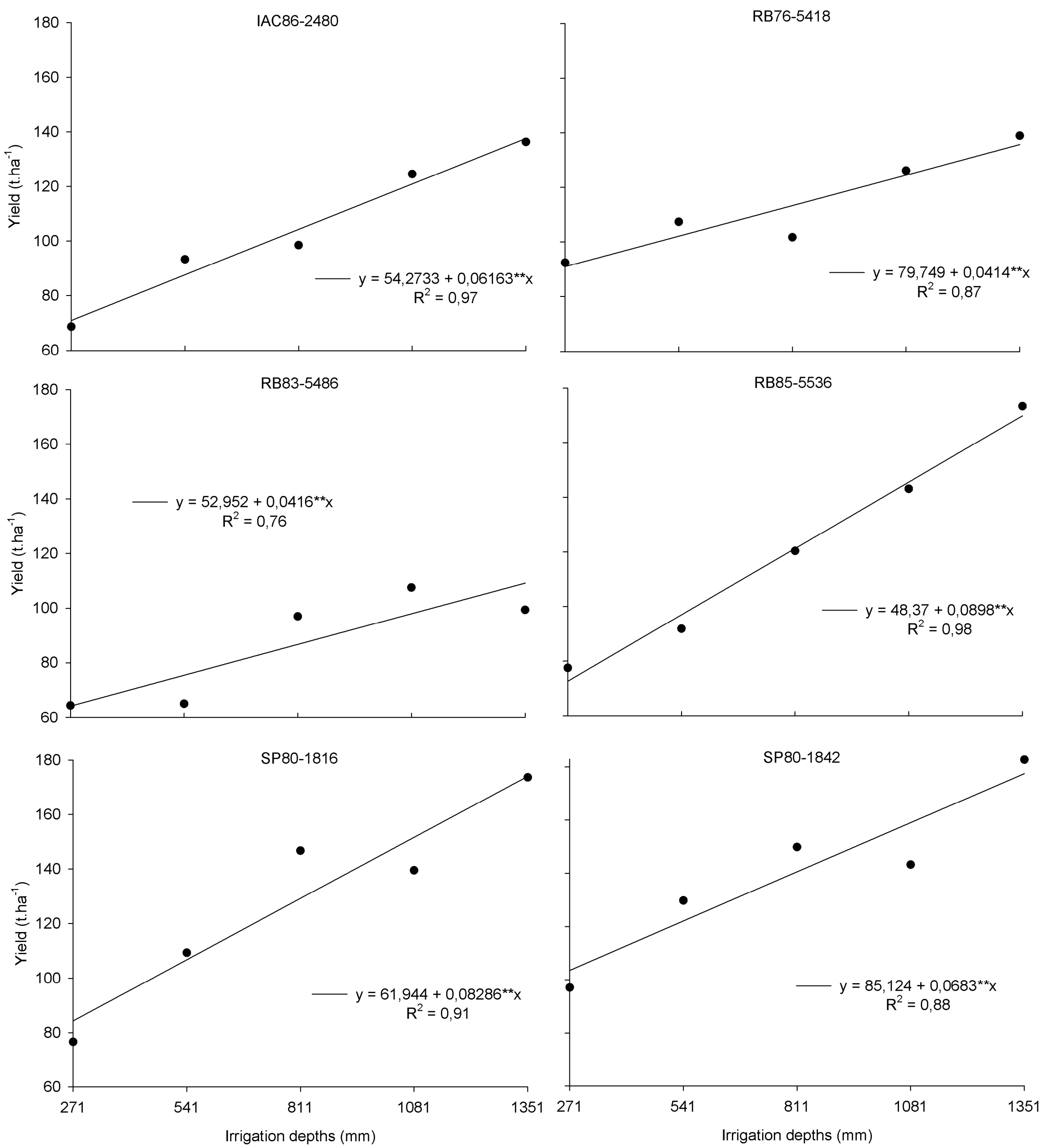

Fig. 3. Yield of sugarcane under five different irrigation depths, 11 months after planting
*** Equations are significant by F test, 1% probability (P≤0.01)*

The storage of water on in the soil, caused by the highest irrigation depths throughout the cropping cycle has notorious importance, since this crop has a high water demand to for biomass accumulation [36].

Water storage in the soil is related to different factors, as higher nutrient availability to plant absorption [29]. Niu et al. [37] reinforce this assertion, reporting that low water availability can harm root development and thus harm phosphorus (P) absorbance by the plant. Therefore, there is a limitation for sugarcane development, since the availability of this element is directly related to culm production, affecting total yield [38]. However, it is important to emphasize that the absorption of other nutrients, besides P, can be impaired under hydric deficit, thus, resulting in less transport and accumulation on plant tissues.

Evapotranspiration is another factor to be considered, regarding water accumulation in the soil. Silva et al. [8] evaluating the variety RB92-579, observed that additional irrigation have a significant effect on evapotranspiration and consequently on sugarcane yield in tropical conditions. According to the authors, yield increase is linearly correlated to an increase in plant water consumption.

Lower evapotranspiration can result on water absorption restriction, reducing stomatal conductance and limiting leaf metabolism. According to Benesová et al. [39], the reduction of water loss is a physiological mechanism controlled partially or completely by stomata closing, culminating in changes of leaf water-status, which are directly related to the photosynthetic process.

Within the metabolic mechanisms that sugarcane utilizes on hydric deficit situations (as low irrigation depths), there is the accumulation of compatible solutes as trehalose, betaine glycine and proline [40]. However, according to the authors, the accumulation of these solutes does not prevent the reduction of sugarcane dry matter accumulation on severe conditions.

Thus, it is important to emphasize on other factors that can be associated to the sugarcane responses to irrigation.

4. CONCLUSION

The varieties SP80-1842 and SP80-1816 presented the highest growth, culm diameter, and yield of sugarcane among the six evaluated varieties. They should be considered the most promising for the semi-arid conditions of Minas Gerais state. The irrigation depth 1351 mm presented the best results to sugarcane yield in the studied semi-arid conditions and is proposed to be adopted.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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