

Original Research Article

Agronomical performance of sugarcane varieties in function of different irrigation depths on semi-arid conditions

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 blocks design (DBC), 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 on 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

31 is an important tool to investigate yield capacity and the irrigation effects on the crop [8]. On
32 sugarcane breeding experiments, this tool can also be used, aiming on yield maximization.

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

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

40 41 **2. MATERIAL AND METHODS**

42 43 **2.1 Local, soil and plant material**

44
45 The experiment was conducted in Brazil, on the semi-arid region of Minas Gerais state,
46 Jaíba city, at the experimental farm Mocambinho (FEMO). Mocambinho is owned and
47 managed by the EPAMIG institution. The coordinates of the experimental area were 15° 05'
48 34"S latitude and 43° 58' 44"W longitude. Mean temperature is 25,5 °C (18.7 °C minimum
49 and 32.3 °C maximum). Annual insolation is 2987 hours. Relative humidity 65.5%. Mean
50 rainfall is approximately 800 mm annually, concentrated between October and March.

51 Previously to the experiment, soil samples were collected on the experimental area. The 0-
52 20 and 20-40 cm profundities were used to texture and fertility analysis. The soil was
53 classified as dystrophic red latosol, presenting a medium texture (LVD) [10]. Following the
54 fertility test results, fertilizing was performed according to Korndörfer et al. [11], consisting in
55 applying, before planting, 150 kg.ha⁻¹ of ammonium sulfate and 750 kg.ha⁻¹ of single
56 superphosphate. Liming and micronutrients correction were not performed following the
57 fertility analysis. Pre-planting fertilizing was performed on the trenches.

58 Before planting, the soils was prepared, aiming to reduce compaction, by subsoiling, plowing
59 and two processes of harrowing. The six following sugarcane varieties were used, IAC86-
60 2480, RB76-5418, RB83-5486, RB85-5536, SP80-1816 and SP80-1842. Seedlings were
61 distributed on trenches, 25 to 30 cm depth, with 1.20 m within each other. Stalk selection
62 criteria was 3 to 5 buds per stalk, resulting on 16 to 18 gems for each trench meter. Stalks
63 were covered by a 5 to 10 cm soil layer.

64 Cover fertilizing was performed 90 days after planting (DAP), consisting of 150 kg.ha⁻¹ of
65 (NH₄)₂SO₄. During the crop cycle, the occurrence of pests and diseases was monitored and
66 control was performed as necessary, following chemical and biological procedures
67 recommended to the sugarcane crop [12]. Weed control was performed trough chemical
68 spraying, following weeds identification and procedures recommended to the sugarcane crop.

69 70 **2.2 Irrigation treatments**

71
72 To all varieties, five irrigation depths were employed, consisting of 271, 541, 811, 1081 and
73 1351 mm, corresponding to 25, 50, 75, 100 and 125% of the recommended depth,
74 respectively. Irrigation was performed by line Source sprinkling, being one line of 11 nozzles,
75 NAAN 5035 model, distributed evenly spaced. Water was applied on decreasingly levels and
76 perpendicular to the tubulation. Sprinklers height was proportional to plant growth and
77 spaced 12 m from each other. Irrigation outflow was 3100 L.h⁻¹.

Irrigation management was performed using potential reference evapotranspiration (ET_o), calculated according to (Equation 1). 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 [13].

Equation 1. Potential reference evapotranspiration by Hargreaves methodology.

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

Being: ET_o= 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.

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 evaluations were performed when the plants were 11 months old.

2.3 Agronomical evaluations

Agronomical evaluations were performed following the methods proposed by Gheller [14]. 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 [15] (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 blocks design (DBC), 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 arranged parallel to the irrigation lines. Sub-parcels presented 33,75 m² (7,5 x 4,5 m) and were composed of five 8m 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 was not significant interactions between varieties and irrigation depths. To all evaluated characteristics, it was observed significant effect to varieties and irrigation depths. The varieties IAC86-2480 and SP80-1842 presented the lowest and highest growth, comparing to the remaining varieties (Table 1).

All the varieties presented mean height superior to 2.00 m (Table 1), similar to the results noticed by Silva et al. [16], evaluating the SP83-5073 variety under different irrigation depths. Campos et al. [17] observed similar positive effects of irrigation on the height of several varieties, on a semi-arid region.

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

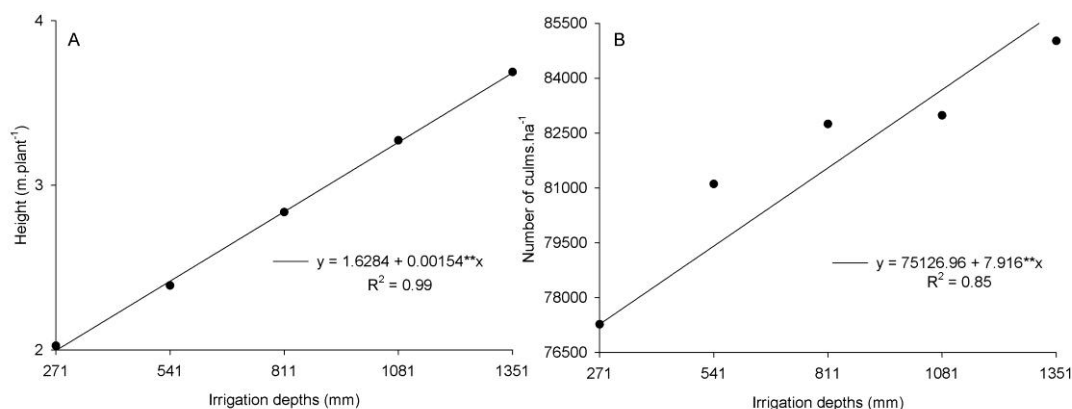
*Means followed by the same letters not differ by the Tukey Test, 5% probability ($P = 0.05$).

The variety IAC86-2480 was superior regarding the number of culms, with mean 99092 culms.ha⁻¹. According to Taupier & Rodrigues [18], 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 the RB76-5418, RB85-5536 and SP80-1842 varieties regarding number of culms. The lowest value was observed to the RB83-5486 variety, 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 presents a considerable relation between growth and soil humidity. According to Silva et al. [19], plant height is a major component to evaluate sugarcane yield potential and irrigation is a tool to

158 full genetic potential expression. However, it is important to emphasize that excessive plant
159 height can entail on plant bedding, leading to yield losses (Oliveira & Braga [20].



160

161 **Fig. 1. Plant height (A) and number of culms (B) of sugarcane under five different**
162 **irrigation depths, 11 months after planting. **Equations are significant on 1%**
163 **probability (P<0.01)**
164

165 Number of culms and irrigation depths presented a crescent linear response. The highest
166 number of culms was achieved with the highest irrigation depth 1351 mm (Figure 1B).
167 Differently from Silva *et al.* [16], a dependence between irrigation and number of culms to
168 the SP83-5073 variety, on similar conditions, was not observed. According to Singh *et al.*
169 [21], the enhanced transport of water and nutrients provided by irrigation, and/or rainfall, has
170 a direct effect on culm production and sugarcane water-use efficiency.

171
172 To culm diameter and yield, there was significant interactions regarding variety and irrigation
173 depth. All the varieties presented culms diameter values that can be considered medium (20
174 to 30 mm), regardless of the irrigation depth [22] (Table 2). Plant bedding can be
175 considerably reduced with higher culms diameter values [23].
176

177 **Table 2. Culms diameter (mm.plant⁻¹) of 6 sugarcane varieties under 5 irrigation**
178 **depths, 11 months after planting.**

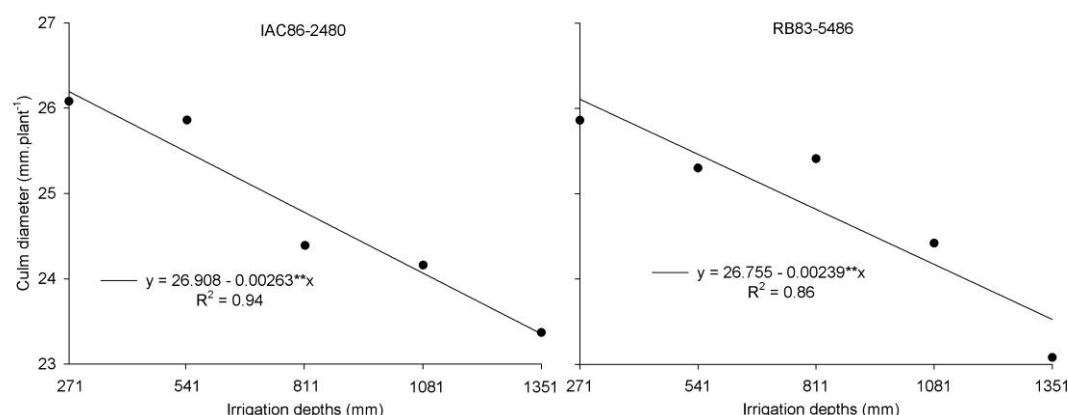
Varieties	Irrigation depths (mm.plant ⁻¹)				
	271	541	811	1081	1351
IAC86-2480	26.08 a	25.86 a	24.39 b	24.16 ab	23.37 bc
RB76-5418	25.06 a	24.85 a	23.99 b	23.61 b	24.35 abc
RB83-5486	25.86 a	25.30 a	25.41 ab	24.42 ab	23.08 c
RB85-5536	25.56 a	24.21 a	25.70 ab	24.97 ab	25.35 ab
SP80-1816	24.98 a	26.07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

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

180 Significant differences were not observed on culms diameter between all varieties on the
181 lowest irrigation depths (271 and 541 mm). Silva *et al.* [19] evaluated the initial growth of
182 different sugarcane varieties, under different hydric schemes, and did not observed
183 significant differences to this parameter. Significant differences were observed on the
184 between the varieties on the 811, 1081 and 1351 mm irrigation depths.

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

188 The varieties IAC86-2480 and RB83-5486 presented, in a general manner, similar behavior
189 regarding culms diameter, with a reduction on this parameter in response to irrigation
190 increase, comparable to results obtained by Carlos et al. [24] (Fig. 2).



191

192 **Fig. 2. Culm diameter of sugarcane under five different irrigation depths, 11 months**
193 **after planting. ** Equations are significant by F test, 1% probability ($P \leq 0.01$).**

194 These results, however, differ from Silva et al. [16] and Oliveira et al. [25], who observed an
195 increase on culm diameter in response to higher irrigation depths. This difference can be
196 explained due to genetic characteristics, the occurrence of tillering, plant spacing, leaf area
197 and environmental conditions [26].

198 According to Ferreira et al. [27], the most efficient sugarcane selection regarding yield is
199 performed based on culms number and diameter. Similarly. Silva et al. [28], report that
200 tillering, jointly with plant height and culm diameter are evidences of yield potential. Cesnik &
201 Miocque [22], however, assert that culm diameter is poorly influenced by environment, being
202 an intrinsic genetic characteristic of each variety.

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

207 As well as the 271 mm depth, significant differences on yield were not observed to all the
208 varieties at 1081 mm depth. At 1351 mm depth, the varieties SP80-1842, SP80-1816 and
209 RB85-5536 presented the highest values, corresponding to 182.76, 173.66 and 173.42 t ha⁻¹
210 respectively. At the same irrigation depth, the RB83-5486 variety presented the lowest yield,
211 99.37 mm (Table 3).

212

213

214 **Table 3. Yield of 6 sugarcane varieties under 5 irrigation depths, 11 months after**
 215 **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

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

217 The variety SP80-1842 presented a superior yield on all irrigation depths (Table 3).
 218 Therefore, this variety can be considered the highest producer within the analyzed varieties
 219 on this region, regardless of the soil humidity conditions. This variety possess characteristics
 220 that can enhance the responses to irrigation. Rapid vegetative growth, adequate ratoon
 221 sprouting, high sucrose content, low isoporization and tolerance to diseases and pests are
 222 some of the characteristics [29].

223 Studying three sugarcane varieties on the first cultivation cycle, under similar conditions as
 224 this present study, Oliveira et al. [30] observed similar results. The observed yields were
 225 197.7, 140.3 and 133.1 t ha⁻¹ to the varieties RB72-454, RB85-5113 and RB85-5536
 226 respectively.

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

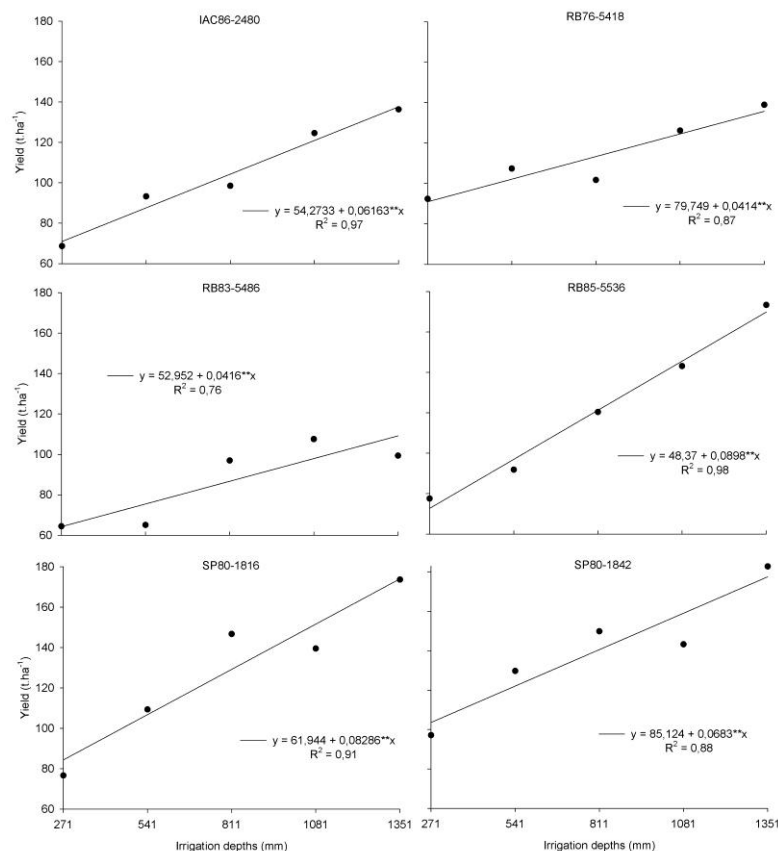


Fig. 3. Yield of sugarcane under five different irrigation depths, 11 months after planting. ** Equations are significant by F test, 1% probability (P≤0.01).

The results corroborate with Silva et al. [8], which 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 through the cycle, can enhance productivity, as observed on the varieties IAC86-2480, RB76-5418, RB85-5536, SP80-1816 and SP80-1842 (Figure 3).

Oliveira et al. [31] evaluated different sugarcane varieties, on similar conditions, and observed that fertilization and irrigation suppression affects directly these attributes. However, Moraes et al. [32] report that different soil preparing systems, as plowing, harrowing and liming, poorly affect the agronomic sugarcane characteristics, reinforcing the irrigation effects on the observed results.

The storage of water on soil, caused by the highest irrigation depths through the cycle has notorious importance, since this crop has a high water demand to biomass accumulation [33].

Water storage on soil is related to different factors, as higher nutrient availability to plant absorption [26]. Niu et al. [34] 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 on sugarcane development, since the availability of this element is directly related to culm production, affecting total yield [35]. 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 on soil. Silva et al. [8] evaluating the RB92-579 variety, observed that additional irrigation have a significant effect on evapotranspiration and consequently on sugarcane yield on tropical conditions. According to the authors, yield increase is linearly correlated to an increase on plant water consumption.

Lower evapotranspiration can result on water absorption restriction, reducing stomatal conductance and limiting leaf metabolism. According to Benesová et al. [36], the reduction of water loss is a physiological mechanism controlled partially or completely by stomata closing, culminating on changes on 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 [37]. However, according to the authors, the accumulation of these solutes do not prevents the reduction of sugarcane dry matter accumulation on severe conditions.

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

4. CONCLUSION

The varieties SP80-1842 and SP80-1816 presented the best agronomical performances within the evaluated varieties, being promising to semi-arid conditions. The irrigation depth 1351 mm presented the best results to sugarcane yield, on the studied semi-arid conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. USDA. United States Department of Agriculture. Sugarcane production. 2017. Accessed 22 July 2017. Available: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/17_03_23_17_00_58_conj.pdf.
2. CONAB. National Supply Company. Follow-up of the Brazilian sugarcane harvest. Brasilia DF. 2016; 3: 1-65. Accessed 12 January 2017. Available: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/15_12_17_09_03_29_bio_bulletin_english_-_3o_lev_-_15-16.pdf.

- 301 3. Rudorff BFT, Aguiar DA, Silva WF, Sugawara LM, Adami M, Moreira MA. Studies on
302 the Rapid Expansion of Sugarcane for Ethanol Production in São Paulo State
303 (Brazil) Using Landsat Data. *Remote Sensing*. 2010;2(4):1057-1076.
- 304 4. Lisar SY, Motafakkerazad R, Hossain MM, Rahman, IM. Water stress in plants:
305 causes, effects and responses. *Water stress*. InTech. 2012. Accessed 25 July 2017.
306 Available: <https://cdn.intechopen.com/pdfs-wm/27305.pdf>.
- 307 5. Abreu ML, Almeida Silva M, Teodoro I, Almeida de Holanda L, Dantas Sampaio
308 Neto G. Growth and productivity of sugarcane as a function of the water availability
309 of the Coastal Trails of Alagoas. *Bragantia*. English. 2013; 72 (3): 262-270.
- 310 6. Ribeiro RV, Machado RS, Machado EC, Machado DFSP, Magalhães Filho JR,
311 Landell MGA. Revealing drought-resistance and productive patterns in sugarcane
312 genotypes by evaluating both physiological responses and stalk yield. *Exp. Agric*.
313 2013;49(2):212-224.
- 314 7. Boaretto LF, Carvalho G, Borgo L, Creste S, Landell MG, Mazzafera P, Azevedo R.
315 A. Water stress reveals differential antioxidant responses of tolerant and non-
316 tolerant sugarcane genotypes. *Plant physiology and biochemistry*. 2014; 74:165-
317 175.
- 318 8. Silva VPR, Silva BB, Albuquerque WG, Borges CJ, Sousa IF, Neto JD. Crop
319 coefficient, water requirements, yield and water use efficiency of sugarcane growth
320 in Brazil. *Agricultural water management*. 2013;128(1):102-109.
- 321 9. Garg KK, Bharati L, Gaur A, George B, Acharya S, Jella K, Narasimhan B. Spatial
322 mapping of agricultural water productivity using the SWAT model in Upper Bhima
323 Catchment, India. *Irrigation and Drainage*. 2012;61(1)60-79.
- 324 10. Santos HG. Brazilian system of soil classification. 3rd ed. Brasília-DF: Embrapa;
325 2013.
- 326 11. Korndörfer GH, Ribeiro AC, Andrade LAB. Sugarcane: fertilization suggestions for
327 large annual or perennial crops. In: Ribeiro AC, Guimarães PTG, Alvarez VH,
328 editors. Recommendations for the use of correctives and fertilizers in Minas Gerais -
329 5th approximation. 1st ed. English. Viçosa: UFV; 1999.
- 330 12. Dinardo-Miranda LL, Vasconcelos ACM, Vieira SR, JV Failure, Greek CR. Use of
331 geostatistics in the evaluation of the spatial distribution of Mahanarva fimbriolata in
332 sugarcane. *Bragantia*. English. 2007; 66 (3): 449-455.
- 333 13. Bernardo S, Soares AA, Mantovani EC. Manual of Irrigation. 1st ed. Viçosa: UFV;
334 2006.
- 335 14. Gheller, H. Technical scientific cooperation program in the area of genetic
336 improvement of sugarcane. 1st ed. Araras: UFSCAR; 1997.
- 337 15. Martins LM, Landell MGA. Concepts and criteria for experimental evaluation in
338 sugarcane used in the Cana IAC Program. 1st ed. Pindorama: IAC; 1995.
- 339 16. Silva NF, Cunha FN, Teixeira MB, Soares FAL, Santos CC, Cabral Filho FR, Silva
340 EC, Morais WA. Sugarcane cultivation submitted to water replacement via irrigation
341 bar. *African Journal of Agricultural Research*. 2016;11(32):2983-2993.
- 342 17. Campos PF, Alves Júnior J, Casaroli D, Fontoura PR, Evangelista AWP. Varieties of
343 sugarcane submitted to supplementary irrigation in the cerrado of Goiás. *Agricultural
344 engineering*. English. 2014; 34 (6): 1139-1149.
- 345 18. Taupier LOG, Rodrigues, GG. The sugarcane. In: ICIDCA. Ed. Handbook of
346 Sugarcane Derivatives: diversification, raw materials, bagasse derivatives, molasses
347 derivatives, other derivatives, waste, energy. Brasília: ABIPTI; 1999.
- 348 19. Silva MDA, Soares RAB, Landell MGDA, Campana MP. Agronomic performance of
349 sugarcane families in response to water stress. *Bragantia*. Portuguese. 2008;67(3):
350 655-661.
- 351 20. Oliveira AR, Braga MB. Flowering and lodging of sugarcane cultivars submitted to
352 different irrigation slides. 1 ed. Research and Development Bulletin: Embrapa; 2011.

- 353 21. Singh PN, Shukla SK, Bhatnagar VK. Optimizing soil moisture regime to increase
354 water use efficiency of sugarcane (*Saccharum* spp. Hybrid complex) in subtropical
355 India. *Agricultural Water Management*. 2007;90(1):95-100.
- 356 22. Cesnik R, Miocque J. Improvement of sugarcane. 1st ed. Brasília: Embrapa
357 Information Technology; 2004.
- 358 23. May A, Albuquerque CJB, Silva AD, Pereira Filho IA. Management and cultural
359 dealings. In: Durães FOM, May A, Parrella, RDC, editors. *Embrapa system of*
360 *agroindustrial production of sorghum for bioethanol: BRS1G-Embrapa Quality*
361 *Technology System*. English. Sete Lagoas: Embrapa Maize and Sorghum; 2012.
- 362 24. Carlos HDA, Silva CT, Filho RRG. Yield of sugar and alcohol from sugarcane
363 submitted to different levels of irrigation. *Brazilian Journal of Agricultural Sciences*.
364 English. 2009; 4 (1): 72-77.
- 365 25. Oliveira ECA, Oliveira RI, Andrade BMT, Freire FJ, Lira Júnior MA, Machado PR.
366 Growth and accumulation of dry matter in sugarcane varieties grown under full
367 irrigation. *Brazilian Journal of Agricultural and Environmental Engineering*. English.
368 2010; 14 (9): 951-960.
- 369 26. Oliveira AR, Braga MB. Flowering and lodging of sugarcane cultivars submitted to
370 different irrigation slides. 1st ed. Brasília: Research and Development Bulletin,
371 Embrapa, 2011.
- 372 27. Ferreira FM, Barros WS, Silva FD, Barbosa MHP, Cruz CD, Bastos, IT. Phenotypic
373 and genotypic relationships among components of sugarcane production. *Bragantia*.
374 English. 2007; 66 (4): 605-610.
- 375 28. Silva MA, Arantes, MT, Rhein AFL, Gava GJC, Kolln OT. Productive potential of
376 sugarcane under drip irrigation as a function of varieties and cycles. *Brazilian*
377 *Journal of Agricultural and Environmental Engineering*. English. 2014; 18 (3): 241-
378 249.
- 379 29. Duarte Júnior JB, Coelho FC. The sugarcane in no-tillage system compared to the
380 conventional system with and without fertilization. *Brazilian Journal of Agricultural*
381 *and Environmental Engineering*. English. 2008; 12 (6): 576-584.
- 382 30. Oliveira RA, Daros E, Zambon JLC, Weber H, Ido OT, Bepalhok-Filho JC,
383 Zuffellato-Ribas KC, Silva DKT. Leaf area in three cultivars of sugarcane and its
384 correlation with biomass production. *Tropical Agriculture Research*. English. 2007;
385 37 (2): 71-76.
- 386 31. Oliveira FM, Aspiázú I, Koiti Kondo M, Dias Borges I, Facco Pegoraro R, Jardim
387 Vianna E. Technological evaluation of sugarcane varieties influenced by different
388 fertilization and irrigation suppression. *Ceres Journal*. English. 2012; 59 (6): 832-
389 840.
- 390 32. Moraes ER, Silva Domingues L. A, Medeiros MH, Peixoto JVM, Lana RMQ.
391 Productivity and agronomic characteristics of sugarcane in different soil preparation
392 systems. *Journal of Neotropical Agriculture*. English. 2016; 3 (1): 27-32.
- 393 33. Wiedenfeld B. Effects of irrigation water salinity and electrostatic water treatment for
394 sugarcane production. *Agricultural Water Management*. 2008;95(1):85-88.
- 395 34. Niu YF, Chai RS, Jin GL, Wang H, Tang CX, Zhang YS. Responses of root
396 architecture development to low phosphorus availability: a review. *Annals of botany*.
397 112(2):391-408.
- 398 35. Alves V, Montanari R, M Steps, Correa AR, Roque CG. Technological attributes,
399 stand and productivity of cane-plant correlated with aspects of soil fertility. *Journal of*
400 *Neotropical Agriculture*. English. 2015; 1 (1): 75-91.
- 401 36. Benesová M, Holá D, Fischer L, Jedelsky PL, Hnilicka F, Wilhelmová N, Rothová, O,
402 Kocová M, Procházková D, Honnerová J, Fridrichová L, Hnilicková H. The
403 physiology and proteomics of drought tolerance in maize: early stomatal closure as
404 a cause of lower tolerance to short-term dehydration? *Plos One*. 2012;7(6),e38017.

- 405 37. Carlin SD, Santos DMM. Physiological indicators of the interaction between water
406 deficit and soil acidity in sugarcane. Brazilian agricultural research. English. 2009;
407 44 (9): 1106-1113.