AGRONOMIC PERFORMANCE OF SUGARCANE FAMILIES IN RESPONSE TO WATER STRESS (1)

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ABSTRACT

Water deficit is one of the major factors limiting the production of sugarcane, especially in areas where there is a prolonged period of water deficiency, such as the West Central Brazilian region. One way to overcome this problem is to cultivate resistant or tolerant varieties. An experiment was set up at the Jalles Machado Sugar Mill, located near Goianésia, Goiás State, Brazil, to evaluate agronomic performance of several sugarcane families. A comparative analysis was carried out among the families under two irrigation regimes, one under regular environmental conditions and another under monthly irrigations during the period of water deficiency. Evaluated families consisted of 25 progenies planted in a factorial design with three replications with 20 plants each. The first ratoon crop was evaluated for four yield components, stalk height, stalk diameter, stalk number and Brix. By analysis of variance, stalk number and stalk height were influenced by water stress conditions during the initial growth phase, and for stalk diameter and Brix, water regime had no effect on the average expression of the characters during the growth phase. The method of classification in four categories proved to be adequate. Some families had high values for stalk diameter, stalk number and stalk height under water stress conditions. This study showed that it is possible to select sugarcane families under water deficit conditions associated with higher stalk diameter, stalk number and stalk height.

Key words: Selection, water deficit, irrigation, Brix.

RESUMO

DESEMPENHO AGRONÔMICO DE FAMÍLIAS DE CANA-DE-AÇÚCAR EM RESPOSTA AO DÉFICIT HÍDRICO

O déficit hídrico é um dos fatores mais importantes que limitam a produção da cana–de-açúcar, especialmente nas áreas onde existe um período prolongado de seca, como na Região Centro-Oeste do Brasil. Uma forma de contornar este problema é plantar variedades resistentes ou tolerantes à seca. Um experimento foi desenvolvido na Usina Jalles Machado, localizada próxima de Goianésia, no Estado de Goiás, Brasil, para avaliar o desempenho de várias famílias de cana-de-açúcar sob condições de déficit hídrico. Foi realizada uma análise comparativa entre as famílias que foram cultivadas sob duas condições de disponibilidade de água: ambientais regulares ou irrigações mensais durante o período de deficiência de água. O material avaliado consistiu de 25 famílias plantadas em um desenho factorial de três repetições com 20 plantas cada uma, no total de 60 indivíduos. Na colheita da primeira soqueira, avaliaram-se quatro componentes: altura, diâmetro, número de colmos e Brix. Por meio da análise de variância, o número e a altura dos colmos foram influenciados pelas condições de seca durante a fase de crescimento inicial, enquanto o regime de irrigação não afetou as médias de diâmetro do colmo e de Brix durante a fase de crescimento. Pelo método de separação em quatro categorias, em algumas famílias observaram-se elevados valores de diâmetro, número e altura de colmos quando cresceram sob condição de déficit hídrico. Este estudo comprovou que é possível selecionar famílias de cana-de-açúcar sob estresse hídrico associadas com maiores diâmetro, número e altura de colmos.

Palavras-chave: Seleção de plantas, déficit hídrico, irrigação, Brix.

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(1) Recebido para publicação em 8 de outubro de 2007 e aceito em 26 de fevereiro de 2008.
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1. INTRODUCTION

Sugarcane is an important crop not only for sugar production, but also increasingly as a leading potential source for biofuels due to its phenomenal dry matter production capacity. Huge expansions of the sugarcane planting area in Brazil are in marginal areas. One of the most serious problems encountered in these new areas is the occurrence of water stress periods. Under these conditions growers have to rely on irrigation to meet production goals.

There will be pressure on growers to resort to producing sugarcane with less irrigation water in the future. This will lead to increased levels of water stress imposed to the crop. Future sugarcane breeding efforts should include improving tolerance of sugarcane to water stress, utilizing appropriate stress tolerance mechanisms.

Drought is a multi-dimensional stress, which causes various physiological and biochemical effects on plants (Jamaux et al., 1997). Researchers have mostly concentrated on agronomic and physiological traits, which could lead to adaptation to these conditions or be correlated to drought tolerance and that could be used for breeding and development of new varieties (Domaingue, 1996). According to Singh and Reddy (1980) the use of drought tolerant varieties is the more economic way to get around the water stress problems.

According to Landell and Silva (2004), the decisive production attributes for agricultural potential are: stalk height, stalk number and stalk diameter. Most studies concerning agronomic traits in different water regimes, however, were undertaken with specific genotypes. Number of millable stalks has been reduced under restricted water availability (Ramesh and Mahadevaswamy, 2000; Robertson et al., 1999; Silva and Costa, 2004; Singh and Reddy, 1980; Soares et al., 2004). Other studies (Gascho and Shih, 1983; Hellmann, 1977) showed similar tillering and cane number under both wet and dry conditions. Stalk diameter has been found to be influenced by water regime; however, it is also dependent of the genotype (Silva and Costa, 2004), and/or harvest cycle (Soares et al., 2004). Cane elongation and stalk height are negatively and strongly affected under drought conditions (Inman-Bamber and Smith, 2005; Ramesh and Mahadevaswamy, 2000; Silva and Costa, 2004; Singh and Reddy, 1980; Soares et al., 2004). As a result of the reduction in agronomic traits associated with yield, cane and sugar yields are decreased under water stress conditions (Inman-Bamber and Smith, 2005; Ramesh, 2000; Ramesh and Mahadevaswamy, 2000; Silva and Costa, 2004; Singh and Reddy, 1980; Soares et al., 2004; Wiedenfeld, 1995).

It is perceived that there are considerable differences among genotypes in response to water stress. Information about drought response among genotypes is generally obtained after they have been released for commercial planting. Studies on the response of families to drought are restricted to few only. Domaingue (1996) assessed six biparental crosses in Mauritius under a sub-humid environment with drip-irrigation and without irrigation. Results showed that field Brix and stalk diameter were unaltered by the water stress regime. On the other hand, stalk number and internode number were reduced by water stress especially in the plant cane crop, and stalk height and mean length of internodes were the most severely reduced parameters in unirrigated conditions. The author argued that due to the scarcity of data on the performance of families under drought conditions, breeding efforts could not be easily oriented.

The objective of this research was to assess differences in agronomic parameters in sugarcane families under water stressed conditions to provide useful criteria for breeding for drought tolerance.

2. MATERIAL AND METHODS

A field experiment was conducted from April 2002 to April 2004 at the Jalles Machado Sugar Mill S/A, near Goianésia, Goiás State, Brazil (15° 10′ S, 49° 15′ W and 668 m altitude), where the annual average rainfall is about 1540 mm, and the weather is classified according Köppen Climate Classification (2006) as savanna tropical with a dry winter and rainy summer (Aw), with a well defined water stress season between May and October. The soil has been classified as a red-yellow latosoil, dystrophic, deep and flat with a well-drained topography (Prado, 2003).

The experimental design was a factorial one with 25 families and 60 seedlings per family, planted in three replicates with twenty progenies per family per replicate grown under irrigated and rainfed conditions (Table 1). Each progeny was spaced at 0.50 m within each row, which was spaced at 1.50 m.

Irrigation was supplied through a linear-move overhead drag hose system. The plant cane of both treatments (irrigated and unirrigated) was irrigated during all growing phases to guarantee a good stand in all plots. In the first ratoon crop, the irrigated treatment received 80 mm in May 2003 and during the period from June until September 2003 received 50 mm of irrigation each month, totaling 280 mm. The unirrigated treatment received the same irrigation of 80 mm in May 2003 to guarantee the survival of seedlings (rescue irrigation). Thus, the total water received by the irrigated treatment was 1795 mm, and the unirrigated treatment received 1595 mm. Figure 1 shows the temperature, rainfall and irrigation distribution during April 2002 to April 2004. All other agronomic practices were the same between the irrigated and unirrigated treatment.

Table 1. List of sugarcane crosses included in the trial

Family	Parents	
	♀	♂
1	IAC91-2195	Self
2	SP88-724	SP70-1143
3	SP87-585	SP88-607
4	SP86-45	SP88-607
5	IAC91-2216	SP88-607
6	CP70-1133	SP88-607
7	RB855035	Self
8	RB855035	SP86-45
9	RB855035	SP70-1143
10	RB855035	IAC87-3396
11	SP91-1155	SP70-1143
12	IAC91-4216	RB855357
13	SP91-3059	IAC91-1042
14	SP91-3059	IAC89-3124
15	SP91-1155	SP70-1143
16	SP91-1155	SP77-5181
17	SP89-1046	IAC89-2135
18	IAC87-3420	SP88-705
19	SP91-3100	RB855035
20	SP80-1842	IAC87-3396
21	RB835486	SP77-5181
22	SP80-1842	SP77-5181
23	IAC86-3154	SP81-3250
24	IAC87-3396	SP77-5181
25	SP91-3059	CTC93-157

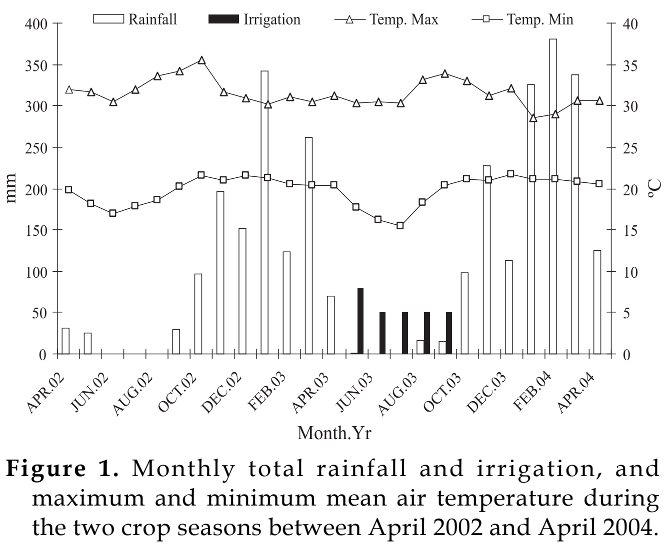

Figure 1. Monthly total rainfall and irrigation, and maximum and minimum mean air temperature during the two crop seasons between April 2002 and April 2004.

Yield components such as stalk height, stalk number, stalk diameter, and average soluble solids (°Brix) were evaluated in April 2004. Stalk number was counted in all stalks in the stool. For the determination of the stalk height component, a ruler was used to measure a sample of five stalks per stool. A caliper was used to measure the diameter of the same five stalks. The average Brix was obtained through the reading of soluble solids from the sugarcane juice from each of the five stalks using a manual refractometer, 0-32% scale.

The significance of treatment differences was tested by analysis of variance (ANOVA) for each variable, in order to assess the main effects of water treatment and families, as well as family x water regime interaction. Means were separated by using the least significant difference test (LSD). The SISVAR 4.6 statistical package (Ferreira, 2000) was used to analyze the data.

3. RESULTS AND DISCUSSION

The traits, stalk number and stalk height were affected by the treatments, and the means of the traits under irrigated conditions were significantly greater than the unirrigated regime (Table 2).

For stalk diameter and Brix there was no difference between the means. Domaingue (1996) did not obtained significant differences for stalk diameter among families between irrigated and unirrigated conditions in plant cane and second ratoon crops. On the other hand, Silva and Costa (2004) observed that the water stress decreased stalk diameter of six among eight genotypes.

The water withheld during the first four months after harvesting in April is during the period of intense tillering for ratoon formation and contributed to a reduction of 8.1% in the stalk number. This value is similar to that obtained by Domaingue (1996), who recorded a reduction of 9.0 and 2.0% in plant cane and second ratoon, respectively. A reduction in stalk population due to water stress was also related by Robertson et al. (1999), Silva and Costa (2004), Singh and Reddy (1980) and Soares et al. (2004). Ramesh and Mahadevaswamy (2000) observed that water stress provides greater tillering reduction when it occurs during the stool formative phase, i.e. between 60 and 150 days after sprouting.

Among all attributes stalk height was the most affected by unirrigated conditions with a reduction of 8.9%. Domaingue (1996) also found a pronounced reduction in cane height and mean length of internodes, and suggested that reduction in the cell elongation was greatly affected by water stress.

Table 2. F values from analysis of variance, mean and coefficient of variation of four attributes measured in first ratoon crop of twenty-five sugarcane families in irrigated and unirrigated conditions

Source	Stalk Diameter	Stalk Number	Stalk Height	Brix
Rep	0.48	7.21**	0.81	0.10
Family (F)	3.34**	3.13**	4.86**	10.60**
Irrigation regime (I)	3.06	11.79**	80.40**	1.70
F x I	0.95	1.38	2.20**	2.71**
Irrigated Mean	1.96	6.30 a[1]	185.95 a	15.73
Unirrigated Mean	1.92	5.79 b	169.29 b	15.88
C.V. (%)	5.65	14.79	6.41	4.22

** = significant at $P < 0.05$. [1] Means within a column and having different letters are significantly different (0.05 probability level).

Silva and Costa (2004) obtained stalk height reduction due to water stress in all the genotypes evaluated. Soares et al. (2004) observed that stalk height in two genotypes was the most influenced biometric attribute by water stress; therefore irrigation produced positive effect on stalk height in plant cane and first ratoon.

As observed by Domaingue (1996), Brix was not affected by water stress conditions. This is probably because the stress condition was imposed during the stool formation period, i.e. of intense growth. According to Gascho and Shih (1983), sugarcane development proceeds through four distinct phases of growth, namely; germination, tillering, grand growth and maturity. Ramesh and Mahadevaswamy (2000) reported that the effect of water stress on sucrose accumulation is observed later in the season, i.e. between 240 and 360 days after planting.

The family x irrigation regime interaction was significant for stalk height and for Brix (Table 2). Domaingue (1996) did not observe a significant interaction for any trait assessed. The effect of the treatments on some families for Brix and stalk height is shown in Figures 2 and 3, respectively. Significant effect was observed in families 2, 14, 17 and 19 for Brix, and for stalk height in families 3, 8, 9, 10, 11, 12, 13, 17, 19, 22, 23 and 24.

For Brix, among four families that showed interaction with irrigation regime, family 2, (SP88-724 x SP70-1143) had higher value under irrigated condition, and the other three, family 14, (SP91-3059 x IAC89-3124), 17, (SP89-1046 x IAC89-2135) and 19, (SP91-3100 x RB855035) showed the highest values under unirrigated conditions (Figure 2).

For stalk height (Figure 3) all families, except for 19, the values were greater under irrigated condition. Domaingue (1996) found the highest mean expression for stalk height under irrigated conditions, both in plant cane as well as in second ratoon crops, but the number of families studied was restricted to six only.

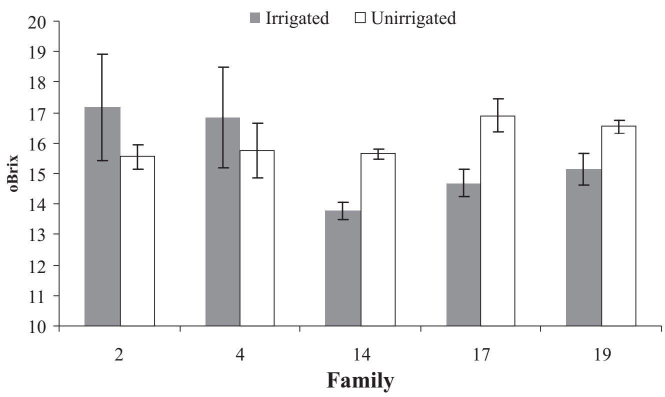

Figure 2. Mean Brix of five families that showed significant differences under irrigated and unirrigated conditions. Data are means (± standard error) of three observations.

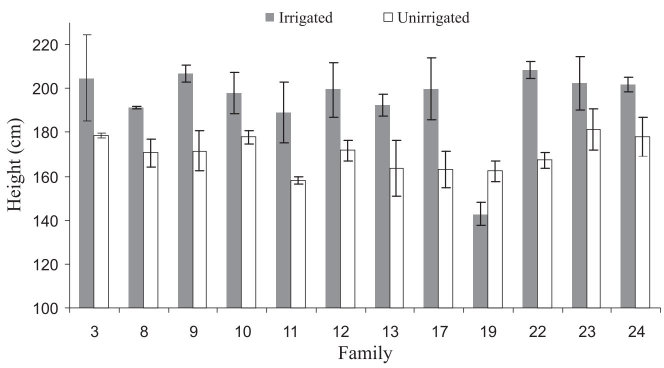

Figure 3. Mean stalk height of 12 families that showed significant differences under irrigated and unirrigated conditions. Data are means (± standard error) of three observations.

Family 19, which resulted from the cross between SP91-3100 and RB855035, besides having taller stalks on the unirrigated condition than the irrigated condition, also had the shortest stalks among all families in the irrigated condition. However, this family cannot be considered tolerant to drought, because it had the lowest mean expression for that trait under water stress.

According to SINGH and REDDY (1980) and DOMAINGUE (1996) genotypes which display proportionally less reduction in an attribute related to yield under unirrigated conditions compared to optimum conditions, could be considered as being more drought tolerant, but only if the reduction in the expression of an attribute is associated with a high mean, because it is of little value if the mean expression of the attribute is too low to satisfy the minimum required criteria.

Therefore, the ANOVA was an useful tool to detect significance for source of variation and difference between means, but it was not a good framework to identify tolerant and susceptible families to water stress.

For solving this impasse, four categories about the behaviour of families in relation to water stress were established in this paper by Instituto Agronômico, Campinas (IAC) sugarcane breeding program: tolerant, responsive, non-responsive and susceptible. The categories are defined by the means of all the families for irrigated and unirrigated conditions. A tolerant family would be one that has an above average value in both favourable (irrigated) as well as unfavourable (unirrigated) conditions. Responsive is the family that has below average yields in dry conditions but, when the environment gets better, in this case irrigated, its value increases to above average. A non-responsive family is one that has an above average value in an inferior environment but a below average value in an improved environment. And finally, a susceptible family shows below average values in both superior and inferior environments. To assess the performance of a given family its mean expression is compared to the average of all families. So, if its average is above the mean of all families it is considered adapted to that environment and the opposite is true if its mean expression is below the average of all families.

Figures 4, 5 and 6 demonstrate the different categories with respect to stalk diameter, stalk number and stalk height respectively. Because Brix was not influenced by drought condition during the development phase, its graph will be not shown. The quadrant A means tolerant families, B responsive, C non-responsive and D susceptible.

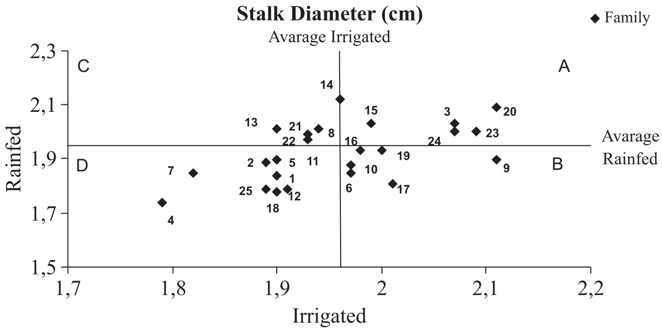

Figure 4. Scatter plot of mean stalk diameter of 25 families under unirrigated and irrigated conditions.

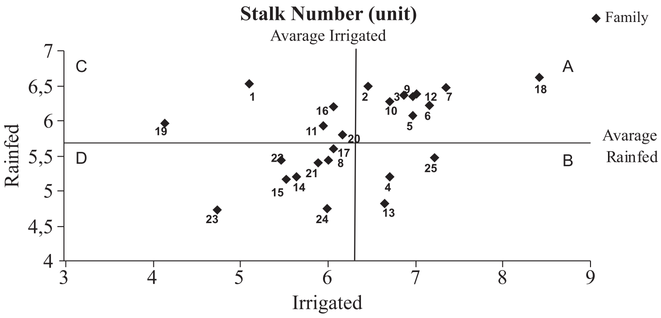

Figure 5. Scatter plot of mean stalk number of 25 families under unirrigated and irrigated conditions.

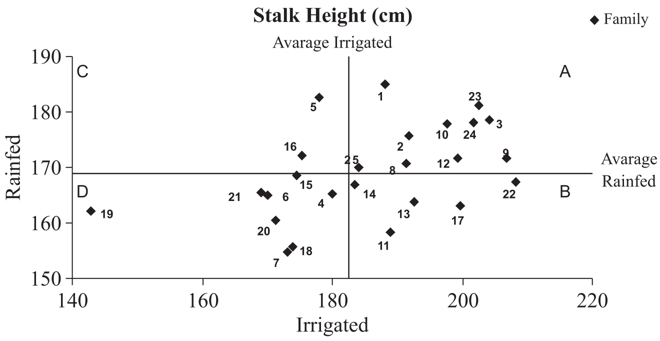

Figure 6. Scatter plot of mean stalk height of 25 families under unirrigated and irrigated conditions.

According to categories, it is possible to identify for stalk diameter the following tolerant families 3, 14, 15, 16, 19, 20, 23 and 24. The responsive families would be 6, 9, 10 and 17; the families 8, 13, 21 and 22 were non-responsive and, finally, the susceptible families would be represented for 1, 2, 4, 5, 7, 11, 12, 18 and 25 (Figure 4). For stalk number, families 2, 3, 5, 6, 7, 9, 10, 12 and 18 grouped as tolerant. Families 4, 13 and 25 were classified as responsive, and 1, 11, 16, 19 and 20 non-responsive. As susceptible, the families 8, 14, 15, 17, 21, 22, 23 and 24 were identified (Figure 5).

Stalk height showed the greatest number of families (10) in the quadrant A (tolerant). The families 1, 2, 3, 8, 9, 10, 12, 23, 24 and 25 grouped in the tolerant quadrant; 11, 13, 14, 17 and 22 responsive; 5, 15 and 16 non-responsive; whereas families 4, 6, 7, 18, 19, 20 and 21 were considered susceptible (Figure 6).

Family 3 (SP87-585 x SP88-607) was tolerant for all attributes, while, families 2 (SP88-724 x SP70-1143), 9 (RB855035 x SP70-1143), 10 (RB855035 x IAC87-3396) and 12 (IAC91-4216 x RB855357) were in the same quadrant (A) for stalk number and stalk height. Between stalk diameter and stalk height there were two families, 23 (IAC86-3154 x SP81-3250) and 24 (IAC87-3396 x SP77-5181), that were coincident in quadrant A. No families (except family 3) were coincident in the tolerant quadrant for stalk number and stalk diameter. Therefore, tolerance to drought is not related to individual characteristics but is more complex in nature.

On the other hand, for stalk diameter, a high number of families (nine) were found in the quadrant D, i.e. as susceptible. No family was susceptible for the three attributes, but families 4 (SP86-45 x SP88-607), 7 (RB855035 x self) and 18 (IAC87-3420 x SP88-705) were susceptible for stalk diameter and stalk height, and family 21 (RB835486 x SP77-5181) was susceptible for stalk number and stalk height.

The present study showed that it is possible to select sugarcane families under water deficit conditions associated with higher stalk diameter, stalk number and stalk height. Therefore, these traits could be considered as useful tools during crop breeding procedure in order to make this process more rapid and cheaper. Besides, this information could be used in hybridization programs to find parents with higher ability to transfer drought tolerance as expressed in different agronomic traits.

4. CONCLUSION

1. There is no effect of water stress regime during the early growth phase on stalk diameter and solubre solids.

2. Stalk number and stalk height are influenced by water stress conditions during the initial growth phase.

3. It was possible to find families with higher stalk diameter, stalk number and stalk height under water stress conditions.

ACKNOWLEDGMENTS

The authors thank Dr. Jorge A. Da Silva, leader of the Texas Sugarcane Breeding Program, Texas A & M University, for reading the manuscript and making suggestions.

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