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JEB

Journal of Environmental Biology

ISSN: 0254 - 8704
CODEN: JEBIDP

Effects of drought stress on biomass and carbohydrate contents of two sweet sorghum cultivars

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Publication Info

Paper received:
31 March 2012

Revised received:
10 August 2012

Accepted:
22 October 2012

Abstract

Sweet sorghum is adapted to the hot and dry climatic conditions. It can be used for different products such as food, feed, fiber and fuel. This study was carried out to evaluate the effects of four irrigation intervals and three harvesting dates on stem height, stem diameter, biomass, juice volume, brix, sucrose and invert sugar of two sweet sorghum cultivars. The results showed that delay in irrigation intervals from 7 to 21 day significantly decreased all the above characteristics expect for invert sugar which was increased. The highest biomass (56.50 t ha^{-1}) and sucrose content (11.35 %) were obtained at 7 to 10 day irrigation interval. Both biomass and sucrose contents decreased significantly as harvesting date delayed from physiological maturity. Since both sweet sorghum cultivars, Keller and Sofra had similar biomass, sucrose content, brix and juice volume across irrigation intervals and harvesting dates, therefore it is suggested to plant either Keller or Sofra irrigated on 7 to 10 day interval and harvested at physiological maturity.

Key words

Sweet sorghum cultivars, Biomass, Sucrose, Physiological maturity, Drought stress

Introduction

Sweet sorghum or *Sorghum bicolor* (L.) Moench is an annual C4 plant belongs to *Poaceae* family. Sorghum is the fifth important food crop after rice, wheat, corn and potato for human consumption. Planting sweet sorghum has significant role in development of agricultural production, energy, sugar purification, paper mill and prevention of air contamination. Sweet sorghum adaptation to drought stress and high temperature has resulted that this plant similar to grain sorghum produces 3-7 t ha^{-1} grain (Almodares and Mostafafi Darany, 2006). But the essence of sweet sorghum in not its seed, but from its stalk, which grows high and is rich in sugar (Almodares *et al.*, 2008). Sweet sorghum is a high energy crop which either is important as seed or sweet shoot production. Seeds may be used for food (Dicko *et al.*, 2006) or feed (Anandanm *et al.*, 2012) and carbohydrates content of the shoot for biofuel production (Erickson *et al.*, 2012). Fiber content of shoot could be utilized in pulp production or paper mill (Ohwoavworhua and Adelakun, 2010), its baggase for bioethanol production (Sipos *et al.*, 2009) or for cogeneration of electricity and heat (Lori *et al.*, 2007). Presently corn, wheat and sugar cane are the main feed-stock for bioethanol production. However, they are used for human and animal consumption and needs moderate to high water requirements. For ethanol production, agricultural products should be used that don't threaten domestic food or feed values. Drought stress arising from inadequacy of water is one of the most important stresses that have restricted agricultural production in hot and dry countries. Sorghum water requirement is less than corn or sugar cane, and has higher production potential than other C4 plants (Gnansounou *et al.*, 2005). Both its seed and rich sugar shoot could be used for ethanol production. In view of the above, the present study was conducted to identify suitable irrigation period and sweet sorghum cultivar to achieve the maximum biomass and total sugar content under hot and dry condition.

Materials and Methods

The experiment was carried out at the University of Isfahan Research Experiment Station in 2010. Four irrigation intervals: 7, 10, 14 and 21day; two sweet sorghum cultivars: Keller and Sofra and three harvesting dates: physiological maturity, 30 days after physiological maturity and 60 days after physiological maturity were assessed in a split split plot design with three replications. The irrigation intervals were assigned to the main plots, sweet sorghum cultivars to the sub-plots and harvesting dates to the sub-sub plots. Each subplot consisted of 5 rows, 8 m long and 0.75m apart. Plots received 300kg ha^{-1} diammonium phosphate and 100kg ha^{-1} urea disked into the soil before planting. Plots were side dressed with 100 kg ha^{-1} urea subsurface banded 30 days after planting. Irrigation treatments started following establishment one month after planting. The amount of irrigation was 122/5 mm^3 /147 m^2. Three meters from two center rows were harvested when the plants reached physiological maturity, 30 and 60 days after physiological maturity. In each harvesting date, biomass, plant height and plant diameter were measured. After filtration through a sieve to remove the chaff, etc., the soluble solids (brix) and sucrose content (pol%) were measured according to Varma (1988) and reducing sugars according to Lane- Eynon (1970). Data were analyzed using the SPSS package statistical computer program. The Duncan's Multiple Range Test ($p \leq 0.05$) was used to compare the means.

Results and Discussion

Plant diameter and plant height in the present study were highest (1.8 cm and 2.3 m, respectively) at 7 day irrigation interval and lowest (1.4cm and 1.7 cm, respectively) at 21 day irrigation interval (Table 1). It seems that increasing irrigation intervals reduced plant height and plant diameter (Stone *et al.,* 2001; Pandey *et al.,* 2000). Earlier several researchers have reported reduction of plant diameter and plant height are strongly related to drought conditions (Inman-Bamber and Smith, 2005; Ramesh, 2000; Ramesh and Mahadev aswamy, 2000; Da Silva and Da Costa, 2001). Rate of shoot and leaves expansions are sensitive to irrigation which affects plant height and plant diameter (Da Silva and Da Costa, 2001). Biomass was not significantly different between 7 and 10 day irrigation intervals and was 56.5 t ha^{-1} (Table1). However, it significantly decreased as irrigation intervals delayed. Biomass at 14 and 21 day irrigation intervals was 46 t ha^{-1} and 38 t ha^{-1}, respectively. Reduction of yield components (stalk height and stalk diameter) under water stress conditions caused biomass to decrease. It seems that under water stress, reduction of soil water potential causes stomata to close and consequently leaf surface reduce using less solar energy which decreases photosynthesis efficiency and reduce biomass. Although brix was not significantly different at 7 and 10 day irrigation intervals (18.6 %), but is was higher than 14 day irrigation interval (16.6 %) and 21 day irrigation interval (15.7 %) (Table 1). It seems that drought stress reduced brix significantly. Tsuchihashi and Goto (2004) reported that sweet sorghum brix was significantly reduced in dry season compared to wet season. The reduction of brix under water stress could be due to the transition of shoot carbohydrate to seed as observed in wheat (Blum, 1998). Sucrose content was higher at 7 and 10 day irrigation intervals (11.35 %) than 14 and 21 day irrigation intervals (9.35 %), although it was not significantly different between 7 and 10 day or 14 and 21 day irrigation intervals. Drought did not effect sugar percentage in sugar beet (Mui *et al.,* 1996). Contrary to sucrose, invert sugar was higher at 14 and 21 day irrigation intervals (2 %) than 7 and 10 day irrigation intervals (1.55 %). It seems as irrigation intervals increased sucrose content decreased while invert sugar increased significantly. The conversion of sucrose to invert sugar under drought stress could be due to the metabolic compatibility of plant. One of the compatibilities of plant under drought stress is osmotic adjustment that plant protects turgid pressure via increasing solution elements such as sugar, organic acids, ions etc. Keller and Ludlow (1993) and Palleschi *et al.* (1997) reported that corn drought stress leads to increase acidic invertase activity and consequently increase invert sugar formation. On the other hand Mui *et al.* (1996) reported drought did not effect sugar percentage in sugar beet. Juice volume was significantly lower (0.42 l m^{-2}) at 21 day irrigation interval

Table 1 : Mean comparisons[1] among irrigation intervals for characteristics measured

Irrigation intervals	**Plant diameter (cm)**	**Plant height (m)**	**Biomass (t ha^{-1})**	**Brix (%)**	**Juice volume (l m^{-2})**	**Sucrose (%)**	**Invert sugar (%)**
7 day	1.8^{a}	2.3^{a}	58^{a}	18.7^{a}	0.75^{a}	11.7^{a}	1.5^{b}
10 day	1.6^{b}	2.0^{b}	55^{a}	18.1^{a}	0.70^{a}	11.0^{a}	1.6^{b}
14 day	1.5^{bc}	1.7^{c}	46^{b}	16.6^{b}	0.56^{ab}	9.5^{b}	1.9^{a}
21 day	1.4^{c}	1.7^{c}	38^{c}	15.7^{c}	0.42^{b}	9.2^{b}	2.1^{a}

[1] Means comparisons were made using Duncan's multiple range tests; Means with the same letter are not significantly different at 5% level

Table 2 : Mean comparisons[1] among harvesting date for characteristics measured

Harvesting date	Diameters (cm)	Height (m)	Biomass (t ha^{-1})	Brix (%)	Juice volume (l m^{-2})	Sucrose (%)	Invert sugar (%)
D1	1.5^{a}	2.0^{a}	57^{a}	17.1^{a}	0.88^{a}	10.3a	1.7b
D2	1.6^{a}	2.0^{a}	49^{b}	17.2^{a}	0.61^{b}	10.9a	1.6b
D3	1.6^{a}	1.9^{a}	41^{c}	17.6^{a}	0.33^{c}	9.8b	2.0a

[1] Means comparisons were made using Duncan's multiple range tests; Means with the same letter are not significantly different at 5% level. D1 : physiological maturity, D2: 30 days after physiological maturity, D3: 60 days after physiological maturity

Table 3 : Interaction between harvesting dates and irrigation intervals for plant height, brix and sucrose content

Treatments	Height (m)	Brix (%)	Sucrose (%)
D1I1	2.3^{ab}	19.2^{a}	12.5^{a}
D1I2	2.2^{abc}	18.7^{b}	11^{b}
D1I3	1.8^{abc}	15.2^{h}	8.6^{e}
D1I4	1.7^{bc}	15.3^{h}	9^{e}
D2I1	2.3^{ab}	18.4^{bc}	11.5^{ab}
D2I2	2.1^{abc}	18.2^{c}	11.5^{ab}
D2I3	1.7^{bc}	17.4^{e}	10.2^{bc}
D2I4	1.7^{bc}	15^{h}	9.3^{cd}
D3I1	2.4^{a}	18.5^{bc}	11.3^{ab}
D3I2	1.8^{abc}	18.3^{c}	10.8^{b}
D3I3	1.6^{c}	17.5^{e}	9.5^{cd}
D3I4	1.7^{bc}	16.5^{g}	8.9^{e}

[1] Means comparisons were made using Duncan's multiple range tests, Means with the same letter are not significantly different at 5% level. Harvesting dates: D1- physiological maturity, D2- 30 days after physiological maturity and D3: 60 days after physiological maturity. Irrigation intervals: I1- 7 day, I2-10 day, I3, 13 day and I4, 21 day

Table 4 : Mean comparisons among cultivars for characteristics measured

Cultivar	Diameters (cm)	Height (m)	Biomass (t ha^{-1})	Brix (%)	Juice volume (l m^{-2})	Sucrose (%)	Invert sugar (%)
Sofra	1.5^{a}	1.7^{b}	48^{a}	16.9^{a}	0.57^{a}	10.5^{a}	1.9^{a}
Keller	1.6^{a}	2.0^{a}	50^{a}	17.7^{a}	0.64^{a}	10.2^{a}	1.5^{b}

Means comparisons were made using Duncan's multiple range tests; Means with the same letter are not significantly different at 5% level

than the other three irrigation intervals. Even though juice volume was not significantly different at 7, 10 and 14 irrigation intervals, but juice volume decreased as the irrigation intervals increased. Juice volume was 0.75, 0.70, 0.56 and 0.42 (l m^{-2}) at 7, 10, 14 and 21 day irrigation intervals, respectively. There is a relationship between dry matter, sugar yield and the quantity of applied water. Vasilakoglou *et al.* (2011) reported that sweet sorghum dry biomass, juice and total sugar yields received 210 mm of irrigation were 49-88 % greater than the yields received 120 mm of irrigation water. Table 2 shows the effects of harvesting dates on plant diameter, plant height, biomass, brix, juice volume, sucrose content and invert sugar. Biomass and juice volume decreased significantly as harvesting date delayed from physiological maturity. Biomass was highest at physiological maturity (57 t ha^{-1}) and lowest (41t ha^{-1}) 60 days after physiological maturity. Almodares *et al.* (2007). reported delay in harvesting stage reduces both biomass and sucrose content. Juice volume was highest (0.88 l m^{-2}) and lowest (0.33 l m^{-2}) at physiological maturity and 60 days after physiological maturity, respectively. Following physiological maturity, it seems gradual decrease in temperature caused biomass and extracted juice to be reduced. Plants harvested at physiological maturity and 30 days after that date had higher sucrose content (10.6 %) than harvested 60 days after physiological maturity (9.8 %). In contrast to sucrose, invert sugar was higher (2.0 %) for plants harvested 60 days after physiological maturity than

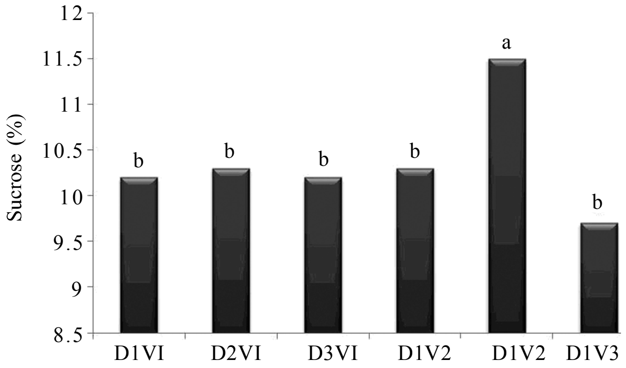

Fig. 1 : Interaction between harvesting dates and sweet sorghum cultivars on sucrose content. Harvesting dates: D1**,** physiological maturity, D2**,** 30 days after physiological maturity, D3**,**60 days after physiological maturity. Sweet sorghum cultivars :Keller, V1 and Sofra,V2

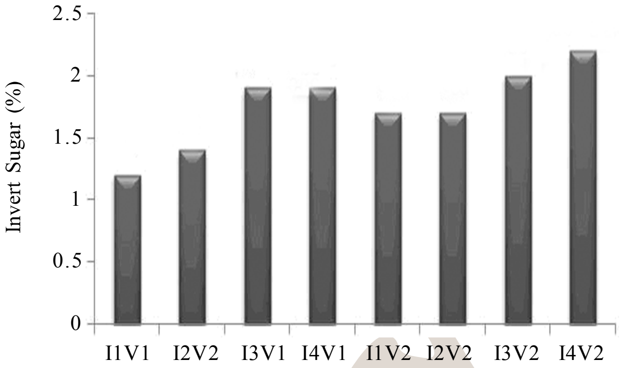

Fig. 2 : Interaction between irrigation intervals and sweet sorghum cultivars on invert sugar. Irrigation intervals : I1, 7 day, I2, 10 day, I3, 14 day and I4, 21 day. Sweet sorghum cultivars: Keller, V1 and Vespa V2

the other harvesting dates (1.65 %). It seems the suitable harvesting date is from physiological maturity up to 30 days after physiological maturity. During this period, plants have highest sucrose content. In addition to cold weather which caused sucrose content to decreased gradually, leaves turn yellow and photosynthesis efficiency will be reduced, therefore plants use the stored sucrose as source of energy. Table 3 shows interactions between harvesting dates and irrigation intervals for plant height, brix and sucrose content. Plant height was higher than 2 m for 7 to 10 day irrigation interval harvested at physiological maturity up to 30 day. Plant height was more than 2 m even 60 days after physiological maturity only if it was irrigated at 7 day interval. Regarding plant height, it seems irrigation interval has a more important role than harvesting date. Almodares *et al.* (1994) reported a significant and positive correlation between plant height and sucrose content. If water is available, sweet sorghum could be harvested from physiological maturity up to the freezing which occurred 60 days after physiological maturity even though sucrose may be converted to invert sugar in cold weather. Brix (19.2 %) was highest for plants harvested at physiological maturity irrigated at 7 day irrigation interval. It was lowest (16.5 %) for plants harvested 60 days after physiological maturity and irrigated at 21 day irrigation interval. It seems that both harvesting dates and irrigation intervals effect on brix. Similar to brix, sucrose content was highest (12.5 %) for plants harvested at physiological maturity and irrigated at 7 day irrigation interval. It was lowest (8.9 %) for plants harvested 60 days after physiological maturity and irritated at 21 day irrigation interval. Both harvesting dates and irrigation intervals significantly effected brix and sucrose content. Sucrose content was not significantly different among harvesting dates for plants irrigated at 7 day interval. It means that harvesting dates could be prolonged if plant irrigated at 7 day irrigation interval. Interaction between harvesting dates and sucrose content for sweet sorghum cultivars was significant (Fig. 1). Sofra had the highest sucrose content harvested 30 days after physiological maturity (11.5 %). Sucrose content of Keller and Sofra was not significant for other harvesting dates. Interaction between irrigation intervals and sweet sorghum cultivars for invert sugar is presented in (Fig 2). Both Sofra and Keller invert sugar increased as irrigation interval increased form 7 to 21 day. It seems drought by means of delay in irritation changed some sucrose to invert sugar. Stem diameter, biomass, brix, juice volume and sucrose content of Sofra and Keller were not significant, but Keller had higher plant height and lower invert sugar than Sofra (Table 4), thus it seems Sofra is more suitable for ethanol production than Keller. The differences between Keller and Sofra measured characteristic could be due to their genetic differences. Based on the results, it is suggested to plant either Sofra or Keller irrigated at 7-10 day interval and harvest at physiological maturity up to 30 day after physiological maturity.

Acknowledgment

The authors wish to thank University of Isfahan and Plant Stress Center for their support.

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