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Effect of sowing dates and nitrogen levels for ethanol production from sweet sorghum stalks and grains

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Sweet sorghum is being investigated as a feedstock for ethanol production in semi-arid countries. It can be grown with fewer inputs than other energy crops. In Iran, due to long growing season, ethanol is produced from both sweet sorghum stem and grain. In other countries, ethanol is not produced from sweet sorghum grain due to low grain yield or short growing season. The purpose of this study was to maximize ethanol production from both stem and grain of sweet sorghum. Four planting dates (July 5, July 14, July 25 and August 4) and three nitrogen levels (50, 100 and 150 kg/ha urea) were assigned to the main and subplots, respectively. Plants were harvested at physiological maturity. Stem measurements were: stalk height, stalk diameter, stalk fresh yield, brix value, sucrose content, total sugar and ethanol yield and grain measurements were: number of grain per panicle, 1000 grain weight, grain yield, biological yield, harvest index and ethanol yield. Stem measurements were highest in July 5 planting and lowest in August 4 planting, while grain measurements were highest and lowest in August 4 and July 5 plantings, respectively. Stem and grain measurements in July 15 and July 25 were intermediate. More grain yield, 1000 grain weight and number of grain/panicle were obtained with the application of 150 kg/ha urea than the other two nitrogen levels. Based on the results, in order to obtain the highest ethanol yield from both stem and grain, it is suggested to plant sweet sorghum as early as possible and apply 150 kg/ha urea.

Key words: Sweet sorghum, temperature, planting date, ethanol production, nitrogen levels.

INTRODUCTION

Biofuels have been promoted for reducing greenhouse gas (GHG) emissions and petroleum fuel consumption. Bioethanol is now the dominant biofuel used in transportation sector (Hao et al., 2013). The feedstock that could be used for ethanol production includes:starch and sugar based crops, as well as crop residues (corn stover, wheat straw, rice straw, and sugarcane straw, among others), dedicated energy crops (for example, switchgrass,miscanthus,mixed prairie grasses, and short-rotation trees), and forest residues. Among them, sweet

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Table 1. Average of some meteorological parameters on growth period Sweet sorghum (2012).

Meteorological parameters \ Month	July	August	September	October	November
Average temperatures C°	37.1	43.25	43.75	33.5	27.3
maximum temperature C°	43.3	47.5	54.5	39.3	33.2
Minimum Temperature C°	31.0	39.0	33.0	27.7	21.4
Rainfall (mm)	0	0	0	0	0
Average relative humidity (%)	23.4	27.0	28.5	30.0	36.3

sorghum (*Sorghum bicolor* L.) Moench) has emerged as a potential feedstock candidate for bioethanol production because of its date is an important agronomic practice for production of ethanol from sweet sorghum. Optimum planting dates may vary by region. Improper planting date at adverse climatic condition could alter both vegetative and reproduction growth stages. Early planting increases biomass but flowering, pollination and grain filling may be affected by hot summer temperature. Late planting reduces biomass, early flowering, prolonging grain filling and damage due to the cold autumn weather. The biomass yield response of sweet sorghum to planting date is well established. Late planting significantly decreased stalk yield, brix value, sucrose content and days to flowering (Almodares et al., 1994).

Due to favorable environmental conditions during the early growing season, higher sweet sorghum grain (2483 kg ha^{-1}) and millable cane yield (37.17 t ha^{-1}) was achieved (Poornima et al., 2008). Sweet sorghum needs enough nitrogen for its full growth and development. But its response to applied N varied with location. Nitrogen rate had no effect on fermentable sugar yield (Smith and Buxton, 1993), total and stalk dry matter yield at harvest (Barbanti et al., 2006), or fermentable carbohydrate and ethanol yield (Lueschen et al., 1991). In Louisiana, biomass yield has been shown to increase by 140% with application of low water demand, short growing period, sugar and biomass yield potential in less desirable conditions, such as semi-arid and salty lands (Zegada-Lizarazu and Monti, 2012). Sweet sorghum has gained a lot of attention because it possesses numerous characteristics that makes it an appealing bioenergy crop. As a bioenergy crop, sweet sorghum could be used to provide grain starch for hydrolysis, stem juice for direct fermentation, and bagasse as cellulosic feedstock for fermentation or boiler fuel (Saballos, 2008).

In planting of 100 kg ha^{-1} N, yield was not increased with an additional 100 kg ha^{-1} N (Ricaud and Arenneaux, 1990). In the same study, total sugar yield was increased by 150% by applying 100 kg ha^{-1} N, with an increase of only 4% from an additional 100 kg ha^{-1} N. Tropical environments differ from temperate ones in both phenology and yield. Both photoperiod and temperature interact, thus further influencing yield especially for very late plantings (Rao et al., 2013). Much information on the impact of planting date on stalk and sugar yields are available on sweet sorghum genotypes grown in temperate climatic conditions (Han et al., 2012; Burks et al., 2013), but information is very limited on mid-summer planting on ethanol production. The present experiment was conducted to identify optimum time of sowing and N level for achieving higher biomass and grain yield for ethanol production.

MATERIALS AND METHODS

The investigation was carried out at sugar cane research station in Ahwaz, Iran during summer 2012. The station is located at an altitude of 8.8 m above mean sea level and it is intersected 48° 22'E latitude and 31° 5' longitude. The weather is very hot and dry from May to October where maximum temperature could reach to 54.5°C in September (Table 1). The duration of sunshine hours is shown in Table 2. It was from 14 h in July to 10 h in November. The treatments consisted of four planting dates that is, July 5, July 15, July 25 and August 4 and three nitrogen levels, that is 50, 100 and 150 kg urea/ha. Urea was applied in two equal doses; at planting and at 6 to 8 leaf stage. The experiment was laid out in a split plot design with three replications, keeping planting dates as main plots and amount of nitrogen as subplots. Individual subplots measured 3.0 m in width and 7.0 m in length. Before planting 60 kg of triple phosphate and 50% of N were applied as basal. The remaining 50% of N was applied when the plants were at 6 to 8 leaf stage. Sweet sorghum cultivar "Sofra" were hand sown at the above dates as the usual method of sowing on one side of ridges (75 × 15 cm) and the plots were irrigated according to local practices. The other agronomic practices were kept normal and uniform for all the treatments. Plants reached physiological maturity after 120 days for the first three planting dates and 107 days for the fourth planting date. At that stage, plants from 1.5 m long of one central row of each treatment were harvested and growth parameters including plant height and plant diameter were measured. Then the plants were weighed and sub-sample of plants were dried for further analysis. Plants from other 1.5 m long of one central row of each treatment were harvested and total fresh weight (leaves, stalks, and panicles) were determined. The leaves along with sheath were stripped. Panicle with the last inner node (peduncle) was separated and fresh stem weight was estimated. Then, fresh stem were passed through three-roller sugar cane mill.

For measuring brix and sucrose content, Juice was sent to the nearby sugarcane factory. Sucrose content of the juice was obtained from the pol reading and uncorrected brix values (Varma, 1988). Total sugar content was calculated based on its correlation to brix degree values using the following equation as estimated by

Table 2. Sunshines hours from planting to harvest.

Month	Sunshine (Hours and minutes)	Month	Sunshine (Hours and minutes)	Month	Sunshine (Hours and minutes)	Month	Sunshine (Hours and minutes)	Month	Sunshine (Hours and minutes)
June21	14.11	Jily22	13.51	Aug.22	13.04	Sep.22	12.07	Oct.24	11.11
22	14.11	23	13.49	23	13.02	23	12.05	25	11.09
23	14.11	24	13.48	24	13.00	24	12.03	26	11.07
24	14.11	25	13.47	25	12.59	25	12.01	27	11.06
25	14.11	26	13.46	26	13.57	26	11.59	28	11.04
26	14.10	27	13.45	27	12.55	27	11.57	29	11.03
27	14.10	28	13.43	28	12.53	28	11.56	30	11.01
28	14.10	29	13.42	29	12.51	29	11.53	31	10.59
29	14.09	30	13.40	30	12.50	30	11.51	Nov.1	10.57
30	14.09	31	13.39	31	12.49	Oct.1	11.5	2	10.55
July1	14.08	Aug.1	13.38	Sep.1	12.48	2	11.48	3	10.54
2	14.08	2	13.36	2	12.46	3	11.45	4	10.52
3	14.08	3	13.34	3	12.42	4	11.44	5	10.51
4	14.07	4	13.33	4	12.41	5	11.42	7	10.49
5	14.07	5	13.32	5	12.38	6	11.41	8	10.47
6	14.06	6	13.31	6	12.37	7	11.38	9	10.45
7	14.05	7	13.28	7	12.35	8	11.36	10	10.45
8	14.04	8	13.27	8	12.34	9	11.35	11	10.43
9	14.04	9	13.26	9	12.33	10	11.33	12	10.41
10	14.03	10	13.24	10	12.31	11	11.31	13	10.40
11	14.02	11	13.22	11	12.28	12	11.29	14	10.38
12	14.01	12	13.21	12	12.25	13	11.27	15	10.36
13	14.00	13	13.20	13	12.23	14	11.25	16	10.35
14	13.59	14	13.19	14	12.21	15	11.23	17	10.34
15	13.58	15	13.18	15	12.19	16	11.21	18	1033
16	13.58	16	13.16	16	12.18	18	11.2	19	10.31
17	13.57	17	13.14	17	12.16	19	11.18	20	10.30
18	13.55	18	13.11	18	12.14	20	11.17	21	10.28
19	13.54	19	13.09	19	12.12	21	11.15	22	10.26
20	13.53	20	13.08	20	12.1	22	11.13	23	10.24
21	13.52	21	13.05	21	12.09	23	11.12	-	-

Liu and Shen (2008). Total sugar content (%) = [0.8111 × Brix (%)]− 0.3728. For calculation of theoretical ethanol production from sweet sorghum fresh biomass, the equations reported by Sakellariou et al. (2007) and Zhao et al. (2009) were modified as follows: total ethanol yield (L ha^{-1}) = total sugar content (%) fresh biomass (Mg ha^{-1}) × 6.5 (conversion factor of ethanol from sugar) × 0.85 (process efficiency of ethanol from sugar) × 1.27(1.00/0.79) (specific gravity of ethanol; gm L^{-1}). Ethanol production from grain sorghum was calculated (ethanol conversion factor, 2.70 gallons per bushel) using USDA report (2006). Biological yield was determined based on the dry samples. The dried panicles were, threshed, weighed and grain yield and its components (No. of grain/panicle, 1000 gr grain weight, and grain weight) were measured. Harvest index was calculated based on the grain yield divided by the biological yield multiplied by 100. Data were analyzed using the SPSS package statistical computer program. The Duncan multiple range test (< 0.05) was used to compare the means.

RESULTS

Stalk plant height, plant diameter, total fresh weight, and stem fresh weight

Sum squares for stem height, stem diameter, fresh weight and stalk fresh weight of four planting dates and three nitrogen levels are presented in Table 3. The effect of planting dates on stem height, stem diameter and total fresh weight were significant at 5% level and for stem fresh weight at 1% level. Mean comparisons for the aforementioned measurements are presented in Table 4. Significant decreases in plant height and plant diameter, total fresh weight and stem fresh weight were found in sweet sorghum planted in August than other planting

Table 3. Sum squares for four planting dates and three nitrogen levels for characteristics measured.

Source of variance	df	Stem height	Stem diameter	Total fresh weight	Stem fresh weight
Block	3	23.30	4.11	8.73	8.33
Planting date (D)	3	2212.86*	55.67*	90.21*	194.57**
Error a	6	172.63	3.47	4.81	3.28
Nitrogen level (N)	2	877.51**	8.37**	15.52	4.33
D x N	6	68.22	0.094	10.67	12.93
Error b	16	71.78	0.50	13.43	15.94
CV%		4.37	4.97	10.32	14.10

**, * significant at 1 and 5 percent level, respectively

Table 4. Mean comparisons* of stem height, stem diameter, total fresh weight and stem fresh weight at four planting dates and three nitrogen levels.

Treatments	Stem Height (cm)	Stem diameter (cm)	Total fresh weight (Kg/ha)	Stem fresh weight (Kg/ha)
Planting dates				
July 5	205.60[a]	17.60[a]	37590[a]	32140[a]
July 15	189.00[b]	14.30[b]	36710[a]	29790[a]
July 25	186.20[b]	13.00[c]	36880[a]	29750[a]
August 4	167.00[c]	11.80[c]	30780[b]	21530[b]
Nitrogen levels (kg/ha)				
50	184.30[b]	13.14[b]	35090[a]	28450[a]
100	192.77[ab]	14.08[ab]	34600[a]	27640[a]
150	203.72[a]	15.07[a]	36770[a]	28810[a]

*Values within a column followed by same letter are not significantly different at 5% using Duncan Multiple Range Test.

dates (Table 4). Plant height and plant diameter gradually decreased from the first planting date in July 5, by 205 cm height and 17.60 cm in diameter to the last planting date in August which was 167 cm in height and 11.80 cm in diameter. Total fresh weight was not significantly different in the first there planting dates and on average it was 37060 kg/ha. They were significantly higher than August planting which was 30780 kg/ha. Similarly, stem fresh weight was not significant for the first three planting dates. The average stem weight for the first three planting dates was 30560 kg/ha. August 4 planting had significantly lowest stem weight (21530 kg/ha) than the other planting dates. The effect of nitrogen levels on stem height and stem diameter were significant at 1%. Nitrogen increased stem height and stem diameter. They were lowest with the application of 50 kg/ha urea and highest with 150 kg/ha urea. Stem height was 184.30 cm with the application of 50 kg/ha urea and increased to 203.72 cm with 150 kg/ha urea. Similarly, stem diameter was 13.1 cm with the application of 50 kg/ha urea and increased to 15.07 cm with the application of 150kg/ha urea. Plant height and plant diameter with the application of 100 kg/ha urea was not significantly different between application of 50 or 150 kg/ha urea.

Stalk brix, total sugar, sucrose, purity and ethanol yield

Sum squares for brix value, sucrose content, total sugar, juice purity and ethanol yield are presented in Table 5. The effect of planting dates on sucrose content, juice purity and ethanol yield was significant at 1% level and for Brix value and total sugar at 5% level. Mean comparisons for the aforementioned measurements are presented in Table 6. Lowest and highest brix value, sucrose, total sugar, purity and ethanol yield was obtained in early planting (July 5) than late planting (August 4). Brix value was 16.13% in July 5 planting and reduced to 12.50% in August planting. Total sugar decreased from 13.10% to 9.83% as planting date delayed from July 5 to August 4. Sucrose content had similar pattern as total sugar. It was 12.10% in July 5 and 6.71% in August 4. Purity reduced considerably from July

Table 5. Sum squares for four planting dates and three nitrogen levels for characteristics measured.

Source of variance	df	Brix	Sucrose	Total sugar	Juice purity	Ethanol
Block	2	4.46	2.25	2.93	17.97	171599
Planting date (D)	3	32.71*	30.78**	21.52*	691.83**	3717037**
Error a	6	2.18	1.29	1.43	21.16	124111
Nitrogen level (N)	2	0.33	0.02	0.22	1.35	71932
D × N	6	1.32	0.94	0.87	22.68	154372
Error b	16	0.47	0.32	0.31	10.44	144819
CV%		4.69	11.63	4.73	4.82	15.9

**, *significant at 1 and 5 percent level, respectively.

Table 6. Mean comparisons* for brix, total sugar, sucrose content , purity and ethanol yield at four planting dates and three nitrogen levels.

Treatments	Brix %	Total sugar %	Sucrose %	Purity %	Ethanol yield l/ha
Planting dates					
July 5	16.13[a]	13.10[a]	12.10[a]	74.15[a]	2864.56[a]
July 15	15.93[a]	13.04[a]	11.74[a]	72.48[a]	2622.90[b]
July 25	14.57[b]	11.44[b]	9.47[b]	66.65[b]	2389.11[c]
August 4	12.50[c]	9.83[c]	6.71[c]	54.78[c]	1475.35[d]
Nitrogen levels (kg/ha)					
50	15.21[a]	11.76[a]	9.94[a]	67.40[a]	3130.19[a]
100	14.34[a]	11.78[a]	9.23[a]	66.81[a]	3046.09[a]
150	14.78[a]	12.00[a]	10.06[a]	66.82[a]	3345.03[a]

*Values within a column followed by same letter are not significantly different at 5% using Duncan Multiple Range Test.

5 planting to August 4 planting. It was 74.15 and 54.78% in July 5 and August 4, respectively. Delay in planting considerably had effects on ethanol yield. It was significantly reduced from July 5 planting to August 4 planting. It was 2864.56 l/ha in July 5 planting and it reduced consideratetly to 1475.35 l/ha in August 4 planting.

Correlation coefficient

Correlation coefficient among characteristics measured is shown in Table 7. Ethanol yield was significantly correlated with stem height, stem diameter, stem fresh weight, total fresh weight, brix value, sucrose content, total sugar and purity. Delayed planting date from July 5 to August 4 reduced stem diameter, stem height, total fresh weight and stem fresh weight considerably (Table 4). So in order to increase ethanol yield, sweet sorghum should be planted early in the season. Also other characteristics such as brix value, sucrose content, total sugar and purity decreased by late planting (Table 6). Thus in order to achieve the highest ethanol yield, sweet sorghum should be planted as early as temperature or following wheat harvest in Kuzestan province.

Grain and its components

Sum squares for grain yield, 1000 grain weight, number of grain/panicle, biological yield, harvest index and ethanol yield is presented in Table 8. The effect of planting dates on grain yield, biological yield, harvest index and ethanol yield was significant at 1% level and for 1000 grain weight and number of grain/panicle at 5% level. Mean comparisons for the above measurements are presented in Table 9. Grain weight, 1000 grain weight, number of grain/panicle, harvest index and ethanol yield were lowest in July 5 planting and highest in August planting. But biological yield was highest in July 5 planting and lowest in August 5 planting. The afore-mentioned measurements were intermediate in July 15 and July 25 plantings. Grain yield increased from 1437.73 kg/ha in July 5 planting to 2411.92 in August planting. Number of grain/panicle increased from 1195.11 in July 4 planting to 1457.57 in August planting. 1000 grain weight was 10.91 and 15.07 for July 5 planting and August 4 plantings, respectively. Ethanol yield was 619.70 l/ha in

Table 7. Correlation coefficient among characteristics measured.

Trait	Stem height	Stem diameter	Stem fresh weight	Total fresh weight	Brix value	Sucrose content	Total sugar content	Purity %	Ethanol yield
Stem height	1								
Stem diameter	0.898**	1							
stem fresh weight	0.733**	0.731**	1						
total fresh weight	0.746**	0.712**	0.764**	1					
Brix value	0.726**	0.749**	0.791**	0.987**	1				
Sucrose content	0.746**	0.712**	0.764**	1.000 **	0.987**	1			
Total sugar content	0.712**	0.756**	0.752**	0.968**	0.991**	0.968**	1		
Purity %	0.781**	0.765**	0.960**	0.910**	0.920**	0.910**	0.883**	1	
Ethanol yield	0.698*	0.630*	0.962**	0.673*	0.675*	0.673*	0.620*	0.902**	1

**Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level.

Table 8. Sum squares for four planting dates and three nitrogen levels for characteristics measured.

Source of variance	df	Grain yield	1000 grain weight	Number of grain/panicle	Biological yield	Harvest index	Ethanol yield
Block	2	0.11	5.16	11174	0.45	8.23	171599
Planting date (D)	3	1.44**	26.3*	111148*	32.34**	325.03**	3717037**
Error a	6	0.04	1.83	7711	1.16	3.17	124111
Nitrogen level (N)	2	0.38**	5.13*	1221*	3.16	12.30	71932*
D × N	6	0.009	0.62	2569	1.83	3.82	15437
Error b	16	0.01	0.57	1549	1.46	4.01	144819
CV%		6.72	5.8	2.98	9.68	12.48	15.9

**, * significant at 1 and 5 percent level, respectively.

Table 9. Mean comparisons* for number of grain/panicle,1000 grain weight, grain yield, biological yield, harvest index and ethanol yield at four planting dates and three nitrogen levels.

Treatments	Number of grain/panicle	1000 grain weight/gr	Grain yield kg/ha	Biological yield kg/ha	Harvest index %	Ethanol yield l/ha
Planting dates						
July 5	1195.11[d]	10.91[c]	1437.73[c]	14523.00[a]	10.10[c]	619.70[c]
July 15	1298.22[c]	13.03[b]	1877.02[b]	12879.00[b]	14.56[b]	809.00[b]
July 25	1372.79[b]	13.22[b]	1997.80[b]	12644.00[b]	15.88[b]	861.00[b]
August 4	1457.57[a]	15.07[a]	2411.92[a]	9945.00[c]	24.40[a]	1039.50[a]
Nitrogen levels (kg/ha)						
50	1312.17[b]	12.61[b]	1805.21[c]	12380.00[a]	15.40[a]	778.00[b]
100	1312.33[b]	12.77[b]	1854.28[b]	12050.00[a]	15.88[a]	779.20[b]
150	1367.50[a]	13.81[a]	2133.87[a]	13050.00[a]	17.34[a]	919.30[a]

*Values within a column followed by same letter are not significantly different at 5% using Duncan Multiple Range Test.

July 5 and increased to 1039.50 l/ha in August 4 planting. Harvest index was 10.10 and 24.40 for July 5 and August 4 plantings, respectively. Biological decreased from 14523.00 kg/ha in July 5 planting to 9945.00 kg/ha in August planting. The effect of nitrogen levels on grain yield was significantly different at 1% level and for 1000

Table 10. Correlation coefficients for grain yield and its components.

Trait	Grain yield	1000 grain weight	Number of grain/panicle	Biological yield	Harvest index	Ethanol yield
Grain yield	1					
1000 grain weight	0.986**	1				
Number of grain in panicle	0.943**	0.888**	1			
Biological yield	-0.796**	-0.806**	-0.793**	1		
Harvest index	0.961**	0.961**	0.905**	-0.903**	1	
Ethanol yield	0.913**	0.926**	0.860**	-0.775**	0.925**	1

**Correlation is significant at the 0.01 level.

grain weight, number of grain/panicle and ethanol yield at 5% level. Mean comparisons for the aforementioned measurements are shown in Table 9. All the measurements were lowest with the application of 50 kg/ha urea and highest with the application of 150 kg/ha urea. Grain yield increased from 1805.21 kg/ha with the application of 50 kg/ha urea to 2133.87 kg/ha with the application of 150 kg/ha urea. 1000 g weight increased from 12.61 g to 13.81 g with the application of 50 and 150 kg/ha urea. Ethanol yield increased from 778.00 l/ha with application of 50 kg urea/ha to 919.00 kg/ha with the application of 150 kg urea/ha.

Correlation coefficient

Correlation coefficient for grain and its components are shown in Table 10. Grain yield is positively significantly correlated to 1000 grain weight, number of grain/panicle and harvest index, ethanol yield and negatively significantly correlated with biological yield. Grain yield, 1000 grain weight, number of grain/panicle and harvest index had significantly positive effect on ethanol yield.

Biological yield was significantly negatively correlated to grain yield, 1000 grain weight, number of grain/panicle and harvest index.

DISCUSSION

Stalk plant height, plant diameter, total fresh weight, and stem fresh weight

Significant decreases in plant height and plant diameter were found in sweet sorghum planted in August (Table 5). Plant height and plant diameter gradually decreased from the first planting date in July 5 to the last planting date in August. In general, long growing season increased plant height and plant diameter. Sweet sorghum plant height increased with earlier planting date (Rao et al., 2013; Almodares and Darany, 2006). July planting (July 5, 15 and 25) had similar and significantly more biomass (35393 kg/ha) than August planting (30780 kg/ha) (Table 5). Similarly, they had more stem fresh weight (30560 kg/ha) than August planting (21530 kg/ha). Earlier reports from temperate climates showed that sweet sorghum biomass and stalk yield decreased when planted late (June and July) rather than early planting (April and May) (Han et al., 2012; Teetor et al., 2011; Burks et al., 2013). Early plantings (May) had significantly higher fresh stalk yield than June planting (Almodares and Darany, 2006). Early planting allowed for a longer growing period and earlier canopy development for sunlight interception during the long days of June and July. Our results showed that planting sweet sorghum in early July was optimal for maximum stalk yield under this climatic condition.

In Khuzestan province where the experiment was conducted, growing sweet sorghum in May following wheat harvest was possible. Sweet sorghum is newly introduced to this area and farmers are used to planting corn at the end of July to reduce the risk of low pollination due to high temperature. If corn is planted early, farmers obtain low yield due to coincidence of hot temperature with pollination. Following wheat harvest, agricultural lands are in fallow for nearly two months before corn planting. When considering the introduction of sweet sorghum, the acceptance of farmers and their willingness to integrate ecologically appropriate crops must be guaranteed. The motivation of farmers may increase if sorghum cultivars provide direct benefits, such as acceptable biomass and biofuel production from land where other crops are unproductive (Almodares and Hadi, 2009). Planting sweet sorghum early in the season will produce the highest biomass due to long growing season before panicle initiation. Sorghum is a short day plant, with panicle initiation starting when day length reaches 12.0 h (Miller et al., 1968). This suggests that planting sweet sorghum can be staggered from July 5 to July 25 without appreciate reduction of biomass (Table 5). Biomass in August planting was reduced considerably because days from planting to panicle initiation was not long enough for vegetation phase. Higher total biomass and stalk yield of sweet sorghum from early planting may be due to higher total accumulated thermal time and higher ambient air and soil temperatures associated with longer day length during pre-flowering stages (Rao et al., 2013).

Physiological mechanisms in plants are capable of sensing differences in day length. Under most conditions, late planting is associated with a reduction in number of days to panicle initiation and flowering, which affect temperature and photoperiod (Balole, 2001). For the first planting dates, the growing season from planting to flowering was long and assimilates were used for vegetative growth. For the last planting date the growing season was short and there was not much time for vegetative growth. Temperature stresses (high and low temperature) are the major environmental factors affecting plant growth and development. They also induce morphological, physiological and biochemical changes in plants (Waraich et al., 2012). High temperature decreases photosynthesis (Wise et al., 2004) which causes shoot and root growth inhibition and yield reduction in plants (Vollenweider and Gunthardt-Goerg, 2005). Due to the high temperature in August planting, stem height, stem diameter, total fresh weight and stem fresh weight were significantly lower than the other planting dates. High performance of sweet sorghum in early planting could be due to long growing season which coincide with more fresh leaves, higher photosynthesis (Net Assimilation Rate, NAR), and more growth (relative growth rate, RGR and crop growth rate, CGR). Although stem height, stem diameter, total fresh weight and stem fresh weight were higher with the application of 150 kg/ha urea than other nitrogen applications, but their differences were not significant (Table 5). Higher N application of 150 kg/ha recorded higher sweet sorghum biomass compared to lower dose of N application (Poornima et al., 2008). Erickson et al. (2011) reported that biomass was not affected by N fertilization rate. It seems high rate of nitrogen was not uptake by reduced roots due to high temperature and consequently lower plant growth and development.

Brix, total sugar, sucrose, purity and ethanol yield

Early plantings (July 5 and July 15) had higher brix, total sugar, sucrose and purity than late plantings (July 25 and August 4 (Table 6). Sweet sorghum produced higher sugar and ethanol yields in early plantings (April to May) in temperate (Han et al., 2012; Teetoor et al., 2011) and Mediterranean climates in Egypt (El-Razek and Besheit, 2009). Delaying planting from mid-June to early July and mid-July reduced the average estimated total ethanol yields for six cultivars from 5189 to 3852 and 2808 L ha^{-1}, respectively (Houx and Fritschi, 2013). Sweet sorghum was planted in May 4, March 19, June 4 and June 18 (Almodares and Darany, 2006). Results showed plant height, plant diameter, fresh stalk yield, total dry weight, brix value, sugar content and grain yield was higher in the first planting date than the other planting dates. Planting of full season varieties commonly increases potential ethanol yield (Zhao et al., 2009; Putman et al., 1991). The results of monthly planting of sweet sorghum in a temperate climate showed May plantings produced more fermentable sugars, sugar, and ethanol yields than other months (Han et al., 2012; Teetor et al., 2011). In published papers, the effect of nitrogen fertilizer on sweet sorghum brix value is contradictory. Nitrogen application did not increase fresh stalk yield, brix value and sugar yield and the mean brix value was negatively related to N rate (Almodares and Darany, 2006). On the other hand, both stalk and juice yield increased with increasing rates of nitrogen application (Kumar et al., 2008). Although sweet sorghum responds well to fertilizers, especially nitrogen but our results showed (Table 5 and 7) showed that sweet sorghum performance was not affected by application of nitrogen fertilizer. It seems that the performance of sweet sorghum with the application N application varies under different environmental conditions.

Grain and its components

Number of grain/panicle, 1000 grain weight, grain yield, biological yield, harvest index and ethanol yield were affected by planting dates (Table 8). The aforementioned measurements were significantly highest in the last planting date (August 4) and lowest in the first planting date (July 5). In contrast, biological yield was highest in the first planting date and lowest in the last planting date. Planting dates significantly affected biomass. Harvest index is related to number of grain per panicle, 1000 grain weight and grain yield. Harvest index increased from July 5 and it was highest in August 4. Grain yield reduction in July could be due to hot temperature and dry weather condition which reduces flowering. Thus farmers in the experiment site area plant corn in August, so the plant pollinates when the temperature is cool enough not to reduce pollination. The climatic condition in tropics ismuch different from temperate. Almodares and Darany (2006) reported sweet sorghum fresh stalk weight, sugar yield, grain yield and its components were highest in May planting and lowest in June planting. The results showed grain yield was significantly increased by nitrogen application. It was highest with application of 150 kg urea/hectare. This could be due to the number of grain per panicle and 1000 grain weight which were higher with the application of 150 kg urea per hectare than other nitrogen applications. Our results are in agreement with (Kaufman et al., 2013; Miko and Manga, 2008). Ethanol yield was highest with the application of 150 kg urea/ha and lowest with the application of 50 kg urea/ha. Ethanol yield is positively correlated with grain yield (Table 10).

Correlation coefficients

Both biomass and carbohydrate content had effect on ethanol yield, therefore ethanol yield will be increased by higher growth parameters such as stem height, stem diameter, total fresh weight, etc and carbohydrate content: brix value, sucrose content and purity. Ethanol yield was significantly positively correlated with stem height, stem diameter, stem fresh weight and brix value, sucrose content and purity (Table 8) and grain yield, 1000 grain weight and of number of grain/panicle (Table 10). It significantly negatively correlated with biological yield. Biological yield refers to the total dry matter accumulation of a plant system. If more photosynthates translocate to vegetative organs, such as stem and leaves, there is less photosyntates to translocate into organs having economic yield such as grain and vice versa. So, biological yield and grain have negative correlation.

Total ethanol yield

Stem ethanol yield was highest in the first planting date (July 5) and lowest in last planting date (August 4). On the other hand, grain ethanol yield was highest and lowest in last planting date and first planting dates, respectively. Stem ethanol yield significantly correlated to plant growth and developments and carbohydrates (Table 7). All of these characteristics will be reduced by late planting. Grain yield and its components increased with late planting because flowering coincide with cool temperature. Grain ethanol yield is significantly correlated with grain and its components (Table 10). Since ethanol production from stem is several times more than ethanol from grain, therefore total ethanol from stem and grain was higher in the first and second planting dates 3484 and 3431 l/ha, respectively than third planting date (3250 l/ha). Lowest total ethanol yield was obtained (2514 l/ha) in last planting date.

Conflict of Interests

The authors have not declared any conflict of interests.

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