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Full Length Research Paper

Sweet corn yield response to alternate furrow irrigation methods under different planting densities in a semi-arid climatic condition

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A field study was conducted to investigate sweet corn variety KCS 403 performance for yield and yield components under treatments of every furrow irrigation (EFI), semi-alternate furrow irrigation (SAFI) and alternate furrow irrigation (AFI), with different planting densities in shallow and deep groundwater regimes. Plots under SAFI were irrigated every other furrow from sowing till six weeks, followed by full irrigation on every furrow till the end of growing season. Plots under EFI were irrigated every furrow throughout the growth period, while those under AFI were irrigated every other furrow throughout growth period. Results showed significant effects of the three irrigation regimes for fresh ear yield, 1000-kernel weight, ear diameter, cob diameter, number of kernel rows per ear, number of kernels per row, number of kernels per ear (all at $p \leq 0.01$), and fresh ear weight ($p \leq 0.05$). However, there was no significant difference on the effects between EFI and SAFI for all the traits measured in the study. This indicates that yield and yield components of sweet corn under SAFI treatment were comparable with those under EFI. Unexpectedly, fresh ear yield and number of kernels per ear were found to be significantly higher under SAFI at the density of eight plants per m^2 than the other irrigation treatment combinations. The results also revealed significant effects of planting densities for all the traits measured except fresh ear weight. Plants at lower density produced ears with higher quality, however the overall performance was found to be higher while the number of plants per unit area was higher. This might be due to the level of competition among the individual plants for water, sunlight and nutrients at the different planting densities. In general, sweet corn yield under SAFI at the density of eight plants per square meter was found to be same as those under EFI, with 30% less water supplied. It can be concluded that SAFI is a way to save water in arid and semi-arid areas where corn production relies heavily on repeated irrigation.

Key words: Sweet corn, alternate furrow irrigation, crop growth rate, leaf area index, agriculture water use efficiency.

INTRODUCTION

Water availability is the most limiting factor for crop production during the summer months in the semi-arid Mediterranean-type environments. The limited water resources in the area, which are mainly from aquifers and river intakes, and the cost of pumping irrigation water, are the most important factors that force many farmers to reduce irrigation in many arid and semi-arid regions of the Islamic Republic of Iran. Among crops, corn is known to be highly sensitive to water availability, such that possible limitation of this factor is generally overcome by heavy irrigation application which is not a possible practice in arid and semi-arid environments (Vamerali et al., 2003). Furrow irrigation in which soil surface is used

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to channel and infiltrate water is used widely throughout the world because of its simplicity and low capital costs (Mostafazadeh-Fard et al., 2009). Increasing water use efficiency (WUE) associated with crop production is a way for arid and semi-arid areas to increase their agricultural production where there is little or no prospect for expansion of water resources (Webber et al., 2006). Alternate furrow irrigation (AFI) is a method whereby water is applied to every other furrow rather than to every furrow. Therefore, less water is usually applied with alternate furrow irrigation methods. Since a reduced amount of water applied (gross water application) does not consistently reduce yields, water use efficiency may be increased (Graterol et al., 1993). Alternate furrow irrigation has been widely applied worldwide to improve irrigation efficiency with good results in corn, sorghum, potato, cotton and peppermint (Box et al., 1963; Fischbach and Mullinter, 1974; Graterol et al., 1993; Kang et al., 2000; Mitchell et al., 1995; Sepaskhah and Khajehabdollahi, 2005; Tsegaye et al., 1993). Irrigating plants at alternate furrows allows water to be applied to bigger areas than irrigating every furrow from a given water source for a given period than irrigating them at every furrows (Yonts et al., 2007). In addition, alternate furrow irrigation methods may supply water in a manner that greatly reduces the amount of surface wetted, leading to less evapotranspiration and less deep percolation (Graterol et al., 1993). Generally, alternate furrow irrigation regime has been found to be a trade-off; “a lower yield for a higher WUE”, in which water has been saved mainly by reduced evaporation from the soil surface (Graterol et al., 1993; Hodges et al., 1989; Kang et al., 2000; Musick and Dusek, 1982; Stone and Nofziger, 1993). Fischbach and Mulliner (1974) found that every other furrow irrigation required 40% less gross water than conventional furrow irrigation of corn. Graterol et al. (1993) reported that approximately same yield levels were obtained under both practices in soybeans, with significantly less water (46%) applied under every other furrow irrigation. Yonts et al. (2007) reported that water application can be reduced by 20 to 30% through every other row irrigation while corn yield was not much reduced. Baker et al. (1997) reported that the use of AFI reduced sugar cane yield when the same irrigation frequency was applied as every furrow irrigation (EFI). The water requirements of corn on a fine textured soil (with deep and shallow water table) were not met by AFI even at 4-day irrigation intervals (Sepaskhah and Khajehabdollahi, 2005). It was also reported by many investigators that AFI can improve agricultural water use efficiency (Fischbach and Mullinter, 1974; Musick and Dusek, 1982; Sepaskhah and Kamgar-Haghighi, 1997; Sepaskhah and Khajehabdollahi, 2005; Stone and Nofziger, 1993). Sepaskhah and Khajehabdollahi (2005) reported that decrease in corn yield due to water stress in AFI was mainly due to the decrease in the number of kernels per cob and to a lesser extent to the decrease in1000-kernel weight. There has not been any report on semi-alternate furrow irrigation in which plants are irrigated through a combination of every furrow and alternate furrow irrigations throughout the growth period.

There is a need to use optimum plant density, which is expected to bring about a maximum yield of corn when all the other inputs of production have been adequately met (Ogunlela et al., 1988). Plant density has been recognized as a major factor determining the degree of competition between plants (Heitholt and Sassenrath-Cole, 2010). Hence, it is expected to decrease yield per plant as the density per unit area increases. Reduction in sweet corn yield is mostly due to ear barrenness (Hashemi et al., 2005), low number of kernels per ear (Capristo et al., 2007), low kernel weight (Monneveux et al., 2005) or a combination of two or more of these components. Corn yield is low at low planting density because of little plasticity in leaf area per plant (Tetio-Kagho and Gardner, 1988). Additionally, sweet corn plants have a small capacity to develop new reproductive structures in response to an increase in available growth resources per plant (Loomis and Connor, 1992). In contrast, sweet corn yield declines due to increase in number of aborted kernels and barren stalks (Hashemi et al., 2005). Corn is more sensitive to variations in plant density than other members of the grass family (Sangoi, 2001). At low densities, many modern sweet corn hybrids do not tiller effectively and quite often produce only one ear per plant. Sweet corn does not share the trait of most tillering grasses of compensating for low leaf area and small number of reproductive units by branching (Gardner et al., 2003). On the other hand, the use of high populations heightens interplant competition for light, water and nutrients. This may be detrimental to final yield because it stimulates apical dominance, induces barrenness and ultimately decreases the number of ears produced per plant and kernels set per ear (Sangoi, 2001). Therefore, finding the optimum plant density that produces the maximum yield per unit area is of importance. The canopy light extinction coefficient (k) can be used for identifying optimal plant population density for cereals since it is an important index for an appropriate partitioning of radiant energy between the crop canopy and the soil surface (Tahiri et al., 2006).

The main objective of this study was to investigate the effects of three furrow irrigation methods in relation to three planting densities on yield and yield components of sweet corn.

MATERIALS AND METHODS

An experiment was conducted on a clay loam soil (pH 6.5) at the Agricultural Experiment Station of Islamic Azad University, Karaj branch, located at 35°43' North, 50°56' East, and 1160 m above the sea level, from June to July, 2008. The site is in a semi-arid zone with an average annual rainfall of about 200 mm and an underground water table 35±38 m below the soil surface.

Field capacity, defined as the water content at -0.02 MPa, was approximately 0.312 m in the upper 1.0 m of the soil profile with the bulk density of about 1.5 g cm^{-3}. The soil water content was near

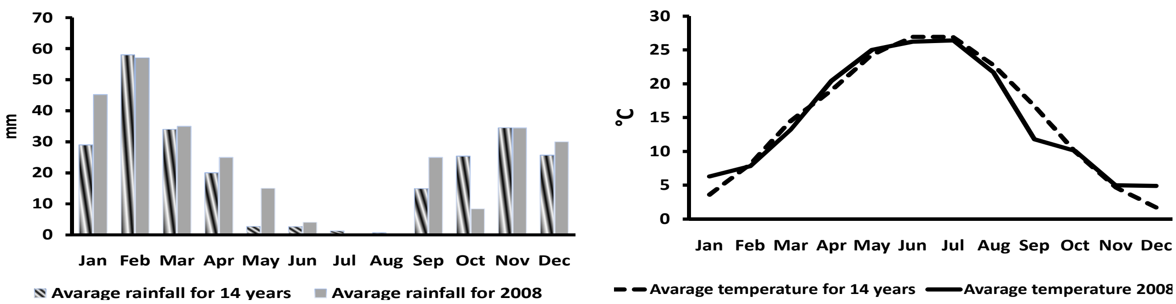

Figure 1. Average rainfall distributions and temperature changes at the study site.

the field capacity at sowing.

The experiment consisted of a split plot arrangement of treatments with the two factors and their respective levels with irrigation method being the main plot (EFI = every furrow irrigation throughout the growth period, SAFI = semi-alternate furrow irrigation for six weeks after sowing, subsequently followed by every furrow irrigation, AFI = alternate furrow irrigation throughout the growth period) and plant density as sub-plot (D1, D2, and D3 represented by 7, 8, and 9 plants/m^2, respectively) in a randomized complete block design with four replications. Single-cross Hybrid KSC 403 which has performed well and widely planted throughout the country was selected as planting material. Each experimental unit consisted of nine 20-m long plant rows and V-shaped furrows with 0.75 m spacing, where only the four middle rows measuring 14 m in length were used as the harvest area. Nitrogen and phosphorus at rates of 116 and 42 kg ha^{-1}, respectively, were applied prior to planting and thoroughly mixed into the top soil. Nitrogen at the rate of 46 kg ha^{-1} was applied at the fifth week after sowing when the plants reached a height of 50 to 60 cm. Seeds of a local single-cross hybrid KSC403, with about 80-day growth cycle, were sown in the first week of June, 2008 in single rows at a spacing of 19.1, 16.7, and 14.8 cm for D1, D2, and D3, respectively. Water at the rate of 55 mm at each irrigation treatment with 7-day interval was supplied using gated pipes with gates open at every-furrow for EFI treatment, while gates were opened only at alternate furrows for SAFI and AFI treatments. Water was measured using single-jet water meters (DLJSJ75, Daniel L. Jerman Co.) installed at each gate. Plants were irrigated 10 times throughout the growth season. With this arrangement, EFI treatment received 550 mm of water throughout the growth season while SAFI treatment and AFI treatment received 385 and 275 mm, respectively. No rain occurred during the growing season (Figure 1).

For better understanding of the crop behavior, pre-harvest data were taken, which include total dry weight (TDW), leaf dry weight (LDW) and leaf area index (LAI) from five plants per plot every 10 days from sowing using the destructive sampling method. Leaf area index was measured using LI-COR LAI-2000 (LI-COR Inc., 1992). After normalization of the data using loge transformation, TDW, LDW and LAI were non-linearly regressed versus days after sowing (DAS) using quadratic function as follows (Hunt, 1982):

$$Y=\frac{\alpha}{1+\beta e^{(-\delta x)}}$$

where Y is TDW/LDW/LAI, while α, β and δ are regression constants. The α is the asymptotic level of each parameter, while the initial value of each parameter was α/(1+β). χ is number of the days after sowing (DAS).The PROC NLIN (METHOD=DUD) of SAS package (SAS Institute Inc., 2005) was used in the analysis of model development. The aforementioned function is the most popular model in describing organism or organ growth versus time. It can be expanded to describing the growth involving both biological and physical processes (Selamat et al., 2008).

By taking the derivative of the aforementioned equation, crop growth rate (CGR) was computed using TDW data as follows (Gardner et al., 1985):

$$\frac{d_y}{d_x}=\frac{\alpha\beta\delta e^{-\delta x}}{(1+\beta e^{-\delta x})^2}$$

This equation can be further converted to:

$$\mathrm{CGR}=((\alpha+\beta\chi)\frac{1+\alpha}{e^{(\beta\chi+\delta\chi^2)}})$$

Data were also taken from post-harvest characters as follows: ear diameter (mm), cob diameter (mm), kernel depth (mm), number of kernel rows per ear, number of kernels per row, 1000-kernel weight (kg ha-1) and dehusked ear fresh yield (kg ha^{-1}). The analysis of variance (ANOVA) and protected Duncan's New Multiple Range Test (DNMRT) were used to analyze the data. All analyses were done using SAS Software Version 9.1 (SAS Institute Inc., 2005).

The light extinction coefficient (k) which defines the light interception in a vertical crop profile was estimated based on Monsi and Saeki (1953) as follows:

$$I_i = I_o\ e^{-kLAI}$$

$$k=\frac{e^{I_o}\ -\ e^{I_i}}{LAI}$$

where Io is the total light above the canopy, Ii is the available light under canopy, LAI is integrated leaf area index between Io and Ii and k is the light extinction coefficient.

Field Scout External Light Sensor Meter (3415FX, Data Logger) and 6 Sensor Quantum Light Bar (3668i6, Light Sensor) were used to measure light intensity above and below canopy (Spectrum Technologies Inc.).

RESULTS

Results showed that when sweet corn plants were

Table 1. Mean values for the traits measured under different irrigation methods, plant densities and their combinations.

	Fresh ear yield	Fresh ear weight	No. of ear ha^{-1}	1000-kernel weight	No. of kernels per cob	Kernel depth	Ear diameter	Cob diameter	No. of rows per ear	No. of kernels per row
EFI	9071a	710.3a	7934a	327.8a	809.5a	1.30a	6.54a	3.50a	23.2a	41.6a
SAFI	8862a	689.9a	8779a	317.4a	788.3a	1.25a	6.40a	3.31a	22.7a	41.8a
AFI	6871b	623.6b	7459a	250.9b	623.9b	1.23a	5.38b	2.85b	20.1b	34.6b
D1	6999b	687.1a	6796b	335.6a	728.1ab	1.46a	6.55a	3.22a	23.8a	40.2a
D2	8812a	674.0a	8690a	297.9ab	811.9a	1.20b	6.28a	3.40a	21.7b	35.4b
D3	8994a	662.6a	8685a	262.7b	681.7b	1.11b	5.50b	3.04b	20.5c	42.5a
EFI D1	8432abc	773.9a	6793a	414.3a	836.7ab	1.49a	7.22a	3.50a	25.0a	45.3a
EFI D2	8698abc	666.9a	8047a	294.5a	816.6bcd	1.49a	6.84a	3.68a	23.1a	38.7a
EFI D3	10084ab	690.0a	8961a	274.7a	717.8cd	1.42a	5.57a	3.34a	21.5a	36.5a
SAFI D1	7710c	691.0a	8153a	344.9a	775.3bc	1.21a	6.95a	3.37a	24.6a	37.1a
SAFI D2	10522a	674.4a	9975a	330.0a	972.7a	1.25a	6.53a	3.48a	22.3a	39.5a
SAFI D3	8354abc	704.5a	8208a	277.3a	687.8bcd	1.14a	5.72a	3.07a	21.1a	29.7a
AFI D1	4854d	596.5a	5441a	247.7a	629.8ab	1.21a	5.47a	2.79a	21.7a	42.4a
AFI D2	7762c	646.6a	8049a	269.1a	674.4bcd	1.01a	5.47a	3.05a	19.7a	47.3a
AFI D3	7997bc	627.7a	8886a	236.0a	554.1d	1.12a	5.21a	2.70a	18.8a	37.7a
C. V. (%)	17.6	9.8	18.5	17.9	14.4	10.1	5.5	6.0	8.7	12.1

EFI = every furrow irrigation throughout the growth period; SAFI= semi-alternate furrow irrigation for six weeks after sowing, subsequently followed by every furrow irrigation; AFI= alternate furrow irrigation throughout the growth period, and D1, D2 and D3=7, 8 and 9 plants m $^{-2}$, respectively. Means followed by the same letter in the same column separately for main factors and their combinations are not significantly different at $p \leq 0.05$ based on DNMRT.

irrigated alternately throughout the growth season as in AFI, yield and yield components were found to be significantly less than those irrigated by EFI for all the traits measured except number of ears per hectare and kernel depth (Table 1). This indicates that significantly lower yield and magnitudes of yield components were obtained when lower amount of water was supplied during the growth period. Highest fresh ear yields were obtained in EFI plots followed by SAFI and AFI, with yields of 9071, 8862 and 6871 kg ha^{-1}, respectively. No significant difference was observed between the yields obtained from the plants under EFI and SAFI treatments. The significant difference between the yields of the plants under EFI and SAFI, and that under AFI was mainly manifested through the ear weights, since higher ear weights were achieved under EFI and SAFI.

The irrigation methods applied had no significant influence on the number of ears per hectare. In addition, plants under EFI and SAFI treatments were found to be similar for all the traits measured in the study, although 30% less water was supplied to the plants under SAFI treatment. Results showed that plant population density had significant effects (at $p \leq 0.05$) on fresh ear yield (Table 1). The highest fresh ear yield was obtained from the density of 9 (D3) plants m^{-2} (8994 kg ha^{-1}) followed by the densities of 8 plants m^{-2} (D2) and 7 (D1) plants m^{-2} (8812 and 6999 kg ha^{-1}, respectively) (Table 1). The plots planted with the density of D1 yielded significantly lower than those planted with the densities of D2 and D3, while no significant difference was observed in fresh ear yields obtained from the densities of D2 and D3. A similar pattern was also obtained for ear dry weight and number of ears per hectare, where the plots planted with the densities D2 and D3 had values significantly higher than those from D1. In contrast, the highest values for 1000-kernel weight, kernel depth, ear diameter, cob diameter, number of kernels per ear, number of kernel rows per ear and number of kernels per row were obtained from the plants with the density of 7 plants m^{-2}.

Interaction effects of irrigation method and plant density were found to be significant only for fresh ear yield and number of kernels per ear (Table 1). The highest fresh ear yield was obtained from SAFI-D2 with yield of 10522 kg ha^{-1} which was not significantly different from those of EFI-D3 (10084 kg ha^{-1}), EFI-D2 (8698 kg ha^{-1}) and EFI-D1 (8432 kg ha^{-1}). The lowest fresh ear yield was obtained from AFI-D1 with the yield of 4854 kg ha^{-1}. The highest number of kernels per cob was achieved from plants under SAFI-D2 (972.7), which was not significantly higher than those obtained from EFI-D1 and EFI-D2 (836.7 and 816.6, respectively).

The above-ground biomass (TDW), leaf area index (LAI) and crop growth rate (CGR) which were positively associated with yield were compared among the irrigation methods and different plant population densities during the growth period, in order to identify the critical growth attributes (Figure 2). Table 2 shows that the constants of non-linear regression functions used to estimate the relationship between the dependent variables TDW, LDW and LAI, and the independent factor DAS were

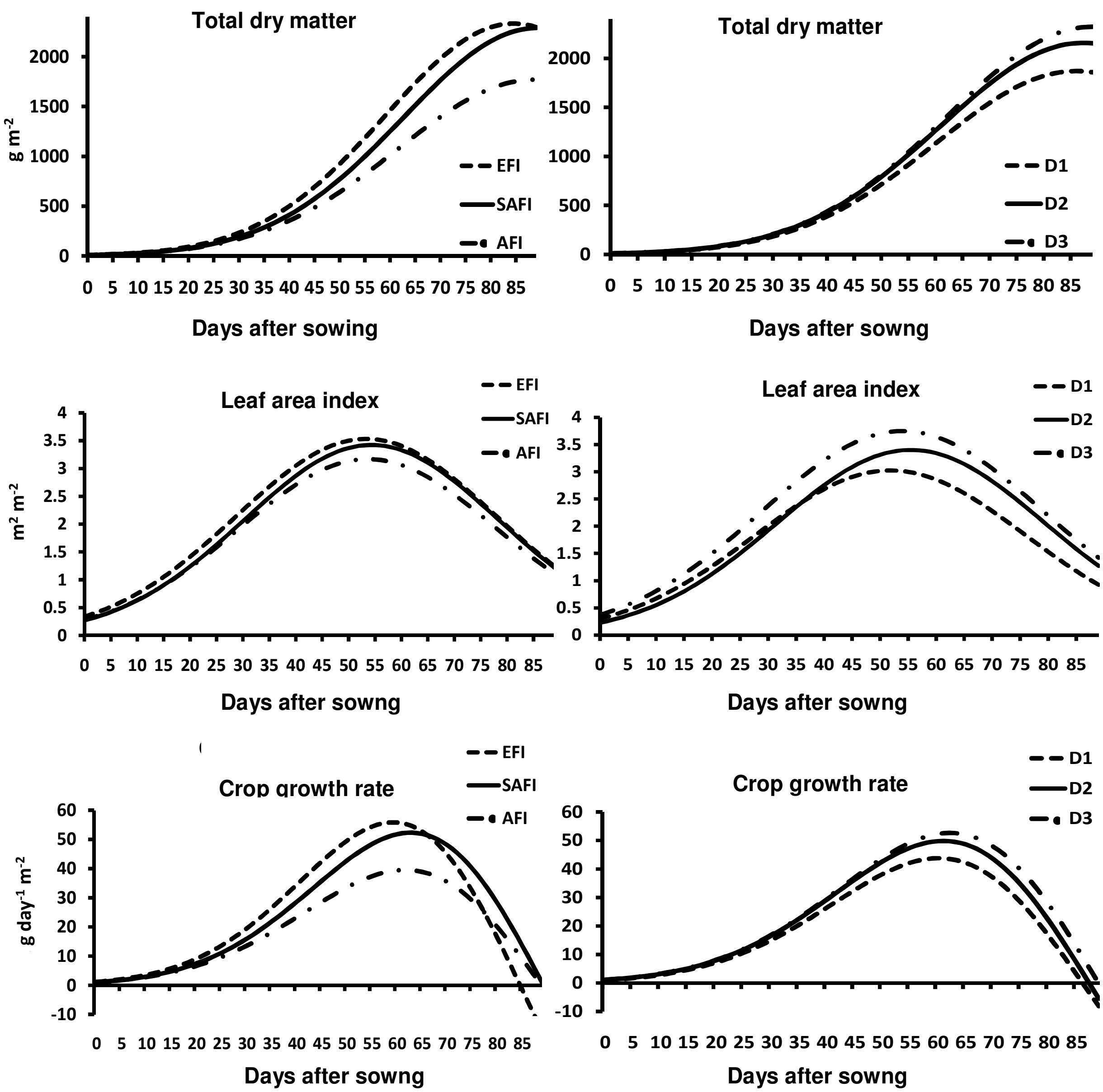

Figure 2. Relationships between total dry weight (TDW), leaf area index (LAI) and crop growth rate (CGR), and number of days after sowing under different irrigation methods (left) and different planting densities (right). EFI = every furrow irrigation throughout the growth period; SAFI = semi-alternate furrow irrigation for six weeks after sowing, subsequently followed by every furrow irrigation; AFI= alternate furrow irrigation throughout the growth period, and D1, D2 and D3 = 7, 8 and 9 plants m^{-2}, respectively.

Table 2. Result of non-linear regression analysis for sweet corn total dry weight (TDW) and leaf area index (LAI) as dependent variables and days after sowing (DAS) as independent variable, in irrigation and plant density treatments and their combinations.

Treatment	Regression equation	R^2	Mean squares for regression model
EFI	TDW = exp[2.06288 + (0.13313*DAS) – (0.00077841*DAS2)]	0.93	106.5**
	LAI = exp[-1.17383 + (0.08962*DAS) – (0.00082434*DAS2)]	0.83	14.4**
SAFI	TDW = exp[1.96467+ (0.12799*DAS) – (0.00070962*DAS2)]	0.92	110.3**
	LAI = exp[-1.40835+ (0.09538*DAS) – (0.00086186*DAS2)]	0.82	16.7**

Table 2. Contd.

AFI	TDW = exp[2.02324+ (0.12158*DAS) – (0.00067736*DAS2)]	0.93	98.5**
	LAI = exp[-1.36490+ (0.09213*DAS) – (0.00084269*DAS2)]	0.80	15.3**
	TDW = exp[1.90166+ (0.12943*DAS) – (0.00074349*DAS2)]	0.92	104.7**
	LAI = exp[-1.29130+ (0.09075*DAS) – (0.00085866*DAS2)]	0.83	14.5**
D2	TDW = exp[2.04038+ (0.12778*DAS) – (0.00072413*DAS2)]	0.93	105.0**
	LAI = exp[-1.58086+ (0.09927*DAS) – (0.00087838*DAS2)]	0.86	18.8**
D3	TDW = exp[2.10875+ (0.12549*DAS) – (0.00069778*DAS2)]	0.91	105.4**
	LAI = exp[-1.07492+ (0.08711*DAS) – (0.00079185*DAS2)]	0.84	13.8**
EFI D1	TDW = exp[2.00990+ (0.13282*DAS) – (0.00077989*DAS2)]	0.94	35.0**
	LAI = exp[-1.04438+ (0.08345*DAS) – (0.00080175*DAS2)]	0.84	4.1**
EFI D2	TDW = exp[2.05612+ (0.13434*DAS) – (0.00079123*DAS2)]	0.95	35.6**
	LAI = exp[-1.55089+ (0.10445*DAS) – (0.00094339*DAS2)]	0.90	6.7**
EFI D3	TDW = exp[2.12262+ (0.13224*DAS) – (0.00076412*DAS2)]	0.92	36.0**
	LAI = exp[-0.92623+ (0.08096*DAS) – (0.00072788*DAS2)]	0.87	4.1**
SAFI D1	TDW = exp[1.90856+ (0.12805*DAS) – (0.00071968*DAS2)]	0.92	35.8**
	LAI = exp[-1.43587+ (0.09596*DAS) – (0.00090239*DAS2)]	0.85	5.4**
SAFI D2	TDW = exp[1.93953+ (0.12997*DAS) – (0.00073020*DAS2)]	0.92	36.9**
	LAI = exp[-1.58285+ (0.09539*DAS) – (0.00080657*DAS2)]	0.90	6.5**
SAFI D3	TDW = exp[2.04593+ (0.12595*DAS) – (0.00067899*DAS2)]	0.92	37.6**
	LAI = exp[-1.20633+ (0.09478*DAS) – (0.00087662*DAS2)]	0.84	5.3**
AFI D1	TDW = exp[1.78654+ (0.12742*DAS) – (0.00073091*DAS2)]	0.95	33.9**
	LAI = exp[-1.39366+ (0.09285*DAS) – (0.00087183*DAS2)]	0.82	5.1**
AFI D2	TDW = exp[2.12549+ (0.11904*DAS) – (0.00065094*DAS2)]	0.94	32.7**
	LAI = exp[-1.60883+ (0.09796*DAS) – (0.00088518*DAS2)]	0.86	5.9**
AFI D3	TDW = exp[2.15769+ (0.11829*DAS) – (0.00065024*DAS2)]	0.92	31.9**
	LAI = exp[-1.09220+ (0.08559*DAS) – (0.00077105*DAS2)]	0.83	4.5**

EFI= every furrow irrigation throughout the growth period; SAFI= semi-alternate furrow irrigation for six weeks after sowing, subsequently followed by every furrow irrigation; AFI= alternate furrow irrigation throughout the growth period, and D1, D2 and D3=7, 8 and 9 plants m^{-2}, respectively. ** Significant at P ≤ 0.01.

significant. This indicates that TDW, LDW and LAI were precisely regressed by time based on the data obtained from the samples from each experimental plot. Figure 2 clearly indicates that total dry weight of the plants under AFI was less than those under EFI and SAFI.

The plants under AFI and SAFI produced similar dry matter and both were less than those under EFI during the first six weeks after sowing, but the plants which received more water under SAFI treatment could recover after blocked furrows were opened from day 42 after sowing onwards. This pattern can also be seen for both leaf area index and crop growth rate, where the plants under SAFI treatment recovered themselves after receiving more supplemental water. The extra supplemental water applied to the plots under SAFI caused non-significant difference in total dry weight between the plants under EFI and SAFI at harvest time. The maximum crop growth rate of plants under EFI was achieved at day 60 (55.8 g day^{-1} m^{-2}), while maximum CGR was achieved at day 66 for the plants under SAFI

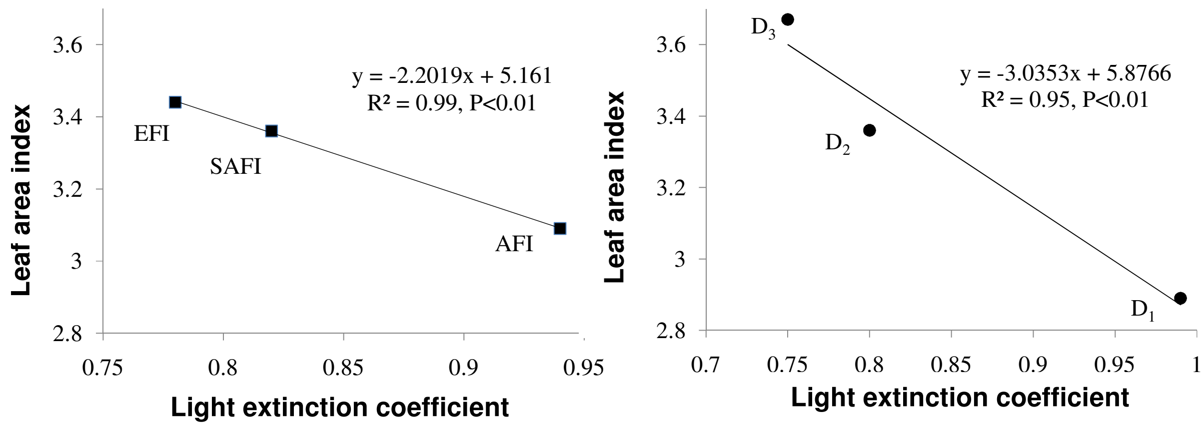

Figure 3. Relationship between leaf area index (LAI) and light extinction coefficient (k) under different irrigation methods (left) and different planting densities (right). EFI = every furrow irrigation throughout the growth period; SAFI = semi-alternate furrow irrigation for six weeks after sowing, subsequently followed by every furrow irrigation; AFI = alternate furrow irrigation throughout the growth period, and D1, D2 and D3 = 7, 8 and 9 plants m^{-2}, respectively.

(52.3 g day^{-1} m^{-2}) and at day 63 under AFI (39.5 g day^{-1} m^{-2}).

After this stage, CGR started to decrease at all the irrigation regimes, where the reduction rate was more drastic for plants under EFI (-0.00078) compared to those under SAFI and AFI (-0.00071 and -0.00068, respectively). The high CGR displayed by the plants under SAFI could be attributed to their ability to produce more leaves as sources for synthesis of carbohydrates and their assimilation in sinks after receiving more water, since the plants under SAFI treatment produced higher LAI due to the extra water applied compared to those under AFI. However, plants under SAFI and AFI methods had approximately the same LAI over the first seven weeks after sowing.

The plant density of 9 plants m^{-2} could produce the highest TDW, LAI and CGR compared to D1 and D2 (Figure 1). This might be due to the increase in the number of plants per unit area. The light extinction coefficient (k) obtained from D3 (0.75) on day 60 after sowing was significantly lower than that obtained from D1 (0.99). In addition, there was no difference in k between the experimental plots under D2 and D3 densities (0.80 and 0.75, respectively). At this stage, 8.9% of total light above the canopy could reach the soil surface in D1, while the percentages of light under canopy for D2 and D3 were 8.8 and 8.3%, respectively.

Light extinction coefficient (k) had a significant negative relationship with leaf area index (Figure 3). Every furrow irrigation (EFI) at high planting density (D3) led to high LAI and low value of k.

DISCUSSION

It was revealed that corn yield was significantly higher under every furrow irrigation (EFI) treatment than that under alternate furrow irrigation (AFI). This increase in yield and magnitudes of yield components was due to the availability of 50% more water to the plots under EFI treatment. Similar results in which the full water requirements of corn were not met by alternate furrow irrigation treatment were also reported by other investigators (Kang et al., 2000; Sepaskhah and Kamgar-Haghighi, 1997; Sepaskhah and Khajehabdollahi, 2005). The decrease in yield due to water stress in AFI was mainly due to the decrease in ear weight and numbers of kernels per ear, and to a lesser extend to the decrease in 1000-kernel weight. A similar result was also reported by Sepaskhah and Khajehabdollahi (2005).

The plots under semi-alternate furrow irrigation (SAFI) were treated similar to those under AFI for the period of 42 days after sowing, which received six out of a total of 10 irrigations throughout the growth period. Therefore, the higher fresh ear yield obtained from plots under SAFI compared to those under AFI was because of the extra 110 mm water supplied to the plots under SAFI. This indicates that water use efficiency increased with SAFI treatment. It could be due to the development of more roots of the plants under SAFI. Kang et al. (2000) reported that primary root numbers, total root dry weight and root density were significantly enhanced by alternate furrow irrigation treatment. The development in root system might be enhanced by continuous regulation by a root drying signal of the stomatal opening (Kang et al., 1998, 2000). When roots are in drying soil, even in a situation where only part of the root system is dry, substantial abscisic acid (ABA) is produced in the roots and transported through the xylem to the shoots where stomatal opening is regulated (Davies and Zhang, 1991). The plants under SAFI took advantage of this physiological response and exposed part of their root systems to the drying soil. Hence, corn plants under semi-alternate furrow irrigation method could absorb and utilize water more efficiently once they were supplied twice the amount of water they had been receiving before. The extra water together with more developed root system of the plants under SAFI resulted in higher leaf area index and consequently higher crop growth rate compared to those under AFI. This resulted in the production of the same amount of total biomass by SAFI at harvest time compared to that by EFI.

Plant population densities applied in this study had significant effect on all the traits measured except ear weight. This indicates the importance of optimum density to bring about a maximum yield of sweet corn. The highest fresh ear yield and number of ears per hectare were obtained from 9 plants m^{-2}. This indicates that high planting density could produce higher quantity of ears per unit area. Adipala (1995) reported that corn density significantly influenced grain yields of different cultivars. This increase in sweet corn yield might be due to high net photosynthetic activity during the vegetative growth period obtained by increasing planting density (Kapustka and Wilson, 1990). The plots under 9 plants m^{-2} significantly obtained the highest LAI compared to those under 7 and 8 plants m^{-2}. The high leaf area caused high net photosynthetic activity and consequently high CGR and TDW in the plots under 9 plants m^{-2}. The result also showed that 9 plants m^{-2} had the highest crop growth rate (CGR) (52.7 g day^{-1} m^{-2}) compared to 7 and 8 plants m^{-2} (43.8 and 49.8 g day^{-1} m^{-2}, respectively). The canopy light extinction coefficient (k) can be utilized as an important index for an appropriate partitioning of radiant energy between the crop canopy and the soil surface. It can therefore be used for identifying optimal plant population density for cereals (Tahiri et al., 2006). Result also showed that the lowest k was obtained from 9 plants m^{-2} (0.80) which was significantly lower than that obtained from 7 plants m^{-2} (0.99). This indicates a negative relationship between k and plant density. Values less than 1.0 are often found for non-horizontal leaves or clumped-leaf distributions, while values greater than 1.0 are common for horizontal leaves or more regular arrangement in space (Jones, 1992). For corn, various investigators reported different values of k, which includes 0.40 (Kiniry et al., 1989), 0.65 (Allen et al., 1964), 0.72 for inbreds with more horizontal leaves (Pepper et al., 1977), and 0.84 for modern varieties (Lindquist et al., 2005). Previous investigations showed that increase in radiation use efficiency (RUE) and crop growth rate (CGR) were strongly correlated with decrease in k (Lindquist et al., 2005; Skeehy and Cooper, 1973). This indicates that RUE and CGR could be improved through reduction of k. Therefore, increase in sweet corn planting density could be a proper way to improve RUE and CGR. Similar results were also reported in winter wheat, where cultivars with low k values had a higher level of RUE than cultivars with high k values (Green, 1989).

The highest ear weight, 1000-kernel weight, kernel depth, ear diameter, cob diameter and number of kernel rows per ear were obtained from 7 plants m^{-2}. Ogunlela et al. (1988) reported that increased plant density led to reduced ear diameter, kernel depth and number of ears per plant. When number of plants per unit area is low, they may be able to receive from the relatively large volume of soil available to the individual plant an adequate supply of plant nutrients. Arnon (1978) concluded that, depending on plant density, there may be no competition for nutrients between neighboring plants, competition for mobile nutrients only, or competition for both relatively mobile nutrients and those with limited mobility (Ogunlela et al., 1988). The highest fresh ear yield in this study (10522 kg ha^{-1}) was obtained from the plants under semi-alternate furrow irrigation regime and density of 8 plants m^{-2} (SAFI-D2) which was not significantly different from that obtained from every furrow irrigation and density of 9 plants m^{-2} (10084 kg ha^{-1}), where 30% more water and about 3 kg more hybrid planting seeds were supplied. This indicates that the more developed root system of the plants under SAFI treatment together with the optimum planting density of 8 plants m^{-2} could produce the highest fresh ear yield achieved in this study, while 30% less water was supplied. It was predicted that the 30% of water consumption saved from SAFI method at the optimum planting density could approximately produce 3157 kg ha^{-1} extra fresh ear yield.

Conclusion

Semi-alternate furrow irrigation (SAFI) can be used as a simple and efficient method for corn production in arid and semi-arid areas where production is heavily dependent on irrigation. SAFI method allows planting on large land area with efficient use of available water. This method enables the production of as much sweet corn yield as those offered by EFI method, while utilizing 30% less amount of water. The plant density of 8 plants m^{-2} was found to be compatible with the SAFI method, and produced the maximum yield. Thus, the improved irrigation management in combination with the optimum planting density can increase the performance of deficit irrigation scheduling in semi-arid regions where water is the most limiting input to crop production.

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