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Full Length Research Paper

Effect of different levels of irrigation and planting pattern on grain yield, yield components and water use efficiency of corn grain (*Zea mays* L.) hybrid SC. 704

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Corn production management including irrigation and planting pattern might be different under various conditions. This research was conducted to study the effects of different levels of irrigation and planting pattern on grain and biological yield, yield components, and water use efficiency of grain corn (hybrid SC.704) in 2010 cropping season at Natural Resources and Agricultural Researches Center of Khuzestan, south-west Iran. The study was split-plot experiment, using Randomized Complete Block Design (RCBD) with three replicates. Three irrigation levels consisting of optimum irrigation (I_1), drought moderate stress (I_2) and drought severe stress (I_3), (irrigation based on 100, 80 and 60% water requirement, respectively) were considered as main plots and subplots consisted of two planting pattern, planting in furrow (P_1) and planting on raised bed (P_2). The amount of water applied was determined by Class-A Pan evaporation every day. Required irrigation water was applied as 70 mm of evaporation of Class-A Pan. The total evaporation from Class-A Pan was measured with a manual limnimeter that has 0.1 mm accuracy. These measurements were checked with the readings from the water flow meters mounted in every plot. The results indicated that the effect of drought stress and planting pattern on grain and biological yields was significant at 1% probability level. The maximum grain yield of about 998 gm^{-2} was obtained from optimum irrigation treatment. Drought severe stress reduced the grain yield by 30% compared to the optimum irrigation condition. This reduction was mainly due to reduction in grain number per ear and average of grain weight. Step-wise regression analysis indicated that about 88% of grain yield variation was related to the grain number per ear. Increasing amount of water applied, while planting in furrow improved economical and biological water use efficiency mainly due to increased grain and biological yields. The results also indicated that selecting suitable treatments (optimum irrigation with planting in furrow system) and change in leaf area index would be optimal for corn grown in semi-arid regions with saline soil similar to the area in south west of Iran where this study was conducted and can cause plant growth increase and high yield access.

Key words: Corn, irrigation, planting pattern, water use efficiency.

INTRODUCTION

Iran, with having different and proper climate is a potentially capable area for the crop production. The province of Khuzestan is also appropriate for growing crops especially grain corn because this area has flat and fertile lands with a lot of solar energy. Corn is highly adapted to such hot climates due to the fact that it is a C_4 plant and has high potential for biomass production in this area u(Lack et al., 2005). Although, the cultivation of corn has developed after harvesting of wheat in recent years

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on the south west of Iran, but water deficiency especially in warm summer seasons has been the main factor to limit its cultivation. Despite corn has well yield in the northern region of the province because of the mediterranean climate of these areas, but due to the lack of proper land in these regions, corn must be cultivated in the other regions of the province. Generally, the southern regions of the province are hot and arid with heavy-saline soils, and as one moves to southern of the province, the salinity of soil raises. In order to grow corn in these areas, we should change the planting patterns. Studies have shown that changes in the amount of irrigation and planting pattern can create the necessary conditions to planting corn in these areas.

El-Hendawy et al. (2008) studied the amount of irrigation corresponding to 60, 80 and 100% of the estimated evapotranspiration and plant population (4.8, 7.1 and 9.5 plant m^{-2}) on yield and WUE of corn and revealed that by increasing the amount of irrigation and decreasing of plant population, the yield and WUE improved. The lowest grain yield belonged to the irrigation treatment corresponding to the estimated 60% of evapotranspiration.

Zaidi et al. (2008) reported that drought stress reduces the corn yield through the reduction of the leaves chlorophyll and negative impacts on silk production and pollination periods. According to Barzegari et al. (2005), water consumption was reduced up to 28% in planting in furrow in comparison with planting on raised bed; meanwhile, it seems planting in furrow cause salt washing around the roots of corn, which affects salinity reduction and more development of aerial roots. Saif et al. (2003) evaluated the effects of one-row and two-row planting patterns and different levels of irrigation on yield and yield components of grain corn and concluded that planting patterns did not affect yield and yield components but frequency of irrigation significantly influenced yield and yield components. Oktem et al. (2003) expressed that the change from an alternation corn cultivation pattern to the one-row pattern through improving the WUE leads to the increase in the yield. Kang et al. (2002) found that grain yield and water use efficiency responses to irrigation varied considerably with differences in soil–water contents and irrigation schedules. Olsen et al. (2000) expressed that although irrigation increased yields, there were no significant differences in WUE and harvest index in wheat subjected to three different irrigation strategies, since the increases were almost solely due to increased transpiration. In addition, excessive irrigation can reduce crop WUE (Jin et al., 1999). Barzegari (2006) reported that irrigation efficiency (the amount of stored water in the root zone in proportion to the water input to the field) in the treatment of planting in furrow was higher than that on bed.

The objectives of this study were to determine the effect of different levels of irrigation and planting pattern on grain and biological yields, yield components, water saving in irrigation and maximizing water use efficiency and the development and promotion of corn planting in saline soil by the use of planting patterns in furrow.

MATERIALS AND METHODS

The influence of different levels of irrigation and planting pattern on grain and biological yields, yield components, and water use efficiency of grain corn (hybrid SC. 704) was assessed in 2010 cropping season in experimental field in Natural Resources and Agricultural Researches Center of Khuzestan, South-West Iran (latitude 31° 20 N, longitude 48° 41 E and altitude 22.5 m) with moderate winter and hot summer. The soil texture was silty clay (average 44% clay content, 48% silt and 8% sand). The organic matter was less than 1% (0.93%), available phosphorous 16.2, potassium 317.9 (all values of nutrients in mg/kg of dry soil). The soil pH was 7.3 and soil electrical conductivity (Ec_e) 2.9 ds/m. The study was split-plot experiment, using randomized complete block design (RCBD) with three replicates. Three irrigation levels consisting of optimum irrigation (I_1), moderate drought stress (I_2) and severe drought stress (I_3), (irrigation based on 100, 80 and 60% water requirement, respectively) were considered as main plots and subplots consisted of two planting pattern, planting in furrow (P_1) and planting on raised bed (P_2). The amount of water applied was determined by Class-A Pan evaporation every day (Kanber, 1984). Required irrigation water was applied as 70 mm of evaporation of Class-A Pan.

The amount of irrigation water was calculated using Equation 1 (Oktem et al., 2003):

$$I = AE_{pan} K_{cp} \quad (1)$$

Where I is the amount of irrigation water (mm), A plot area (m^2), E_{pan} cumulative water depth from Class A Pan based on irrigation frequencies (mm), K_{cp} is crop pan coefficient.

The total amount of water applied was 748, 598 and 449 mm m^{-2} in I_1, I_2 and I_3, respectively. Base fertilizer-consisting of 180 kg N ha^{-1} in the form of urea (N 46%), 100 kg P ha^{-1} in the form of super phosphate (P_2O_5 45%), and 50 kg K ha^{-1} in the form of potassium sulfate (K_2O 45%). Half of the N and all of P and K were applied before sowing (incorporated by disk). The remaining N was applied as a top dressing one month after sowing. The area of each of the fresh leaves of the sampled plants was determined immediately after harvesting them, by multiplying their manually measured length and maximal width with a shape factor, k, empirically determined to be 0.75 for maize (McKee, 1964). Leaf area index (LAI) values for each plot was then calculated by multiplying the leaf area values by the plant density (7.5 plants m^{-2}). Total dry matter, relative grain yield and, hence, the harvest index (HI) (Equation 2) and yield components were estimated after physiological maturity by harvesting interior rows (the outer rows excluding at least 0.5 m from either end of the rows).

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 \quad (2)$$

Water use efficiency, defined as the ratio of grain yield per hectare to the amount of irrigation water, was calculated using the methodology provided by Tanner and Sinclair (1983). Statistical analysis was made using the SAS statistical program. Differences between traits means were assessed using Duncan test.

Table 1. Summary of analysis of variance for LAI at silking, yield components, grain and biological yields, harvest index and economical and biological water use efficiency.

S.O.V	Mean square									
	df.	LAI at silking	No. Rows per ear	No. grain per ear	1000-grain weigh	Grain yield	Biological yield	Harvest index	Economical water use efficiency	Biological water use efficiency
Replication	2	0.001	0.962	0.681	135.531	3653.704^{ns}	2464.29	32.08	0.056	0.072
(I) Irrigation	2	1.055**	4.962^{ns}	83.764**	16781.3**	713394.858**	2514059.187**	13.181*	1.937*	2.796**
Ea	4	0.001	0.803	1.597	154.6^{ns}	176.566	1716.844	4.392	0.178	0.016
Planting pattern (P)	1	0.105^{ns}	0.845^{ns}	19.014**	1560.1^{ns}	55500.01**	169656.988**	2.561^{ns}	0.144**	0.74**
I × P	2	0.054**	0.062 ^{ns}	0.097**	20.5**	6057.075**	15338.895**	0.092**	0.026**	0.075**
Eb	6	0.004	0.289	0.903	345.2	1500.526	6725.592	9.146	0.009	0.009

ns, * and **: Non significant, significant at the 0.05 and 0.01 probability level, respectively.

RESULTS AND DISCUSSION

Leaf area index

Results indicated that irrigation had significant effect on leaf area index (Table 1). Irrigation reduction lowered maximum LAI approximately 23 and 27% in I_2 and I_3 treatments compared to I_1 treatment, respectively. According to positive and significant correlations between LAI and RWC (r = 76%), it seems that LAI reduction in I_2 and I_3 treatments was due to reduction of relative water content (RWC) of leaves (unpublished data). Decrease in relative water content of leaves caused decrease growth and development of leaves and therefore, leaf area index reduced. Under water stress conditions, leaf area index (LAI) of crops and yield decreases. The reduction in yield and its degree depend upon the timing of water stress on the crops and the period of irrigation events (Jeminson et al., 1995). These results were in agreement with the results of Cosculleola and Fact (1992) that reported the reduction of LAI under water deficit conditions may result from reduction in the RWC. The differences between planting pattern for LAI were not significant (Table 1). Irrigation × planting pattern interactions for leaf area index was significant, indicating that the irrigation levels responded dissimilar to change in planting pattern for this character.

Yield components

All yield components except for number of rows per ear were responded to the changes in amount of water applied (Table 1). As amount of water applied increased, grain number per ear and 1000-grain weight increased whereas irrigation treatments had no significant effect on number of rows per ear. These results are comparable to those observed earlier by Lack et al. (2005), Setter et al. (2001), Lafitte and Edmeades (1995) and Banziger et al. (2002). No significant difference was found between planting patterns for number of rows per ear and 1000-grain weight, however, planting in furrow increased grain number per ear. Similar results have been obtained by Gozubenli (2010) and Alavi et al. (2010). Increasing amount of water applied, while planting in furrow, improved grain number per ear and 1000-grain weight mainly due to increased leaf area index, leaf area duration and decrease in soil salinity.

Grain yield

The results of analysis of variance showed that the effect of irrigation on grain yield was significant in 1% probability level (Table 1). The highest grain yield about 998 gm^{-2} was obtained in optimum irrigation treatment (I_1). Drought severe stress reduced grain yield by 63% compared to the optimum irrigation condition, this reduction was mainly due to reduction in grain number per ear and average grain weight (Table 2). Step-wise regression analysis indicated that about 88% of grain yield variation was related to the grain number per ear (unpublished data). Since drought stress causes a decrease in leaf area index (Jamieson et al., 1995; Stone et al., 2001), a reduction in yield is observed because of low photosynthesis. Pandey et al. (2000) and Lack et al. (2010) reported that the highest leaf area index for corn was obtained in well-irrigated conditions. A positive correlation between leaf area index and

Table 2. Mean comparison for LAI at silking, yield components, grain and biological yield, harvest index and economical and biological water use efficiency.

Treatment	LAI at silking	No. rows per ear	No. grain per ear	1000-grain weight	1000-grain weight	Grain yield ($g. m^{-2}$)	Biological yield ($g. m^{-2}$)	Harvest index (%)	Water use economical efficiency ($kg. m^{-3}$)	Water use biological efficiency ($kg. m^{-3}$)
Irrigation										
I_1	4.2^a	13.3^a	27.8^a	382.7^a	382.7^a	998^a	1912.3^a	52.2^a	2.85^a	1.85^a
I_2	3.4^b	12.5^a	23.3^b	324.4^b	324.4^b	562.8^b	10741^b	52.4^a	1.92^b	1.05^b
I_3	2.8^c	11.5^a	20.4^c	277.1^c	277.1^c	317.1^c	638.7^c	49.7^b	1.52^b	0.75^c
Planting pattern	3.6^a	12.6^a	24.8^a	337.4^a	337.4^a	681.5^a	1305.5^a	51.8^a	2.3^a	1.31^a
P_1	3.4^a	12.2^a	22.8^b	318.7^b	318.7^b	570.5^b	1111.3^b	51^a	1.89^b	1.13^b

I_1, I_2 and I_3 are optimum irrigation, moderate drought stress and sever drought stress; P_1 and P_2 are planting in furrow and planting on raised bed. *Means followed by similar letters are not significantly different ($p<0.05$) – Using Duncan test.

seasonal water consumption was also reported (Kang et al., 1998). Two reasons were considered for yield reduction at deficit irrigation: high water holding capacity of soil and existence of drought stress throughout the growing season were cited (Musick and Dusek, 1980). A linear relationship has been reported between crop yield and seasonal water consumption (Stewart et al., 1975; Mogenson et al., 1985; Musick et al., 1994). The difference in grain yield between different planting patterns was significant (Table 1). Planting in furrow produced higher yield compared to planting on raised bed. This different was mainly attributed to the positive effect of planting in furrow on reduction of water evaporation and deeper root extension.

Saif et al. (2003) reported that the planting in furrow significantly increased the grain yield of corn. Barzegari et al. (2005) reported that it is probably because of increasing in water use efficiency, reduction of salt in the surrounding area of corn plant, and increasing growth and development of corn root system that corn grain yield increases in planting pattern in the furrow. These factors influence water and nutrients absorption and increase the efficiency in the use of fertilizers. Interactive effect between irrigation levels and planting pattern on grain yield was significant. The increase of water used, especially in planting in furrow, caused a significant increase in grain yield (Tables 3 and 4).

Biological yield

The results indicated that the effect of irrigation levels on biological yield was significant. The highest rate of biological yield (1912 gm^{-2}) was obtained from optimum irrigation treatments (Tables 1 and 2). Increasing amount of water applied improved the weight of stem and leaf mainly due to increased leaf area index and leaf area duration. The dry matter production of non-stressed plants is usually higher compared to stress plants since drought-stressed plants cannot utilize solar radiation effectively. The response of biological yield to change in planting pattern was positive. Planting in furrow increased biological yield, the highest rate of biological yield (1305 gm^{-2}) obtained from planting in row treatment (Tables 1 and 2). The main reason of this situation was salt accumulation above the rows compared to furrow. Increased amount of water applied and planting in furrow, through reduction soil salinity, caused significant increase in biological yield (Table 3). These results were in agreement with literature data (Paez et al., 1995; Sowder et al., 1997).

Harvest index

Harvest index that is, assimilate distribution efficiency, decreased with decreasing amount of water applied (Table 1). Decrease in amount of water applied not only decreased biological yield, but also caused a tribulation in allocation of carbohydrates to grains and consequence harvest index decreased. Pandey et al. (2000) confirm the result; however, there was no significant difference between means of this trait in different planting patterns. Alavi et al. (2010) also reported similar result. The interaction effects of irrigation and planting pattern on harvest index was significant. However, harvest index decreased significantly when amount of water applied in planting on bed increased.

Economical and biological water use efficiency

Increasing amount of water applied, improved

Table 3. Mean comparison of interaction effects of irrigation and planting pattern on LAI at silking stage, yield components, grain and biological yield and water use economical and biological efficiency.

Treatment	LAI at silking	No. rows per ear	No. grain per ear	1000-grain weight	Grain yield (g. m^{-2})	Biological yield (g. m^{-2})	Harvest index (%)	Economical water use efficiency (kg. m^{-3})	Biological water use efficiency (kg. m^{-3})
I_1P_1	*4.4^{a}	13.7^{a}	29^{a}	389.9^{a}	1086.2^{a}	2060.5^{a}	52.6^{a}	2.02^{a}	3.18^{a}
I_1P_2	4.1^{b}	13^{a}	26.7^{b}	375.5^{b}	909.8^{b}	1764.1^{b}	52^{b}	1.69^{b}	2.53^{b}
I_2P_1	3.4^{c}	12.6^{a}	24.3^{c}	334.9^{c}	616.5^{c}	1170.1^{c}	51.7^{bc}	1.1^{c}	2.09^{c}
I_2P_2	3.4^{c}	12.3^{a}	22.3^{d}	313.9^{d}	509.3^{d}	9781^{d}	51.6^{bc}	1.01^{d}	1.75^{d}
I_3P_1	3.1^{d}	11.7^{a}	21.3^{e}	287.3^{e}	341.9^{e}	685.8^{e}	50^{e}	0.81^{e}	1.63^{e}
I_3P_2	2.5^{e}	11.3^{a}	19.5^{f}	266.9^{f}	292.3^{f}	591.7^{f}	49.4^{f}	0.69^{f}	1.41^{f}

I_1, I_2 and I_3 are optimum irrigation, moderate drought stress and sever drought stress, P_1 and P_2 are planting in furrow and planting on bed. *Means followed by similar letters are not significantly different ($p<0.05$) – Using Duncan test.

Table 4. Simple coefficient correlation between traits.

	No. rows per ear	No. grain per ear	1000-grain weight	Grain yield	Biological yield	Harvest index	Water use efficiency
No. Grain per ear	0.98**						
1000-grain weight	0.93**	0.99**					
Grain yield	0.93**	0.99**	0.98**				
Biological yield	0.97**	0.98**	0.99**	0.99**			
Harvest index	0.78^{ns}	0.38^{ns}	0.71**	0.33^{ns}	0.41^{ns}		
water use efficiency	0.96**	0.98**	0.95**	0.98**	0.98**	0.58*	
LAI	0.97**	0.98**	0.90**	0.96**	0.96**	0.71**	0.94**

ns, * and **: Non significant, significant at the 0.05 and 0.01 probability level, respectively.

economical and biological water use efficiencies mainly due to increased grain and biological yields. The highest rate of economical and biological water use efficiency (1.85 and 2.85 kg. m^{-3}) was obtained from optimum irrigation treatments (Tables 1 and 2). The differences between planting patterns for economical and biological water use efficiencies was significant, planting on bed lowered economical and biological water use efficiencies. The responses of these efficiencies to change in amount of water applied in planting pattern were different. Increasing amount of water applied especially in planting in furrow, increased significantly economical and biological water use efficiencies. The findings obtained in this study were in good agreement to those values previously reported in the literature for corn crop (Koksal, 1995; Lyle and Bordovsky, 1995; Gencoglan, 1996). The use of herbicides in furrow compared with planting pattern on bed increased water use efficiency significantly. This issue indicates that a positive effect of using planting in furrow increases saving in water irrigation.

In corn planting in furrow and furrow irrigation about 30% of soil surface becomes wet and therefore only at this surface weeds grow. In 70% of the soil surface that remain dry, weeds grow less and therefore the competition between corn and weeds reduces (Ghanbari et al., 2010).

Conclusion

In this study, the highest grain yield was obtained from optimum irrigation treatment as 998 gm^{-2}

while the lowest yield was found to be 317 gm^{-2}. Grain yield was reduced as the amount of irrigation water decreased. The results of this research indicated that optimum irrigation with planting in furrow system would be optimal for corn grown in semi-arid regions with saline soil and high evaporation similar to the area in south west of Iran where this study was conducted.

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