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Full Length Research Paper

The effect of alternate furrow irrigation under different nutritional element supplies on some agronomic traits and seed qualitative parameters in corn (*Zea mays* L.)

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A new irrigation method under different nutritional element supplies for maize production was designed and tested for some agronomic traits and seed qualitative parameters with a split-plot field experiment. Irrigation was applied through furrows in three ways as the main plots: alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), and conventional furrow irrigation (CFI). AFI means that one of the two neighboring furrows was alternately irrigated during consecutive watering. FFI means that irrigation was fixed to one of the two neighboring furrows. CFI was the conventional way where every furrow was irrigated during each watering. Each irrigation method was further divided into five sub-treatments with different fertilizer combinations: (1) P+N (control) (2) P+N+K (3) P+N+K+Zn (4) P+N+K+Zn+B (5) P+N+K+Zn+B+Fe. The results indicate that water stress effects caused by furrow irrigation on yield may be alleviated by more frequent irrigation intervals. We concluded that AFI is a way to save water in arid areas where maize production relies heavily on repeated irrigation. Fertilized combinations influenced dry matter partitioning to seed filling. Thus, sufficient both macro and micro nutritional elements increased harvest index which was mostly due to more number of seeds per row than higher individual grain weight. Complete fertilizer combination increased total above ground biomass through more radiation use efficiency and by increasing leaf area. In order to utilize the water sources efficiently and increase corn production under limited water supply, we propose the use of circular irrigation care along with instance, K, Zn, B and Fe fertilizer.

Key words: Alternate furrow irrigation, corn (*Zea mays* L.), fertilizer combination, water stress.

INTRODUCTION

Corn (Zea mays L.) is the world's third most important cereal after wheat and rice grown primarily for grain and secondarily for fodder (Nelson, 2005). Globally, irrigated corn is 17% of total acreage producing 40% of total grain yield (Carbtree et al., 1985; Popova et al., 1998b). Corn is a high water demanding crop in all stages of its physiological development and can achieve high yields when water and nutrients are not limiting (Song and Dia, 2000; Traore et al., 2000). However, maize is very sensitive to water stress. The effects of water stress on maize include the visible symptoms of reduced growth, delayed maturity and reduced biomass and crop grain yield. For example, water stress and four days of visible wilting between the boot stage (a week prior to tasseling) and the milk stage may reduce yield by 50% or more (Earl and Davis, 2007; Fischabach and Mulliner, 1974). Drought stress decreased corn seed yield by lowering individual grain weight but nitrogen supply increased yield components (Popova and Petrova, 1993; Popova et al., 1998a). Grain yield can be reduced by yield components like: grain number, grain weight, water stress and nutrient deficiencies during the seed filling can reduce the seed yield and its efficiency (Lauer, 2006). Water stress on maize has been shown to reduce plant height, diameter of shank, leaf area index and root growth (Wilson et al., 2006).

However, the number of leaves did not decrease under water shortage in different varieties (Sepaskhah and

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Haghighi, 1990). Deficit irrigation decreases the effective filling period of seed, but it doesn't affect the collection of dry material existing in the endosperm and the germ (Wasson et al., 2002), thus decreasing the quantity of seeds in corn. Similarly, Stikic et al. (2004) reported that corn seed yield wasn't very different between normal and deficit irrigation and that the functional components been weren't influenced notably. It has been shown that during a specific stage of plant development, controlled deficit irrigation along with adjusting the humidity of soil can result in water reservation (Monteith, 1973; Lehrsch et al., 2000). Deficit irrigation during germination and medium deficit irrigation during growth of shank can be an appropriate way to save water for corn production in the semi-drought areas of the world (Taleghani et al., 1999; Wilson, 2006). It seems vital to evaluate ways for increasing water and nutrient use efficiency and resistance to drought stress. Scientists have confirmed the effect of nutritional elements on the resistance of plant against deficit irrigation (Pritchard et al., 1999).

Nutrient elements supply, uptake and transport are impaired without sufficient water (Baker, 1997). Among the micro-nutrient elements, Bohr has the most importance in the process of seed development (Parasad and Power, 2002), and also has a metabolic role to control the biochemical reactions and protecting the plant from penetration of living and non-living factors into the cell (Popova, 1990). When the plant has access to elements such as B, K and Zn the growth of root and also the proportion of shank: root increases thus producing more carbohydrates and proteins enabling the plant to utilize the humidity of soil more efficiently specifically during the drought periods (Parasad and Power, 2002). Utilization of these elements will increase the efficiency of plant when utilizing the water (Nasri, 2008). Potassium plays a great role in drought conditions and plants which can access K much easier can sustain the deficit irrigation much better (Krauss, 1999). Marschner (1999) declared that using Zn and Fe elements increases the total amount of carbohydrate, starch and proteins in plant and this increases the resistance of plant against the deficit irrigation. At the attempts to increase food production by means of application of more fertilizers some new problems have been recognized (Popova, 1994b). Excessive amounts of nutrient elements can cause losses through leaching of ions into surface and ground waters (Tandon, 1995). Deep water percolation and chemical leaching is a recognized environmental problem with furrow irrigation (Earl and Davis, 2007).

Furrow irrigation is commonly used in arid and semi-arid zones to supply crops with water and furrow-irrigated maize has been identified as a major contributor to groundwater nitrate pollution (Kuldeep et al., 1997). As much as 40% of the available NO_3-N lost from the root zone from one 300 mm irrigation on a clay soil (Kang, 2003). Elements poisoning is the problem encountered with attempts to utilize drought damaged corn and unable to produce enough carbohydrate by photosynthesis to combine with nitrite ions, these plants have the highest accumulation of nitrates near the base of the stalk. If no ear is formed or if ears cannot be pollinated, these plants will accumulate the largest stores of nitrates (Popova et al., 1994a; Benjamin et al., 1998). Alternate furrow irrigation was proposed as a method to increase water use efficiency and decrease chemical leaching compared with every-furrow irrigation and with small yield losses for different crops compared with fixed furrow irrigation system (Baker et al., 1997; Mailholl et al., 2001). Fertilizer leaching is reduced when the applied fertilizer was spatially separated from the irrigation water in a furrow irrigation system (Boyer, 1999). It seems that placing fertilizer in the non-irrigated furrow of an alternate-furrow irrigation system or placing fertilizer in the row with either alternate- or every-furrow irrigation has the potential to decrease fertilizer leaching and nutrient elements poisoning without reducing crop productivity (Sepaskhah and haghighi, 1991; Kajdi and Pocsia, 2003). The objective of the present study was to evaluate the response of maize growth; yield and quality parameters to different irrigation management and nutrient supply with a view to reducing irrigation applied and extend the farming lands with a minimum of yield loss.

MATERIALS AND METHODS

A new irrigation method under different nutritional element supplies for maize production was designed and tested for some agronomic traits and seed qualitative parameters with complete randomized block experimental design with split-plot arrangement with three replications. This study was conducted under various irrigation strategies and fertilizer combinations with the corn hybrid "KSC704". The field experiment was carried out in Varamin, Iran, in 2007. The site is located at 19':35"N latitude, 39':51"E longitude, with an altitude of 1000 m above sea level. This region has a semi-arid climate (<200 mm annual rainfall). The soil was a montmorillonite clay loam, low in nitrogen (0.4 mg.kh^{-1}), low in organic matter (7 mg.kg^{-1}) and alkaline with a pH of 7.4 and electrical conductivity of EC = 0.87 dS m^{-1}. Irrigation was applied through furrows in three ways as the main plots: alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), and conventional furrow irrigation (CFI). AFI means that one of the two neighboring furrows was alternately irrigated during consecutive watering. FFI means that irrigation was fixed to one of the two neighboring furrows. CFI was the conventional way where every furrow was irrigated during each watering. Each irrigation method was further divided into five sub-treatments with different fertilizer combinations: (1) P+N (control) (2) P+N+K (3) P+N+K+Zn (4) P+N+K+Zn+B (5) P+N+K+Zn+B+Fe. So, each block was consisted of 15 irrigation × fertilizer combination patterns. A subplot size of 4.5 × 5 m, having six rows five meter long each was used. Uniformity of sowing depth was achieved by using a hand dibbler to make holes of 5-7 cm deep. The space between rows was 75 cm wide and sowing was done in the top side of hills at the rate of 20 seeds per square meter. Before anthesis, all the experimental units were irrigated uniformly when the water soil content reached 75% of the amount of available soil water content (SWC) corresponding to the difference between the SWC at field capacity (FC) and at wilting point (WP).

After anthesis, control and under-water stress plots were irrigated when the soil water content decreased to 75 and 25% of field capacity – wilting point (FC-WP), respectively. Soil water content was controlled with two rectangular electrodes embedded in a block of gypsum with wires attached to each electrode, extruded from the gypsum block, and connected to the tensiometer. Gypsum blocks located at two depths (20 and 40 cm) in the soil profile near the fibrous root zone were used to determine the timing of the irrigation depending on the water regime. For installation of the gypsum blocks, the hole was augured at angles of 45 degrees to the horizontal plane to prevent preferential water penetration down the backfilled augured hole. After soil analysis, the required fertilizer was consisted of 300 kg ha^{-1} urea, 60 kg ha^{-1} triple phosphate and 120 kg ha^{-1} potassium sulphate. All of these fertilizers except urea were added when plowing. One third of nitrogenous fertilizer was used at sowing and the remaining was used at the beginning of germination. Required Fe was extracted from iron sequestering fertilization source (13% Fe) whereas Zn and B were extracted from their commercial resource and according to advices of laboratory, The Zn, Fe and B micro-fertilizers with 4000, 8000 and 6000 ppm condensations concentrations respectively were used through three stages and the beginning of implantation.

The fertilizer solution was sprayed by back-hanging cylinders and steadily at the days without wind blowing. During growing season, weed removal was performed manually three times within experimental blocks whereas between replications, a rotavator machine was used. Before harvesting, yield components such as the number of plants per m^{-2}, the number of spikes per plant, number of rows and the number of grains in each row were recorded. Grain yield was calculated in each split-plot after grain moisture reached 14% and the weight of each grain was determined after counting and finally the harvest index was calculated by ratio of grain yield to total above ground biomass. Within each plot, an area of 4 m^2 was hand harvested to determine grain yield, leaf area index and total above ground biomass. Dry weights were recorded after the plant material had been oven-dried at 70°C for 48 h. Oil and protein percentage of seed were determined with infra red grain analyzer (IRGA) and oil and protein yields were calculated by multiplying grain yield to oil and protein percentage of seed, respectively. Data were statistically analyzed using analysis of variance technique appropriate for randomized complete block-design with fertilizer combinations factor split on irrigation strategy. Duncan's multiple range tests ($p < 0.05$) was applied for mean separation when F values were significant.

RESULTS AND DISCUSSION

The results declared that the differences between various levels of grain yield, biological yield, harvesting index, 1000 grains weight, the quantity of grains per row and the quantity of spikes per plant among the various irrigation levels were notable (Table 1). Although the quantity of rows in each spike wasn't influenced irrigation levels, but fertilization cares caused a notable difference for this quantity (Tables 1 and 3). According to the Table 1, the average of various irrigation levels and also fertilization cares couldn't influence the quantity of plants per square meter. Because the quantity of plants per SM depends on the implantation density and the implantation density in this research was equal in all splits, the mentioned characteristic wasn't influenced by the searched cares. Thus, we conclude that AFI is a way to save water in arid areas where maize production relies heavily on repeated irrigation. In other hand, if alternate-furrow irrigation is used to increase water use efficiency in furrow-irrigated fields, placing the fertilizer in the non-irrigated furrow of the alternate-furrow irrigation system could decrease N availability because of drier soil conditions in the no-irrigated furrow. Row placement of N fertilizer seems to be beneficial in both alternate-furrow and every-furrow irrigation applications. Fertilized combinations influenced dry matter partitioning to seed filling.

Water stress decreased the grain yield mainly through decreasing the number of grains per cluster and in a lesser degree by decrease in 1000-seed weight (Tables 2 and 3). Sufficient of both macro and micro nutritional elements increased harvest index which was mostly due to more number of seeds per row than higher individual grain weight (Tables 2 and 3). Complete fertilizer combination increased total above ground biomass through more radiation use efficiency and not by increasing leaf area (Tables 2 and 3). So, regarding to mentioned consequences, in order to utilize the water sources efficiently and increase the farming volume and the resistance of plant in this area, we can perform circular irrigation care along with instance, K, Zn, B and Fe fertilizer. It has been showed that there is a significant linear relation between dry matter production and the absorbed radiation. Radiation use efficiency (RUE) significantly was affected by irrigation strategy. Thus, conventional irrigation and alternate furrow irrigation showed higher light use efficiency than fix furrow irrigation method (0.136 vs. 0.127 $Kcal^{-1}$ m^{-2}). Highest (0.168 $Kcal^{-1}$ m^{-2}) and lowest (0.104 $Kcal^{-1}$ m^{-2}) amounts of radiation use efficiency were resulted from complete (P+N+K+Zn+B+Fe) and control (N+P) fertilizer combinations, respectively (Table 2).

Lack of Fe (P+N+K+Zn+B vs. complete fertilizer combination) or presence of K (N+P+K vs. N+P) did not change RUE (Table 2). In the present study, the highest number of spikes per plant was resulted from alternate furrow irrigation and conventional irrigation with 11.54 and 11.18 spikes average respectively and the B5 fertilization care acquired the highest quantity with an average about 11.37 spikes with in comparison with the instance care with an average about 9.90 spikes per plant 13% increase. The interactive effects of irrigation levels and fertilization cares on the quantity of spikes per each plant were notable and the normal and circular irrigational cares and also B5 fertilization care with an average about 12.16 and 11.75 spikes per plant respectively have been positioned in the A statistical grade and the fixed irrigation and instance fertilization care were positioned in the last grade with an average of 8.10 spikes per plant. The effects of irrigations and the performance of nutrients on the yield of corn have been reported by many scientists (Tandon, 1995) and the quantity of spikes per each plant is included in these reports. If the plant can access to required water and nutrients, then can grow much faster and the corn plant can have more extensive photosynthesis level and finally can nurture more spikes.

The results show that the quantity of grains per row is simply affected by the nutritional and irrigational cares.

Table 1. Mean squares of some agronomic traits and seed qualitative parameters

S.O.V	df	Mean Squares						
		Grain yield (kg ha^{-1})	Seed oil percentage (%)	Oil yield (kg ha^{-1})	Seed protein percentage (%)	Protein yield (kg ha^{-1})	Leaf area index	Radiation use efficiency (Kg kcal^{-1}m^{-2})
Block	2	589882.3ns	0.688 ns	3.25ns	1.557ns	678.21ns	0.375ns	0.039ns
Irrigation (A)	2	21582314.21**	4.251 *	29.45*	17.251**	7774.34*	5.893*	0.354*
Error(a)	4	374249.44	1.182	18.22	0.559	5250.44	1.525	0.051
Fertilizer (B)	4	6579938.11**	14.285**	151.803**	3.997*	22635.15**	29.354**	0.128**
A×B	8	33414111.39**	10.425**	119.42**	34.829**	2747.71**	17.421**	0.268**
Error(b)	24	253928.21	0.921	12.29	0.529	1589.51	0.980	0.020
C.V		15.89	4.88	7.19	3.49	12.92	6.12	7.80
S.O.V	**df**	**Plants per square meter**	**Number of spikes per plant**	**Number of rows per spike**	**Number of grains per row**	**1000 grains weight (g)**	**Total above ground biomass (kg ha^{-1})**	**Harvest Index (%)**
Block	2	0.023ns	0.072ns	0.691*	69.21ns	1201.49ns	368541.55ns	1.238ns
Irrigation (I)	2	0.45ns	3.98*	1.27ns	29.88**	2485.47**	1897921.35**	34.11**
Error(a)	4	374249.44	1.182	18.22	0.559	5250.44	1.525	0.051
Fertilizer (F)	4	1.03ns	2.48*	6.99**	135.42**	**71.2142	**26.1241392	19.25**
I×F	8	0.78ns	15.81**	5.88**	75.42**	**47.2701	**35.998841	11.37**
Error(b)	24	253928.21	0.921	12.29	0.529	1589.51	0.980	0.020
C.V (%)		3.48	3.21	11.11	14.25	45.8	45.19	6.14

*, ** means significant in 0.05 and 0.01 level of probability respectively and NS: non-significant.

The normal and circular cares with an average between 30.56 - 31.36 grains excluded the most quantity and the fixed irrigation was at the minimum level with an average about 26.24 grains per row. Because the quantity of grains per row is one of the most important bases of yielding components and is related to the general function directly, more the quantity of grains per row, better the function grain. The quantity of grains per row, in addition to congenital characteristics, relates to various factors such as suitable irrigation, existence of enough nutrients and suitable insemination time and climatic situation. The lack of each of these factors leads to emptiness of spike grains and decreases the quantity of grains per row (Marschner, 1999). Deficit irrigation will lead to a delay in insemination and the distribution of granules will encountered with problem (Wasson et al., 2002; Koleva, 1973; Denmead and Shaw, 2002) and finally the number of grains per row and total number of grains will decrease. Generally, the drought tension will ban the action of fundamental cells specifically in the burst stage and eventually influence the quantity of grains in spike (Lauer, 2006).

Regarding to acquire consequences in this inspection, it is clear that the products which received the most water and fertilizers had the most number of grains per row which is conformed to other's findings. The weight of 1000 grains is influenced completely by the interactive irrigation and fertilization cares and the difference was so clear. The most weight of 1000 grains was

Table 2. Means of some agronomic traits and seed qualitative parameters.

Treatments	Grain yield ($kg\ ha^{-1}$)	Seed oil percentage (%)	Oil yield ($kg\ ha^{-1}$)	Seed protein percentage (%)	Protein yield ($kg\ ha^{-1}$)	Leaf area index	Radiation use efficiency ($Kg\ kcal^{-1}m^{-2}$)
CFI (A1)	11156a	6.4a	714a	12.55c	1400b	3.55a	0.136a
AFI (A2)	10944a	6a	656.65a	14.65b	1603.3a	3. 25ab	0.135a
FFI (A3)	9056.6b	4.7b	425.7b	15.86a	1431b	2.8b	0.127b
P+N (B1)	8930.6e	5.29b	472.5c	13.11b	1171b	2.79c	0.104c
P+N+K (B2)	9639d	5.576ab	537.5bc	13.94b	1343.7c	2.97bc	0.111bc
P+N+K+Zn (B3)	10104.6c	5.71ab	577b	14.9a	1505.5b	3.125b	0.125b
P+N+K+Zn+B (B4)	11356.6b	6.11a	694a	14.8a	1681a	3.28ab	0.150a
P+N+K+Zn+B+Fe (B5)	11896.6a	6.156a	732.35a	14.65a	1743a	3.46a	0.168a

CFI, AFI and FFI: conventional furrow irrigation, alternate furrow irrigation and fixed furrow irrigation, respectively. Means with the same letter in each column have not statistically significant difference.

Table 3. Means of some agronomic traits and seed qualitative parameters

Treatments	Plants per square meter	Number of spikes per plant	Number of rows per spike	Number of grains per row	1000 grains weight (g)	Total above ground biomass ($kg\ ha^{-1}$)	Harvest Index (%)
CFI (A1)	6.6a	11.54a	17.6a	31.36a	346.8a	22514a	49.3a
AFI (A2)	8.6a	11.18a	17.6a	30.56a	342.2a	22234a	49.08a
FFI (A3)	6.4a	9.18a	16.8a	26.24b	319.2b	19570b	46.16b
P+N (B1)	6.3a	9.9b	16b	24.1e	317c	19617.3e	45.4 b
P+N+K(B2)	6.3a	10.23b	17.3ab	26.56d	323c	20452.3d	47ab
P+N+K+Zn(B3)	7a	10.7ab	17.3ab	28.96c	333.6bc	21370c	47.1ab
P+N+K+Zn+B(B4)	6.3a	10.97ab	18a	32.5b	343.3b	22287b	51.1 a
P+N+K+Zn+B+Fe(B5)	7a	11.37a	18a	34.76a	363.3a	23470a	50.5 a

CFI, AFI and FFI: conventional furrow irrigation, alternate furrow irrigation and fixed furrow irrigation, respectively. Means with the same letter in each column have not statistically significant difference.

acquired from normal and circular irrigation with an average of between 342.2 and 346.8 gr in comparison with the fixed irrigation of an average of 319.2 gr was 8% better. The water tension in corn, because of leaf welter, decreases the photosynthesis and transposition of the materials and excludes the growth of seed (Nelson, 2003) and so the weight of 1000 grains declines. The simple effects of fertilization cares also change the weight of 1000 grains. B5 fertilization care and also B1 instance care with averages of 363.3 and 317 gr, respectively acquired the most and least weight of 1000 grains. Marschner (1999), after his inspections, announced that using Fe and Zn increases the total carbohydrate, starch and protein of grain and so increases the weight of 1000 grain. The inspections declared that the total carbohydrate, starch and protein of grain have increased using Fe and Zn and thus the resistance of plant against the deficit irrigation increase (Marschner, 1999).

Deficit irrigation in the regeneration stage of corn leads to the death of granule tube in spike and using some elements such as enough Zn, B and K in the soil leads to lessening this damage and their processes in the soil increase the resistance of plant against the possible damages resulted from deficit irrigation (Lauer, 2006; Boyer, 1999). Practicing the fertilization care in this inspection resulted in almost 25% increase in the grain yield. Regarding to the vital role of B, Zn, Fe and K in the plant, this event is predictable, specifically from the results of interactive effects which describe that the highest grain yield acquires from circular and normal irrigation and B5 fertilization care which itself describes the importance of mentioned elements in this study. Using the mentioned elements in the normal condition increases the growth of root and also in this condition the plant utilizes the humidity of soil more efficiently (Pandey and Agarwal, 2004; Simuneh et al., 1999).

The highest biologic yield was acquired from normal irrigation with an average about 22514 kg/ha which wasn't so different from the circular irrigation and both were in the same statistic grade. But the fixed irrigation with an average about 19750 kg/ha was about 13% less efficient than perfect irrigation and positioned in the second place. Also the fertilization levels categorized the biologic yield into 5 statistic groups and B5 fertilization care, with an average about 23470 kg/ha was positioned at a grade and the instance fertilization care with an average about 19617.3 kg/ha was positioned at E grade. Also their interactive effects on the biologic yield was notable and B5 fertilization care and normal irrigation with averages about 24920 and 24760 kg/hectare respectively was in the statistic grade and the fixed irrigation with an average about 18431 kg/hectare occupied the lat position. The most surprising result was that AFI maintained high grain yield with up to 50% reduction in irrigation amount and as a result, WUE for irrigated water was substantially increased (Table 2).

Thus, Alternate furrow irrigation and conventional furrow irrigation resulted in same grain yield, leaf area index, radiation use efficiency, kernel oil percentage and oil yield but alternate furrow irrigation significantly increased kernel protein percentage and protein yield by 14.33 (12.55 to 14.65%) and 12.66% (1400 to 1603 kg ha^{-1}), respectively (Tables 2 and 3). Grain yield was significantly increased by 17.2% (1094 to 9056 kg ha^{-1}) under alternate furrow irrigation vs. fixed furrow irrigation which was due to 6% more radiation use efficiency, but leaf area index did not change (Table 2). These results indicate that water stress effects caused by furrow irrigation on yield may be alleviated by more frequent irrigation intervals.

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