

Growth analysis, agronomic and physiological characteristics of three hybrid varieties of maize under deficit irrigation conditions

Amir Abbas Rostami Ajirloo¹, Mohamad Reza Asgharipour^{1*}, Ahmad Ganbari¹, Mahdi Joudi² and Mahmoud Khoramivafa³

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¹Unit of Agroecology, Department of Agronomy, College of Agriculture, University of Zabol, Zabol, Iran.

²Meshkinshahr College of Agriculture, University of Mohaghegh Ardabili, Ardabil, Iran.

³Department of Agronomy and Plant Breeding, Campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran.

*Corresponding author; Email: m_asgharipour@yahoo.com

Abstract

Determining appropriate deficit irrigation regimes and varieties under these conditions is necessary to optimize the use of available water in arid and semi-arid regions. In this regard, field experiments were carried out for two years (2014-2015) at the Moghan plain, Iran. The experimental design in each year was split plot based on randomized complete blocks with three replications. The main plots consisted of four irrigation levels: normal irrigation, 80% of maximum daily crop evapotranspiration (ET_c), 70% ET_c and 50% ET_c. Three maize hybrids (SC704, SC703, SC705) were arranged in the sub-plots. Mean comparisons showed that deficit irrigation caused a significant decrease in grain yield and other agronomic traits, physiological characteristics (chlorophyll a, b and relative water content) and growth parameters (leaf area index, crop growth rate, relative growth rate). On the other hand, leaf rolling percentage increased due to the water deficit stress. By increasing deficit irrigation intensity (especially at 50% ET_c), chlorophyll a, b and relative water content decreased in SC705 more than the other two hybrids (SC703, SC704) and the leaf rolling percentage at the severe stress condition reached to 60% in SC705. The highest grain yield (8.51 t/ha) and biomass (19.36 t/ha), averaged over two years, were observed under normal irrigation for the SC705 hybrid. However, this hybrid had minimum grain yield and biomass at 50% ET_c. By increasing water deficit from normal irrigation to 50% ET_c, significant decrease was observed for leaf area index, plant growth rate, relative growth rate and net photosynthesis rate of SC705. Due to the sensitivity of physiological characteristics and growth parameters to the deficit irrigation and the influence of grain yield from these traits, it seems necessary to prevent the occurrence of water deficit at critical stages of maize growth. In conclusion, due to the sensitivity of the SC705 to water shortage, this hybrid is not recommended to water deficit conditions and it would rather be planted when enough irrigation water is available. On the other hand, SC704 seems suitable for the water deficit environments, especially at the severe water stress condition (50% ET_c).

Keywords: Agronomic traits; Grain yield; Growth parameters; Hybrid cultivars; Physiological characteristics; Water deficit

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Introduction

Maize (*Zea mays* L.) is used as food, feed and industrial products. Maize is the most important cereal grain with the production amount of over 1.03 billion metric tons in the world (Statista 2018). Maize is also an important crop in the Northwest of Iran. In these areas, optimal condition for the production of this crop is available except

sufficient water. Water stress limits yield production in the arid and semiarid regions. In these regions, irrigation of the crops is necessary in order to maximize production per unit area (Doorenbos and Kassam 1979). Deficit irrigation is one of the useful means of maximizing water use efficiency (Bekele and Tilahun 2007). The main idea behind deficit irrigation is to save water, labor

and energy, by eliminating the irrigations with low effects on yield (Shan *et al.* 2000). However, deficit irrigation may affect the growth of crops adversely by imposing water stress. The response of corn plants to water deficit is different from one type of hybrid cultivar to another (Lorens *et al.* 1987) and can be improved by upgrading the technology level (Dale and Daniels 1995).

The degree of success of limited irrigation in maize has been different. Water deficit delayed maturity and reduced growth and yield of maize crop (Dogan *et al.* 2003; Payero *et al.* 2006). According to Reta and Faz (1999), water deficit reduced grain yield from 23 to 34% and number of grains per ear from 15 to 26% during differentiation and beginning of the ear growth and kernel weight by 17% during grain filling period. In a study, deficit irrigation in the early vegetative and reproduction stages significantly decreased leaf area index, plant growth rate and dry matter of maize (Pandey *et al.* 2000). Lack *et al.* (2008) showed that by increasing the intensity of water deficit, yield and yield components of maize decreased significantly. In a study by Di Marco *et al.* (2007), irrigation increased grain yield by 43%. Ge *et al.* (2012) showed that water deficit in every growth stage of corn decreased the value of yield and physiological and morphological characteristics.

Maize plant response to water deficit could be measured by changes in physiological characteristics. Water deficit affects the process of photosynthesis directly or indirectly (Madeh Khaksar *et al.* 2014). Several physiological characteristics such as relative water content,

chlorophyll fluorescence and content of chlorophyll and carotenoids have been used to evaluate the effects of water stress on plants (Farooq *et al.* 2009; Prasad *et al.* 2011). Results of Ahmed and Mekki (2005) indicated that water deficit treatment reduces the rate of stomatal conductivity in maize. Valentovic *et al.* (2006) by studying the effect of water deficit on different maize hybrids reported the increase in leaf proline content at the deficit irrigation treatment as compared to normal irrigation condition. According to Kebede *et al.* (2014), the chlorophyll a/chlorophyll b ratio decreased by reducing the percentage of water requirement from 100 to 50%.

A positive relationship has been indicated between growth indices and yield under normal and deficit irrigation conditions (Setter *et al.* 2001; Chaves *et al.* 2002; Subrahmanyam *et al.* 2006). Plant growth analysis is usually utilized to study the trend of plant growth through several important growth parameters such as leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) (Wilson 1981). Pandey *et al.* (2000) showed that deficit irrigation during vegetative and reproductive stages reduced LAI, CGR, RGR and biomass production.

Ibrahim *et al.* (2013) evaluated the effects of four water deficit treatments on sorghum growth in Malaysia. The results showed that sorghum yield at 100 and 75 percentages of water requirement were more than those of 50 and 25%. Therefore, they suggested that in terms of crop yield reduction, the deficit irrigation with 75% of the water requirement is more suitable in the area under

study.

Due to water scarcity in arid and semi-arid areas, selecting an appropriate water deficit treatment is necessary to avoid higher yield losses. Maize is a major irrigated crop in the northwest Iran. It needs supplemental irrigation of about 600 to 700 mm to accomplish the maximum yield (Akhavan and Shiri 2009). Therefore, the present study was conducted to determine the effect of water deficit condition on growth, physiological and agronomic characteristics of three maize hybrid cultivars at the Moghan plain, Iran.

Materials and Methods

A field experiment was conducted during 2014 and 2016 growing seasons in the Moghan Plain, Iran, in order to evaluate the efficiency of different maize hybrid cultivars under water deficit conditions. The experimental site is situated within the latitude of 29°12'-39°42' N and longitude of 47°10'-48°21' E. The area has semi-arid climatic condition with the average annual precipitation of 271 mm and average annual temperature of 288 K (Anonymous 2015).

The experiment in each year was carried out as the split-plot design based on randomized complete blocks with three replications. Main plots consisted of four irrigation levels: IR1 (normal irrigation), IR2 (80% Etc), IR3 (70% Etc) and IR4 (50% Etc) and sub-plots included three maize hybrids (C1: SC704, C2: SC703, C3: SC705). Each plot consisted of four rows of 5-meter along with the between-row and within-row spacing of 75 cm and 15 cm, respectively. To avoid the leakage of water between the irrigation plots, a two-meter space was considered between main plots. Land

preparation before planting included moldboard ploughing and ridge formation for furrow irrigation. The seeds were sown by hand on June 25 of 2014 and 2016. Based on the soil tests (Table 1), NPK fertilizers were applied as: 300 kg/ha of urea (46%), 250 kg/ha of triple superphosphate (27%) and 10 kg/ha of potassium nano-fertilizer (K₂O, 27%). Weeds were controlled by hand regularly until the milky stage. In order to control the insects, especially the leaf borer larvae, 200 ml/ha of Indoxacarb (15%) was sprayed on the plants.

Water was supplied by furrow irrigation. All plots were irrigated equally until the initial fourth leaf emergence and after this stage, irrigation treatments were applied. The irrigation treatments comprised of four water levels based on the crop evapotranspiration (ET_c) of maize. In order to determine the amount of irrigation water, daily evaporation values were obtained from the Class A Pan of the Research Center of Moghan, Iran. Estimation of the irrigation requirements were based on the crop coefficient (K_c) described by Allen *et al.* (1998):

$$ET_c = K_c \times K_p \times ET_p$$

where, ET_c= maximum daily crop evapotranspiration in mm, ET_p= evaporation from a class A pan in mm, K_p= pan coefficient with the range between 0.7 and 0.9 and K_c= crop coefficient with ranges between 0.4 and 1.2 depending on the growth stage.

Several agronomic characters such as number of rows per ear, number of kernels per row, 1000 kernel weight at 14% water content and grain yield at 14% grain water content were measured in this experiment. All measurements were made in the

Table 1. Soil physical and chemical properties of the experimental site.

Texture	Sand %	Silt %	Clay %	Zn mg/kg	Fe mg/kg	Mn mg/kg	Cu mg/kg	K mg/kg	P mg/kg	Organic matter (%)	pH	EC dS/m	Depth (cm)	year
Clay	17	18	65	0.87	6.6	30	6.4	444	4.6	0.95	7.1	0.93	0-45	2014
Clay	17	18	65	0.86	6.6	29.9	6.399	443	4.6	0.944	7.1	0.93	0-45	2016

two central rows of each hybrid cultivar within each plot. Grain yield was determined by harvesting the two central rows in the length of 5 m. Percentage of leaf rolling, chlorophyll a (Chl a) and chlorophyll b (Chl b) content and relative water

content (RWC) were determined as the physiological characteristics. At the silking stage, average percentage of leaf rolling was measured by the following equation (Saneoka and Agata 1996):

$$\text{Percentage leaf rolling} = \frac{(\text{maximum leaf width at the rolling condition})}{(\text{maximum leaf width of the same leaf in the normal condition})} \times 100$$

A prometer (ELE model) was used for measuring the stomatal conductivity (Cardon *et al.* 1994). Chlorophyll a and b were determined on the same young and fully expanded leaves. Two 10-mm diameter leaf discs were taken from the middle part of the blade, placed in the vials containing 2 ml absolute ethanol and incubated for 24 h at room temperature (25°C) in the dark. Chl a and Chl b were then determined by measuring absorbance at 645 and 663 nm wavelengths on a spectrophotometer (Beckman Coulter DU 800 Spectrophotometer, Brea, CA, USA), respectively and were computed following the method of Hendry and Price (1993). RWC was determined using six leaf discs with the diameter of 17 mm which were taken from the youngest fully expanded leaves of each plant. The leaf samples were kept in vials in a cooler during sampling in the greenhouse, and as soon as they were brought to the lab, the fresh weight was determined for each

sample, followed by flotation in the deionizer water for 8 hr. The turgid weight was then recorded and the leaf tissue was subsequently oven-dried to a constant weight at about 70 °C for three days. RWC was then calculated as follows (Matin *et al.* 1989):

$$\text{RWC (\%)} = \frac{[(\text{FW}-\text{DW})/(\text{TW}-\text{DW})]}{\times 100}$$

where, FW is fresh weight, DW is dry weight and TW is turgid weight of leaf samples.

Growth analyses were performed by determining LAI, NAR (g/m².day), CGR (g/m².day) and RGR (g/g.day) according to methods outlined by Hunt (1990). The results were presented graphically with best-fitted polynomial equations plotted against growth degree days (GDD), calculated from emergence time using a base temperature of 10 °C. Leaf area was determined by a leaf area meter. For measuring the dry weight of the samples, they were dried at 65 °C for 48 hr and then weighed.

Data were analyzed using the SAS 9.3 software (SAS Institute 2016). Treatment means

were compared using Fisher's protected least significant difference (LSD) test at $p \leq 0.05$. LSDs for different main effects and combination of factors were calculated using the appropriate standard error terms (Gomez and Gomez 1984).

Results and Discussion

Physiological characteristics

Results of combined analysis of variance for physiological characteristics of maize varieties under different irrigation regimes are shown in Table 2. There were significant differences among irrigation treatments for all physiological traits under study. Among-varieties mean squares were significant except for RWC, percentage of leaf

rolling and chlorophyll a. The irrigation condition \times variety interaction was also significant for RWC, percentage of leaf rolling and chlorophyll b which indicates that the difference among varieties was not stable from one irrigation condition to another. Although there was no significant difference among varieties for the chlorophyll b content, but the variety \times year interaction was significant for this character. Neither water deficit \times year nor water deficit \times cultivar \times year was significant for these traits. However, significant differences were observed between two years for all physiological characteristics indicating the instability of environmental conditions in these years.

Table 3 shows that the highest leaf rolling

Table 2. Combined analysis of variance over years for some physiological characteristics of three maize hybrid cultivars under different water deficit conditions.

SOV	df	Chlorophyll a	Chlorophyll b	Percentage of leaf rolling	Relative water content
Year	1	0.630**	0.050**	27.30**	40.72**
Rep/Year	4	0.002 ^{ns}	0.001 ^{ns}	0.01 ^{ns}	0.22 ^{ns}
Water deficit	3	2.180**	0.360**	4044.32**	1260.60**
Year \times Water deficit	3	0.003 ^{ns}	0.008 ^{ns}	0.77 ^{ns}	2.77 ^{ns}
Water deficit \times Rep/Year	12	0.009 ^{ns}	0.007 ^{ns}	0.99 ^{ns}	7.35**
Cultivar	2	1.500**	0.290 ^{ns}	3444.00**	494.22**
Year \times Cultivar	2	0.102 ^{ns}	0.300**	0.24 ^{ns}	0.92 ^{ns}
Water deficit \times Cultivar	6	0.099 ^{ns}	0.023**	46.00**	33.47**
Year \times Cultivar \times Water deficit	6	0.003 ^{ns}	0.004 ^{ns}	0.30 ^{ns}	1.77 ^{ns}
Error	32	0.050	0.005	0.56	2.06
C.V. (%)	-	5	10	3.2	1.74

ns, *, **: not significant and significant at 5% and 1% probability levels, respectively; Rep: replication, LAI: leaf area index, CGR: crop growth rate, NAR: net assimilation rate, RGR: relative growth rate.

percentage was in the severe deficit irrigation condition (50 percentage of water requirement) for the SC704 hybrid and the lowest was in the normal irrigation condition for the SC703 variety. It could be suggested, therefore, that SC704 was more sensitive to drought stress than the others hybrids. Over all, leaf rolling percentage rose by increasing drought stress. Leaf rolling is regarded as a defense system to reduce plant transpiration. However, in this condition the transferring of assimilates to

sinks is reduced which affects grain yield adversely. Alavi Fazel *et al.* (2013) also reported similar results.

Means of three maize cultivars and different irrigation conditions for the chlorophyll a content and the combination of the two factors for the chlorophyll b content are shown in Tables 4 and 3, respectively. Both chlorophyll a and chlorophyll b decreased by reduction of the available water. SC704 hybrid had significantly higher chlorophyll

a content than SC703 and SC705 hybrids. Maximum concentration of chlorophyll b was observed at normal condition for the SC705 hybrid (1.09 mg/g leaf). Madeh Khaksar *et al.* (2014) studied the effect of water deficit on chlorophyll content and reported that water deficit decreased leaf chlorophyll content. Based on Sanchez *et al.* (1983), water stress reduced chlorophyll level, stomatal conductance and photosynthesis in maize.

According to the Table 3, RWC values varied among treatments and the highest amount was observed in the SC705 hybrid under normal condition (91%). By increasing the deficit irrigation intensity RWC decreased and the lowest amount belonged to the 50 percent water

requirement treatment in the SC703 hybrid (50%). It seems that the reason for the reduction of RWC under drought stress is the lack of plants access to adequate water in the root zone to adjust for the osmotic pressure (Kocheiki and Sarmadnia 2005).

Growth analysis

Effect of water deficit on CGR was significant (Table 5). There were also significant differences among hybrids for CGR and NAR. No significant difference was observed among hybrid cultivars for RGR, but the cultivar \times year interaction was significant for this trait. The effects of irrigation treatments and cultivars on LAI were not significant, however, the trends among cultivars

Table 3. Means of three maize cultivars over two years under different irrigation conditions for some physiological traits.

Treatment	Chlorophyll a (mg/g of leaf)	Chlorophyll b (mg/g of leaf)	Percentage of leaf rolling	Relative water content (%)
IR ₁ C ₁	2.98	1.011	8.8	86
IR ₁ C ₂	2.95	1.033	7	89
IR ₁ C ₃	3.01	1.090	12	91
IR ₂ C ₁	2.40	0.860	27	80
IR ₂ C ₂	1.36	0.830	20	77
IR ₂ C ₃	1.30	0.838	24	75
IR ₃ C ₁	1.26	0.828	44	70
IR ₃ C ₂	1.21	0.800	38	67
IR ₃ C ₃	1.20	0.802	36	66
IR ₄ C ₁	1.18	0.705	66	56
IR ₄ C ₂	1.17	0.610	56	50
IR ₄ C ₃	1.15	0.554	60	51
LSD 5%	0.016	0.082	0.892	1.7

IR₁ (100% of water requirement), IR₂ (80% of water requirement), IR₃ (70% of water requirement) and IR₄ (50% of water requirement); C₁: SC704, C₂: SC703 and C₃: SC705.

Table 4. Means of different irrigation conditions and three maize cultivars over two years for chlorophyll a content.

Irrigation conditions	Chlorophyll a	Maize cultivar	Chlorophyll a
IR ₁	2.98	C ₁	1.96
IR ₂	1.69	C ₂	1.67
IR ₃	1.22	C ₃	1.67
IR ₄	1.17		
LSD 5%	0.132	LSD 5%	0.114

IR₁ (100% of water requirement), IR₂ (80% of water requirement), IR₃ (70% of water requirement) and IR₄ (50% of water requirement); C₁: SC704, C₂: SC703 and C₃: SC705.

Table 5. Combined analysis of variance over years for the growth indices of three maize hybrid cultivars under different water deficit conditions.

SOV	df	LAI	CGR	NAR	RGR ($\times 10^6$)
Year	1	0.006ns	1.55ns	0.068ns	12.0ns
Rep (Year)	4	0.030ns	7.56ns	0.564ns	4.5ns
Water deficit	3	4.628ns	294.32**	4.940ns	4.7ns
Water deficit \times Year	3	2.660ns	4.69 ns	5.500ns	86.0ns
Water deficit \times Rep (Year)	12	2.560**	11.56**	10.560**	560.0**
Cultivar	2	0.930ns	4.14*	2.036**	5.6ns
Cultivar \times Year	2	0.035ns	1.94ns	0.460ns	65.0**
Water deficit \times Cultivar	6	0.042ns	1.24ns	0.323ns	9.2ns
Water deficit \times Cultivar \times Year	6	0.004ns	1.11ns	0.598*	35.0**
Error	32	0.500	0.74	0.242	4.0
C.V. (%)	-	7.21	4.92	8.76	4.99

ns, *, **: not significant and significant at 5% and 1% probability levels, respectively; Rep: replication, LAI: leaf area index, CGR: crop growth rate, NAR: net assimilation rate, RGR: relative growth rate.

and among irrigation treatments were not similar (Figures 1 and 2). SC705 hybrid had higher LAI than other cultivars, especially around 65 days after planting (Figure 1). According to Figure 2, by increasing drought from normal irrigation to the 50% water requirement, LAI decreased. This decrease was more pronounced for the 50% and 70% water requirements, especially at the end of growing season. The reduction of LAI under drought stress have been reported by several researchers (Earl and Davis 2003; Hopkins and Huner 2004; Mansouri-Far *et al.* 2010). This reduction could be attributed to the decrease in photosynthesis rate (Banziger *et al.* 2000) and enhancing of leaf aging (Betran *et al.* 2003).

Results for CGR trend under drought stress conditions are shown in Figure 3. By increasing water stress from 100% to 50% water requirements, CGR decreased. CGR reached its maximum value at the middle of the growing season and then decreased. Ahmadpour *et al.* (2016) by evaluating CGR of maize under different drought stress conditions found similar results. As assimilation is more controlled by leaf area and photosynthesis rate under water deficit condition (Edmeades *et al.* 1996), the shortage of water

decreased LAI and consequently resulted in a decline in the photosynthesis rate and dry matter production (Boomsma and Vyn 2008). Therefore, CGR under deficit irrigation regimes was lower than the normal irrigation condition (Figure 3). There were no meaningful differences among the three maize hybrids early in the growing season, however, at the end the CGR in SC705 hybrid was lower than other hybrids (Figure 4). Similar results were also reported by Nori Azhar and Ehsanzedeh (2007).

NAR declined with the aging of corn plant at all irrigation treatments (Figure 5). This reduction was higher at 50% water requirement than other irrigation treatments. NAR is influenced by many factors and measuring their effects is not easy. Therefore, the results about NAR differ among researchers. The trend of NAR was different among corn hybrids. SC705 had lower NAR than SC704 and SC703 (Figure 6).

RGR reflects changes in dry weight relative to the initial dry weight per unit of time. The reduction in RGR reflects changes in dry weight relative to the initial dry weight per unit of time. The reduction in RGR about 20 days after planting can be attributed to the increase in structural tissues

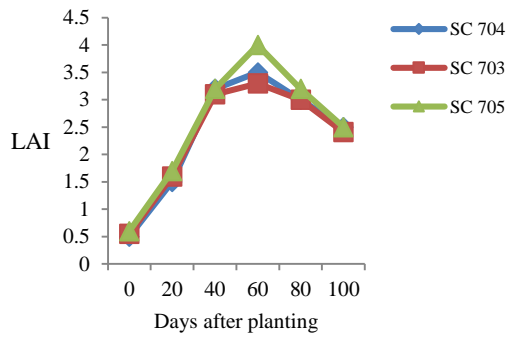


Figure 1. The trend of leaf area index (LAI) for different maize cultivars averaged over irrigation conditions and years.

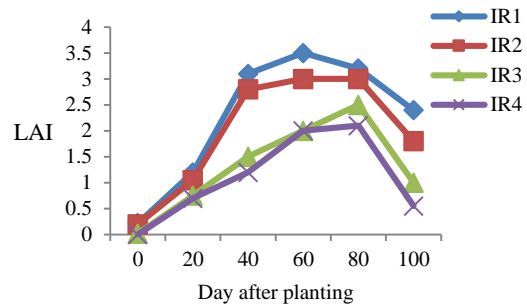


Figure 2. The trend of leaf area index (LAI) for different irrigation conditions averaged over maize cultivars and years; IR1 (100% of water requirement), IR2 (80% of water requirement), IR3 (70% of water requirement) and IR4 (50% of water requirement).

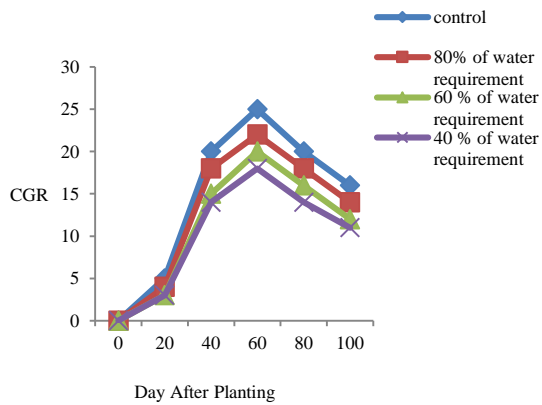


Figure 3. The trend of crop growth rate (CGR) for different irrigation conditions averaged over maize cultivars and years.

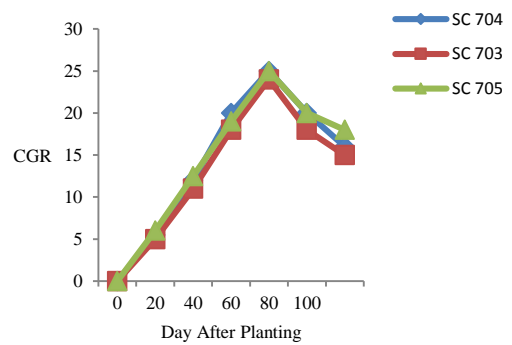


Figure 4. The trend of crop growth rate (CGR) for different maize cultivars averaged over irrigation conditions and years.

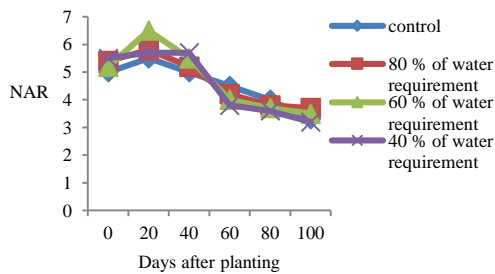


Figure 5. The trend of net uptake rate (NAR) for different irrigation conditions averaged over maize cultivars and years.

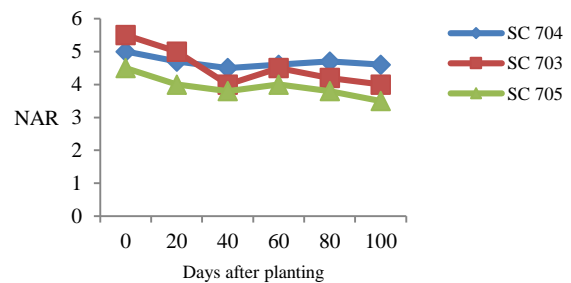


Figure 6. The trend of net uptake rate (NAR) for different maize cultivars averaged over irrigation conditions and years.

as compared to the metabolic tissues. Figure 7 shows the RGR of different irrigation treatments. RGR declined by increasing the water stress. This decline was more pronounced for the 70% and 50% water requirements especially between 40 and 80 days after planting. Alavi Fazel *et al.* (2013) also

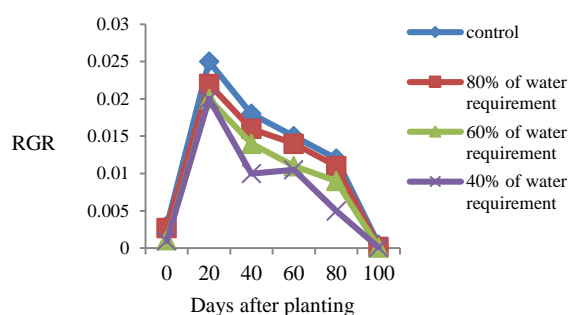


Figure 7. The trend of relative growth rate (RGR) for different irrigation conditions averaged over maize cultivars and years.

Agronomic traits

Combined analysis of variance indicated the significant effects of water regimes on all agronomic traits under study (Table 6). The effects of cultivars and water deficit \times cultivar interaction was only significant for biomass, 1000 grain weight, number of kernels per row and number of rows per ear. Although there was no significant difference among hybrids for grain yield, however, cultivar \times year interaction was significant for this trait, indicating that the differences among hybrid cultivars were not similar in different years. Also, water deficit \times year interaction was significant for grain yield and 1000 grain weight. Furthermore, the differences between years were significant for grain yield and harvest index, suggesting the changes in climatic conditions from 2014 to 2015. At last, the three way interaction of water deficit \times

reported the decline in RGR by increasing the water stress intensity. According to Table 5, there was no significant differences among varieties in the terms of the RGR, however, the amount of RGR was slightly higher for SC705 than other hybrids during the growing season (Figure 8).

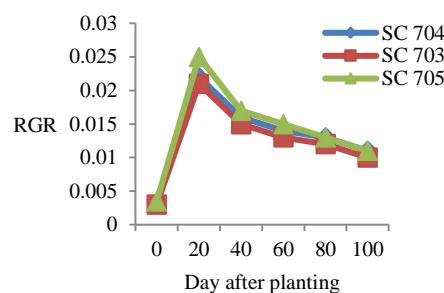


Figure 8. The trend of relative growth rate (RGR) for different maize cultivars averaged over irrigation conditions and years.

cultivar \times year was significant for grain yield, biomass and 1000 grain weight, showing that water deficit \times cultivar interaction was not similar from one year to another. The combination of irrigation regimes with cultivars for number of rows per ear, number of kernels per row, 1000 grain weight and biomass were presented in Table 7. Number of rows per ear in the normal condition was higher on the average than the water deficit conditions. By increasing the water stress, number of rows per ear decreased and the lowest amounts belonged to the irrigation treatments with 50% of water requirement (Table 7). Other investigators have shown that number of rows per ear is influenced by the irrigation treatments at the end of vegetative stage and start of flowering (Payeroet *al.* 2006). SC705 had the highest number of rows per ear at normal, 80% of water requirement and 50% of

Table 6. Combined analysis of variance over years for the agronomic characters of three maize hybrid cultivars under different water deficit conditions.

SOV	df	Grain yield	Harvest Index	Biomass	1000 grain weight	Number of kernels per row	Number of rows per ear
Year	1	7.592**	467.67**	0.38ns	5.1ns	0.0001ns	0.0001ns
Rep (Year)	4	0.194ns	20.00ns	0.53ns	4223.4**	24.36*	0.53ns
Water deficit	3	72.460**	376.40**	195.72**	249995.7**	2047.48**	8.83**
Water deficit × Year	3	0.840**	46.73ns	1.52ns	6159.0**	0.0001ns	0.04ns
Water deficit × Rep (Year)	12	0.140*	21.94ns	1.88*	661.5ns	4.77**	0.16ns
Cultivar	2	0.063ns	46.43ns	5.79**	24717.6**	266.06**	10.51**
Cultivar × Year	2	0.328ns	9.36ns	1.58ns	2777.7ns	0.0001ns	0.04ns
Water deficit × Cultivar	6	1.233ns	38.72ns	21.88*	15756.6*	105.09**	3.246*
Water deficit × Cultivar × Year	6	0.461**	4.81ns	4.38**	3260.9*	0.0001ns	0.02ns
Error	32	0.066	18.68	0.82	976.1	1.58	1.62
C.V. (%)	-	5.06	11.10	7.03	6.42	3.089	8.91

ns, *, **: not significant and significant at 5% and 1% probability levels, respectively; Rep: replication, LAI: leaf area index, CGR: crop growth rate, NAR: net assimilation rate, RGR: relative growth rate.

water requirement conditions, although its difference with other hybrids was not significant at some irrigation treatments. Furthermore, SC705 with 61.3 kernels per row, had the highest value at the normal irrigation condition (control). This hybrid had also more kernels per row at the severe water deficit intensity (50% water requirement). As shown in Table 7, kernels per row decreased from normal to water deficit condition. The effect of drought stress on kernel number per row seems to be the result of decline in ovary water potential. Kernel number in corn heavily depends on the pre-flowering stored assimilates. As a result, cutting the irrigation at each growth stage had an adverse effect on kernel number per ear. These results are in concordance with those indicated by Lack *et al.* (2008). Ghadiri and Majidian (2003) also reported the adverse effect of drought stress during vegetative stage on kernel number per ear.

According to Table 7, SC705 had the highest (733 g) and lowest (316 g) 1000 grain weight at the normal condition and 50% water requirement, respectively. All water deficit treatments decreased 1000 grain weight as compared to the control. At

the grain filling stage, assimilates transfer from sources to sinks (grains). Thus, any water deficit at this stage leads to the production of smaller grains and consequently the reduction in the grain weight. Based on Setter (2001) and Lack *et al.* (2008), the lowest grain weight was obtained under severe stress condition at the reproductive stage.

SC705 had the highest biomass (19.36 t/ha) at the normal irrigation condition and lowest values at all water deficit treatments as compared to other varieties (Table 7). Biomass declined from normal to water stress conditions. The reduction of biomass at water deficit treatments was due to the lack of moisture required for vegetative and flowering growth stages. Oktem (2008) has also reported similar results. In our research the three-way interaction of irrigation condition × cultivar × year was significant for grain yield (Table 6). SC-705 had the highest biomass (19.36 t/ha) at the normal irrigation condition and lowest values at all water deficit treatments as compared to other varieties (Table 7).

Biomass declined from normal to water stress conditions. The reduction of biomass at water

Table 7. Means of three maize cultivars over two years under different irrigation conditions for some agronomic traits.

Treatment	Number of kernels per row	1000 grain weight (gr)	Number of rows per ear	Biomass (tn. ha ⁻¹)
IR ₁ C ₁	55.5	630.0	15.22	17.70
IR ₁ C ₂	50.0	666.0	15.00	16.00
IR ₁ C ₃	61.3	733.0	16.14	19.36
IR ₂ C ₁	30.0	433.7	14.00	12.30
IR ₂ C ₂	21.0	412.0	14.16	9.66
IR ₂ C ₃	28.0	391.0	15.00	9.00
IR ₃ C ₁	46.0	516.7	14.00	12.33
IR ₃ C ₂	43.3	505.2	14.12	14.31
IR ₃ C ₃	39.3	332.7	14.00	7.03
IR ₄ C ₁	41.3	500.3	13.18	13.68
IR ₄ C ₂	38.0	445.5	13.00	12.66
IR ₄ C ₃	45.5	316.0	13.50	8.60
LSD 5%	1.31	80.68	1.131	2.957

IR1 (100% of water requirement), IR2 (80% of water requirement), IR3 (70% of water requirement) and IR4 (50% of water requirement); C1: SC704, C2: SC703 and C3: SC705.

deficit treatments was due to the lack of moisture required for vegetative and flowering growth stages. Oktem (2008) has also reported similar results.

In this research the three-way interaction of irrigation condition \times cultivar \times year was significant for grain yield (Table 6). The grain yield of the three maize hybrids under different irrigation conditions for two separate years are presented in Figure 9. The grain yield of all maize hybrids decreased by increasing the water stress intensity. Apparently, moisture stress decreases assimilate supply to the sink, leading to the decrease in grain yield and yield components. Khayatnezhad *et al.* (2011) have also demonstrated that under drought stress imposed at the pollination stage, the grain yield of all corn cultivars reduced mainly because of pollen sterility. The grain yield of SC705 was higher than other hybrids under normal condition (8.51 t/ha; two-year average). However, under all stress treatments SC704 acquired the highest grain yield among the hybrid cultivars. SC705 is a high

yielding commercial hybrid, but its grain yield was adversely affected by the drought stress than did SC704. Therefore, it seems that SC704 is a suitable hybrid for the Moghan plain under deficit irrigation condition. However, under normal water availability, the SC705 hybrid is recommended for this area.

Figure 10 shows the harvest index of different water regimes. The highest harvest index belonged to the control treatment and 80% of water requirement. Increasing the water stress beyond the 80% of water requirement, decreased harvest index sharply. Bolaños and Edmeades (1993), Ghadiri and Majidian (2003) and Lack *et al.* (2008) also reported the reduction in harvest index due low water supply. Water deficit may upset the partitioning of carbohydrates to grains which leads to a decrease in the harvest index.

Conclusion

Deficit irrigation adversely affected most of the agronomic, physiological and growth parameters

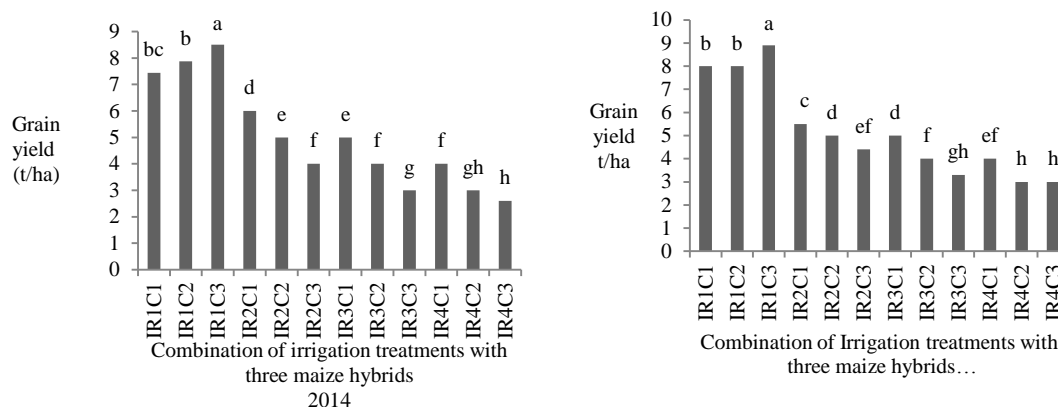


Figure 9. Grain yield of three maize hybrids under different irrigation regimes in two years (2015, 2015); IR1 (100% of water requirement), IR2 (80% of water requirement), IR3 (70% of water requirement) and IR4 (50% of water requirement); C1: SC704, C2: SC703 and C3: SC705. In each year, means with different letters are significantly different based on protected least significant difference test.

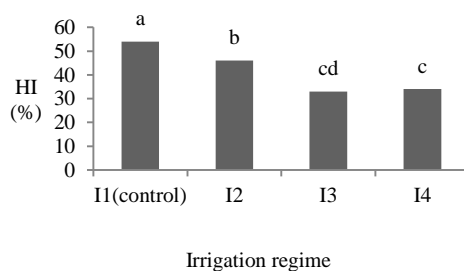


Figure 10. Harvest index (HI) for different irrigation conditions averaged over maize cultivars and years. I1 (100% of water requirement), I2 (80% of water requirement), I3 (70% of water requirement) and I4 (50% of water requirement).

of the three maize hybrids under study. The highest grain yield (8.51 t/ha; two-year average), number of rows per ear, number of kernels per row, 1000 kernel weight and harvest index were observed for the SC705 hybrid at the normal condition. However, this cultivar showed the lowest values for these traits (except for number of kernels per row), chlorophyll a and chlorophyll b and lower relative water content and leaf rolling percentage than SC704 at the 50% water requirement condition. In terms of growth parameters (LAI, CGR, RGR) maximum values were observed for

normal irrigation treatment and the highest values, averaged over years and irrigation regimes, were recorded for the SC705 hybrid. In order to use the water supply efficiently, selecting appropriate varieties is utmost important. Based on our results, SC704 and SC703 hybrids were more resistant to water deficit stress than SC705 in the Moghan plain of Iran, while SC705 showed sensitivity to the water deficit condition. Therefore, SC704 is suitable for the Moghan plain under water scarcity. However, under normal irrigation condition, SC705 is recommended for this area.

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آنالیز رشد و خصوصیات زراعی و فیزیولوژیک سه هیبرید ذرت تحت شرایط کم آبیاری

امیر عباس رستمی اجیرلو^{۱*}، محمد رضا اصغری پور^۱، احمد قنبری^۱، مهدی جودی^۲ و محمود خرمی وفا^۳

۱- گروه زراعت، دانشکده کشاورزی، دانشگاه زابل، زابل

۲- دانشکده کشاورزی مشکین شهر، دانشگاه محقق اردبیلی، اردبیل

۳- گروه زراعت و اصلاح نباتات، پردیس کشاورزی و منابع طبیعی، دانشگاه رازی، کرمانشاه

*مسئول مکاتبه؛ Email: Abasat.rostami@yahoo.com

چکیده

کم آبیاری و انتخاب واریته مناسب مطلوبترین روش در مصرف آب کمتر به ویژه برای مناطق خشک و نیمه خشک می باشد. بر این اساس، آزمایشات مزرعه‌ای در دو سال زراعی (۹۳-۹۴) در دشت مغان انجام شد. این آزمایش در هر سال به صورت طرح کرت‌های خرد شده در قالب طرح بلوک‌های کامل تصادفی با سه تکرار انجام شد. بر این اساس، چهار سطح آبیاری شامل آبیاری نرمال، ۸۰ درصد ETC، ۷۰ درصد ETC و ۵۰ درصد ETC به عنوان کرت‌های اصلی و سه هیبرید ذرت (سینگل کراس‌های ۷۰۴، ۷۰۳ و ۷۰۵) به عنوان کرت‌های فرعی منظور شدند. مقایسه میانگین‌ها نشان دادند که کم آبیاری عملکرد دانه و سایر خصوصیات زراعی، فیزیولوژیک (کلروفیل a، b و محتوای نسبی آب) و پارامترهای رشدی (شاخص سطح برگ، سرعت رشد محصول، سرعت رشد نسبی) را تقلیل داد. از طرف دیگر، درصد لوله‌ای شدن برگ‌های ذرت با اعمال تنش کم آبیاری بیشتر شد. با افزایش شدت تنش کم آبیاری، میزان کلروفیل a، b و محتوای نسبی آب در هیبرید سینگل کراس ۷۰۵ نسبت به دو هیبرید دیگر (سینگل کراس‌های ۷۰۳ و ۷۰۴) بیشتر کاهش یافت و درصد لوله‌ای شدن برگ در هیبرید سینگل کراس ۷۰۵ در شرایط تنش شدید کم آبی به ۶۰ درصد رسید. همچنین، بالاترین میزان (متوسط دو سال) عملکرد دانه (۸/۵ تن در هکتار)، بیوماس (۱۹/۳۶ تن در هکتار)، برای هیبرید سینگل کراس ۷۰۵ در شرایط آبیاری نرمال به دست آمد. با وجود این، هیبرید یاد شده کمترین عملکرد دانه و بیوماس را در کم آبیاری ۵۰ درصد ETC داشت. با افزایش کم آبیاری از آبیاری نرمال تا ۵۰ درصد، معیارهای فیزیولوژیک از جمله شاخص سطح برگ، سرعت رشد محصول، سرعت رشد نسبی و نرخ فتوسنتز خالص در هیبرید سینگل کراس ۷۰۵ کاهش معنی داری داشتند. در نتیجه، در میان هیبریدهای مرود بررسی، سینگل کراس ۷۰۵ در شرایط آبیاری نرمال و سینگل کراس ۷۰۵ در شرایط وجود کم آبی برای دشت مغان توصیه می‌شود.

واژه‌های کلیدی: خصوصیات فیزیولوژیک؛ شاخص‌های رشدی؛ صفات زراعی؛ عملکرد دانه؛ کم آبی؛ واریته‌های هیبرید