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The effect of drought stress and different levels of nitrogen on yield and yield components of sorghum

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Abstract

In order to study the effect of drought stress and different levels of nitrogen on yield and yield components of grain sorghum (Kimia) a split plot experiment as randomized complete block design with three replications was carried out in Shahid Salemi research field located in Ahvaz in the summer of 2012. The experiment factors included three moisture levels in three levels of optimal irrigation (I_1=60), mild stress (I_2=90), severe stress (I_3=130) mm evaporation from class A evaporation pan as the main and the sub factor included three levels of nitrogen as 80, 160, 240 kgNha^{-1} respectively. The results of the research showed that drought stress significantly decreased biological yield, grain yield, and yield components. Also, the effect of nitrogen on biological yield, grain yield, and yield component was significant. Increasing the rate of applied nitrogen at optimal irrigation and mild drought stress significantly increased the grain yield and biological yield. The grain yield decreased as the drought stress increased and the rate of nitrogen applied decreased to the level of 80 kg/ha which was mainly due to the decrease of the number of grains per panicle and 1000-grain weight. Leaf area index was affected by water deficit stress and shortage of nitrogen and as the water stress increased it significantly decreased. The highest leaf area index was achieved byapplying 240 kgNha^{-1}. By increasing nitrogen application it is possible to relatively compensate for the decrease of grain yield. In this research, the effect of different levels of nitrogen (80,160,240 kg ha) on grain yield was not significant in evaporation conditions of 130mm. Therefore, the increase of nitrogen fertilizer in evaporation conditions of 130 mm (severe stress) didn't have any significant effect on grain yield.

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Introduction

One of the main factors reducing the crop yield throughout the world is water constraints and lack of proper distribution of it during the growth season. In other words, for optimal allocation of water to crops production there should be a proper relationship between the amount of consumed water and the produced crop. Due to its proper characteristics such as adaptation to different climatic conditions sorghum has rapidly spread all over the world. Considering the need of country to protein and also the role of sorghum in feeding livestock and poultry, the necessity to increase sorghum production in Iran is quite sensible. To achieve this objective it is necessary to do research in order for proper utilization of soil and water resources and agricultural potentials in arid areas of the country and to use improved cultivars (Khakpoor, 1996).

Considering the fact that 90% of the country's lands are in arid and semiarid areas the lack of nitrogen and drought stress particularly in Khuzestan with high temperature is more pronounced. Therefore, with regard to water constraint, the efficient use of water in producing more and more sorghum is necessary and saving water and applying proper rate of nitrogen could be effective in improving water use efficiency. With regard to current challenges within the country and the region in relation to the rate of consumed nitrogen fertilizer and the occurrence of water stress in case of water resources constraint in the region, this research was conducted to achieve reasonable water efficiency by proper management. Studies show that more than 50% of food production increase is due to the use of chemical fertilizers and nitrogen fertilizer has a high share in this regard (Raun and Johnson, 1999). Nitrogen is the first element whose shortage is discussed in arid and semiarid areas. In such areas the rate of organic materials which are the main sources of nitrogen reservation is low due to different reasons such as high temperature, the low average of consumption of animal manure-green manure, and low rainfall (Malakooti and Homaei, 2004). Studies done by Farzanjoo *et al.* (2002) indicate that there is a high correlation between the rate of dry matter production in sorghum and the application of different levels of nitrogen fertilizer. In a test on grain sorghum, Judy *et al.* (2013) concluded that water deficit during vegetative growth stage decreased the total weigh of plant shoots. Water deficit during the vegetative growth of plant decreased plant height, leaf area, leaf and stem weight and reduced the total weight of sorghum shoots 15-17%.

As reported by Jana *et al.* (2012) water deficit stress in sorghum (lack of irrigation for 2-4 weeks during vegetative and reproductive stages) decreased the number of grains during the vegetative growth stage and decreased the grain weight during the grain filling stage. The results of studied conducted by Tabatabaei (2012) on sorghum showed that simultaneous increase of soil moisture and nitrogen led to the increase of yield; on the other hand, in a constant level of nitrogen if humidity increased, the yield would increase too. Moreover, in a constant level of soil humidity (low and high) the increase of nitrogen led to the increase of yield but the increase slope of yield to the components of each unit of nitrogen consumption was more than the increase of each unit of irrigation water. Nitrogen intake is more dependent on consumed nitrogen than reacting to utilized water even though water stress leads to the decrease of nitrogen consumption. The present experiment aimed to study the effect of irrigation regimes and different levels of nitrogen on the yield of grain sorghum.

Materials and methods

Field experiment

The research was carried out in the research center of Shahid Salemi in Ahvaz at longitude 48°40´E and altitude 31°20´N and altitude of 22.5 m above the sea level in the summer of 2012.. It was a split plot experiment in the form of randomized complete block design with three replications. The experiment factors included three moisture levels in three levels of optimal irrigation (I_1=60), mild stress (I_2=90), severe stress (I_3=130) mm evaporation from class A evaporation pan as the main and the sub factor included three levels of nitrogen as 80, 160, 240 kgNha-1 respectively which were supplied by the source of urea.

Each sub plot included 6 planting lines as long as 5 meter and 75cm spacing from each other. The space between the seeds on the furrow with regard to the plant density of12000 plants per hectare was 12 cm. The space between each two sub plots was kept by two non-planting lines (1.5m) and the space between each two main plots was kept by three non-planting lines (2.25m). Therefore, considering the space between experimental units, the area of each sub plot was 44 m^2 and the area of each main plot was 131 m^2. The required nitrogen was provided by the urea source, so that 50% was distributed during sowing stage, 25% during plant 6-leave stage and 25% at the beginning of clustering.In order to apply considered nitrogen some furrows were first made in irrigation streams and the applied nitrogen was evenly placed in the furrows. Then they were covered by soil and immediately irrigated. The amount of phosphorus fertilizer was calculated and consumed based on 90 kg phosphorus (P2O5) per hectare from triple superphosphate supply. All the phosphorus fertilizer was distributed to field surface uniformly together with the final leveling and then was buried under the soil by the disc. Irrigation was done based on 60 mm evaporation from class A evaporation pan until the 4-leaf stage (plant establishment) and after the complete establishment of plant water stress treatments were applied. Yield components of final harvest plant of each plot, including the number of sub clusters per ears, number of grains per sub cluster, and 100-grain weight (based on two 500-grain samples in each plot) were separately measured. The harvest index (HI) was calculated based on the following formula:

$$HI = \frac{GY}{BY} \times 100$$

In this equation GY is grain yield and BY is biological yield of plant (Gardner *et al*., (1994).

Leaf Area Index

In order to determine leaf area index since early stem elongation first the area of each sorghum leaf (A) in cm^2 was calculated by measuring the leaf length (l) and the widest width of each leaf (W) in cm and then the index was calculated based on the equation suggested by Watson (1964):

A = L * W * 0.75.

Data variance analysis

Data variance analysis was done by means of SAS software the means were compared by Duncan s multi range tests 5% and 1% probability levels and EXCEL software was used to draw diagrams and curves.

Results and discussion

Number of grains per Ear

According to the ANOVA results (Table 1) the effect of irrigation levels and rate of nitrogen was significant at 1% probability level. Among different levels of drought stress, the highest and the lowest number of grains per ear by 1506.52 and 880.45 belonged to optimal irrigation and sever water stress respectively. The findings of the research were consistent with the findings of Alizadeh *et al.* (2007) and Actim (2003) who stated that drought stress decreased the number of grains per ear due to impairing fertility and increasing sterility and abortion percentage. Westgate and Boyer (1986) stated that water deficit decreased grain formation by reducing the ears access to assimilate.

1000-grain weight

According to the ANOVA results (Table 1) the effect of irrigation levels, rate of nitrogen was significant at 1% probability level but the interactive effect of irrigation and nitrogen fertilizer was not significant. The coincidence between grain filling stage and water stress in water stress treatments and the shortening of this stage due to the decrease of leaf area continuity were the main causes of reduction of grain weight. Alavi Fazel *et al.* (2008) and Sepehri *et al.* (2002) stated that the highest effect of drought stress on grain weight was during the grain filling stage and the stresses which would occur after that could make grains smaller by shortening grain filling period. As nitrogen application increased in high levels of nitrogen (160 and 240 kg ha), 1000-grain weight increased. Since the increase of nitrogen increased dry matter production and leaf area continuity, consequently current photosynthesis during the grain filling stage increased and as Robert *et al.* (1993) and Uhart and Andrade(1995) reported the average weight of grain depends on assimilates mobilization into the grain between glowering stage and grain maturity stage which in turn depends on the leaf lifelong after pollination stage and also the relationship between the source and the target; so it was expected that the weight of grain would increase as the nitrogen consumption increased.

Table 1. The ANOVA results of the effect of different levels of irrigation and nitrogen on yield and yield components of grain sorghum.

Harvest index	Biological yield	Grain yield	1000-grain weight	Number of grains per ear	Leaf area index	Degree of freedom	S.O.V
39.965	105947	581	1.866	879	0.1805	2	Repetition
343.769*	579025 *	179747**	143.544**	891885**	6.3981**	2	Water stress (I)
35.260	68342	622	2.714	11329	0.1119	4	Error a
ns31.201	81163 **	19802**	7.394**	129668**	0.9031**		Nitrogen (N)
15.258 ns	38953*	11158**	0.483ns	93992**	n.s0.0495	4	Water stress* Nitrogen
9.151	10768	499	1.027	5291	0.0292	12	Error b
3.4	3.8	4	5.6	5.1	5		C.V

ns, *, **: non-significant difference, significant difference at probability level of 5% and 1% respectively.

Grain Yield

According to the ANOVA results (Table 1) the effects of drought stress and different levels of nitrogen were significant at 1% probability level. As drought stress increased, grain yield significantly decreased. The main reason of grain yield reduction in drought stress treatment was the significant decrease of number of grains per ear and grain weight (Table 2). Ehsanzadeh *et al.* (2007) stated that drought stress would decrease grain yield by decreasing the number of grains per ear and decreasing 1000-grain weight. Roy and Tripathi (1987) found that the increase of irrigation intervals would decrease the number of grains per ear and the weight of 1000-grain. Rafiei Manesh *et al.* (2010) stated that water deficit stress during vegetative and reproductive stages would decrease the number of grains and also it would decrease the weight of grain during the grain filling stage which consequently would lead to the decrease of grain yield. Water deficit would provide the ground for the decrease of leaf area index and consequently the decrease of assimilates distribution and would have a negative effect on grain production in ear and would decrease the grain yield. Gardner and Andrew (2001) stated that improper water regime not only decreases the leaves area but also increases their aging and would decrease their production much more than the reduction due to the decrease of photosynthesis. The increase of applied nitrogen would increase the grain yield significantly which was mainly due to larger number of grains per ear and higher weight of 1000-grain at high level nitrogen (Table 2). Researchers have reported that the main effect of nitrogen on increasing grain yield is through the number of grains. Moreover, in many cases grain weight is affected by nitrogen and has increased (Rezaei and Malakooti, 2003; Ghasemi, 2001). The result was consistent with the results of other researchers who showed that the effectof nitrogen on the increase of grain yield was through the number of grains per ear and the weight of grain (Uhart and Andrade,1995; Marschner, 1995). The interactive effect of drought stress and nitrogen was significant at 1% probability level (table 1). Application of 160 and 240 kgNha^{-1} allocated the highest grain yields to itself in optimal irritation conditions which were placed in the same statistical group and the lowest grain yield belonged to severe drought stress at different levels of nitrogen application (Table 2). In this research, the increase of nitrogen application within severe drought stress conditions had no significant effect on the increase of grain yield even though high application of nitrogen slightly increased the grain yield. In other words, in case of sever deficit of soil moisture, nitrogen intake by the plant is impaired and the required nitrogen fro critical growth stages is not provided even if the soil nitrate is increased.

Table 2. mean comparison of simple effects of irrigation and auxin hormone on yield and yield components of grain sorghum.

Harvest index (percent)	Biological yield (g/m^2)	1000-grain weight (g)	Grain yield (g/m^2)	Number of grains per ear	Leaf area index	
						Water stress
33.21a	1514.89a	29.79a	495.65a	1506.56a	4.98a	I1 = 90 mm
25.81	1340.33b	27.51b	343.58b	1136.11b	4.25b	I2=120 mm
20.94	1015.11c	22.02b	213.28c	880.46c	3.30c	I3=150 mm
						Nitrogen)kg/ha)
24.50	1200.22c	25.71b	300.43b	1038.56b	3.82b	N1 = 80
27.67	1280.67b	26.17ab	358.89a	1218.36a	4.30a	N2=160
27.87	1389.44a	27.46a	393.20a	1266.21a	4.41a	N3=240

*The means which have the same letters in each column based on Duncan's multi range tests at 5% level are not significantly different from each other.

Biological Yield

The ANOVA results showed that the effects of water stress and the interactive effect of stress and nitrogen were significant at 5% probability level and the effect of different levels of nitrogen was significant at 1% probabilty level (Table 1). As the irrigation intervals increased dry matter decreased and water stress treatments were placed in three separate statistical groups so that the highest biological yield by 1514.89 and the lowest with33% reduction in relation to optimal conditions by 1015.11 g/m^2 were respectively related to optimal irrigation and severe drought stress (Table 2). The increase of plants biomass in optimal irrigation conditions was due to further development and better continuity of leaf area which lead to the development of a sufficient and strong phisiological source for better use of recieved light and production of dry matter (Pandi, 2000; Al-Kaisi, 2003).

As the application of consumed nitrogen decreased from 240 to 160 kg/ha, the total biomass relatively decreased as much as 119 g/m^2 (Table 2).It seems like that the effect of nitrogen on the increase of biological yield in this research was due to positive effect of nitrogen on allocating assimilates to different parts of leaf and stem and the increase of accumulated materials on the grains.

The interactive effect of different levels of irrigation and nitrogen on biological yield was significant so that in optimal irrigation conditions and mild drought stress as the application of nitrogen increased biological yield increased significantly. However, in severe drought stress the positive effect of nitrogen was not noticeable (Table 2). In other words, the lack of positive effect of nitrogen in production of plant shoots was due to the limitation of nitrogen intake and lack of its transmission to photosynthetic organs in severe drought stress which led to biomass reduction (Jokela and Randal, 1989).

Harvest Index

The effect of drought stress on the harvest index was significant at 5% level (Table 1). The means comparison table of the effects of irrigation treatments on harvest index showed that as the drought stress increased the harvest index decreased significantly (Table 2). The insignificant harvest index in optimal irrigation treatments and mild drought stress in the research showed that in temporal drought stress not only less material was produced in all organs of the plant but also less assimilate was proportionally allocated to economic organs and the changes of grain weight with and without stress approved of this point. However, dramatic decrease of grain yield in severe drought stress led to significant decrease of harvest index (Fredrick *et al.*, 1990, Eck, 1986).

Different levels of nitrogen had no significant effect on the harvest index. Table (2) shows that different levels of nitrogen were placed in the same statistical group in terms of their effect on the harvest index. The insignificant effect of nitrogen shows the roughly similar changes trend of grain yield and total biomass. In other words it seems like that nitrogen application made no changes in assimilates distribution. The interactive effect of irrigation and nitrogen on harvest index was not significant.

Conclusion

According to the results of the research optimal irrigation not only ensures and improves the yield, but also makes it possible to make optimal use of nitrogen in order to improve production and increase water use efficiency. Sufficient nitrogen fertilizer increased grain yield and biological yield significantly under mild drought stress (95 mm Evaporation) as well as optimal irrigation conditions. Therefore, if enough water is not available and plant is faced with mild drought stress (60 mm evaporation) during the growth stage, the increase of nitrogen application could relatively compensate for grain yield reduction in such conditions. In this research the effect of different levels of nitrogen (80, 160, 240 kg/ha) on grain yield with 130 mm evaporation was not significant. Therefore, the increase of nitrogen fertilizer under the condition of 130mm evaporation (severe stress) had no significant effect of grain yield.

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