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Increased Water Productivity of Wheat under Supplemental Irrigation and Nitrogen Application in a Semi-arid Region

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ABSTRACT

Limitations of water and nitrogen in soil usually restrict plant growth. The objective of this study was to evaluate the effects of different amounts of supplemental irrigation at different growth stages and application of different rates of nitrogen fertilizer on grain yield and water productivity of wheat cultivars. A field experiment was conducted in the agricultural research station of Shahrekord University, Iran, for 2 years. The experiment had a split-split plot design with 3 replications. Five irrigation treatments occupied the main plots, two wheat cultivars were the sub-plots, and three levels of nitrogen were allocated to the sub-subplots. Seed yield and water productivity increased with the total amount of water available to plants. Water productivity increased linearly with increasing additional irrigation from the jointing stage to the seed filling stage, in both years. However, the rate of grain yield and water productivity in irrigation treatment at the jointing stage was greater than the other irrigation treatments. Both wheat varieties showed positive response to supplemental irrigation treatments and nitrogen fertilizer, but the rate of grain yield and water productivity was greater in Azar2 cultivar. Additional nitrogen fertilizers also increased seed yield and water productivity in both years. Generally, the combination of supplemental irrigation at jointing stage and application of 100 kg nitrogen ha^{-1} have important roles in the improvement of seed yield and water productivity of Sardari wheat cultivar under semi arid region.

Keywords: Nitrogen, Seed yield, Supplemental irrigation, Water productivity, Wheat.

INTRODUCTION

The impact of climate change in the next few decades will increase risks of wheat production under dryland conditions (Miranzadeh *et al*., 2011). Cereal production, which is primarily rain-fed, is mainly constrained by drought due to the low rainfall accompanied by nitrogen deficiency (Ryan *et al*., 2009).

To cope with the limitation of water and the high demand for food crop production, improving crop water productivity will be a major solution to the current problems (Zhang *et al*., 2003). Maximizing water productivity, and net yield per unit of land, is a good strategy for farming systems (Oweis and Hachum, 2006). There are many techniques to improve water productivity and water management to conserve water resources. Among the most promising and efficient techniques for optimizing the use of the limited water available from renewable resources in rain-fed areas are supplemental irrigation (SI) and water harvesting (WP) that can improve farmers' income in dry environmental conditions (Oeies and Hachum, 2003). Information on the water use efficiency, crop production, and water productivity will play a vital role in water management (Sander *et al*., 2007). Water productivity indicator is a useful index indicating the improvement of crop yield

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(Singh *et al*., 2006). Under limited water conditions, the available water should be used more efficiently (Bessembinder *et al*., 2005).

Supplemental irrigation is a common practice in the dry regions and the aim is to improve and stabilize crop yields by adding small amounts of water to rain-fed crops during the times when rainfall fails to provide sufficient moisture for normal plant growth (Oweis, 1997). Ilbeyi *et al*. (2006) indicated that, when rainfall was inadequate for crop germination, supplemental irrigation given at sowing substantially increased wheat yield by more than 65% (from about 2.0 t ha^{-1} to the average dry-farming yield of 3.2 t ha^{-1}) in the Central Anatolian Plateau of Turkey. Zhang and Oweis (1999) showed that yields and water use efficiency in northern Syria increased significantly by applying 75 to 212 mm of supplemental irrigation in the beginning to the end of anthesis.

There is a synergy effect between nitrogen fertilizer and water used on the crops yield (Prihar *et al*., 2000). Water-nitrogen relationship and production functions are considered as useful tools in the management of water and nitrogen application, to achieve maximum crop productivity (Kibe *et al*., 2006). Nitrogen fertilizer plays a major role in achieving higher wheat yield, and higher nitrogen use efficiency is desired to protect surface and ground waters (Cassman *et al*., 2003; Araujo *et al*., 2009). Nitrogen deficiency has been found to be responsible for cereal yield loss in actual farming system of the Mediterranean environmental conditions (Passioura, 2002). Crop response to nitrogen fertilization depends on the soil water availability, amount and distribution of rainfall during the growth period of crop, as well as amount and timing of nitrogen applications (Latari-Souki *et al*., 1998). In a field experiment on winter wheat, N application increased water use efficiency by 140 kg ha^{-1} per 50 mm of applied water in the no-stress conditions, by 70 kg ha^{-1} per zero mm of applied water during stress treatments in the tillering, jointing, heading and grain filling stages and grain filling, but had no effect on the treatment of stress throughout the growing period (Eck, 1988). Both water and nitrogen deficiency in the anthesis stage of wheat, reduced number of grain per unit land area due to flower abortion (Acevedo *et al*., 2002). Abderrazak *et al*. (1995) reported that increasing the rates of N fertilizer up to 140 kg ha^{-1} in wheat, significantly increased the water use efficiency, grain yield, grain protein content, and total plant protein, while capacity for nitrogen uptake decreased. Hussain and Aljaloud (1995) reported that the WUE improved from 0 to 100% with increase in nitrogen rates. Results from the experiment with four irrigation treatments (non-irrigation and 65, 50, and 35% depletion of soil-available water) with four levels of nitrogen (0, 40, 80, and 120 kg ha^{-1}) showed a satisfactory grain yield of 4.13 t ha^{-1} with the highest water use efficiency of 196.5 kg under 65% depletion of soil-available water ha^{-1} with the application of 80 kg N ha^{-1} (Karim *et al*., 1997; Saad and Libardi,1994.). The water use efficiency of wheat gradually decreased with increasing irrigation levels, while an increasing nitrogen rate of up to 120 kg ha^{-1} caused reduction of water use efficiency in wheat (Rahman *et al*., 1999).

The objective of this study was to evaluate the influence of supplemental irrigation applied at different growth stages and rates of nitrogen application on the seed yield and water productivity of wheat

MATERIALS AND METHODS

Field experiments were conducted for two years (2006/2007 and 2007/2008) in the research farm of, Shahrekord University, Iran. The geographical location of the experimental site was 32°2´N, 50°49´E, and an altitude of 2,050 meter. The experiment had a split-split plot design with 3 replications. Supplemental irrigation at jointing, booting, flowering, and grain

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filling, and the control (dry-farming) were the treatments allocated to the main plot, wheat cultivars Azar2 and Sardari were in the sub-plots, and nitrogen treatments (50 and 100 kg N ha^{-1}) were assigned to the sub-subplots. Wheat cultivars were sown on 11 November 2006 and 18 November 2007. Nitrogen fertilizer was applied as urea (46% N) two times per year: two thirds of the total rate was applied at planting and the rest was top-dressed in the early spring. The soil was a clay loam, with 0.49% organic carbon in the top layer and a pH of 7.8. In both years, before sowing, 100 kg ha^{-1} of P_2O_5 as super phosphate (46% P_2O_5), and 50 kg ha^{-1} of K_2O as potassium sulfate (50% K_2O) were incorporated into the soil surface layer during land preparation.

Soil water content was determined after oven-drying of soil samples at 120ºC up to the time it reached constant weight (Li *et al*., 2005). Available water content (AWC), total storage water (TSW) and soil water use (SWU) were calculated by the following equations:

$$AWC = SWC - PWP \quad (1)$$

$$TSW = SWC \times HT \times 10 \quad (2)$$

$$SWU = TSWs - TSWe \quad (3)$$

Where, in the Equation (1), SWC and PWP are soil water content and permanent wilting point, respectively (Kramer, 1969). In the Equation (2), *HT* is soil layer thickness (m), and in the Equation (3), *TSWs* and *TSWe* are *TSW* at the start and end of a defined period of the growing season, respectively. Supplemental irrigation was applied by sprinkler (line source). Due to decrease of rainfall from March to June and increase in air temperature and the rate of evapotranspiration in these months, the amount of applied water was increased in later irrigations. In order to measure the wheat yield response under different amounts of water supply in each irrigation treatment, five cans were placed 2 m apart perpendicularly to the line source for water collection The amount of water given at 2 m from the line source was calculated to be sufficient to refill the root zone close to field capacity (Oweis *et al*., 2004). This situation was called fully irrigated condition in this study.

The field experiment area of the main plot and subplots were 30×30 and 3×3 m^2, respectively. In both experiments, broad leaf weeds were controlled by 2,4-D at the rate of 1.5 kg ha^{-1} .

The weather data was collected from a meteorological station near the experimental site. In the experimental site, rainfall normally started during the fall and winter and continued till mid spring (May). Normally, about 80% of the annual rainfall precipitated during the fall and winter.

At harvesting time, five neighboring rows of 1 meter length in each plot were selected for yield measurement. To measure grain yield at or around 12% seed moisture, the grain samples were oven-dried at 70°C for 48 hours before weighing. Water productivity (WP) expressed in kg m^{-3} was calculated as the ratio of grain yield (kg ha^{-1}) to the amount of water applied (m^3 ha^{-1}). Data were subjected to ANOVA by using the SAS statistical program. Correlation analysis was performed on grain yield and applied water.

RESULTS AND DISCUSSION

The monthly rainfalls in 2006/2007 and 2007/2008 are presented in Figure 1. From the autumn to early spring (November–March), rainfall was 56 mm lower than the 30-year average in 2006/2007, but, in 2007/2008, the amount of rainfall in November–April was 70 mm more than the average. The annual rainfall for 2006/2007 and 2007/2008 were 244 mm and 370 mm, respectively. The amount of rainfall received in 2006/2007 was not only insufficient for normal plant growth but also was not well distributed.

The results showed that the reaction of cultivars to availability of water was similar, but the increase in the grain yield of both cultivars was dependent on optimum environmental condition and genetic potential of cultivars.

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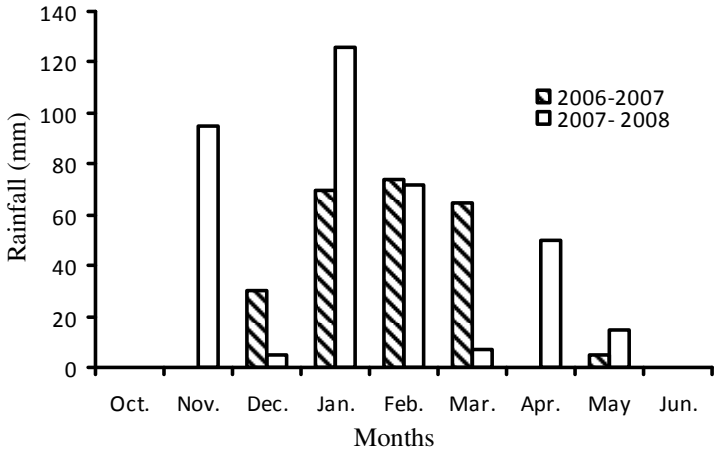

Figure 1. Monthly rainfall (mm) at the experimental site in 2006/2007 and 2007/2008.

The combined analysis of variance for grain yield revealed that the effects of year was not significant, but all other main factors and their interactions, except cultivar×fertilizer, were significant (Table 1).

In the absence of rainfall, moisture stress started and continued until the end of the season, therefore, in the rain-fed treatment, the final yield was reduced significantly. Different growing conditions produced different grain yield and water productivity. In both years, irrigation showed a clear effect on the grain yield and water productivity and the yield steadily increased from dry farming to fully irrigated conditions. Grain yields and water productivity in both years were affected

Table 1. Results of combined ANOVA of grain yield (kg ha^{-1}) and water productivity (kg m^{-3}).

Source	DF	Grain yield	Water productivity
Replication	2	58139.25^{ns}	2.64^{ns}
Year	1	192162.37^{ns}	3.15**
Error 1	2	35075.94	0.004
Irrigation	4	3305569.18**	28.35**
Year×Irrigation	4	204092.67**	4.96*
Error 2	4	4574.89	0.009
Cultivar	1	154930.10**	2.54**
Year×Cultivar	1	802870**	1.91**
Irrigation×Cultivar	4	21935.06**	0.42*
Year× Irrigation×Cultivar	4	29357.23**	0.39**
Error 3	4	2516.36	0.018
Fertilizer	2	10906880.48**	17.56**
Year×Fertilizer	2	18620.74**	0.91*
Irrigation×Fertilizer	8	94710.07**	3.11**
Year× Irrigation×Fertilizer	8	13385.36**	0.31*
Cultivar×Fertilizer	2	6794.80^{ns}	0.11*
Yaer×Cultivar×Fertilizer	2	16374.81*	0.23**
Irrigation×Cultivar×Fertilizer	8	8023.14*	0.54*
Year×Irrigation×Cultivar×Fertilizer	8	7953.33*	0.02*
Error 4	116	4352.85	0.026

* $P< 0.05$; ** $P< 0.01$, ns: Non significant.

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significantly by supplemental irrigation treatments, wheat cultivars, and nitrogen fertilizers (Table 1). Grain yield under supplemental irrigation, significantly increased up to 50% compared to the control (Table 2).

In the first year experiment, under SI+rainfall treatments, compared to the control treatment (dry-farming), the grain yield and water productivity varied from, respectively, 1,670 to 2,252 kg ha^{-1} and 0.54 to 0.79 kg m^{-3}. In the second year, the grain yield was between 1,733 to 2,338 kg ha^{-1} and water productivity varied between 0.40 to 0.58 kg m^{-3}. The grain yield increased from 148 to 200% and from 146 to 222%, in the first and second year, respectively (Table 2). The highest grain yield obtained was 2,252 kg ha^{-1} in 2006/2007 season and 2,338 kg ha^{-1} in the next season under rainfall+supplemental irrigation treatments (Table 2). Grain yield and water productivity were related linearly with the total amount of available water (SI+Rainfall) at the different stages (Figures 2 and 3). As the amount of available water increased, the slope of the correlation between grain yield and water productivity increased in both seasons (Figures 2 and 3). Zhang and Oweis (2000) indicated that water productivity was about 0.96 kg of wheat grain per m^3 of water under dry farming conditions and 1.36 kg of wheat grain per m^3 under supplemental irrigation. Other authors have found a linear relationship between grain yield and supplemental irrigation (Iibeyi *et al*., 2006). Under rain-fed conditions, supplemental irrigation during the wheat critical growth stage can improve grain yield and *WP*, even with small amount of water.

In this experiment grain yield and water productivity significantly increased in all supplemental irrigation treatments, although the greatest yield was obtained in the treatment irrigated at jointing stage.

This effect may be due to an increase in biomass and nutrient uptake in the whole plant. This result was confirmed by Oweis *et al*. (1998). Oweis and Hachum (2004) also reported that supplemental irrigation of wheat resulted in higher amount of water productivity.

Statistical analysis showed that grain yield and *WP* increased in the two cultivars significantly with the increase in SI and N application (Table 1). In both experiments, the Azar2 cultivar produced greater grain yield and water productivity compared to Sardari cultivar (Table 3).

In both years, nitrogen application showed significant effect on the grain yield and water productivity (Table 1). Among different levels

Table 2. Amount of available water, mean grain yield and water productivity under different irrigation treatments in each year.

Irrigation Treatments (SI applied at)	Amount of available water		Grain yield (kg ha^{-1})		Water productivity (Kg m^{-3})		
	SI (mm)	SI+Rainfall I (mm)	Increase due to SI	SI+Rainfall	Dry farming	SI	SI+Rainfall
			2006/2007				
Jointing	38.4	282.4	1128 [a]	2252 [a]	0.64 [a]	2.9 [a]	0.79 [a]
Booting	48.9	292.9	861 [b]	1985 [b]	0.64 [a]	1.7 [b]	0.67 [b]
Flowering	55.8	299.8	679 [c]	1803 [c]	0.64 [a]	1.2 [c]	0.60 [c]
Grain filling	60.1	304.1	546 [d]	1670 [c]	0.64 [a]	0.90 [c]	0.54 [c]
			2007/2008				
Jointing	30	400	1150 [a]	2338 [a]	0.32 [a]	3.8 [a]	0.58 [a]
Booting	39	409	904 [b]	2092 [b]	0.32 [a]	2.3 [b]	0.51 [b]
Flowering	48.6	418.6	716 [c]	1904 [c]	0.32 [a]	1.4 [c]	0.45 [c]
Grain filling	59.4	429.4	545 [d]	1733 [d]	0.32 [a]	0.91	0.40 [c]

* Means followed by the same letter in each column in each year, are not significantly different at $P< 0.05$, in Duncan's New Multiple Range Tests.

Rainfall: 2006/2007 and 2007/2008 244 and 370 mm respectively

Grain yield under dryland: 2006/2007 and 2007/2008 1,124 and 1,188 kg ha^{-1} respectively.

SI: Supplemental irrigation.

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of nitrogen fertilizer, the 100 kg N ha^{-1} produced the greatest grain yield and water productivity (Table 4). Generally, in the first year the response of the grain yield and water productivity to nitrogen fertilizer was lower than that in the second year (Table 4). With N application, seed yield increased by an average of 144% and 138% for both cultivars in, respectively, the first and second years, compared to the control.

Interaction between irrigation treatments and wheat cultivars significantly affected the grain yield in both seasons and the water productivity in the second season (Table 1). The maximum grain yield and water productivity were achieved by supplemental irrigation at jointing stage in Azar2 cultivar (Table 3). A similar field experiment was carried out in 1992–1997 (Zhang *et al*., 1999). They reported that, one irrigation at jointing to booting in wet years, two irrigations at jointing and heading to milk stages in normal years and three irrigations before over wintering, jointing, and heading to milk stages in dry years produced maximum profits (Zhang *et al*., 2000).

In both seasons, the interaction between supplemental irrigation treatments and different levels of N fertilizer showed significant effect on the grain yield and water productivity (Table 1). Supplemental irrigation at jointing stage produced greater grain yield and higher water productivity with application of 100 kg N ha^{-1} (Table 4).

The results of this experiment showed that supplemental irrigation with sufficient nitrogen fertilizer at earlier stages of wheat had a better response in dry farming and achieved maximum yield and water productivity. This is in agreement with some earlier reports by Oweis *et al*. (1998); Akasheh and Abu-Awwad. (1997), and Zhang *et al*., 2000.

Interaction between wheat cultivars and nitrogen fertilizers also significantly affected the grain yield and water productivity in both study seasons (Table 1). The maximum grain yield and water productivity were obtained from Azar2 cultivar and 100 kg N ha^{-1} (Tables 3 and 4).

Different irrigation scheduling, wheat cultivars, and levels of nitrogen fertilizer treatments showed significant interaction on the grain yield and water productivity in 2006-07 and 2007-2008 seasons (Table 1). The greatest grain yield and water productivity were observed in SI at jointing stage of Azar2 cultivar with application of 100 kg N ha^{-1}. Nitrogen fertilizer increased the yield

Table 4. Amount of available water, mean grain yield and water productivity under dry farming, SI, and SI+dry farming in nitrogen fertilizers for both years experiments (2006/2008).

Treatment	Amount of available water	Grain yield (kg ha^{-1})			Water productivity (Kg m^{-3})		
	SI (mm)	Dry farming	Increase due to SI	SI+Rainfall	Dry farming	SI	SI+RainfallI
			2006/2007				
Nitrogen							
N0	47.07	1051 ^{c}	349 ^{c}	1400 ^{c}	0.43 ^{c}	1.3 ^{b}	0.51 ^{c}
N50	47.07	1348 ^{b}	458 ^{b}	1706^{b}	0.55 ^{b}	1.7 ^{a}	0.66 ^{b}
N100	47.07	1524^{a}	463 ^{a}	2194 ^{a}	0.71 ^{a}	1.7 ^{a}	0.81 ^{a}
Nitrogen							
			2007/2008				
Nitrogen							
N0	50.80	1321^{c}	328 ^{c}	1786^{c}	0.28 ^{c}	1.4 ^{c}	0.35 ^{c}
N50	50.80	1385 ^{b}	350 ^{b}	1935^{b}	0.37 ^{b}	1.5 ^{b}	0.44 ^{b}
N100	50.80	1792 ^{a}	409 ^{a}	2414^{a}	0.48 ^{a}	1.9 ^{a}	0.56 ^{a}

* Means followed by the same letter in each column in each treatment, are not significantly different at $P<$ 0.05, in Duncan's New Multiple Range Tests.
Rainfall: 2006/2007 and 2007/2008 244 and 370 mm respectively
SI: Supplemental irrigation, WP: Water productivity.

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components especially the number of spikelets per plant and the seed weight per plant. Grain yield and water productivity were highly correlated with supplemental irrigation and N treatments. Generally, grain yield and water productivity in the control treatment i.e. dry farming and low N fertilizer, and in supplemental irrigation treatments i.e. rainfall+SI+high N were higher for Azar2 than Sardari (Table 3). Water productivity was slightly increased by irrigation and nitrogen fertilizer. Addition of 100 kg N ha^{-1} increased *WP* by 60% for the rain-fed crops and by 70% for the irrigated crops. Under dry farming condition, the study on the relationship between supplemental irrigation and nitrogen application can be useful for managing wheat production.

Dry farming treatment was affected by both grain number and grain size, while the supplemental irrigation treatments provided optimum conditions for yield components. On the average, the mean seed yield in both wheat cultivars was higher in 2007/2008 compared to 2006/2007 (Table 4).

Generally, irrigation treatments increased the yield and water productivity with levels of additional nitrogen fertilizer (N_{50}, and N_{100}) for each mm of water applied as rainfall or irrigation in both seasons (Tables 1 and 4). In this study, the relationship between grain yield and water productivity, nitrogen application showed a positive correlation (r^2= 0.88) with available water. These results indicated that application of fertilizer nitrogen not only increased the grain yield but also increased the water productivity in both years of study. Rahman *et al*. (1999) also reported a linear relationship between water use, yield, and yield components of wheat under various irrigation and nitrogen application treatments.

The positive interaction of the yield components resulted in higher grain yield in each cultivar. Nitrogen fertilizer application and supplemental irrigation treatments enhanced the grain yield of the two wheat cultivars. Various other studies have also shown interactions between grain yield and nitrogen fertilizer (Oweis *et al*., 1998; Li *et al*., 2000).

CONCLUSIONS

In our study, the highest grain yield obtained was 2,252 kg ha^{-1} in 2006/2007 and 2,638 kg ha^{-1} in 2007/2008 under rainfall+SI treatments. Yield and water productivity increased linearly with the total amount of water applied (rainfall+SI) from the jointing to the grain filling stage (Figures 2 and 3). In this study, there are relationship between grain yield and water productivity, nitrogen application showed a positive correlation (r^2=0.88) between grain yield, WP, and nitrogen application with available water. Nitrogen fertilizer application and supplemental irrigation treatments enhanced the grain yield of the two wheat cultivars.

The general concepts of this experiment indicated that applying supplemental irrigation at jointing stage and utilization of nitrogen fertilizer at the rate of 100 kg ha^{-1} were the most effective parameters in the production of wheat grain yield and increase of water productivity in the rain-fed area.

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افزایش بهره‌وری آب گندم با آبیاری تکمیلی و کاربرد نیتروژن در یک منطقه نیمه خشک

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چکیده

محدودیت آب و کمبود نیتروژن خاک در شرایط دیم معمولا رشد گیاهان را محدود می‌سازد. به منظور بررسی اثرات مقادیر مختلف آبیاری تکمیلی و کود نیتروژن بر عملکرد و بهره وری آب ارقام گندم، آزمایشی مزرعه‌ای در مزرعه تحقیقاتی دانشگاه شهرکرد به مدت ۲ سال به اجرا درآمد. آزمایش به صورت کرت‌های دوبار خرد شده در قالب طرح بلوک‌های کامل تصادفی با ۳ تکرار به اجرا درآمد. ۵ تیمار آبیاری به عنوان عامل اصلی و ۲ رقم گندم به عنوان عامل فرعی و ۲ سطح نیتروژن به عنوان عامل فرعی فرعی انتخاب شدند. عملکرد دانه و بهره‌وری آب با افزایش مقدار آب قابل دسترس افزایش یافت. بهره‌وری آب با افزایش مقادیر آبیاری به صورت خطی از مرحله غلاف رفتن تا پر شدن دانه در هر دو سال آزمایش افزایش داشت. مقادیر نیتروژن اضافه شده باعث تاثیر معنی دار بر عملکرد دانه و بهره‌وری آب شد. در این پژوهش ترکیبی از آبیاری تکمیلی و کاربرد کود نیتروژن نقش موثری در بهبود عملکرد دانه و بهره وری ارقام گندم تحت شرایط خشک داشتند.

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