ISSN: 2641-6379
World Journal of Agriculture and Soil Science
DOI: 10.33552/WJASS.2019.01.000515
Iris Publishers

Research Article

Wheat Response to Nitrogen and Irrigation under Semi-Arid Conditions

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Received Date: October 26, 2018

Published Date: February 05, 2019

Abstract

Drought is the most important limiting factor of the agricultural plants production in Egypt and the world. Nitrogen application management under water limited condition needs to be refined for low yielding environments. Therefore, to see how restricted irrigation and different nitrogen fertilizer affect yield, its components, water use efficiency and nutrients uptake of wheat, an experiment was conducted in a semi-arid area in Assiut, Upper Egypt in 2013/2014 and 2014/2015. Split-plot experimental design was used, based on a complete randomized block design with three replications. The variables were two water treatments and three levels nitrogen fertilization. The main plots were used to express irrigation regimes (100% of water requirements (I_{100}= 5370 $m^3\ ha^{-1}$) and 75% water requirements (I_{75}= 4027 $m^3\ ha^{-1}$)). The split units were assigned for nitrogen fertilizer levels (N_{120}=120, N_{180} =180, and N_{240} =240 kg ha^{-1}). The results showed that fertilization of drip irrigated wheat grown under I_{75} with N_{360} increased the uptake of N, P, and K by 17, 32, and 2%, respectively, compared with N_{220}. Fertilization of drip irrigated wheat grown under I_{75} with N_{240} increased the grain, straw, and biological yield by 51, 14, and 22% respectively, compared with N_{120}. Fertilization of drip irrigated wheat grown under I_{75} with N_{240} increased the WUE by 22 and 23% in the first and second seasons respectively, compared with N_{120}.

Keywords: Drip irrigation; Water stress; N fertilization; Nutrients uptake; Water use efficiency

Introduction

Wheat (*Triticum aestivum L.*) is the most important cereal crop in the world and the major source of staple food for the inhabitants of Egypt. The nutritional value of wheat (protein) is higher than maize and rice. The local production of wheat in 2015 was around 9.0 million tons [1]. Wheat growth and high productivity depend mainly on the proper water and fertilizer management [2]. Drip irrigation has become more popular for several crops and also for wheat, several studies about the possibility of wheat production under drip irrigation in Egypt were conducted out and most of these studies found that more yield and water use efficiency occurred when such technique was used [2-7]. Drip irrigation system allows the addition of small amounts of water and nutrients to field with ensuring uniformity of distribution [8,9]. This advantage can be benefit in the application of deficit irrigation more efficiently than in other irrigation systems. Deficit irrigation applied by increasing the time between irrigation intervals or by omitting one or more irrigation [10]. It is well known that deficit irrigation by the two mentioned ways causes several negative effects on growth and reduces yield [11].

Drought stress limits plant growth and productivity more than any other environmental factor in the arid and semi-arid area. Water scarcity in the next decades is a real threat to food production in arid and semi-arid areas where water is the limiting factor in the expansion of cultivated land. Decreasing water availability under drought generally results in limited total nutrient uptake and their diminished tissue concentrations in crop plants. An important effect of water deficit is on the acquisition of nutrients by the root and their transport to shoots. Lowered absorption of the inorganic nutrients can result from interference in nutrient uptake and the unloading mechanism, and reduced transpiration flow [12,13].

Crop production in arid and semi-arid regions is restricted by soil deficiencies in moisture and plant nutrients (especially nitrogen). The importance of N fertilization in increasing wheat production has been well documented, but still it is difficult to determine the quantities to apply under water stress condition. Nitrogen fertilization is one of the most important and effective implements in agriculture, stimulating a lot of vital processes in plants. The amount of applied nitrogen in plants must be carefully managed to ensure that, N will be available throughout the growing season and the vegetative and reproductive development will be not restricted [14,15]. The previous studies indicated that abundant nitrogen encouraged cell division and elongation increased leaves number which consequently enhanced plant growth, and this may explain the favorite effect of increasing N rate on plant growth [16,17].

Nitrogen deficiency due to drought stress largely contributes to growth inhibition under water deficit [18] mainly affecting the leaf size through decreasing the cell number and cell size [19]. Reduction in leaf production, individual leaf area, and total leaf area under N deficient conditions were also reported by [20-22] reported that with increased N supply, the leaf area index, leaf area duration, crop photosynthetic rate, radiation interception, and radiation use efficiency were increased in wheat. Similarly, in sunflower increased cell production and cell expansion led to an increase in final leaf area with high N availability, as reported by Trapani et al. [23]. Plant metabolic processes, based on proteins, leading to increase in vegetative and reproductive growth and yield are totally dependent upon the adequate supply of nitrogen [24]. Disturbance in protein metabolism as a result of water stress has also been reported by Ranieri et al. [25]. Reduction in protein contents of wheat genotypes under water stress conditions may be the result of reduced RNA contents due to increased RNA se activity induced by dehydration [26]. Kettlewell & Juggins [27] observed increase in protein content with the application of urea and slight increase in leaf starch in wheat.

There is a conflict between the effects of water deficit and of additional N fertilizers in crop production [28-31]. To increase biomass, a larger LAI and a longer duration for which LAI is maintained are required: these can be obtained by adding fertilizer N. Increased biomass generally, but not necessarily, results in increased grain yield. Under drought conditions, smaller LAI and shorter crop duration are desirable to decrease water transpiration by the crop [32,33]. Thus, the benefits of applying nitrogen under semi-arid conditions will depend on the frequency and intensity of drought and on the amounts and timing of N applications.

The objectives of the present study were to investigate the effect nitrogen fertilization rate on water stress resistance of wheat grown under drip irrigation wheat yield, its components, nutrients uptake and some water relations such as water use in Upper Egypt.

Materials and Methods

The field experiments

The present experiments were carried out at the farm of Agricultural Experimental Station of the Faculty of the Agriculture, Assiut University, Egypt (Latitude: 27_o 12 N and longitude 310 09 E longitude at an altitude of 51 m a.s.l.). The soil was classified as Typic Torrifluvents according to Soil Taxonomy [34] and Table 1 shows some physical and chemical properties of the experimental site. Wheat experiment consists of two factors i.e., two irrigation treatments. The main plots were used to express irrigation regimes (100% of water requirements (I_{100}= 5370 m^3 ha^{-1}) and 75% water requirements (I_{75}= 4027 m^3 ha^{-1})). The split units were assigned for nitrogen fertilizer levels (N_{220}=120, N_{180}=180, and N_{240}=240 kg ha^{-1}). The experimental site was irrigated using a drip irrigation system. The in-line GR dripper laterals were installed 0.7 m apart. The emitters were spaced 0.30 m apart with a flow rate of 2.1 L h^{-1}.

Table 1: Some physical and chemical soil properties (0-30 and 30-60 cm).

Properties	0-30 cm	30-60 cm
Sand (%)	24.1	24.3
Silt (%)	62.4	62.5
Clay (%)	13.5	13.2
Texture	Silty Loam	Silty Loam
Field capacity (v%)	42.7	42.5
Witling point (v%)	21.1	20.1
$CaCO_3$ (%)	5.42	5.08
pH (1:2.5 suspension)	7.54	7.78
ECe (dS m^{-1})	0.99	0.95
Organic matter (g kg^{-1})	2.41	2.25
Total N (mg kg^{-1})	560	520
Available N (mg kg^{-1})	67.2	62.4
Available Olsen P (mg kg^{-1})	11.78	11.32
Available K (mg kg^{-1})	258.1	477.4

Each value represents a mean of three replicates.

ECe: The Electric Conductivity of the saturated soil extract.

Wheat grains (Triticum aestivum vulgar, cv Solala 6) at rates of 190 kg ha^{-1} were sown directly beneath the dripper's line and on the two sides of it. Sowing dates were the5th and the 1st of December in 2013 and in 2014 growing seasons respectively. All the agriculture practices were applied at the recommendations of the Ministry of Agriculture and Land Reclamation (Egypt). Phosphorus in the form of super phosphate (15.5% P_2O_5) at a rate of 238 kg ha^{-1} was added directly to the soil in one dose before planting. Potassium fertilizer in the form of potassium sulphate (48% K_2O) at a rate of 120 kg ha^{-1} was added with the irrigation water in four equal portions (20,35,50 and 70 days after sowing). Nitrogen fertilizer levels were applied with the irrigation water in the form of urea (46%N) at five equal doses (initiated 25 days post planting and were administered on 10 days interval). Wheat plants were harvested on May 7th, 2014 and May 6th, 2015 in the first and second seasons respectively.

Calculation of irrigation water requirements

The daily reference evapotranspiration (ET_o) was estimated using Penman–Monteith's modified equation [35]. The actual evapotranspiration (ET_c) was calculated according the equation Kc values used for wheat were 0.65, 0.70, 0.75, 0.70 for growth stages initial, development, mid, and end, respectively [35]. Based on the climate data in Table 2, the ET_c values for wheat were calculated. The estimated ET0 was 602 and 558 mm and the ET_c was 431 and 399mm in 2014 and 2015 respectively. The total irrigation water requirement during the whole growth season was 5581 and 5163

m^3 ha^{-1} in the first and second season respectively (the application efficiency for drip irrigation (%) (Ea=85) and the leaching fraction was considered as 10% of water requirement). The irrigation treatments started after 20 days of transplanting. During the first 20 days (initial stage), the wheat plants were irrigated according to the calculated irrigation requirements, while in other stages (development, mid, and end) the plants irrigated by 100 or 75% of water requirements. The data in Table 3 show Evapotranspiration, consumptive water use and irrigation water applied at different wheat growth stages during the winder seasons of 13/2014 and 14/2015. Water use efficiency (WUE) was calculated using the equation, where GY equals grain yield, ET_c equals seasonal actual evapotranspiration (mm).

Table 2: Average monthly maximum (Tmax) and minimum (Tmin) temperature, relative humidity (RH), wind speed (WS) and reference evapotranspiration (ETo) during 2014 and 2015 growing seasons.

Month	T_{max}	T_{min}	RH (%)	WS (km h^{-1})	ET_o (mm)
December, 2013	20.6	7.6	40.5	2.8	2.8
January, 2014	22.4	6.3	55.2	3.95	2.42
February, 2014	23.8	7.4	49.2	6	3.58
March, 2014	27.9	12.1	42.4	5.75	4.68
April, 2014	32.8	15.8	34.9	5.45	5.84
December, 2014	23.2	8.5	48.4	7.2	3.15
January, 2015	20.5	5.5	44	8	3.25
February, 2015	22.7	7.6	38.8	8.2	4.11
March, 2015	27.2	12.2	34	9.69	5.77
April, 2015	29.3	14.6	25.6	9.93	6.93

Rainfall was 0 for the two growth season.

Data were obtained from a suit weather station and Central Laboratory for Agricultural Climate.

Table 3: N, P and K uptake by 70 days-old wheat as affected by irrigation and nitrogen levels. (All the data expressed in kg ha^{-1}).

Irrigation Treatments	Nitrogen Rates	2014			2015		
		N	P	K	N	P	K
I_{100}	N_{120}	101^{d}	17^{bc}	85^{c}	103^{bc}	19^{b}	95^{b}
	N_{180}	115^{c}	19^{b}	101^{b}	108^{b}	22^{b}	109^{ab}
	N_{240}	164^{a}	29^{a}	143^{a}	163^{a}	30^{a}	143^{a}
I_{75}	N_{120}	74^{E}	11^{E}	52^{f}	64^{c}	18^{b}	92^{b}
	N_{180}	98^{d}	13^{dE}	62^{E}	101^{bc}	23^{b}	123^{ab}
	N_{240}	130^{b}	14^{cd}	74^{d}	112^{b}	22^{b}	96^{b}

Collection of plant samples

Composite plant samples each represent to $1/2m^2$ were taken from each experimental unit after 70 days of planting (18 samples) and were used to study the uptake of nitrogen, phosphorus, and potassium. These plant samples were cleaned, washed with tap and distilled water, air dried, then dried in oven at 70 °C until constant weight, ground and stored for chemical analysis. Wheat plants were harvested on May 7th, 2014 and May 6th, 2015 in first and second seasons respectively and the grain and total yield were recorded. Also, grain and straw samples from each experimental unit were taken.

Soil and plant analysis

Composite soil sample was collected before cultivation from the 0-30 and 30-60cm. Air-dried, crushed, and sieved to pass through 2-mm. Selected physical and chemical properties of the soil were determined according to Burt [36]. The soil pH was measured in 1:2.5 soil to water suspension using a digital pH meter. The electrical conductivity (EC) was estimated using the salt bridge method [37]. Available soil nitrogen was extracted by 2M potassium chloride, and then nitrogen in the extract was determined using micro-kjeldahl method Burt [36]. Available soil phosphorus was extracted by 0.5M sodium bicarbonate solution at pH 8.5 according to Olsen et al. [38] and phosphorus was determined by spectrophotometer. Available potassium was extracted by ammonium acetate method and was measured by flame photometry [39].

Plant samples were digested with a mixture of 350ml H_2O_2, 0.42g Se powder, 14g $LiSO_4·H_2O$ and 420 ml concentrated H_2SO_4 [40]. The digestion of a suitable amount [~0.2g] of plant samples was performed with 10ml digestion mixture solution in a digestion block by heating with a starting temperature of 50 °C that ends to 350 °C for 6 hours. Then were analyzed for N, P, and K as described by Page et al. [41].

Data analysis

The experimental design was Randomized Complete Block Design with four replicates. The Analysis of Variance (ANOVA) and Duncan multiple range tests at 5% level of probability were used to test the significant of between the treatments. Data statistical analyses were performed using SPSS statistical software, version 15.

Results and discussion

Effect of N fertilization and water stress on wheat growth

The data illustrated in Figures 1 & 2 shows the effect of nitrogen fertilization rates on 70 days-old wheat under different levels of irrigation. The interaction between irrigation and nitrogen rates affected significantly ($P<0.05$) on the dry weights of 70 days-old wheat as well as the plant height in the two growth seasons. Under the I_{100}, increasing the rates of nitrogen increased the plant height and dry weights of 70 days-old wheat. Also, the same phenomenon was observed for the plants of drip irrigated wheat grown under water stress (I_{75}). Fertilization of drip irrigated wheat grown under water stress with N_{240} increased the dry weights and plant height by 45 and 19%, respectively, in the first season and by 36 and 14%, respectively, in the second season compared the low N_{120}. Based on the Figures 1 & 2, reducing the irrigation level to I_{75} caused a significant reduction on plant growth but increasing nitrogen fertilization rates lessened the hazards of water stress. Gevrek et al. [42] suggested that the application of nitrogen to wheat leads to sufficient plant growth and root development resulting in a better adaptation to water stress resistance. Muchow & Davis [22] reported that with increased N supply, the leaf area index, leaf area duration, crop photosynthetic rate, radiation interception, and radiation use efficiency were increased in wheat. The application of nitrogen increases photosynthetic capacity of leaves by increasing stromal and thylakoid proteins in leaves [44]. Wheat plants were grown under low and high nitrogen supply, and water stress was imposed at various stages of plant's life cycle [45]. The performance of plants was better under high fertility conditions, at all stages, under different intensities of water stress.

Effect of N fertilization rates and water stress on N, P, and K uptake

Nitrogen (N), phosphorus (P), and potassium (K) uptake by 70 days-old wheat affected significantly ($P<0.05$) by the interaction between irrigation levels and nitrogen fertilization rates as shown in Table 3. Under both normal and water stress irrigation, increasing nitrogen fertilization rates increased the N, P and K uptake by wheat. In general, the water stress (I_{75}) reduced the uptake of N, P and K in the shoot of drip irrigated wheat. Fertilization of drip irrigated wheat grown under water stress with N_{240} increased the uptake of N, P, and K by 75, 32, and 42%, respectively, in the first season and by 75, 21, and 5%, respectively, in the second season compared N_{120}. The current study revealed that increasing nitrogen fertilization rates increased the uptake of N, P, and K by drip irrigated wheat grown under water stress conditions. When the water inside plant declines below a threshold level, stomata close which causes a reduction in transpiration resulting in a reduction of water transport through the plant. This affects the ability of the roots to absorb water and nutrients as effectively as when undergoing normal transpiration [46]. Inhibition of nutrient uptake of plants under water stress also relates to the nutrient transport in soil by mass flow and diffusion [47,48], which may diminish nutrient availability at the root surface as well as the decrease in mineralization of organically bound nutrients [49,50]. Nitrogen fertilization enhanced the nutrient uptake by wheat plants [51,52] and may reduce the adverse effects of water stress. Zhang et al. [59] reported that added N increased the growth of roots and produced a mass of fine roots and this will increase the plant ability to absorb more nutrients. Moreover, increasing nitrogen fertilization rates plays important role increasing the movement and availability of soil nutrients [54-59].

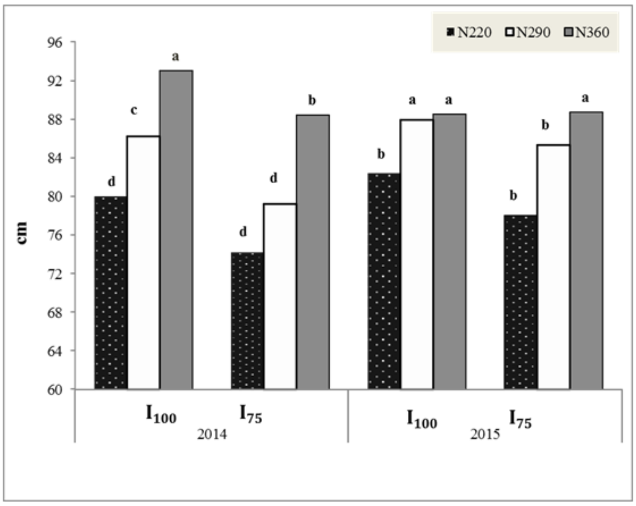

Figure 1: Plant height of 70 days-old wheat (cm) as affected by nitrogen fertilization and irrigation rates.

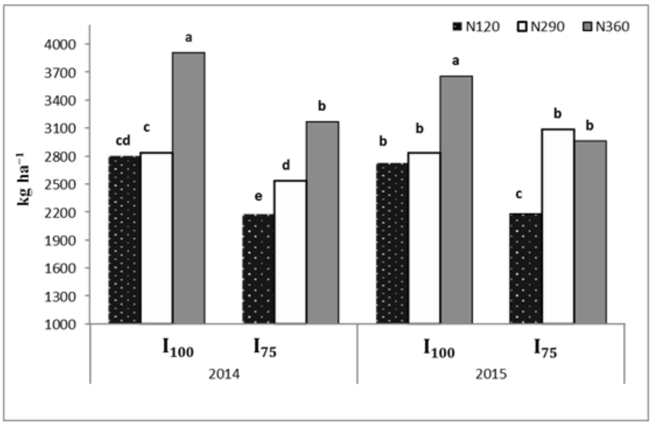

Figure 2: Dry weights of 70 days-old wheat (kg ha^{-1}) as affected by nitrogen fertilization and irrigation rates.

Effect of N fertilization rates and water stress on yield

The data in table 4 show the effect of nitrogen and irrigation treatments on the yield of drip irrigated wheat. Increasing irrigation level to I_{100} increased the straw and biological yield of wheat compared to the low irrigation treatment I_{75}. The grain yield of wheat grown under the low irrigation treatment was higher than that irrigated by I_{100}. In the both irrigation levels increasing fertilization rates of nitrogen increased the grain, straw, and biological yield of wheat. Yield of drip irrigated wheat grown under water stress responded significantly to nitrogen fertilization rates. Increasing N_{240} for wheat grown under water stress increased the grain, straw, and biological yield by 24, 25, and 25%, respectively, in the first season and by 51, 15, and 24%, respectively, in the second season. Significant reduction in wheat yield as a result of the water stress was found in the current study. However, this reduction was more distinct with the nitrogen application. Nitrogen at higher rates effectively balanced the adverse effect of water stress [60]. Thus, it may be stated that decrease in yield due to water stress was compensated significantly by providing N at high rates. Similar results were reported by [42,61-63] reported that increasing nitrogen fertilization rates to wheat grown under water stress increased the grain yield.

Effect of nitrogen rates and water stress on water use efficiency

The data illustrated in Figure 3 show the effect of nitrogen fertilization rates on the water use efficiency (WUE) of wheat under different levels of irrigation. The interaction between irrigation and nitrogen rates affected significantly ($P<0.05$) on WUE. Under the normal irrigation I_{100}, increasing the rates of nitrogen increased the WUE of wheat. Also, the same phenomenon was observed for drip irrigated wheat grown under water stress I_{75}. Fertilization of drip irrigated wheat grown under water stress with N_{240} increased the WUE by 22 and 23% in the first and second seasons, respectively compared the low N_{120}. Based on the data in Table 4, it is clearly that nitrogen fertilization increased the water use efficiency for drip irrigated wheat grown under water stress. Nitrogen fertilization enhanced the water productivity by increasing the wheat grain yield grown under water stress. The findings of the current study are in a good agreement with the results of [63,64]. Inorganic fertilization has been reported to mitigate the adverse effects of water stress on crop growth and development [65,66] particularly N.

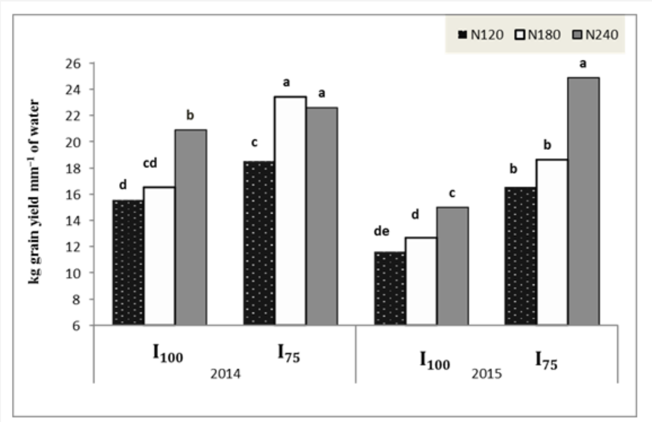

Figure 3: Water use efficiency of wheat (kg grain yield mm^{-1} of water) as affected by nitrogen fertilization and irrigation rates.

Table 4: Grain (GY) Straw (SY) and Biological yield (BY) of wheat as affected irrigation and nitrogen levels. (All the data expressed in tonnes ha $^{-1}$).

Irrigation Treatments	Nitrogen Rates	2014			2015		
		GY	SY	BY	GY	SY	BY
I_{100}	N_{120}	6.6^{c}	20.3^{a}	26.9^{b}	5.1^{c}	19.6^{cd}	24.7^{c}
	N_{180}	7.0^{c}	20.8^{a}	27.8^{b}	5.5^{bc}	23.9^{ab}	29.4^{b}
	N_{240}	8.9^{ab}	22.5^{a}	31.5^{a}	6.6^{b}	25.6^{a}	32.2^{a}
I_{75}	N_{120}	7.9^{bc}	17.2^{b}	25.1^{b}	5.6^{bc}	17.9^{d}	23.5^{c}
	N_{180}	9.9^{a}	15.9^{b}	25.8^{b}	6.3^{b}	23.5^{b}	29.8^{b}
	N_{240}	9.7^{a}	21.6^{a}	31.3^{a}	8.4^{a}	20.7^{c}	29.1^{b}

Acknowledgement

None.

Conflict of Interest

No conflict of interest.

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