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Wheat growth and nitrogen use efficiency under drip irrigation on semi-arid region

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Abstract

Irrigation water is limiting factor for crop production in arid and semi-arid regions. Modern irrigation system such as drip irrigation are widely used in Egypt and also used in other countries especially have limited irrigation water resources. Drip irrigation provides the efficient use of limited water resources with increasing water productivity (WP). Application of nitrogen to wheat is needed to ensure the N availability throughout the growing season due to its important role in promoting both vegetative and reproductive growth. A field experiment was carried out during growing season of 2017/2018 at a private farm located at a newly reclaimed sandy soil at El-Sadat district El-Menofiya governorate , Egypt to study the effect of two nitrogen fertilizer types (ordinary and slow release N fertilizers) as urea 46.5%N and urea formaldehyde (38%N) with four application rates i.e., 0, 40, 60 and 100 kg N fed^{-1} (1 feddan=4200 m^2) combined with drip irrigation moisture depletion from filed capacity (FC) (I1=100% of FC) and (I2=50% of FC) on wheat crop. The results showed that application of water depletion at (I1) through drip irrigation along with 100 kg N fed^{-1}, from two sources of nitrogen recorded the highest yield of straw and grain and the nitrogen content as well as nitrogen use efficiency compared with the other rate and levels of nitrogen and irrigation, respectively. Also, water productivity increased with irrigation I1 FC and nitrogen levels and reached the highest values at 100 kg N fed^{-1} as fertigated urea compared with urea formaldehyde as slow release fertilizer.

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Introduction

Crops production in arid and semi-arid regions was affected by water scarcity and plants nutrients private nitrogen nutrient. About one third of the developing world's wheat (*Triticum aestivum* L.) area is located in environments that are regarded as marginal for wheat production because of drought and heat factors. Despite these limitations, the world's dry and difficult cropping environments are increasingly crucial to food security in the developing world. For example, it has been reported that 32% of the 99 million hectares of wheat grown in developing countries experiences varying levels of drought stress (Rajaram et al., 1996). In recent years, however, growing competition for scarce water resources has led to applying modified techniques for maximizing water productivity and improving crop yields and quality, particularly in arid and semi arid regions as like in Egypt. Modern irrigation systems such as drip irrigation are widely used in Egypt and also in other countries have limited irrigation water resources. Drip irrigation provides the efficient use of limited water with increasing water productivity (Viswanatha et al., 2002). Little technically, economically and environmentally feasible studies had been focused on the application possibility of the alternative drip irrigation systems (surface and subsurface drip); an evaluation and implementation consideration exists under intensive field crop conditions, which had been carried out by Alam et al. (2018). El-Boraie (2004) showed that in arid regions as Egypt, where irrigation is essential for crop production, improving

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management of irrigation water may yield substantial water saving, which can be used for agriculture horizontal expansion. One of the best approaches to achieve good water management program is knowing the amount of actual evapotranspiration (ETa) or crop consumptive use.

Wheat (*Triticum aestivum* L.) was mainly crop, occupy 75% of agricultural areas and directly contribute to the food security of the country. Recently, in Egypt cultivated the wheat crop in sandy soils, therefore the irrigation scheduling is a key factor to help farmers increase crop yield and save water regarding limited water resources. El-Rahman (2009) found that high irrigation water productivity (WP) for wheat could be achieved by saving irrigation rates under drip system. Application of nitrogen to wheat is needed to ensure the N is available throughout the growing season due to its important role in promoting both vegetative and reproductive growth. High yielding wheat, especially new varieties need high and regular supply N to develop high photosynthetic capacity and maintain the proper nitrogen concentration in the leaves so that CO_2 assimilation is not affected when large rates are required for ear growth and grain filling period Lawlor (1995). Increasing cultivated for wheat production of unit land area are the most important national objectives in Egypt for minimizing the gap between the production and population consumption. That could be achieved by improving agricultural practices especially in desert area such as irrigation and fertilizers.

The objectives of this study were to improve wheat grain yield and nitrogen use efficiency under different irrigation water depletion conditions by using the different nitrogen fertilizer type's and rates, and also to asses soil nitrate distribution in the different soil layers under drip irrigation method.

Material and Methods

A field experiment was conducted during winter growing seasons of 2017/2018 at a private farm located at a newly reclaimed sandy soil at, El-Sadate district El-Menofiya governorate, Egypt (Latitude, 31°15'25" and N latitude, 30°01'4" E longitude). The climate of the experimental site is semi-arid (Table 1). The main chemical and physical soil characteristics presented in Table 2 were determined according to Dewis and Freitas (1970) and Klute (1986).

Table 1. Weather data during the experiment period 2017- 2018.

Month	Min Temp., °C	Max Temp., °C	Humidity, %	Wind, m/s	Sun, hours	Rad, $MJ/m^2/day$	ETo, mm/day
October	20.80	27.10	60.00	2.40	11.30	20.20	3.95
November	16.00	25.10	59.00	2.20	10.40	16.10	3.40
December	10.60	17.80	63.00	2.90	10.00	14.40	2.80
January	6.70	17.50	67.00	2.10	11.60	16.80	2.90
February	8.90	19.00	67.00	1.90	11.00	19.00	2.94
March	13.50	21.30	61.00	2.40	11.80	23.30	4.12
April	13.50	22.90	60.00	3.70	12.80	27.50	4.70
Average	12.86	21.53	63.29	2.51	11.27	19.61	

The experiment was conducted in a split block design with eight treatments. Two moisture depletion were applied as irrigation-1 (I1) at 100% of FC and irrigation-2 (I2) at 50% of FC on the main plots with four N rates from two types of nitrogen fertilizers on the sub-plots. Each treatment was replicated three times under drip irrigation system. Distance between irrigation laterals was 1 m, distance between drippers was 35 cm, and the rate of dripper discharge was 4 liters h^{-1}, and number of drippers per feddan (4200 m^2) was 12000 (48 m^3 h^{-1}). Wheat (Triticum aestivum, CV Giza 168) was sown on 20 November 2009 and harvested 10 April 2010 a seeding rate of 70 kg fed^{-1} with 10 cm row spacing. Phosphorus and potassium were applied during land preparation in the form of single superphosphate and potassium sulfate at the rate of 15 kg P_2O_5 fed^{-1} and 24 kg K_2O fed^{-1}, respectively. Also 20 m^3 fed^{-1} farmyard manure (FYM) was incorporated in all plots during land preparation. Also, nitrogen fertilizers for ordinary or slow release types as urea 46%N and urea-formaldehyde (UF) 38% N were applied as N fertilizer sources, respectively. During time of sowing UF fertilizer was mixed with the upper 20 cm of soil surface, while urea was applied with irrigation at different stages of growth up to 75 days after sowing. The whole plot factors were two irrigation treatments (I1 and I2) in the main plots, and eight N treatments including a combination of two N sources (urea and urea-formaldehyde) with four N rates (0, 40, 60 and 100 kg N fed^{-1}) in the sub plots. At maturity, one square meter was selected randomly from each plot and subjected to determine some wheat growth parameters (number of spikes per m^2, plant height (cm), number of tillers per plant, biological, grain and straw yields and weight of 1000 grains). Nitrogen and water productivity was calculated as the ratio of grain yield, kg fed^{-1} to amount of applied N units and total water quantity concerned in m^3 per fed, respectively (Huggins and Pan, 1993; Hussain and Al-Jaloud, 1995).

Table 2. Some main physical, chemical and nutritional characteristics of the experimental soil at initial state.

Soil characteristics	Value	Soil characteristics	Value
Sand, %	92.10	Organic matter content, %	0.08
Silt, %	2.20	pH (1: 2.5)	7.50
Clay, %	5.70	ECe , dS m^{-1}	1.55
Textural class	Sand	Available N, mg kg^{-1}	18.70
Bulk Density (BD), g cm^{-3}	1.62	Available P, mg kg^{-1}	2.81
Saturation (SP), %	18.00	Available K, mg kg^{-1}	40.00
Field capacity (FC), %	5.42	Available Fe, mg kg^{-1}	3.60
Wilting point (WP), %	2.06	Available Mn, mg kg^{-1}	0.52
Available water (AW), %	3.36	Available Zn, mg kg^{-1}	0.45
$CaCO_3$, %	1.40		

Soil water content at different depths (from soil surface to 0.80 m) was measured using gravimetric method. Soil samples were taken and extracted at the harvest of wheat plants from all treatments at the depths of 0-20, 20-40, 40-60 and 60-80 cm, in order to determine NO_3. Field capacity (FC) was determined by estimating soil moisture content. for 0-20, 20-40, 40-60 and 60-80 cm soil depths. The fresh weight of the soil samples was immediately recorded with a portable weighing balance. The soil samples were placed in an oven for 24h at 105°C. The dry weight of the samples was then recorded for drip irrigation treatments. Based on the soil water balance method in which the drainage and runoff were neglected, the net irrigation depth was estimated by using soil moisture contents. Water productivity (WP, kg/mm) was calculated by dividing the total grains yield (kg $fed.^{-1}$) by total water applied.

Results and Discussion

Effect on wheat attributes

The data cited in Table 3 show a significant effect of irrigation and nitrogen fertilization on plant height, number of spikes per m^2, spike length (cm) and weight of 1000 grains. The results indicated that the highest values of the above mentioned attributes were obtained by soil moisture depletion at 100% from FC (I-1) compared with the limited available water at 50% from FC (I-2).

Table 3. Effect of different nitrogen sources and moisture content on some growth parameters of wheat plants

Treatments			Plant	Number of	Spike	Weigh of 1000
Irrigation	N-sources	N-Rate, kg fed^{-1*}	height, cm	spikes/m^2	length, cm	grain, g
100% of FC (I-1)	Urea	0	70.43	154.00	7.30	32.00
		40	75.33	180.00	8.00	34.00
		60	77.90	200.98	8.40	34.90
		100	90.00	230.98	8.50	35.87
		Mean	78.42	191.49	8.05	34.19
100% of FC (I-1)	UF	40	79.12	200.00	8.00	35.22
		60	87.14	260.76	9.90	37.12
		100	99.89	290.97	12.00	38.11
		Mean	88.72	250.58	9.97	36.82
50% of FC (I-2)	Urea	0	67.00	132.00	6.20	31.00
		40	70.39	160.00	7.30	33.00
		60	74.09	176.00	7.80	33.76
		100	75.21	190.00	8.10	34.88
		Mean	71.67	164.50	7.35	33.16
50% of FC (I-2)	UF	40	69.99	158.00	7.20	33.81
		60	71.09	160.00	7.70	33.50
		100	72.90	185.90	7.70	33.89
		Mean	71.33	167.97	7.53	33.73
$LSD_{0.05}$ (Irrigation)			0.38	0.23	0.70	0.76
$LSD_{0.05}$ (N- sources)			NS	0.65	0.24	0.01
$LSD_{0.05}$ (Irrigation x N- sources)			0.01	0.01	0.01	0.01

*1 feddan=4200 m^2

In the case of the effect of nitrogen levels and sources the results indicated that the highest values of the same parameters were obtained from the application of urea-formaldehyde at rate of 100 kg N fed^{-1} with irrigation (I-1). At the same time the lowest values were related to the lack of nitrogen and irrigation. Slow release nitrogen fertilizers were compared with the other soluble and the scientists emphasized their superiority in increasing yield and its components of many crops Hamdallah et al. (1988). The superior of slow release than ordinary urea can be attributed to the slow release of N to meet the plant's requirement, where it has a low dissolution rate than the others which reduces nitrogen loss from soil profile and gives a chance for more uptake by plant root.

Biological, grain and straw yields and harvest index

Results presented in Table 4 indicated that straw, grain, and biological yields as well as harvest index of wheat plants were significantly affected by increasing rates of the two nitrogen types with irrigation treatments. Wheat growth in soil amended with 40 and 60 kg N fed^{-1} as slow release (urea-form) fertilizer with irrigation at 100% of FC (I-1) and 50% of FC (I-2) treatments had the highest value compared with the control (without N fertilization) and urea treatments. Also, I-1 recorded the highest value of measured yield parameters compared to I-2 treatment. These results may be reflects moisture status in root zone of plants. With increasing moisture content to near the field capacity, it may reducing the occurrence of water stress on plants especially during the reproduction stage of growth. This could be due to the increase in the available soil moisture content, which enhance nutrients uptake and increasing photosynthetic metabolic translocations from leaves to grain also, slow release nitrogen fertilizer may help reduce nitrate leaching and increase nitrogen use efficiency.

Table 4. Effect of different nitrogen source and moisture content on straw, grain, biological yields and harvest index of wheat plants

Treatments			Straw yield,	Grain ield,	Biological yield	Harvest
Irrigation	N-sources	N-Rate, kg fed^{-1*}	kg fed^{-1}	kg fed^{-1}	kg fed^{-1}	Index, %
100% of FC (I-1)	Urea	0	636.00	400.00	1036.00	62.89
		40	994.00	644.00	1638.00	64.78
		60	1271.00	890.98	2161.98	70.10
		100	1585.00	1265.00	2161.98	79.81
		Mean	1121.5	800.00	1749.49	69.40
100% of FC (I-1)	UF	40	1189.45	789.45	1978.90	66.37
		60	1200.11	987.11	2187.22	82.25
		100	2072.00	1678.09	3750.09	80.98
		Mean	1487.19	1151.55	2638.74	76.53
50% of FC (I-2)	Urea	0	564.00	332.00	896.00	58.86
		40	825.00	475.00	1300.00	57.57
		60	1099.00	690.93	1789.93	62.86
		100	1180.00	884.78	2064.78	74.98
		Mean	917.00	683.57	1718.24	65.14
50% of FC (I-2)	UF	40	598.00	390.87	988.87	65.36
		60	909.00	588.98	1497.98	64.79
		100	1034.00	743.87	1777.87	71.94
		Mean	847.00	574.57	1421.57	67.36
$LSD_{0.05}$ (Irrigation)			0.69	0.26	0.43	0.32
$LSD_{0.05}$ (N- sources)			0.01	0.46	0.56	0.01
$LSD_{0.05}$ (Irrigation x N- sources)			0.01	0.01	0.01	0.23

*1 feddan=4200 m^2

Also, the highest value of wheat yield attributes was obtained when the ultimate level of N was applied (Table 4). It is clear from these data that N fertilization to wheat enhanced plants vegetative growth which increased photosynthetic activity and the metabolites required to produce wide and heavy panicles. It worth to mentioned that at high rate (100 kg N fed^{-1}) of urea formaldehyde with I-2 deficit irrigation gave the lowest yield production compared with the same rate fertilized with urea. These results may be attributed to low soil moisture content causing slow nitrogen mineralization from urea formaldehyde due to limited microbial activity thus lowering the N availability (Paramasivam and Alva, 1997) correspondingly the emission of ammonia by volatilization was usually reduced when moisture content increased. These results may be due to that sandy soil characterized by the limited water holding capacity and high nutrient leaching losses. Hanafi et al. (2002) reported that the uncoated compound fertilizer such as urea gave significantly higher amounts of nutrients loss compared to slow release N fertilizer. Zeidan and El Kramany (2005) found that the use of slow release nitrogen fertilizer increased grain yield of wheat compared with other nitrogen sources.

Nitrogen concentration, N-uptake and protein content of grains were significantly affected by all interactions between nitrogen source and irrigation intervals treatments under study (Table 5). In general, the highest nitrogen concentration, nitrogen uptake and protein content of grains were obtained when irrigated at I-1 using urea formaldehyde as nitrogen sources and receiving 100kg N fed^{-1}. Guo et al. (2007) found that water productivity of plants may be increased by nitrogen management, as the localized ammonium application by Cultan-technique or the releasing fertilizers in combination with nitrification inhibitors.

Table 5. Effect of different nitrogen sources and moisture content on N concentration, uptake, protein content and grain nitrogen recovery(GNR).

Treatments			N-concentration,	N-uptake by	Protein	GNR
Irrigation	N-sources	N-Rate, kg fed^{-1}	%	grain kg fed^{-1}	content, %	
100% of FC (I-1)	Urea	0	0.88	3.68	5.50	----
		40	1.10	7.08	6.87	8.50
		60	1.44	12.83	9.00	15.25
		100	1.61	20.36	10.06	16.68
		Mean	1.26	10.99	7.86	10.11
100% of FC (I-1)	UF	40	1.71	13.49	10.68	24.52
		60	1.94	19.14	12.12	25.76
		100	2.46	41.28	15.37	37.60
		Mean	2.04	24.64	12.72	29.29
50% of FC (I-2)	Urea	0	0.82	2.72	5.13	----
		40	1.00	4.75	6.25	5.07
		60	1.40	9.67	8.75	11.58
		100	1.48	13.09	9.25	10.37
		Mean	1.18	7.56	7.35	6.76
50% of FC (I-2)	UF	40	1.42	5.55	8.87	7.07
		60	1.64	9.65	10.25	11.55
		100	2.12	15.77	13.25	13.05
		Mean	1.73	10.32	10.79	10.56
LSD $_{0.05}$ (Irrigation)			0.70	0.54	0.51	0.33
LSD $_{0.05}$ (N- sources)			NS	0.01	0.01	0.01
LSD $_{0.05}$ (Irrigation x N- sources)			0.32	0.01	0.01	0.01

*1 feddan=4200 m^2

Grain nitrogen recover (GNR)

The effect of different nitrogen types and soil moisture content on nitrogen use efficiency (NUE) was shown in Table 5. Application of urea formaldehyde as a slow N fertilizer increased N-use efficiency of wheat grains as compared to the ordinary (fast release) urea. The interaction between irrigation intervals and nitrogen sources on NUE, the obtained results show that, the highest value of NUE was recorded from treatments received urea formaldehyde at rate of 100kg N fed^{-1} under irrigation by I-1 moisture content. These results are in agreement with those obtained by Amal et al. (2007). They concluded that slow release N fertilizer was long-term effects including reduced leaching losses and enhanced N-uptake as well as positive effects on both health and soil nutrient levels. Koivunen and Horwath (2005) evaluating winter wheat, as influenced by a coated urea, showed that maximum yield and NUE were grater with coated urea versus common urea.

Residual soil nitrogen

Distribution of nitrate (NO_3) in four depths (0-20), (20-40), (40-60) and (60-80) cm after harvest of wheat plants for different nitrogen sources and rates as well as two irrigation treatments can be seen in Table 6. The data show that in general high amounts of nitrogen existed in the upper depth (0-20 cm) of the soil and it decreased gradually with the soil depth up to 60-80 cm.

Results also indicated that the concentration of nitrate in different soil depths were significantly higher in the fertigated urea than in the urea formaldehyde ones at different irrigation levels. The highest value of NO_3-N was obtained at high rate of N as urea with irrigation I-1 for depth (60-80 cm), while the lowest value of NO_3-N was obtained in urea formaldehyde at a rate of 40 kg N fed^{-1} with irrigation I-1 at depth 40-60 cm. Likewise, excessive application of irrigation water can produce accelerated downward movement of NO_3 -N especially when the application of nitrogen in the form fast releases urea. Also, it's worth to notice, that the concentration of NO_3-N decreased markedly in the 80 cm of soil depth due to application of urea formaldehyde with two levels of irrigation, suggesting that there was not large amounts of NO_3-N leached to ground water. These results are in harmony with Chikowo et al. (2004) who found that when use different mineral N concentrations at different sampling dates to determine N leaching per soil layer and for the whole soil profile. Nitrate leaching losses are directly associated with percolation of water and fertilizer application and solubility. In potatoes, controlled release nitrogen (CRN) produced less nitrate leaching, greater fertilizer-N recovery, and greater marketable yields than split applications (Zvomuya et al., 2003). It is important to note that the concentration of NO_3, besides being consistently lower under slow release fertilizer (urea formaldehyde) than under nitrogen fertilizer as urea by chemigation in the deep soil depth (60-80 cm). Zvomuya et al. (2003) found that a single application of poly coated urea improved recovery of N and reduced NO_3 leaching compared with three applications of urea. Similar results were reported by Waddell et al. (2000) comparing SCU with urea treatment. Also, Wen et al. (2001) indicated that a field study on sandy soil on peanuts yields were 81 to 137% higher with a mixture of resin-coated N fertilizers and nitrogen recovery was 79 to 94 % with the coated N and only 10 to 32% with ammonium sulfate. The highest recoveries were associated with the matched N release of coated fertilizer and the crop N uptake and the fertilizer placement.

Table 6. Effect of different nitrogen sources and moisture content on N concentration in different depths.

Treatments			Soil depths (cm)			
Irrigation	N-sources	N-Rate kg fed^{-1}	0-20	20-40	40-60	60-80
			NO_3- N (mg kg soil^{-1})			
100% of FC (I-1)	Urea	0	8.50	5.21	5.10	4.32
		40	18.90	12.45	14.99	22.21
		60	23.98	15.99	18.94	25.68
		100	33.21	21.99	23.78	44.88
		Mean	21.15	13.91	15.70	24.27
100% of FC (I-2)	UF	40	12.43	10.00	9.80	14.87
		60	15.88	12.00	10.74	18.43
		100	17.34	15.98	15.87	23.43
		Mean	15.22	12.66	12.14	18.91
50% of FC (I-1)	Urea	0	9.92	7.21	4.21	4.11
		40	24.81	20.00	15.99	11.23
		60	28.09	23.90	17.23	12.90
		100	32.11	27.90	20.11	15.99
		Mean	23.73	19.75	14.39	11.06
50% of FC (I-2)	UF	40	11.87	6.90	5.11	5.12
		60	14.21	11.56	11.00	12.11
		100	16.21	13.75	12.90	14.23
		Mean	14.10	10.74	9.67	10.49
$LSD_{0.05}$ (Irrigation)			0.30	0.24	0.21	0.33
$LSD_{0.05}$ (N- sources)			0.32	0.01	0.01	0.01
$LSD_{0.05}$ (Irrigation x N- sources)			0.32	0.01	0.01	0.01

Water productivity (WP)

The results in Table 7 showed that there were significant differences in WP of wheat plants due to soil application of nitrogen fertilizers and the highest value of WP was recorded with nitrogen application as ureaformaldhyde when compare to the urea ones. Concerning the effect of different irrigation levels, the mean values of water productivity at 50% from FC were highest when compared to the highest level of water application. Also, the interaction between amount of irrigation water and form of nitrogen fertilizers the data showed that the highest values of WP were recorded by application of urea with 50% of FC.

Conclusion

Applying nitrogen from a slow release fertilizer provides an efficient way to increase the N use efficiency and to minimize NO_3-N leaching as well as to prevent environmental pollution by the excess of nitrogen in the soil profile. Also managing soil moisture content under drip irrigation to 100% from soil FC enhanced lowering nitrogen deep movement and increased wheat productivity. It may be concluded that a slow release N fertilizer with a rate of 100 kg N fed^{-1} can be applied to cultivate wheat with using drip irrigation at 100% of FC under semi-arid conditions.

Table 7. Effect of different nitrogen sources and moisture content on WP.

Treatments			Grain Yield	Applied water, mm	WP
Irrigation	N-sources	N-Rate, kg fed^{-1}			
100% of FC (I-1)	Urea	0	400.00	3.68	1.11
		40	644.00	7.08	1.79
		60	890.98	12.83	2.47
		100	1265.00	20.36	3.51
		Mean	800.00	10.99	2.22
100% of FC (I-1)	UF	40	789.45	13.49	2.19
		60	987.11	19.14	2.74
		100	1678.09	41.28	4.66
		Mean	1151.55	24.64	3.20
50% of FC (I-2)	Urea	0	332.00	2.72	1.84
		40	475.00	4.75	2.64
		60	690.93	9.67	3.84
		100	884.78	13.09	4.92
		Mean	595.68	7.56	3.31
50% of FC (I-2)	UF	40	390.87	5.55	2.17
		60	588.98	9.65	3.27
		100	743.87	15.77	4.13
		Mean	574.57	10.32	3.19
$LSD_{0.05}$ (Irrigation)					0.14
$LSD_{0.05}$ (N- sources)					0.01
$LSD_{0.05}$ (Irrigation x N- sources)					0.01

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