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Nitrogen Recovery Efficiency and Grain Yield Response Index of Some Wheat Varieties as Affected by Nitrogen Fertilizer Rates

Mostafa G. Shahin

Agronomy Department, Faculty of Agriculture, Ain Shams University, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt

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ABSTRACT

Considering the importance of nitrogen as a critical factor in agriculture and the high costs of nitrogen fertilizers, its benefit must be maximized. So, studies evaluating nitrogen use efficiency (NUE), nitrogen agronomic efficiency (NAE) and Grain yield response index (GYRI) are becoming increasingly necessary in crop production. Therefore, two field experiments were conducted in split-plot design during the 2018/2019 and 2019/2020 seasons to evaluate the productivity of four wheat varieties (Gemmiza-11, Giza-168, Misr-1 and Sids-12) under five nitrogen (N) fertilizer rates (0, 30, 60, 90 and 120 kg N fed^{-1}). The results showed significant differences among wheat varieties in both seasons for yield and its components as well as NUE and its attributes. Misr-1 gave the highest values of number of spikes m^{-2}, number of grains spike^{-1}, grains yield fed^{-1}, total N uptake and NUE. However, Sid-12 recorded the highest straw yield and the heaviest 1000 grain weight obtained by Gemmiza-11. Giza-168 recorded the highest N uptake and N content in grains and straw. Increasing N fertilizer rates from 0 to 90 kg N fed^{-1} increased yield and its components, as well as grains N%, straw N%, grains N uptake and straw N uptake but decreased NUE. Yield, its components, NUE, and its attributes were affected significantly by the interaction among wheat varieties and N fertilizer rates in both seasons. The maximum NAE was recorded with Misr-1 and with 90 kg N fed^{-1}. GYRI values showed that Misr-1 and Gemmiza-11 belonged to the efficient-responsive group in both growing seasons.

Keywords: Wheat, Nitrogen fertilizer rates, N use efficiency, N uptake, N agronomic efficiency, Grain yield response index

Introduction

Nitrogen (N) is a vital macronutrient for plant function and it occupies a prominent place in the plant metabolism system. All vital processes in plants are related to protein, which nitrogen is a fundamental constituent. Also, N enters in chlorophyll molecule synthesis, which leads to increasing photosynthesis efficiency. Further, nitrogen enhances the uptake of other nutrients, i.e., phosphorus and potassium (Bloom, 2015).

Consequently, N plays an integral role in agriculture *via* increasing crop yield (Massignam *et al.,* 2009; Koutroubas *et al.,* 2014). The change in supply and demand dynamics resulted from increasing expanding utilization and cost of nitrogen fertilizers (FAO, 2015). In this regard, the researchers' main issue and goal are to increase nitrogen use efficiency (NUE). However, the current nitrogen strategies are remarkably ineffectual in wheat crop (Noureldin *et al.,* 2013), ranging from 17.1 to 57.0 (Todeschini *et al.,* 2016; Abd El-All *et al.,* 2017; Mansour *et al.,* 2017). Based on many studies, they attribute the decrease in NUE value to more reasons like as volatilization, denitrification and leaching (Sylvester-Bradley and Kindred 2009; Ercoli *et al.,* 2012). Generally, NUE decreases at the plants' maturity stage and stops vegetative growth (Leghari *et al.,* 2016).

Wheat (*Triticum aestivum* L.) is the most important grains crop, and a large section of human populations in many parts of the world depend on it as a food source. Wheat can be grown in a broad zone of ecosystems. However, many of these ecosystems have development and productivity problems (FAO, 2016). Egypt production of wheat covers less than half of the local needs. Increasing wheat productivity is a nation target to reduce the gap between wheat production and consumption. The production of wheat can be increased by increasing the cultivated area or yield productivity per feddan. Actually, it is hard to increase the wheat cultivated area result to rivalry with other winter crops as well

Corresponding Author: Mostafa G. Shahin, Agronomy Department, Faculty of Agriculture, Ain Shams University, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt.
E-mail: mostafa_shahin@agr.asu.edu.eg

as water shortage hinder wheat cultivation in reclaimed lands. Therefore, the other solution is using high-yielding varieties that are distinguished by their tolerance of environmental stresses, especially the lack of nitrogen in the soil. Wheat cultivars genetically differ in NUE due to differences in N uptake (Radwan *et al.,* 2014; Mansour *et al.,* 2017). Accordingly, the plant breeders have worked diligently to improve NUE for plants. Le Gouis *et al.* (2000) stated that genotype variation affects nitrogen accumulation and yield under low nitrogen conditions in wheat. It is challenging to identify field-observed phenotypes' genetic control associated with NUE, the intricacy of N metabolism during plant growth stages, and the impact of ecosystem factors (DoVale *et al.,* 2012). Many types of research have been performed to test wheat varieties variation at different N levels to improve yield and its component as well as NUE (Gaju *et al.,* 2014; Mahjourimajd *et al.,* 2016; Nguyen *et al.,* 2016; Arata *et al.,* 2017; Guttieri *et al.,* 2017). Consequently, the present work aims to evaluate four wheat varieties' performance, NUE, N agronomic efficiency, N uptake, and grain yield response index under different N fertilizer rates.

Material and Methods

Experimental site and treatment

Two field experiments were conducted at Shalakan Experimental Farm, Faculty of Agriculture, Ain shams university, Qalubia Governorate, Egypt, during the 2018/2019 and 2019/2020 growing seasons. Sowing dates were the 22nd and 25th of November in the first and second seasons, respectively. The experimental design was split-plot in three replicates, where wheat varieties (Gemmiza-11, Giza-168, Misr-1, and Sids-12) occupied the main plots and N fertilizer rates (zero, 30, 60, 90 and 120 Kg N fed^{-1}, as a urea 46% N) were distributed in sub-plots. In both seasons, the previously cultivated crop was maize. Standard agronomic practices were applied as recommended for wheat. Each N level was applied in two equal portions before the first and second irrigations. The area of the experimental unit was 10.5 m2, consisting of 15 rows each 0.20 m apart and its length was 3.5 m. The soil of the experiment was clay texture in both seasons. The soil samples were taken before applying fertilizers to analyze the physical and chemical properties (Table 1) according to Soil Survey Staff, 1999. The meteorological data of the study location are illustrated in Fig. 1. Which were obtained from the Central Laboratory for Agricultural Climate, Dokki, Giza, Egypt, during the 2018/2019 and 2019/2020 growing seasons.

Table 1: Physical and chemical properties of the soil of the study site at Shalakan region, Qalubia Governorate, Egypt, during two growing seasons 2018/2019 and 2019/2020.

Season	Physical property			Chemical property					
	Sand%	Silt%	Clay%	pH	EC (dS m^{-1})	OM%	Available nutrients (mg kg^{-1} soil)		
							N	P	K
2019	27.40	20.20	52.40	7.11	0.45	1.12	16.45	7.41	218.40
2020	28.10	21.80	50.10	7.18	0.47	1.85	17.64	9.40	202.41

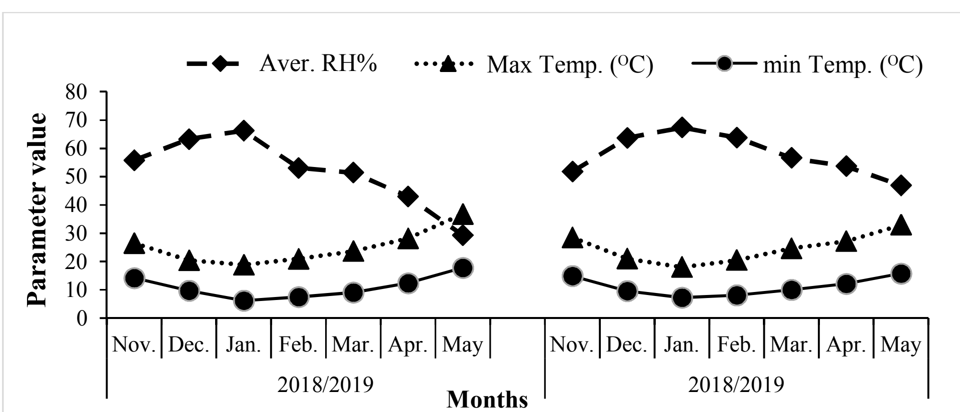

Fig. 1: Averages of relative humidity (RH %), air maximum and minimum temperature (°C) in 2018/2019 and 2019/2020 seasons.

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Crop measurements

Wheat plants were harvested at the end of May, then a random sample from 1 m^2 was chosen from each plot to evaluate spikes number m^{-2}, number of grains $spike^{-1}$, and 1000 grains weight. In each experimental plot, all plants were harvested and separated into straw and grain to calculate straw and grain yields fed^{-1}. Grains and straw samples were taken from all experimental units, dried at 65°C until steady weight, and then pulverized. Total N in straw and grains was determined using the micro-Kjeldahl method according to AOAC (2012). N uptake (kg fed^{-1}) was calculated by multiplying grain or straw yield by their respective N% content. Nitrogen agronomic efficiency (NAE) was determined according to Delogu *et al.* (1998) by the following equation:

$$NAE(Kg\ grain\ kg\ N^{-1}) = \frac{Grain\ yield\ at\ N\ treatment - Grain\ yield\ at\ zero\ N}{Applied\ N\ at\ N\ treatment}$$

Grain yield response index (GYRI) was estimated for each variety, according to Fageria and Barbosa Filho (1981) using the following equation:

$$GYRI\ (Kg\ grain\ kg\ N^{-1}) = \frac{Grain\ yield\ under\ high\ N\ level - Grain\ yield\ under\ low\ N\ level}{High\ N\ level - low\ N\ level}$$

Where: low N level = 0 kg fed^{-1} and high N level = 90 kg fed^{-1}

According to the GYRI value, wheat varieties could be categorized into four groups:

1- Efficient and responsive group (ER); gave high grain yield at low and high nitrogen fertilizer rates.
2- Efficient and not responsive group (ENR); has high grain yield at low nitrogen rate with lower response to increasing nitrogen fertilizer than ER.
3- Not efficient but responsive group (NER); produced low grain yield in response to increasing nitrogen fertilizer.
4- Neither efficient nor responsive group (NENR); gave low grain yield with a low response to increasing nitrogen fertilizer.

Nitrogen recovery efficiency (NRE %) was computed according to Shivay *et al.* (2010), using the following equation:

$$NRE\% = \frac{Grain\ N\ uptake\ in\ treated\ plots - Grain\ N\ uptake\ in\ zero\ kg\ N\ \text{feddan.}^{-1}\ plots}{Applied\ N\ in\ treated\ plots} \times 100$$

Statistical analysis

Data obtained from each season were subjected to appropriate statistical analysis of variance using Costat software, version 6.303 (2004), according to Casella (2008). Duncan's Multiple Range compared the differences among means of data at significance at 5 % level.

Results

Yield and its components

Data presented in Table 2, yield and its components, i.e., spikes number m^{-2}, number of grains $spike^{-1}$, 1000 grain weight, as well as grain and straw yields, were markedly affected by wheat varieties, wheat varieties, nitrogen fertilizer levels and their interaction at two growing seasons 2018/2019 and 2019/2020. In this respect, spikes number m^{-2} highest values were recorded by Misr-1, while Sid-12 gave the lowest values. The increments of spikes number m^{-2} were 10.66 and 13.01% compared to Sids-12 on both growing seasons, respectively. Misr-1 was the vigorous variety for producing the highest number of grains $spike^{-1}$, exceeding Gemmiza-11 by 14.32% in the first season and Giza-168 by 13.46% in the second season. In both growing seasons, Gemmiza-11 was the effective variety for achieving the maximum values of 1000 grain weight, while Sids-12 gave the lowest values. Increments in 1000 grain weight were 10.86 and 11.37% in both seasons, respectively, compared to Sids-12. Different varieties significantly influenced grain yield. The highest grain yield was recorded by Misr-1 compared to other

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Table 2: Effect of wheat varieties, nitrogen fertilizer rates and their interaction on yield and it components in 2018/2019 (1st) and 2019/2020 (2nd).

Treatment		Spikes number m^{-2}		Number of grain $spikes^{-1}$		1000 grain weight (g)		Grain Yield (Ton fad^{-1})		Straw yield (Ton fad-1)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Varieties											
Gemmiza-11		304.36 b	278.43 b	56.29 c	55.56 b	43.88 a	41.03 a	2.070 b	1.917 b	4.652 b	4.469 a
Giza-168		297.58 bc	271.34 bc	58.73 b	53.20 c	41.59 b	38.78 b	1.966 c	1.796 c	4.435 c	4.240 b
Misr-1		326.67 a	300.98 a	64.30 a	60.36 a	40.98 b	38.16 b	2.185 a	1.998 a	4.310 d	3.925 c
Sids-12		295.24 c	266.33 c	57.96 b	53.99 bc	39.58 c	36.84 c	1.974 c	1.814 c	4.820 a	4.562 a
N Fertilizer rates											
0 kg		249.20 d	223.50 d	50.98 d	46.58 e	34.43 e	31.66 e	1.292 e	1.179 e	2.979 e	2.915 e
30 kg		277.23 c	250.82 c	55.75 c	51.99 d	38.12 d	35.38 d	1.659 d	1.485 d	3.841 d	3.464 d
60 kg		320.76 b	292.74 b	60.61 b	56.88 c	41.81 c	38.99 c	2.204 c	2.046 c	4.846 c	4.492 c
90 kg		364.23 a	338.69 a	67.41 a	64.01a	47.66 a	44.95 a	2.695 a	2.498 a	5.994 a	5.826 a
120 kg		318.39 b	290.61 b	61.85 b	59.42 b	45.52 b	42.55 b	2.394 b	2.200 b	5.112 b	4.798 b
Interaction											
Gemmiza-11	0 kg	242.13 jk	217.11 jk	48.87 j	45.13 k	36.68 j	33.80 i	1.260j k	1.187 hi	2.932 i	2.838 k
	30 kg	283.57 gh	253.16 h	51.22 j	49.50 j	41.26 h	38.30 g	1.680 h	1.554 g	3.527 gh	2.994 jk
	60 kg	325.00 de	302.71 de	58.58 gh	58.59 ef	44.42 f	41.64 e	2.226 f	2.060 e	5.090 d	5.038 def
	90 kg	352.73 bc	325.47 bc	63.63 de	65.04 b	49.63 a	46.77 a	2.706 b	2.536 b	6.509 a	6.489 a
	120 kg	318.37 ef	293.72 efg	59.17 fg	59.53 de	47.43 bc	44.64 bc	2.478 cde	2.246 cd	5.199 cd	4.987 def
Giza-168	0 kg	240.40 k	220.00 jk	49.63 j	45.59 k	33.94 k	30.91 j	1.218 k	1.051 i	2.535 j	2.454 l
	30 kg	263.47 hi	239.25 hi	54.86 j	49.78 j	36.94 j	34.09 i	1.470 i	1.276 h	3.631 g	3.155 ij
	60 kg	309.33 ef	278.26 fg	59.02 g	54.23 hi	42.15 gh	39.80 f	2.184 f	2.066 e	4.723 e	4.463 g
	90 kg	365.00 b	341.14 b	68.45 b	59.60 de	48.05 b	45.65 ab	2.520 cd	2.322 cd	6.147 b	6.048 b
	120 kg	309.70 ef	278.05 fg	61.69 ef	56.78 fg	46.85 cd	43.44 cd	2.436 de	2.265 cd	5.139 cd	5.078 de
Misr-1	0 kg	274.74 hi	248.81 hi	55.02 i	51.68 ij	34.02 k	31.55 j	1.344 j	1.254 h	3.054 i	3.042 jk
	30 kg	300.80 fg	278.10 fg	60.79 fg	57.98 ef	37.19 j	34.45 i	1.764 h	1.537 g	3.693 g	3.352 i
	60 kg	323.17 de	294.29 efg	65.49 cd	59.59 de	41.38 h	38.29 g	2.388 e	2.208 d	4.394 f	3.710 h
	90 kg	391.04 a	368.72 a	73.75 a	69.18 a	47.20 bc	44.46 bc	2.991 a	2.767 a	5.337c	5.225 d
	120 kg	343.57 cd	314.96 cd	66.42 bc	63.35 bc	45.11 ef	42.06 de	2.436 de	2.226 cd	5.071 d	4.297 g
Sids-12	0 kg	239.53 k	208.06 k	50.40 j	43.92 k	33.08 k	30.36 j	1.344 j	1.223 h	3.394 f	3.325 i
	30 kg	261.09 ij	232.77 ij	56.13 hi	50.69 j	37.11 j	34.68 i	1.722 h	1.572 g	4.512 ef	4.355 g
	60 kg	325.51 de	295.68 ef	59.35 fg	55.11 gh	39.29 i	36.22 h	2.016 g	1.848 f	5.175 cd	4.759 f
	90 kg	348.15 bc	319.44 cd	63.80 de	62.21 cd	45.75 de	42.91 de	2.562 c	2.365 c	5.981 b	5.541 c
	120 kg	301.91 fg	275.70 g	60.12 fg	58.00 ef	42.69 g	40.04 f	2.226 f	2.062 e	5.039 d	4.830 ef

varieties. Meanwhile, the lowest grain yield was recorded by Sids-12 in both seasons. As for the straw yield, Sids-12 achieved the highest straw yield at 2018/2019 and 2019/2020 seasons, while the lowest straw yield was recorded br Giza-168 and Misr-1 at the first and second seasons, respectively.

Nitrogen fertilizers levels significantly affected yield and its attributes in both seasons in Table 2. Thence, increasing N fertilizer rate up to 90 kg fed^{-1} resulted in increases over Zero Kg N fed^{-1}, which reached 46.16 and 51.54% for spikes number m^{-2}, 32.23 and 37.42% for number of grains $spike^{-1}$, 38.34 and 41.98% for 1000 grain weight, 108.59 and 111.87% for grain yield as well as 101.21 and 99.86% for straw yield in 2018/2019 and 2019/2020 seasons, respectively. Despite N fertilizer enhancing yield and its components, raising the N fertilizer dose to 120 kg diminished.

It is clear from Table 2 that yield and its components were significantly affected by the interaction among N fertilizer rates and wheat varieties in 2018/2019 and 2019/2020 seasons. Increasing N fertilizer level from zero to 90 kg fed^{-1} under different wheat varieties displayed the maximum values of spikes number m^{-2}, number of grains $spike^{-1}$, 1000 grain weight, and grain and straw yields in both growing seasons. The combination of Misr-1 and 90 kg N fed^{-1} gave the maximum values of spikes number m^{-2}, number of grains $spike^{-1}$ and grain yield. However, the combination of Gemmiza-11 and 90 kg N fed^{-1} recorded the heaviest 1000 grain weight and the most significant straw yield.

Nitrogen use efficiency and its attributes

As illustrated in Table 3, wheat varieties, N fertilizer rates, and their interaction showed remarkable effects on nitrogen content and N uptake at grains and/or straw of wheat, total N uptake, and nitrogen use efficiency (NUE) at both study seasons. Nitrogen percentage in grains differed according to the different genotypes. Giza-168 recorded the highest nitrogen percentage in grains at both growing seasons and Misr-1, which was statistically at par in the second season. However, Gemmiza-11 and Sids-12 recorded the lowest content of nitrogen in grains. Also, variety Giza-168 has nitrogen content at straw higher than other varieties recorded with the lowest nitrogen content at straw recorded by Misr-1 in both seasons and Gemmiza-11 in the second season. Concerning grain N uptake, Misr-1 was the superior cultivar for nitrogen storage in grains in both seasons. The lowest grain N uptake showed by Gemmiza-11 in the first season and Gemmiza-11 and Sids-12 in the second season. However, the highest value of straw N uptake was recorded by Giza-168 in the first season and Giza-168 and Sids-12 in the second. $Misr^{-1}$ had the lowest values of straw N uptake in both seasons. For total N uptake, Giza-168 and Misr-1 in both seasons were the effective varieties for achieving the highest values of total N uptake. Meanwhile, Gemmiza-11 and Giza-168 recorded the minimum values in this respect. In both study seasons, the maximum value of NUE was for Misr-1, which outperformed the other varieties. The cultivars Giza-168 and Sid-12 had a low nitrogen use efficiency.

Generally, N fertilizer rates significantly affected the grains N%, straw N%, grain N uptake, straw N uptake, total N uptake and NUE (Table 3). 90 Kg N fed^{-1} was superior to other N fertilizer treatments, whereas increasing the N fertilizer rate by more than 90 kg N fed^{-1} caused a reduction in all nitrogen content in plant parts. The increments in grains N%, straw N%, grain N uptake, straw N uptake and total N uptake were 80.4, 118.0, 279.2, 348.3 and 292.5%, respectively, in the 2018/2019 season and 85.1, 112.8, 295.7, 326.0 and 301.7%, respectively, in 2019/2020 season. However, increasing the N fertilizer rate decreased NUE, so treatment 30 kg N fed^{-1} presented the efficiency for nitrogen use. This decrement in NUE was 63.9 and 62.9% compared to adding 120 kg N fed^{-1} in the first and second seasons, respectively.

The interaction between wheat varieties and N fertilizers rates significantly affected NUE and its attributes in the 2018/2019 and 2019/2020 seasons (Table 3). Generally, increasing the N fertilizers rate from zero to 90 kg N fed^{-1} with each tested variety showed maximum values of grains N%, straw N%, grain N uptake, straw N uptake, and total N uptake except NUE. Whereas the highest NUE values were recorded using 30 kg N fed^{-1} for all tested varieties.

The highest value of grains N% was presented by the combination between Misr-1 and 90 kg N fed^{-1} in both seasons. Gemmiza-11 X zero kg N fed^{-1} gave the lowest nitrogen content in grain in the first season, and Gemmiza-11 and Sids-12 under non-fertilizer in the second season. However, Gemmiza-11 and Sids-12 plots in the first season, and Giza-168, Misr-1 and Sids-12 plots in the second season fertilized with 90 kg N fed^{-1} achieved the maximum values of straw N%. Grains N uptake recorded the maximum values by combining Misr-1 and 90 kg N fed^{-1} at two growing seasons. In plots received 90 kg N fed^{-1}, the highest values of straw N uptake was shown with Giza-168 and Gemmiza11

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Table 3: Effect of wheat varieties, nitrogen fertilizer rates and their interaction on nitrogen use efficiency and it attributes in 2018/2019 (1st) and 2019/2020 (2nd).

Treatment		Grains N%		Straw N%		Grains N uptake (Kg fad^{-1})		straw N uptake (Kg fad^{-1})		Total N uptake (Kg fad^{-1})		Nitrogen use efficiency	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Varieties													
Gemmiza-11		1.89 c	1.77 b	0.230 b	0.205 c	40.86 c	35.52 c	11.42 b	9.62 b	52.28 b	45.14 b	35.95 b	33.26 a
Giza-168		2.11 a	1.99 a	0.269 a	0.255 a	43.05 b	37.50 b	12.56 a	11.47 a	55.61 a	48.97 a	33.43 c	30.41 b
Misr-1		2.02 b	1.98 a	0.215 c	0.204 c	46.78 a	42.10 a	9.86 c	8.56 c	56.64 a	50.66 a	38.03 a	34.33 a
Sids-12		1.87 c	1.82 b	0.233 b	0.226 b	38.33 d	34.23 c	11.75 b	10.68 a	50.08 b	44.91 b	34.50 c	31.67 b
N Fertilizer rates													
0 kg		1.43 e	1.34 e	0.150 e	0.141 e	18.40 d	15.70 d	4.39 e	4.08 d	22.79 d	19.79 d	-	-
30 kg		1.74 d	1.67 d	0.205 d	0.192 d	28.78 c	24.72 c	7.91 d	6.67 c	36.69 c	31.38 c	55.30 a	49.49 a
60 kg		2.14 b	2.04 b	0.265 b	0.249 b	47.19 b	41.92 b	12.86 b	11.22 b	60.05 b	53.15 b	36.73 b	34.10 b
90 kg		2.58 a	2.48 a	0.327 a	0.300 a	69.77 a	62.12 a	19.68 a	17.38 a	89.45 a	79.50 a	29.94 c	27.75 c
120 kg		1.97 c	1.92 c	0.238 c	0.232 c	47.13 b	42.23 b	12.14 c	11.07 b	59.28 b	53.30 b	19.95 d	18.33 d
Interaction													
Gemmiza-11	0 kg	1.37 m	1.22 k	0.143 l	0.137 l	17.29 i	14.47 h	4.19 lm	3.86 jk	21.49 h	18.33 i	-	-
	30 kg	1.73 jk	1.67 h	0.217 gh	0.203 hij	29.03 h	25.95 f	7.60 j	6.13 hi	36.63 g	32.08 gh	56.00 b	51.81 a
	60 kg	1.95 fg	1.82 f	0.250 ef	0.227 e-h	43.45 ef	37.54 e	12.74 fg	11.44 de	56.20 e	48.97 f	37.10 e	34.34 c
	90 kg	2.55 b	2.41 b	0.333 a	0.250 de	69.07 b	61.21 b	21.41 a	16.26 b	90.48 b	77.48 b	30.07 g	28.18 e
	120 kg	1.84 hi	1.71 gh	0.213 hij	0.210 ghi	45.46 e	38.43 e	11.14 h	10.43 ef	56.60 e	48.86 f	20.65 h	18.72 f
Giza-168	0 kg	1.59 l	1.47 i	0.196 j	0.177 jk	19.41 i	15.50 h	4.93 l	4.31 jk	24.34 h	19.81 i	-	-
	30 kg	1.91 gh	1.73 fgh	0.237 fg	0.217 ghi	28.06 h	22.08 g	8.69 i	6.79 h	36.74 g	28.87 h	49.00 c	42.53 b
	60 kg	2.33 c	2.22 c	0.303 c	0.290 bc	50.94 d	45.93 d	14.39 d	12.92 cd	65.33 d	58.84 de	36.40 e	34.44 c
	90 kg	2.58 b	2.44 b	0.333 a	0.323 a	65.01 c	56.60 c	20.60 ab	19.60 a	85.61 c	76.20 bc	28.00 g	25.80 e
	120 kg	2.13 d	2.09 d	0.277 d	0.270 cd	51.83 d	47.41 d	14.17 de	13.74 c	66.00 d	61.15 d	20.30 h	18.88 f
Misr-1	0 kg	1.35 m	1.34 j	0.110 m	0.103 m	18.18 i	16.85 h	3.39 m	3.18 k	21.58 h	20.03 i	-	-
	30 kg	1.69 k	1.64 h	0.163 k	0.150 kl	29.85 h	25.15 f	6.08 k	5.14 hij	35.93 g	30.29 h	58.80 a	51.23 a
	60 kg	2.25 c	2.17 cd	0.247 ef	0.233 efg	53.76 d	48.05 d	10.89 h	8.75 g	64.65 d	56.79 e	39.80 d	36.81 c
	90 kg	2.71 a	2.69 a	0.313 bc	0.313 ab	81.01 a	74.37 a	16.83 c	16.42 b	97.83 a	90.78 a	33.23 f	30.74 d
	120 kg	2.10 de	2.07 d	0.240 f	0.220 f-i	51.08 d	46.10 d	12.12 g	9.32 fg	63.20 d	55.41 e	20.30 h	18.55 f
Sids-12	0 kg	1.39 m	1.31 jk	0.150 kl	0.147 l	18.69 i	16.00 h	5.06 l	4.98 ij	23.75 h	20.98 i	-	-
	30 kg	1.64 kl	1.63 h	0.203 ij	0.197 ij	28.18 h	25.68 f	9.27 i	8.61 g	37.45 g	34.29 g	57.40 ab	52.40 a
	60 kg	2.01 ef	1.96 e	0.260 de	0.247 def	40.62 fg	36.19 e	13.40 ef	11.78 de	54.02 ef	47.97 f	33.60 f	30.80 d
	90 kg	2.50 b	2.38 b	0.333 a	0.313 ab	64.01 c	56.31 c	19.88 b	17.24 b	83.88 c	73.55 c	28.47 g	26.28 e
	120 kg	1.81 ij	1.80 fg	0.220 gh	0.227 e-h	40.17 g	36.99 e	11.15 h	10.79 ef	51.31 f	47.78 f	18.55 h	17.18 f

in the first season and with Giza-168 in the second season. On the other hand, supplying the Misr-1 variety with 90 kg N fed^{-1} gave the highest total N uptake values in both seasons. Finally, the highest NUE was recorded by Misr-1 and Sids-14; these were fertilized with 30 kg N fed^{-1} in both growing seasons and Gemmiza-11 in the second season.

Nitrogen agronomic efficiency

The differences in nitrogen agronomic efficiency (NAE) values in both growing seasons resulting from the different wheat genotypes and nitrogen levels are shown in Fig. 2 and 3, respectively. The cultivar Misr-1 recorded the maximum values of NAE in 1st season and Gemmiza-11 in the 2nd season. Consequently, the results show that increasing one unit of nitrogen enhances the grain yield by 14.70 and 12.66 for the cultivars Misr-1 and Gemmiza-11, respectively. However, the lowest values of NAE appeared by Sids-12, which reached 11.17 and 10.43 in the 1st and 2nd seasons, respectively. On the other hand, in both seasons, using fertilizer rate at 90 kg N fed^{-1} produced the highest values of NAE that reached 15.59 and 14.65, but these values were non-significant with using 60 kg N fed^{-1} that reached 15.29 and 14.45 in the first and second seasons, respectively. Increasing the N fertilizer rate to 120 kg N fed^{-1} led to decrease AE values.

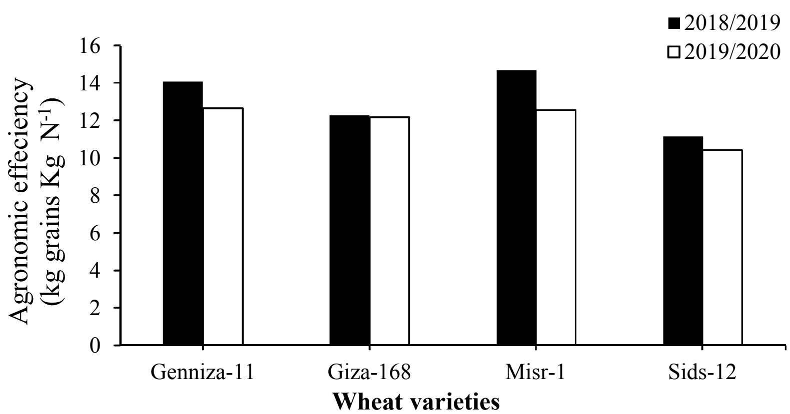

Fig. 2: Effect of different wheat varieties on agronomic efficiency (AE) during the 2018/2019 and 2019/2020 seasons.

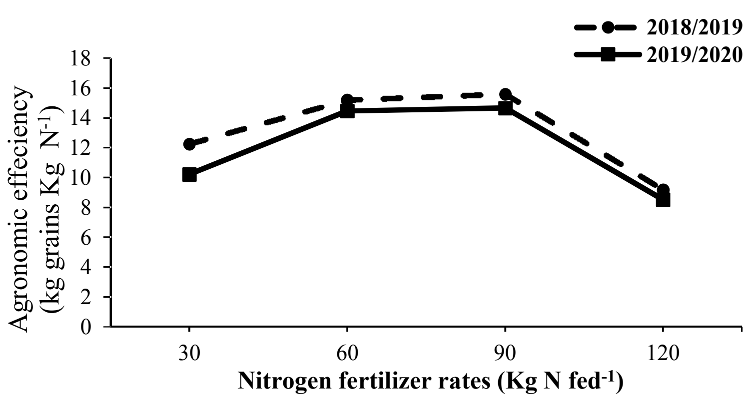

Fig. 3: Effect of nitrogen fertilizer rates on nitrogen agronomic efficiency (NAE) during the 2018/2019 and 2019/2020 seasons

Grain yield response index

The grain yield response index (GYRI) is an indicator to evaluate varieties efficiency in producing higher grain yield at N deficiency and their response to increasing nitrogen fertilizer rates. In this respect, GYRI was calculated based on zero kg N fed^{-1} as a low nitrogen rate and 90 kg N fed^{-1} as a high nitrogen rate.

Also, Fig.4 showed that the mean wheat grain yield at zero N rate was 1291.5 and 1178.67 kg fed−1, and the GYRI mean value for 90 kg N fed^{-1} was 15.59 and 14.65 kg grain kg N fed−1 in 2018/2019 and 2019/2020 seasons, respectively. In both seasons, Misr-1 and Gemmiza-11 belonged to the efficient and responsive (ER) group, exceeding the means of grains yield at zero kg N fed^{-1} rate and GYRI. Sids-12 was neither efficient nor responsive (NENR) since the grains yield at zero kg N fed^{-1} rate and GYRI were lower than the averages in the first and second seasons. Giza-168 belonged to NENR group in the first season while present in the efficient and not responsive (ENR) group in the second season.

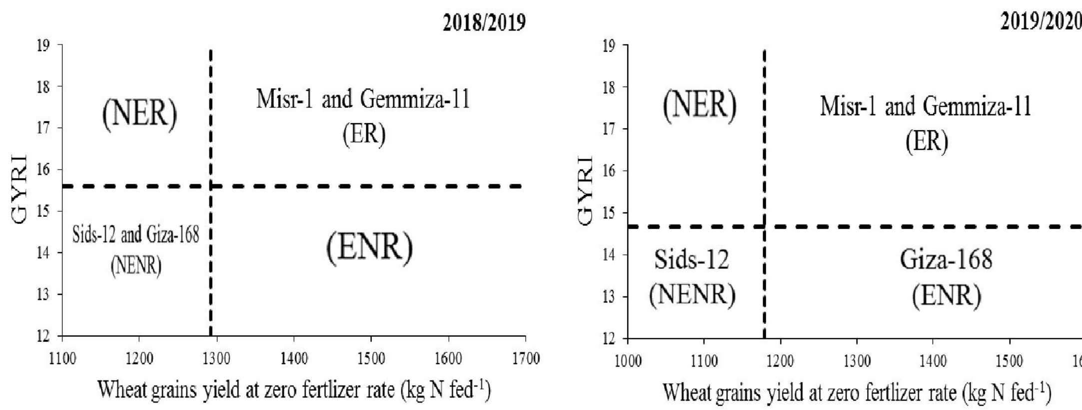

Fig. 4: Grain yield response index (GYRI) of wheat varieties during the 2018/2019 and 2019/2020 seasons

Nitrogen recovery efficiency

Nitrogen recovery efficiency (NRE) was significantly changed among wheat varieties in the two growing seasons of 2018/2019 and 2019/2020 (Fig.5A). Herein, Misr-1 obtained the maximum values of NRE in the first season while statistically equaled with Gemmiza-11 and Giza-168 varieties in NRE during the second season. Sids-12 recorded the lowest values of NRE in both seasons. Also, nitrogen fertilizer rates significantly affected NRE in both growing seasons (Fig.5B). In this connection, increasing nitrogen fertilizer rates from zero to 90 kg N fed^{-1} enhanced values of NRE while exceeding nitrogen fertilizer rates 90 kg N fed^{-1} led to a decline in NRE. On the other hand, NRE was affected by wheat varieties x nitrogen fertilizer rates significantly in both growing seasons (Fig.5C). As for the interaction, Misr-1 variety and 90 kg N fed^{-1} achieved the highest values of NRE while the combination between Sid-12 and 120 kg N fed^{-1} recorded the lowest values of NRE.

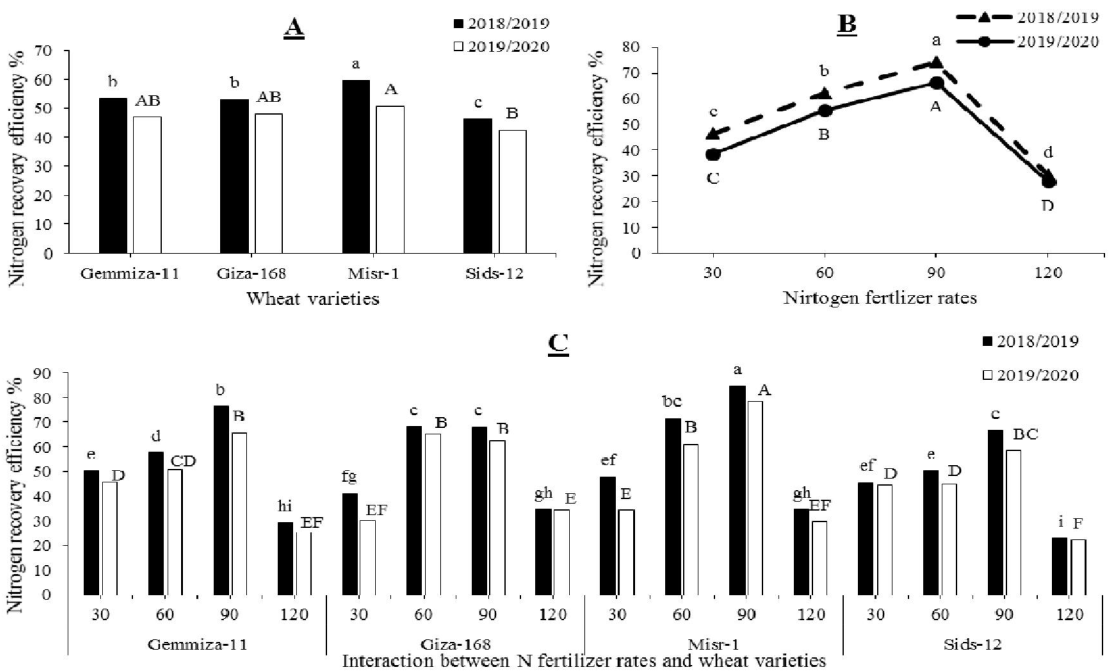

Fig. 5: Effect of different wheat varieties, nitrogen fertilizer rates, and their interactions on nitrogen recovery efficiency (NRE) during the 2018/2019 and 2019/2020 seasons

Discussion

The results of the current study showed the different wheat cultivars' responses to yield and its components (Table 2), N use efficiency and its attributes (Table 3), N agronomic efficiency (Fig. 2 and 3), response grain yield index (Fig. 4), as well as N recovery efficiency (Fig. 5). This refers to the diverse variations among wheat varieties to utilize the absorbed nitrogen owing to their different genetic background. Sial *et al.,* (2007) and Belete *et al.,* (2018) stated that grain yield is the result of the interaction between genotype and environment as well as wheat genotypes vary in absorption, and N utilization depends on the environment. One of the most important goals for plant breeders is elicitation varieties with stability in yield under different environmental conditions. So, the selection of varieties that are appropriate for general farming and others for the specific area and under-defined environments is based on studies of the interaction between genotypes and environment (Khan *et al.,* 2007; Noureldin *et al.,* 2013 and Mansour *et al.,* 2017). El Sayed *et al.,* (2018) explained that the inconsistency in the yield between wheat cultivars from one environment to another may be due to the expression of different groups of genes in different environments or the difference in the responses of the same group of genes to different environments. Moreover, the discrepancy in yield and its components between wheat cultivars may be due to genetic makeup that is reflected in the rate of grain filling and the transfer of photosynthetic products from source to sink (Noureldin *et al.,* 2013). Varietal differences in yield components among wheat cultivars were obtained by El-Habbal *et al.,* (2000), Omar *et al.,* (2014), Kandil *et al.,* (2016) and Gebrel *et al.,* (2019). Wheat varieties evaluation under low and high rates of nitrogen fertilizer conditions is very important. In this respect, some wheat varieties could show high NUE and its attributes, as well as high grain yield under N deficiency. However, under a high nitrogen fertilizer rate, it produces a very low yield (such as Giza-168). These wheat varieties are considered less N-responsive. Therefore, under low N availability conditions, it is recommended to use it. Meanwhile, other wheat varieties could give high yields under low as well as under high N levels, e.g., Misr-1 and Gemmiza-11 These varities are nitrogen efficient and responsive, and they may be suitable for both low and high N availability conditions. In this connection, the positive correlation among grain yield and total N uptake shows diverse responses to nitrogen fertilization recommendations under different environments. These results coincide with the findings of EL-Habbal *et al.,* (2010), Wang *et al.,* (2011), Fageria (2014), Belete *et al.,* (2018).

The increases in wheat yield and its components with increasing N fertilization rate up to an appropriate N dose can be attributed to the dynamic role of nitrogen as an essential component of chlorophyll in dry matter accumulation. N fertilizer affects carbohydrate production by affecting the average leaf area available to intercept solar radiation and absorb carbon dioxide, enhance the efficiency of the photosynthesis cycle. See Table 3, high N supply at optimum range resulted in more productive spikes number m^{-2} (Gomaa *et al.,* 2018), increment in the number of grain $spike^{-1}$ (Ullah *et al.,* 2018 and Al-Naggar *et al.,* 2017), 1000 grain weight (Saleh and Mohamed, 2016 and Mosanaei *et al.,* 2017), and straw yield (Allam, 2005 and Seleem and Abdel-Dayem, 2013). The enhancement in wheat yield under the agreeable increase of N rates were obtained by Sobh *et al.,* (2000), Saudy *et al.,* (2008), and Noureldin *et al.,* (2013). The results cleared that there is a definite trend for the main effect of N rates on wheat yield and its components; it is easy to determine the optimal rate of wheat N fertilization. Therefore, to ensure ample yield, wheat plants can be fertilized with 90 kg N fed−1, as it is more harmonious in achieving high grain yield (Table 4). These results coincide with those reported by Knany *et al.,* (2011), Atia *et al.,* (2012), Atia and Ragab (2013), and Ibrahim *et al.,* (2014). In this respect, this promising treatment (90 kg N fed−1) recorded the highest value of NAE (Fig. 3); this indicated well-applied N exploitation by wheat plants. On the other hand, increasing the N fertilizer rate above 90 kg N fed−1 did not achieve any enhancement for grain yield but led to a decrease in it. In this connection, Kiba *et al.,* 2011 reported that overdose nitrogen fertilizer reduced the filling and weight of grains for middle spikelets compared with those under optimum nitrogen dose. This is because the high nitrogen fertilizer rate inhibited the sucrose transport and accumulation of starch in grains, thereby reducing the grain filling rate.

The GYRI calculation demonstrated the various potentialities of the tested wheat varieties for absorbing and utilising available N in the plant environment. So, grain yields of Misr-1 and Gemmiza-11 were higher, and grain yields of Giza-168 and Sids-12 were lower than the average at N application. This show the ability of both Misr-1 and Gemmiza-11 varieties to absorb N from soil better than Giza-168 and Sids-12. The higher GYRI values than means of Misr-1 and Gemmiza-11 varieties (Fig. 4) mention their genetic potential to be responsive to N fertilizer additions. Differences in GYRI among varieties were obtained by Noureldin *et al.,* (2013) in wheat and Saudy *et al.,* (2018) in sesame.

Conclusions

Wheat varieties clarified diverse performance under difference N rates that was measured by nitrogen recovery efficiency and grain yield response index. The target of nitrogen use should be to match the requirements of each wheat variety as closely as possible with the nitrogen available in the soil to reduce the excess of nitrogen in the soil that is not beneficial to the plant and to avoid pollution of the ecosystem. In light of the increase in fertilizers prices, if nitrogen fertilizers are available, it is preferable to use Misr-1 or Gemmiza-11 with 90 kg N fed, but in case of nitrogen fertilizer shortage it is preferable to use Sids-12 to obtain the highest profitability under the conditions of study area.

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