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NITROGEN USE EFFICIENCY IN BREAD WHEAT ACROSS ENVIRONMENTS

M.A. NAAS[1] and L.I.M. AL-MAJIDI[2*]

[1]Department of Agricultural Research, Ministry of Agriculture, Iraq
[2]Department of Field Crops, College of Agricultural Engineering Sciences, University of Baghdad, Iraq
Corresponding author's emails: ali.nazem@uokerbala.edu.iq, layla.ismael@coagri.uobaghdad.edu.iq
Email address of co-author: Mohammed.Abd1106a@coagri.uobaghdad.edu.iq

SUMMARY

Experiments to evaluate the performance of 10 bread wheat genotypes with nitrogen deficiency and diagnose the optimal genotype for the appropriate environment commenced in the winter seasons, 2021-2022 and 2022-2023, in three locations of Iraq, i.e., Baghdad, Wasit, and Diwaniyah. All the experiments had a randomized complete block design (RCBD) with split-plot arrangement. Nitrogen levels (0, 50, and 100 kg N ha^{-1}) occupied the prime plots, with 10 wheat genotypes (T2, T3, S1, S2, S148, IPA99, Adana99, Rasheed, Buhooth-10, and Buhooth-22) allocated to the subplots with three replications in each location. The interaction of wheat genotypes, nitrogen levels, and locations revealed that genotype S2 with 50 kg N ha^{-1} at Baghdad showed the highest mean nitrogen use efficiency at 105.00 and 96.00 for 2021-2022 and 2022-2023, respectively. However, these values showed nonsignificant differences from the obtained values of wheat genotypes S148 and the IPA-99 during the second season, in the same location and fertilizer level, i.e., 92.87 and 90.00, respectively. Also, the genotype S2 gave the highest grain yield (6.53 t ha^{-1}) with N2 fertilizer level in the Baghdad site, not differing significantly from two other wheat genotypes, S148 and IPA99 (6.13 and 5.85 t ha^{-1}, respectively) in the second season. The presented study authenticated that some wheat genotypes provided good yield under nitrogen stress (50 kg N ha^{-1}), as there were no significant increases in grain yield when doubling the nitrogen level (100 kg N ha^{-1}). Therefore, the study suggested these genotypes' cultivation with nitrogen deficiency to preserve a healthy environment and promote sustainable agriculture.

Keywords: Bread wheat (*Triticum aestivum* L.), cultivars, nitrogen levels, locations, genotype by environment interaction, combined analysis, biological and grain yield

Key findings: Wheat genotype S2 with 50 kg N ha^{-1} in Baghdad for both seasons had the highest nitrogen utilization efficiency of 105.00 and 96.00. Likewise, the genotypes S-148 and IPA-99 yielded 92.87 and 90.00 in the second season at the exact location with the same nitrogen level. In Baghdad, genotype S2 with 100 kg N ha^{-1} produced 6.53 t ha^{-1} and was at par with S-148 and IPA-99, which yielded 6.13 and 5.85 t ha^{-1} in the second season.

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INTRODUCTION

In crop productivity, one of the most challenging schemes is to achieve the better genetic potential of genotypes under diverse and stressful environmental conditions. In genotype-by-environment interaction, the wheat varieties indicate a differing response to varied ecological settings, and the ideal genotype must have the highest mean grain yield and the lowest degrees of variation in productivity when grown under diverse environments. Wheat is a unique cereal crop, given that its flour contains a complex protein called gluten that forms the elastic properties of dough for making bread (Al-Behadili and Ziyad, 2019).

Heritability may vary in a given community depending on the environment in which it grows, and genetic variance depends on the extent of environmental change (Hadi *et al.*, 2019). The introduction and derivation of new genetic patterns suitable for soil and climate conditions in any environment with high bread wheat productivity and genetic stability is necessary (Al-Ubaidi, 2013). Mineral nutrition problems in wheat are regional as the efficiency of added ratios of fertilizers depends upon the specific climatic conditions, multiple soil, and genotypic traits based on its response to environmental conditions and accumulation and transport of minerals (Kostic *et al*., 2021).

Therefore, management in this field effectively influences production toward diagnosing genotypes that respond to low nitrogen levels. There is an increasing focus worldwide on breeding wheat varieties with the potential to improve nitrogen use efficiency (NUE) and reduce excessive fertilizers while maintaining an optimum grain yield (Foulkes *et al*., 2009). Improving NUE is an influential goal because it increases profitability by raising productivity or reducing fertilization costs.

The instability of quantitative genetic traits from one environment to another may arise from gene expression for a group of genes or variation in their response and interaction with the existing environments. Therefore, studies on genetic-environment interactions are crucial in determining the genetic potential of maize genotypes with high productivity and stability over a wide range of environments (Hadi and Hassan, 2021). Al-Hassan (2011) mentioned a significant difference in wheat grain yield with different nitrogen levels, and the level of 200 kg N ha^{-1} was superior by giving the highest mean grain yield (6.254 t ha^{-1}), which did not differ significantly from the level of 150 kg N ha^{-1} (6.204 t ha^{-1}) compared with other levels.

Past studies enunciated that evaluating 20 wheat genotypes under diverse environmental conditions revealed significant differences among the genotypes in the central region of Iraq (Almajidy *et al.*, 2017; Swailam *et al*., 2021; Khan *et al*., 2023). Grain yield enhancement can also occur by increasing the biomass with harvest index in lowland rice and other cereals (Gholizadeh *et al.,* 2017; Yulita *et al*., 2021). Bektash and Naes (2016) found significant differences among the different bread wheat lines for biological yield while studying several genotypes, with the wheat line 12-S recorded with the highest grain yield (16.96 t ha^{-1}).

Benchelali *et al.* (2022) found in their study of four durum wheat (*Triticum durum* Desf.) genotypes with four nitrogen levels (0, 40, 80, and 120 kg N ha^{-1}) over three seasons, the highest NUE (19.06) appeared at fertilizer level 40 kg N ha^{-1}, and the highest fertilizer level (120 kg N ha^{-1}) emerged with the less NUE value (10.91). Possessing a large group of wheat genotypes makes Iraq distinct; hence, it needs to determine the extent to which these genotypes adapted to specific environments or groups of environments under nitrogen-deficit conditions. The pertinent research sought the possibility of diagnosing the ideal wheat genotype for the appropriate surroundings and its adaptation to several environments with high nitrogen use efficiency.

MATERIALS AND METHODS

The presented research focused on 10 bread wheat genotypes with nitrogen deficiency and diagnosing the optimal genotype for the appropriate environment, performed in the winter seasons, 2021-2022 and 2022-2023, in three locations of Iraq, i.e., Baghdad, Wasit, and Diwaniyah. The first location was at the College of Agricultural Engineering Sciences, Baghdad University - Al-Jadriya, Baghdad; the second was at the Agriculture Research Station, Wasit; and the third was at the Agriculture Research Station, Diwaniyah. The second and third locations were also affiliates of the Agricultural Research Department, Ministry of Agriculture, Iraq. All the experiments had a randomized complete block design (RCBD) with split-plot arrangements. Nitrogen levels (0, 50, and 100 kg N ha^{-1}) occupied the main plots, while the 10 wheat genotypes (T2, T3, S1, S2, S148, IPA99, Adana99, Rasheed, Buhooth-10, and Buhooth-22) occupied the subplots with three replications in each location.

Soil preparation operations included plowing and leveling, followed by field planning and adding triple superphosphate fertilizer (P_2O_5 45%) at a rate of 100 kg P_2O_5 ha^{-1} in one installment during soil preparation (Jadoua and Saleh, 2013). Urea fertilizer (N 46%) was used according to treatments (0, 100, and 200 kg N ha^{-1}) as fertilizer application per soil analysis (Table 1) to reach the required level had three installments (planting, elongation, and filling stages). The first irrigation transpired on November 23, 2021, in all locations. Data recording on traits comprised biological yield per unit area and grain yield per unit area (t ha^{-1}), harvest index (%), and nitrogen use efficiency (NUE).

Statistical analysis

Data analysis used the combined analysis of variance over locations per RCBD with a split-plot arrangement (Gomez and Gomez, 1984). The least significant difference ($LSD_{0.05}$) test helped compare and separate the mean differences. The analysis employed the statistics software GenStat12.

RESULTS AND DISCUSSION

Biological yield

Results revealed that the mean for all cultivars, the Baghdad location has recorded 12.30 and 11.33 t ha^{-1} of biological yield for the two winters, 2021-2022 and 2022-2023, respectively, and the Diwaniyah location recorded the lowest mean of 10.82 and 9.39 t ha^{-1} for two seasons, respectively (Tables 2 and 3). It could be due to the soil texture in the Baghdad site having a low salinity and high

Table 1. Analysis of the chemical and physical properties of the soil of the experimental locations.

Parameters	Unit	Growing season 2021-2022		
		Baghdad	Al-Saouara (Wasit)	Diwaniyah
pH	-	7.4	7.2	7.2
Ec	ds.m^{-1}	2.40	4.20	4.35
N	PPM	18	16	14
P	PPM	6.00	4.21	4.20
K	PPM	190	150	160
OM%	%	0.73	0.59	0.44
Sand	%	36.00	14.8	21.00
Clay	%	16.90	50.0	45.5
Silt	%	47.10	35.2	33.5
		Growing season 2022-2023		
pH	-	6.8	7.2	7.4
Ec	ds.m^{-1}	2.0	3.5	4.5
N	PPM	21.0	18.0	14.0
P	PPM	21.0	10.0	8.0
K	PPM	373.0	220.0	190.0
OM%	%	0.75	0.65	0.40
Sand	%	37.00	14.00	45.80
Clay	%	15.00	51.00	20.00
Silt	%	48.00	35.00	34.20

Table 2. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the biological yield (t ha^{-1}) of bread wheat for the 2021-2022 season.

Location	N Level	Wheat genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth 10	Buhooth 22	
Baghdad	N0	10.23	10.15	9.98	10.31	10.04	10.04	10.12	10.78	9.27	10.61	10.15
	N1	12.64	10.60	11.31	15.27	11.37	13.54	12.42	12.03	10.86	13.55	12.36
	N2	13.23	12.88	14.60	18.26	13.43	15.41	14.25	14.41	12.15	15.30	14.39
Wasit	N0	7.80	7.71	7.97	6.53	7.82	7.51	6.56	8.73	8.69	9.23	7.85
	N1	10.38	10.64	11.73	14.56	10.83	14.21	11.26	12.53	11.30	14.42	12.18
	N2	11.92	11.60	13.41	15.52	12.78	16.25	12.28	12.90	12.70	15.76	13.51
Diwaniyah	N0	6.95	7.08	7.45	7.25	8.34	7.41	6.79	8.01	8.24	8.88	7.64
	N1	11.02	10.95	12.13	11.82	11.75	11.72	10.25	12.11	11.64	13.96	11.73
	N2	11.75	13.03	13.01	13.39	12.67	13.89	12.11	12.72	12.65	15.68	13.09
LSD 0.05	0.74											0.31
												N
Genotype × N	N0	8.33	8.31	8.46	8.03	8.73	8.32	7.82	9.17	8.73	9.57	8.55
	N1	11.34	10.73	11.72	13.88	11.32	13.15	11.31	12.22	11.26	13.97	12.09
	N2	12.30	12.50	13.67	15.72	12.96	15.18	12.88	13.34	12.50	15.58	13.66
LSD 0.05	0.42											0.15
												Location
Genotype × Location	Baghdad	12.03	11.21	11.96	14.61	11.61	13.00	12.26	12.41	10.76	13.15	12.30
	Wasit	10.03	9.98	11.04	12.20	10.48	12.66	10.03	11.39	10.90	13.14	11.18
	Diwa	9.90	10.35	10.86	10.82	10.92	11.00	9.72	10.94	10.84	12.84	10.82
LSD 0.05	0.45											0.27
Genotypes		10.66	10.51	11.29	12.54	11.00	12.22	10.67	11.58	10.83	13.04	
LSD 0.05	0.24											

Table 3. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the biological yield (t ha^{-1}) of bread wheat for the 2022-2023 season.

Location	N Level	Genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth10	Buhooth22	
Baghdad	N0	8.40	8.88	8.86	8.23	8.26	8.53	7.66	7.81	8.56	9.21	8.77
	N1	10.43	11.53	11.00	13.00	13.16	13.66	11.73	11.66	10.80	11.66	11.86
	N2	11.90	13.10	12.73	16.56	15.06	14.70	12.46	13.03	13.43	14.06	13.70
Wasit	N0	6.20	6.13	5.93	6.200	7.66	7.36	6.16	6.36	6.33	6.46	6.48
	N1	8.30	8.80	8.70	10.50	11.06	12.90	9.60	10.36	10.60	12.83	10.36
	N2	10.80	11.33	11.13	12.80	13.83	15.20	13.06	12.10	14.33	14.50	12.91
Diwaniyah	N0	5.06	5.86	5.46	5.96	6.80	6.80	6.13	5.80	5.60	7.00	6.05
	N1	8.56	9.03	8.43	9.83	10.66	11.33	7.83	9.10	10.83	12.26	9.79
	N2	10.70	11.46	9.86	12.40	12.73	13.53	11.76	13.83	12.43	14.56	12.33
LSD 0.05	1.10											1.07
												N
Genotype × N	N0	6.55	6.96	6.75	6.80	7.57	7.56	6.65	6.66	6.83	7.56	6.99
	N1	9.10	9.78	9.37	11.11	11.63	12.63	9.72	10.37	10.74	12.25	10.67
	N2	11.13	11.96	11.24	13.92	13.87	14.47	12.43	12.98	13.40	14.37	12.98
LSD 0.05	0.26											0.12
												Location
Genotype × Location	Baghdad	10.24	11.17	10.86	12.60	12.16	12.30	10.62	10.83	10.93	11.65	11.33
	Wasit	8.43	8.75	8.58	9.83	10.85	11.82	9.61	9.61	10.42	11.26	9.92
	Diwa	8.11	8.78	7.92	9.40	10.06	10.55	8.57	9.57	9.62	11.27	9.39
LSD 0.05	1.07											1.07
Genotypes		8.93	9.57	9.12	10.61	11.03	11.55	9.60	10.00	10.32	11.39	
LSD 0.05	0.14											

organic matter (Table 1). The 100 kg N ha^{-1} fertilizer level produced 13.66 and 12.98 t ha^{-1} for the two seasons. It could be because of the nitrogen role in increasing dry matter. Ibrahim (2018) also recorded similar grain yield in wheat genotypes in studying the effects of different levels of nitrogen fertilizer on wheat growth and yield. The latest results further revealed that wheat genotype Buhooth-22 gave 13.04 t ha^{-1} in the first season, and IPA-99 produced 11.55 t ha^{-1} in the second season.

Table 4. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the grain yield (t ha^{-1}) of bread wheat for the 2021-2022 season.

Location	N level	Genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth10	Buhooth22	
Baghdad	N0	2.720	2.367	2.683	2.937	2.407	2.823	2.467	2.480	2.397	2.873	2.615
	N1	4.330	3.350	3.900	5.250	3.757	4.487	4.003	3.587	3.730	4.570	4.096
	N2	5.053	4.297	5.090	6.283	4.457	5.300	4.660	4.457	4.187	5.420	4.920
Wasit	N0	1.963	1.763	2.030	1.907	1.813	1.977	1.473	1.813	2.067	2.460	1.927
	N1	3.457	3.490	4.033	4.800	3.400	4.813	3.503	3.733	3.490	4.790	3.951
	N2	4.063	3.827	4.513	5.230	4.063	5.707	4.060	4.097	4.153	5.360	4.507
Diwaniyah	N0	1.877	1.617	1.967	1.843	1.880	2.047	1.507	1.657	1.980	2.370	1.874
	N1	3.417	3.253	3.913	4.000	3.627	3.967	3.267	3.397	3.583	4.587	3.701
	N2	3.897	3.957	3.937	4.627	4.017	4.777	3.987	3.800	4.700	5.343	4.241
LSD 0.05	N.S											0.257 N
Genotype × N	N0	2.187	1.916	2.227	2.229	2.033	2.282	1.816	1.983	2.148	2.568	2.139
	N1	3.734	3.364	3.949	4.683	3.594	4.422	3.591	3.572	3.601	4.649	3.916
	N2	4.338	4.027	4.513	5.380	4.179	5.261	4.236	4.118	4.137	5.374	4.556
LSD 0.05	0.137											0.301 Location
Genotype × Location	Baghdad	4.034	3.338	3.891	4.823	3.540	4.203	3.710	3.508	3.438	4.288	3.877
	Wasit	3.161	3.027	3.526	3.979	3.092	4.166	3.012	3.214	3.237	4.203	3.462
	Diwa	3.063	2.942	3.272	3.490	3.174	3.597	2.920	2.951	3.211	4.100	3.272
LSD 0.05	0.210											0.328
Genotypes		3.420	3.102	3.563	4.097	3.269	3.989	3.214	3.224	3.295	4.197	
LSD 0.05	0.168											

A reason for this is the difference in wheat genotypes during growth that contributes to accumulating dry matter (Muhammad*,* 2018; Hussein, 2022).

However, the 100 kg N ha^{-1} fertilizer level gave the highest biological yield of 14.39 and 13.70 t ha^{-1} for two seasons, in the Baghdad location but did not differ significantly from the Wasit location with 100 kg N ha^{-1} in the second season (12.91 t ha^{-1}). Conversely, the control treatments provided the lowest biological yield mean of 7.64 and 6.05 t ha^{-1} for the two seasons in the Diwaniyah location. Results further authenticated that the Baghdad site gave the highest mean at all nitrogen levels, which was due to the high organic matter and low salinity in the location, causing a grain yield increase, which is one of the biological yield's major components (Ghimire *et al.*, 2021; Swailam *et al.*, 2021; Khan *et al.*, 2023). In a three-way interaction, the wheat genotype S2 at the Baghdad location with 100 kg N ha^{-1} showed the highest biological yield (18.26 and 16.56 t ha^{-1}) for the two seasons. The genotype Adana in the Diwaniyah area with control recorded the lowest mean (6.79 t ha^{-1}) in the first season; genotype T2 with control at the exact location also showed the lowest biological yield (5.06 t ha^{-1}) in the second growing season.

Table 5. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the grain yield (t ha^{-1}) of bread wheat for the 2022-2023 season.

Location	N Level	Genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth10	Buhooth22	
Baghdad	N0	2.07	2.01	2.08	2.39	2.31	2.30	1.79	1.87	1.99	2.25	2.10
	N1	3.46	3.43	3.47	4.80	4.64	4.66	3.81	3.78	3.86	4.22	4.01
	N2	4.37	4.41	4.20	6.53	6.13	5.85	4.31	4.26	4.90	5.21	5.01
Wasit	N0	1.46	1.33	1.43	1.56	1.65	1.80	1.33	1.31	1.40	1.43	1.47
	N1	2.71	2.76	2.85	3.48	3.60	4.20	2.82	2.93	3.33	4.25	3.29
	N2	3.61	3.46	3.50	4.26	4.50	5.25	3.96	3.82	4.80	5.13	4.23
Diwaniyah	N0	1.23	1.24	1.31	1.41	1.45	1.63	1.29	1.17	1.20	1.59	1.35
	N1	2.50	2.45	2.55	3.12	3.33	3.76	2.21	2.33	3.30	3.86	2.94
	N2	3.36	3.23	3.13	3.86	4.16	4.45	3.54	3.71	4.04	4.95	3.84
LSD 0.05	0.76											0.72
												N
Genotype	N0	1.59	1.53	1.60	1.79	1.80	1.91	1.47	1.45	1.53	1.75	1.64
× N	N1	2.89	2.88	2.95	3.80	3.86	4.21	2.94	3.01	3.50	4.11	3.41
	N2	3.78	3.70	3.61	4.88	4.93	5.18	3.94	3.93	4.58	5.10	4.36
LSD 0.05	0.20											0.08
												Location
Genotype	Baghdad	3.30	3.28	3.25	4.57	4.36	4.27	3.30	3.30	3.58	3.89	3.71
× Location	Wasit	2.60	2.51	2.59	3.10	3.25	3.75	2.70	2.68	3.18	3.60	3.00
	Diwa	2.36	2.30	2.33	2.80	2.98	3.28	2.35	2.40	2.84	3.46	2.71
LSD 0.05	0.73											0.72
Genotypes		2.75	2.70	2.72	3.49	3.53	3.76	2.78	2.80	3.20	3.65	
LSD 0.05	0.11											

Grain yield

Findings disclosed that the grain yield also differed among the wheat genotypes and locations (Tables 4 and 5). On mean and overall genotypes, the Baghdad location resulted in 3.88 and 3.71 t ha^{-1} for 2021-22 and 2022-23, respectively. It could refer to the best soil texture with high organic matter and low salinity (Table 1). The nitrogen fertilizer level (100 kg N ha^{-1}) gave 4.56 and 4.36 t ha^{-1} for the two seasons. Similar results occurred in past studies in wheat (*Triticum aestivum* L.) concerning nitrogen fertilization (Tsvey *et al.,* 2021). The genotypes S-2 and Buhooth-22 produced 4.10 and 4.20 t ha^{-1} in the first season. The genotypes IPA-99 and Buhooth-22 gave 3.76 and 3.65 t ha^{-1} in the second season. The superiority of the wheat genotypes is the presence of a considerable number of spikes per unit area, a high number of grains per spike, and a high grain weight. In morphological and grain yield evaluation, the wheat genotypes varied values under diverse environments (Rasool *et al.*, 2021).

Genotypes S-2, Buhooth-22, and IPA-99 manifested 5.38, 5.37, and 5.26 t ha^{-1}, respectively, with N2 fertilizer level (100 kg N ha^{-1}). In the first season, nonsignificant differences resulted in these genotypes at the N1 fertilizer level (50 kg N ha^{-1}) (4.68, 4.65, and 4.42 t ha^{-1}, respectively). However, it was also noteworthy that when doubling the fertilizer level (100 to 200 kg urea ha^{-1}), the yield increased by 13%–15%. During the second season, genotypes IPA-99 and Buhooth-22 appeared with 5.18 and 5.10 t ha^{-1}. In durum wheat, varied values occurred for grain yield and quality traits under low and high nitrogen conditions (Mariem *et al.,* 2020). The wheat genotype S-2 in the Baghdad location gave 4.82 t ha^{-1} due to the highest biological yield and harvest index in the first season. However, in the second season in the Baghdad site, the genotypes S-2, S-148, IPA-99, and Buhooth-22 gave 4.57, 4.36, 4.27, and 3.89 t ha^{-1}, respectively. The superiority of these genotypes was because S-2 and S-148 have the highest grain weight, IPA-99 has the maximum number of grains per spike, and the genotype Buhooth-22 has more spikes per unit area and number of grains. The N2 fertilizer level (100 kg N ha^{-1}) outperformed others significantly in the Baghdad site by showing grain yields of 4.92 and 5.01 t ha^{-1} for two seasons due to the utmost biological yield and harvest index. In the triple interaction, the genotype S-2 provided the highest grain yield in the Baghdad area with 100 kg N ha^{-1} (6.53 t ha^{-1}); however, it did not differ significantly from two other genotypes, i.e., S-148 and IPA-99 (6.13 and 5.85 t ha^{-1}, respectively) during the second season (Bektash and Naes, 2016).

Harvest Index

The results showed that the Baghdad location outperformed the rest, with the highest harvest index mean (31.02%), while the Diwaniyah area recorded the lowest mean (29.54%) in the first season (Table 6). It may refer to the highest grain yield at this location compared with the Diwaniyah site. The nitrogen level (100 kg N ha^{-1}) provided the highest harvest index of 33.44% and 33.23% for crop seasons 2021-22 and 2022-23, respectively (Tables 6 and 7). It could also be due to the improved efficiency of converting photosynthesis products into grains (Tehulie, 2021). Genotypes differed significantly in the harvest index, with the IPA-99 recording a harvest index of 31.86%, which differed nonsignificantly from two other genotypes, i.e., S-2 and Buhooth-22 (31.84% and 31.53%, respectively) in the first season.

The wheat genotypes S-2, IPA-99, Buhooth-22, and S-148 (31.28%, 31.27%, 30.56%, and 30.55%, respectively) excelled in the second season by indicating the highest efficiency in exploiting available growth factors. Past studies revealed the same findings by studying the response of some bread wheat cultivars to nitrogen fertilizers under sandy soil conditions (Said and Abd-El-Moneem, 2016). In the first season, the genotype T-2 showed the highest harvest index with 100 kg N ha^{-1} (35.16%), while the genotypes T-2 and S-2 resulted in a harvest index of 33.02% and 32.42%, respectively, at the Baghdad location in the first season. As for the second season, genotypes S-2, S-148, IPA-99, and Buhooth-22 signified harvest indexes of 34.92%, 34.67%, 33.70%, and 32.30%, respectively, at the specific location. The Baghdad area recorded a harvest index of 34.22% and 36.12% for two seasons, respectively, with 100 kg N ha^{-1}. The three-way interaction gave a significant difference in the first season, and the wheat genotype T-2 appeared with the maximum harvest index of 100 kg N ha^{-1} in the Baghdad location (38.23%), and genotype Rasheed showed the lowest mean harvest index (20.66%) with the control treatment in the Diwaniyah location.

Table 6. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the harvest index (%) of bread wheat for the 2021-2022 season.

Location	N Level	Genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth10	Buhooth 22	
Baghdad	N0	26.56	23.31	26.86	28.49	23.98	28.09	24.35	22.97	25.86	27.10	25.76
	N1	34.27	31.58	34.47	34.39	33.02	33.13	32.22	29.81	34.32	33.73	33.09
	N2	38.23	33.68	34.86	34.39	33.16	34.39	32.69	30.91	34.46	35.42	34.22
Wasit	N0	25.20	22.89	25.46	29.16	23.19	26.30	22.49	20.73	23.78	26.63	24.58
	N1	33.28	32.79	34.35	32.96	31.36	33.87	31.10	29.78	30.87	33.20	32.35
	N2	34.08	32.98	33.65	33.56	32.80	35.10	33.07	33.08	32.68	34.00	33.50
Diwaniyah	N0	27.00	22.76	26.38	25.40	22.53	27.57	22.15	20.66	24.02	26.71	24.52
	N1	30.99	29.88	32.24	33.71	30.85	33.83	31.86	28.04	30.79	32.87	31.50
	N2	33.17	30.35	32.88	34.55	31.68	34.44	32.89	29.86	32.17	34.07	32.61
LSD 0.05	1.11											0.32
												N
Genotype × N	N0	26.25	22.98	26.23	27.68	23.23	27.32	23.00	21.45	24.55	26.81	24.95
	N1	32.84	31.41	33.68	33.68	31.74	33.61	31.73	29.21	31.99	33.27	32.32
	N2	35.16	32.33	33.80	34.17	32.55	34.64	32.89	31.28	33.10	34.50	33.44
LSD 0.05	0.137											0.301
												Location
Genotype × Location	Baghdad	33.02	29.52	32.06	32.42	30.05	31.87	29.75	27.90	31.54	32.08	31.02
	Wasit	30.85	29.55	31.15	31.89	29.12	31.75	28.89	27.86	29.11	31.28	30.15
	Diwaniyah	30.39	27.66	30.50	31.22	28.35	31.94	28.97	26.19	28.99	31.22	29.54
LSD 0.05	0.64											0.18
Genotypes		31.42	28.91	31.24	31.84	29.17	31.86	29.20	27.32	29.88	31.53	
LSD 0.05	0.370											

Table 7. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the harvest index (%) of bread wheat for the 2022-2023 season.

Location	N level	Genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth10	Buhooth22	
Baghdad	N0	24.57	22.63	23.27	28.93	28.27	26.90	23.50	23.77	23.10	24.33	24.93
	N1	33.00	29.60	31.40	36.80	35.20	34.60	32.43	32.37	35.33	35.83	33.66
	N2	36.33	33.50	32.67	39.03	40.53	39.60	34.00	32.50	36.33	36.73	36.12
Wasit	N0	23.00	21.50	23.73	24.63	21.40	24.27	21.33	20.17	21.70	21.87	22.36
	N1	32.20	31.17	32.47	33.13	32.00	32.13	29.07	28.07	31.30	33.00	31.45
	N2	33.33	30.43	31.00	33.07	32.33	34.40	30.27	31.47	33.33	35.30	32.49
Diwaniyah	N0	24.03	20.67	23.33	23.33	21.00	23.87	20.83	20.27	21.27	22.67	22.13
	N1	29.00	27.07	29.93	31.57	31.67	32.90	28.07	25.63	30.33	31.33	29.75
	N2	31.40	28.17	31.50	31.00	32.57	32.73	29.93	27.00	32.53	33.93	31.08
LSD 0.05	n.s											4.04
												N
Genotype × N	N0	23.87	21.60	23.44	25.63	23.56	25.01	21.89	21.40	22.02	22.96	23.14
	N1	31.40	29.28	31.27	33.83	32.96	33.21	29.86	28.69	32.32	33.39	31.62
	N2	33.69	30.70	31.72	34.37	35.14	35.58	31.40	30.32	34.07	35.32	33.23
LSD 0.05	n.s											0.60
												Location
Genotype × Location	Baghdad	31.30	28.58	29.11	34.92	34.67	33.70	29.98	29.54	31.59	32.30	31.57
	Wasit	29.51	27.70	29.07	30.28	28.58	30.27	26.89	26.57	28.78	30.06	28.77
	Diwa	28.14	25.30	28.26	28.63	28.41	29.83	26.28	24.30	28.04	29.31	27.65
LSD 0.05												n.s
Genotypes		29.65	27.19	28.81	31.28	30.55	31.27	27.71	26.80	29.47	30.56	
LSD 0.05	1.18											

Nitrogen use efficiency

The experimental location of Baghdad incurred the highest nitrogen use efficiency (NUE) of 67.92 compared with the two other locations, i.e., Wasit and Diwaniyah, which recorded 61.51 and 61.35, respectively, in the first season (Table 8). The fertilizer level application of 50 kg N ha^{-1} gave the highest mean of 78.39 and 68.36 for the two seasons, respectively (Tables 8 and 9). In the soil system, the nitrogen use efficiency decreases, and the risk of its loss increases with increasing application rates (Jawad and Laila, 2019). The wheat genotypes differed for NUE as the genotype Buhooth-22 showed 75.72 in the first season, while IPA-99 gave the NUE value of 63.07 in the second season. It could be due to the difference in roots of varied genotypes and their ability to absorb nitrogen fertilizer in the soil (Mahjourimajd *et al.,* 2016). Increased levels of nitrogen fertilizer led to a reduction in NUE for all genotypes, as the genotype S-2 at N1 (50 kg N ha^{-1}) showed an NUE value of 93.58, which did not differ significantly from the genotype Buhooth-22 (92.98) in the first season.

In the second season, the genotype IPA-99 did not differ significantly from the Buhooth-22 with a fertilizer application of 50 kg N ha^{-1}, recording NUE values of 83.09 and 82.20, respectively. The genotypic differences could be due to their ability to absorb nitrogen at different fertilization levels, leading to a difference in NUE (Barraclough *et al.,* 2010). Results further indicated that genotypes showed higher NUE values at the Baghdad location except for the genotypes Buhooth-10 and Buhooth-22, which showed similar means in all locations for two seasons. However, the genotype S-2 gave the highest mean for the said trait in the Baghdad location (83.13 and 72.69, respectively) for both seasons. The soil analysis also revealed that the Baghdad site was less saline than the Wasit and Diwaniyah locations, with affected nitrogen absorption ability and NUE. The N1 fertilizer level in the Baghdad area gave the maximum mean of NUE (81.91 and 80.02) for the two seasons. In the three-way interaction, the genotype S-2 with N1 fertilizer level in the research site of Baghdad gave the utmost mean of 105.00 and 96.00 for the two seasons, respectively.

Table 8. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the Nitrogen Use Efficiency (NUE) of bread wheat for the 2021-2022 season.

Location	N Level	Genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth10	Buhooth22	
Baghdad	N0	75.55	65.75	74.56	81.55	66.87	78.43	68.50	68.90	66.55	79.82	72.65
	N1	86.60	66.80	78.00	105.00	75.13	89.73	80.07	71.73	74.60	91.40	81.91
	N2	50.53	42.97	50.90	62.83	44.57	53.00	46.60	44.57	41.87	54.20	49.20
Wasit	N0	61.36	55.10	63.43	59.59	56.67	61.77	46.07	56.67	64.59	76.90	60.21
	N1	69.13	72.00	80.67	96.00	68.00	96.27	70.07	74.67	69.80	95.80	79.24
	N2	40.63	38.27	45.13	52.30	40.63	57.07	40.60	40.97	41.53	53.60	45.07
Diwaniyah	N0	67.00	57.74	70.23	65.82	67.17	73.09	53.83	59.20	70.73	84.63	66.95
	N1	68.33	65.40	78.27	79.73	72.53	79.33	65.33	67.93	71.67	91.73	74.03
	N2	38.97	39.57	42.70	49.60	40.17	47.83	39.87	38.00	40.70	53.43	43.08
LSD 0.05	4.66											1.94
												N
Genotype × N	N0	67.97	59.53	69.41	68.99	63.57	71.10	56.13	61.59	67.29	80.45	66.60
	N1	74.69	68.07	78.98	93.58	71.89	88.44	71.82	71.44	72.02	92.98	78.39
	N2	43.38	40.27	46.24	54.91	41.79	52.63	42.36	41.18	41.37	53.74	45.79
LSD 0.05	2.67											1.10
												Location
Genotype × Location	Baghdad	70.89	58.51	67.82	83.13	62.19	73.72	65.06	61.73	61.00	75.14	67.92
	Wasit	57.04	55.12	63.08	69.30	55.10	71.70	52.24	57.43	58.64	75.43	61.51
	Diwa	58.10	54.23	63.73	65.05	59.96	66.75	53.01	55.04	61.03	76.60	61.35
LSD 0.05	2.74											1.42
Genotypes		62.01	55.95	64.88	72.49	59.08	70.72	56.77	58.07	60.23	75.72	
LSD 0.05	1.50											

Table 9. Combine analysis of locations, levels of nitrogen fertilization, and genotypes of the Nitrogen Use Efficiency (NUE) of bread wheat for the 2022-2023 season.

Location	N Level	Genotypes										N × Location
		T2	T3	S1	S2	S148	IPA99	Adana99	Rasheed	Buhooth10	Buhooth22	
Baghdad	N0	49.23	47.97	49.23	56.73	54.90	54.70	42.67	44.43	47.47	53.53	50.09
	N1	69.33	68.73	69.53	96.00	92.87	90.00	76.33	74.67	77.33	84.40	80.02
	N2	43.73	44.10	42.00	65.33	61.33	58.57	43.10	42.67	49.00	52.10	50.19
Wasit	N0	40.27	37.00	39.60	43.30	45.47	49.97	36.97	37.33	38.83	40.00	40.87
	N1	54.33	55.20	63.00	69.67	71.33	84.00	56.40	56.67	66.67	85.00	66.23
	N2	36.17	34.60	35.00	42.67	45.00	52.50	39.67	38.20	48.07	51.33	42.32
Diwaniyah	N0	44.00	43.97	45.13	50.00	51.80	58.17	45.90	41.90	42.50	56.67	48.00
	N1	50.00	49.00	51.00	62.47	66.67	75.27	44.20	46.67	66.00	77.20	58.85
	N2	33.67	32.33	31.33	38.67	41.67	44.50	35.47	37.17	40.43	49.50	38.47
LSD 0.05	13.84											13.12
												N
Genotype × N	N0	44.50	42.98	44.66	50.01	50.72	54.28	41.84	41.22	42.93	50.07	46.32
	N1	57.89	57.64	61.18	76.04	76.96	83.09	58.98	59.67	70.00	82.20	68.36
	N2	37.86	37.01	36.11	48.89	49.33	51.86	39.41	39.34	45.83	50.98	43.66
LSD 0.05	4.26											2.69
												Location
Genotype × Location	Baghdad	54.10	53.60	53.59	72.69	69.70	67.76	54.03	54.26	57.93	63.34	60.10
	Wasit	43.59	42.27	45.87	51.88	53.93	62.16	44.34	44.07	51.19	58.78	49.81
	Diwa	42.56	41.77	42.49	50.38	53.38	59.31	41.86	41.91	49.64	61.12	48.44
LSD 0.05	13.10											n.s
Genotypes		46.75	45.88	47.31	58.31	59.00	63.07	46.74	46.74	52.92	61.08	
LSD 0.05	2.10											

However, it did not differ significantly from the genotypes S-148 and IP-A99 in the second season at the particular location and same fertilizer level (92.87 and 90.00, respectively). The variation between the wheat genotypes reflects a wide range of genetic variations for NUE, and the three genotypes, i.e., Buhooth-22, IPA-99, and S-2, exhibited characteristics of higher NUE.

CONCLUSIONS

It is conclusive that the wheat genotypes S-2, IPA-99, and Buhooth-22 revealed highly productive, performing even better under nitrogen deficit conditions, as these genotypes recorded with the highest nitrogen use efficiency, biological yield, and harvest index, as well as not achieving a higher increase in yield when doubling nitrogen fertilizer application. Therefore, the study suggested that these promising wheat genotypes need cultivation under low nitrogen conditions to maintain a healthy environment with sustainable agriculture.

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