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Nitrogen Use Efficiency (NUE) Changes in Durum Wheat Parents and Their F_2 Progenies Under Different Nitrogen Conditions

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Abstract: The intensive use of nitrogenous fertilizers in agricultural fields causes significant environmental and health issues along with increasing production costs. The objective of the study was to evaluate nitrogen use efficiency of 6x6 half diallel durum wheat (*Triticum turgidum* L.) F_2 progenies and their parental lines at N0 (zero N fertilizer), N1 (120 kg N ha^{-1}) and N2 (240 kg N ha^{-1}) nitrogen levels. Significant differences were found among genotypes and nitrogen applications for grain nitrogen yield (GNY), N use efficiency for grain yield (NUEgy) and N use efficiency for grain N yield (NUEgn). N use efficiency (NUE) significantly decreased with increasing nitrogen doses. General combining ability of parents (GCA) was significant for all studied traits. GCA/SCA ratio ≥1 for GNY, NUEgy and NUEgn at different N conditions showed that it dominated by additive gene effects. GNY gradually increased depending on N increase while NUEgy and NUEgn decreased. Among the parents 'Mersiniye' genotype showed positive GCA effects and was the best general combiner for GNY, NUEgy and NUEgn. The best specific combining ability (SCA) for NUEgy was obtained from 'Mersiniye x Spagetti' hybrid. The GCA effects of each parent were generally stable for all traits and nitrogen levels. Our results revealed that it is possible to select promising lines which have high nitrogen use efficiency from the segregating progenies obtained by crossing of high nitrogen use efficiency parents.

Keywords: Diallel, durum wheat, landrace, grain nitrogen yield, nitrogen use efficiency

Farklı Azot Koşullarında Makarnalık Buğday Anaç ve Bunların F_2 Döllerinin Azot Kullanım Etkinliği (AKE) Değişimleri

Öz: Azotlu gübrelerin tarım alanlarında yoğun olarak kullanılmaları önemli çevre ve sağlık problemlerinin yanı sıra üretim maliyetlerinin artmasına neden olmaktadır. Bu çalışma 6x6 yarım diallel makarnalık buğday (*Triticum turgidum* L.) anaç ve bunlara ait F_2 döllerinin N0 (sıfır azot (N)), N1 (120 kg N ha^{-1}) ve N2 (240 kg N ha^{-1}) azot seviyelerinde azot kullanım etkinliğini belirlemek için yapılmıştır. Tane azot verimi (TAV), tane verimi azot kullanım etkinliği (TVAKE) ve tane azot verimi azot kullanım etkinliği (TAVAKE) özellikleri için genotipler ve dozlararasında önemli farklılıklar ortaya çıkmıştır. Artan azot dozlarında azot kullanım etkinliği (AKE) önemli miktarda azalmıştır. Ebeveynlerin genel uyum yeteneği (GUY) çalışmada incelenen tüm özellikler için önemli bulunmuştur. Farklı azot dozlarında TAV, TVAKE ve TAVAKE özellikleri için GUY/ÖUY oranının ≥1 den büyük olması bu özelliklerin eklemeli gen tarafından idare edildiğini göstermektedir. TAV doz artışına bağlı olarak artarken, TVAKE ve TAVAKE azalmıştır. Ebeveyler arasında 'Mersiniye' genotipi olumlu GUY etkisine ve incelenen üç özellik için en iyi kombiner olmuştur. TAVAKE özelliği için en iyi özel uyum yeteneği (ÖUY) 'Mersiniye x Spagetti' hibritinden elde edilmiştir. Ebeveylerin GUY etkileri incelenen tüm özelliklerde ve azot dozlarında genellikle stabil olmuştur. Araştırma sonuçlarına göre yüksek azot kullanım etkinliğine sahip ebeveylerin melezlenmesinden elde edilen döllerden yüksek azot kullanım etkinliğine sahip ümitvar hatların seçilmesinin mümkün olabileceği görülmüştür.

Anahtar kelimeler: Diallel, makarnalık buğday, yerel çeşit, tane azot verim, azot kullanım etkinliği

1. Introduction

Fertilization which is one of the most important production factors increased substantially in wheat cultivated areas after Green Revolution. Meeting the nutritional needs of increasing world population necessitates higher yields for per unit area in cultivated fields. Therefore, the application of fertilizers is of importance in terms of obtaining higher yields in plant production. One of the fertilizers used in increasing the yields in wheat production is nitrogenous fertilizers. It was reported that depending on changing amount of plant available nitrogen and nitrogen application methods, the uptake of plant-available nitrogen by crops was about 50%. The unavailable soil N to plants is predicted to be amount to $ 17.7 billion per year (Karasahin, 2014). Thus the nitrogen application rates meeting plant requirement is of importance. Higher nitrogen application rates than needed decrease N use efficiency (NUE) through increase of nitrogen losses. The fact that the decrease of the NUE cause increase of production costs and considerable environmental and health problems (Socolow, 1999; Raun and Gordon, 1999; Ehdaie et al., 2001; Glass, 2003;).

As unavailable nitrogen to plants brings on economic losses, it is reported by many researches that nitrogen losses through leakage, runoff, and other ways lead to considerable environmental and health problems. Thus, sufficient supply of nitrogen for crop needs is a matter of importance. In order to stave off disadvantages of higher application of nitrogen the nitrogen should be applied in rates meeting plant needs (Le Guise et al., 2000; Limon-Ortega et al., 2000) and N use efficient cultivars should be used. NUE are defined differently by several researchers. Moll et al. (1982) defined the NUE as grain yield obtained in exchange for per unit of plant available nitrogen in fertilizer and soil, while Van Der Hoek (2010) explained it as the proportional difference of nitrogen input and output. NUE has been defined as ratio of per unit of N fertilizer to grain yield (Sowers et al. 1994). Thomason et al. (2002) reported that there were many factors affecting the NUE such as genotype, production systems, N source, timing of N application, N doses, environment and processing techniques. Raun and Johnson (1999) reported that the NUE has been 33% for cereals in worldwide, as Ortiz-Monasterio et al. (1997) stated that NUE of wheat was only 35%. Plant breeding and improved management practices can employ to increase NUE (Moll et al., 1982). In conformity with applied low and high N doses, NUE and utilization efficiency of wheat genotypes can be compared to select the best wheat genotype in a breeding program (Yildirim et al., 2007). In breeding programs, if inheritance of specific traits predetermined by various methods, these basic informations become higher success rate based on breeding programs. Therefore, the features that work on the breeder must be known that created under the influence what kind of genes. Diallel analysis method is one of the developed method to determine the effects of these genes. Today it is of importance to develop N use efficient cultivars to decrease economical losses caused by excessive use of fertilizers. The aim of this present study was to evaluate the genetic variation and general and specific combining abilities for N use efficiency of durum wheats parent and their F_2 progenies at low, medium and high N levels.

2. Material and Method

2.1. Plant material and field experiment

The study was carried out with six durum wheats which consist of 3 landraces (Menceki, Mersiniye and Mısırı) and 3 commercial cultivars (Levante, Zenit, Spagetti) and their 6 × 6 half diallel 15 F_2 populations. These genotypes were grown in a split block design with three replicates at three different N rates (0, 120 and 240 kg N ha^{-1}, respectively) at Dicle University Experimental Station (Diyarbakır, Turkey) with a sowing date of November 21, 2010. Nitrogen doses were the main plots and genotypes were the subplots. Each plot consisted of two rows with 2 m long, 20 cm apart rows and 10 cm between plants. Twenty seeds were sown to each row. N treatments were called as N0, N1 and N2 conditions. Fertilized plots (N1 and N2) received N in two applications (Half of N were applied at sowing and other half at tillering stage as top-dressing). Each parcel took 60 kg ha^{-1} phosphorus as triple superphosphate. The soil was clay loam and contained 11.02% carbonate, 0.81% organic matter, 12.6 kg P ha^{-1}, with a pH 7.6. The trial was conducted under rainfed conditions. Protein content of grain samples were measured with NIT System Infratec 1241 Grain Analyzer (Foss, Hillerod, Denmark) without subjected to milling process. Grain yield (kg ha^{-1}) was measured in harvest plots. Grain N yield (GNY) (kg N ha^{-1}), N use efficiency for grain yield (NUEgy), (kg grain kg^{-1}) and N use efficiency for grain N yield (NUEgn) (kg grain kg^{-1}) were determined according to Yildirim et al. (2007).

2.2. Statistical Analysis

The diallel analysis was conducted according to Griffing (1956) method II (including parents, F_2 and no reciprocals) using an SAS (1998) program with genotype and treatment as fixed effects. The relative importance of GCA and SCA was assessed according to Baker (1978). Comparisons of means were made by using the least significant difference test (LSD) at $P < 0.05$.

3. Results

3.1. Performance of parents and their hybrids at different N conditions

It was found significant differences for Nitrogen (N) doses and genotypes for GNY, NUEgy and NUEgn, while genotype x nitrogen dose interaction was insignificant (Table1).

GNY values of parents and hybrids depending on nitrogen application rates varied as 97.8-145.4 kg ha^{-1}, 155.7-252.0 kg ha^{-1} and 186.2-278.1 kg ha^{-1} for N0, N1 and N2, respectively (Table 2). The highest GNY among parents was obtained from 'Menceki' and 'Mersiniye' for N0, N1 and N2 respectively. The highest GNY among hybrids were observed in 'Mersiniye x Spagetti' at N0 and N1 and in 'Menceki x Levante'at N2

NUEgy values of parents and hybrids changed between 56.9- 86.8 kg grain kg^{-1}, 26.4-42.1 kg grain kg^{-1} and 17.8-25.3 kg grain kg^{-1} at N0, N1 and N2 respectively. The highest values among parents were observed in Menceki at N0, in Mersiniye at N1 and in Levante at N2. The highest values among hybrids were obtained from 'Mersiniye x Spagetti' at N0 and N1 and from Menceki x Levante at N2. NUEgn values of parents and hybrids changed 1.47-2.18 kg grain kg^{-1} at N0, 0.69-1.11 kg grain kg^{-1} at N1 and 0.43-0.72 kg grain kg^{-1} at N2. The highest values among parents were observed in Mersiniye ve Menceki at N0, in Mersiniye at N1 and in 'Levante' at N2. The highest values among hybrids were found in Mersiniye x Spagetti' at N0 and N1 and in 'Menceki x Levante' at N2.

3.2. GCA and SCA effects of traits

GCA effects were found significant for investigated traits while SCA effects were insignificant (Table 1). The high mean square ratio of GCA to SCA exhibited that the additive gene effects were important at the genetic base for all traits (Table 1).

GCA effect for GNY of cultivars were found positive and the highest in 'Mersiniye' and 'Spagetti' and 'Menceki' at N0, in 'Mersiniye' at N1 and in 'Levante' at N2. GCA effect for NUEgy were observed positive and the highest in 'Spagetti' at N0, in 'Mersiniye' at N1 and in Levante' at N2. GCA effect for NUEgn were established positive and the highest in Mersiniye', 'Menceki' and 'Levante' at N0, 'Mersiniye' at N1 and 'Levante' at N2 (Table 3). In terms of all traits under examination, Mısırı and Zenit cultivars were negative for all three N application rates.

SCA effects of hybrid combinations for GNY, NUEgy and NUEgn were identified positive and the highest in 'Mersiniye x Spagetti' at N0, in Mısırı x Levante at N1 and in 'Menceki x Levante' at N2. In addition to the same hybrid combinations, SCA effects for 'Mısırı x Zenit' and 'Zenit x Menceki' combinations were obtained positive for all traits under all three N application doses.

4. Discussion

Six durum wheat cultivars and 15 F_2 hybrid combinations of these cultivars were investigated from the viewpoint of GNY, NUEgy and NUEgn at three N levels. The used parents and hybrids differed significantly among themselves for GNY, NUEgy and NUEgn. This showed that there were considerable genotypic variation among in the used genetic material. This variation showed that selection of N use efficient cultivars was possible for different N application level. Genotype x N interaction of cultivars in terms of examined traits found insignificant. Yildirim et al. (2007) stated that Genotype x N interaction found insignificant for GNY, NUEgy and NUEgn in half diallel wheat cultivars at low and high N application rates. GCA x N and SCA x N interactions were found insignificant in all examined traits. As Yildirim et al. (2007) reported that GCA x N and SCA x N interactions were insignificant, Grony and Sodkiewicz (2001) and Ehdaie et al. (2001) found these interactions significant. Whereas increase of N doses increased GNY in parents and F_2 hybrids, NUEgy and NUEgn decreased depending on increase of N doses (Table 2).

Table 1. Combined analysis of variance (Mean Squares) investigated traits in parents and their F_2 progenies at three N levels

Source of variation	df	GNY		NUEgy		NUEgn	
Nutrition (N)	2	213344.65	***	38095.18	***	22.94	***
Replications	6	4132.25	**	954.71	***	0.63	***
Genotypes (G)	20	2185.22	**	139.35	**	0.09	**
GxN	40	1103.45		61.58		0.04	
GCA	5	4989.58	**	238.70	**	0.20	**
SCA	15	1250.44		106.23		0.06	
GCAxN	5	1052.14		88.83		0.03	
SCAxN	15	641.15		66.95		0.05	
Error	120	1030.61		63.19		0.04	
GCA/SCA ratio		3.99		2.25		3.33	
CV %		17.63		19.35		19.14	

, *, indicates data significant at $P \leq 0.01$, $P \leq 0.001$, respectively

Table 3. GCA and SCA effects at three N levels.

	GNY				NUEgy				NUEgn			
	N0	N1	N2	Average	N0	N1	N2	Average	N0	N1	N2	Average
	General Combining Ability Effects											
Parents												
Mısırı	-9.540*	-23.906**	-7.807	-13.751**	-5.177*	-3.766**	-0.963	-3.302**	-0.143*	-0.105**	-0.020	-0.090***
Zenit	-3.498	-3.506	-1.019	-5.732	-1.476	-0.780	-0.435	-0.897	-0.052	-0.016	-0.026	-0.031
Mersiniye	4.954	16.526*	3.819	8.434*	1.131	2.933**	0.032	1.365	0.074	0.073*	0.010	0.052*
Spagetti	4.839	-0.560	-1.955	0.775	4.275	-0.174	-0.061	1.347	0.073	-0.002	-0.005	0.022
Menceki	4.980	4.881	5.129	4.997	2.131	0.018	0.697	0.949	0.075	0.022	0.013	0.036
Levante	-1.736	6.565	11.003	5.278	-0.883	1.769	0.729	0.538	-0.026	0.029	0.028	0.010
	Specific Combining Ability Effects											
F_2 Populations												
(Mı x Ze)	14.119	8.204	3.472	8.599	7.420	0.339	0.667	2.809	0.212	0.036	0.009	0.086
(Mı x Mer)	-14.452	-37.952*	29.825	-7.526	-4.748	-6.884*	2.527	-3.035	-0.217	-0.168*	0.077	-0.102
(Mı x Sp)	-13.270	-1.145	-0.264	-4.893	-6.916	0.202	-0.611	-2.442	-0.199	-0.005	-0.001	-0.068
(Mı x Men)	-3.966	-14.119	-11.619	-9.903	-1.605	-3.282	-0.993	-1.960	-0.059	-0.062	-0.030	-0.051
(Mı x Le)	15.650	35.600	-25.300	8.650	7.114	8.046*	-1.479	4.560	0.235	0.157	-0.065	0.109
(Ze x Mer)	-6.892	-6.595	-22.845	-12.111	-3.416	-0.089	-1.663	-1.722	-0.103	-0.029	-0.059	-0.064
(Ze x Sp)	-1.216	14.729	17.158	10.224	3.493	4.634	1.970	3.366	-0.018	0.065	0.044	0.030
(Ze x Men)	10.043	3.886	8.706	7.545	6.506	0.341	0.125	2.324	0.151	0.017	0.022	0.063
(Ze x le)	-6.898	-16.578	-4.663	-9.380	-7.445	-3.994	-1.248	-4.229	-0.103	-0.073	-0.012	-0.063
(Mer x Sp)	18.755	24.063	13.800	18.872*	12.802*	5.860	1.361	6.675**	0.281	0.106	0.036	0.141*
(Merx Men)	-18.052	-5.418	-51.191*	-24.887**	-11.856	0.403	-4.130*	-5.195*	-0.271	-0.024	-0.132*	-0.142*
(Mer x Le)	13.904	8.025	13.779	11.903	4.197	-0.197	0.820	1.606	0.208	0.036	0.036	0.093
(Sp x Men)	10.199	-7.801	-3.190	-0.265	3.134	-0.647	-0.443	0.681	0.153	-0.035	-0.008	0.037
(Sp x Le)	12.204	0.201	-32.482	-14.828	9.137	-3.303	-2.845	-5.095*	0.183	0.001	-0.084	-0.089
(Men x Le)	5.072	20.442	37.251	17.541	2.011	2.304	3.223	1.172	0.076	0.090	0.096	0.037

*,**, ***, indicates data significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively

Table 2. General means for grain N yield (GNY), N use efficiency for grain yield (NUEgy) and N use efficiency for grain N yield in parents and their F_2 progenies at three N levels

	GNY (kg ha^{-1})				NUEgy (kg grain kg^{-1})				NUEgn (kg grain kg^{-1})			
	N0	N1	N2	Means	N0	N1	N2	Means	N0	N1	N2	Means
	General Combining Ability Effects											
Parents												
Mısırı	99.7	162.7	216.8	159.7	56.9	27.5	19.1	34.5	1.49	0.71	0.56	0.92
Zenit	100.7	190.4	206.3	165.8	59.1	30.7	20.4	36.7	1.51	0.84	0.53	0.96
Mersiniye	133.5	252.0	252.8	212.7	73.8	40.3	22.3	45.5	2.00	1.11	0.65	1.26
Spagetti	124.2	169.9	229.6	174.6	73.7	26.4	21.6	40.6	1.86	0.75	0.59	1.07
Menceki	133.6	213.8	258.8	202.1	78.7	34.4	24.8	46.0	2.00	0.94	0.67	1.21
Levante	112.7	188.7	278.1	193.1	69.3	33.3	25.3	42.6	1.69	0.83	0.72	1.08
	Specific Combining Ability Effects											
F_2 Populations												
(Mı x Ze)	117.9	181.9	214.0	171.2	69.3	29.3	20.4	39.7	1.77	0.80	0.55	1.04
(Mı x Mer)	97.8	155.7	254.3	169.3	59.8	25.8	22.8	36.1	1.47	0.69	0.66	0.93
(Mı x Sp)	98.9	175.5	218.5	164.3	60.7	29.8	19.5	36.7	1.48	0.77	0.56	0.94
(Mı x Men)	108.3	167.9	214.2	163.5	63.9	26.5	19.9	36.8	1.62	0.74	0.55	0.97
(Mı x Le)	119.3	209.9	202.5	177.2	70.9	38.0	19.6	42.8	1.79	0.93	0.52	1.08
(Ze x Mer)	111.4	207.5	199.3	172.7	64.8	35.6	19.1	39.8	1.67	0.92	0.52	1.03
(Ze x Sp)	116.9	211.7	233.5	187.4	74.9	37.2	22.6	44.9	1.75	0.93	0.60	1.10
(Ze x Men)	128.3	206.3	232.1	188.9	75.7	33.1	21.6	43.5	1.93	0.91	0.60	1.15
(Ze x le)	113.8	191.2	226.5	177.2	65.3	31.7	20.1	39.0	1.71	0.84	0.59	1.05
(Mer x Sp)	145.4	241.1	244.1	210.2	86.8	42.1	22.5	50.5	2.18	1.06	0.63	1.29
(Mer x Men)	108.7	217.1	186.2	170.7	60.0	36.8	17.8	38.2	1.63	0.96	0.43	1.02
(Mer x Le)	127.2	214.3	240.5	194.0	70.0	37.1	21.7	42.9	1.91	0.95	0.62	1.16
(Sp x Men)	136.8	197.6	228.5	187.6	78.1	32.7	21.4	44.1	2.05	0.87	0.59	1.17
(Sp x Le)	110.0	237.3	200.1	182.5	66.2	38.5	18.4	41.0	1.65	1.05	0.52	1.07
(Men x Le)	108.1	230.0	261.8	200.0	62.0	36.7	23.6	40.8	1.62	1.01	0.68	1.10
LSD1 $_{0.05}$	ns	ns	ns	30.741	ns	9.407	ns	7.330	ns	ns	ns	0.191
LSD2 $_{0.05}$				11.325				2.804				0.072
Parent means	117.4	196.3	240.4	184.7	68.6	32.1	22.3	41.0	1.76	0.86	0.62	1.08
Hybrid means	116.6	203.0	223.7	181.1	68.6	34.0	20.7	41.1	1.75	0.89	0.57	1.07
General means	116.8	201.1	228.5	182.1	68.6	33.5	21.2	41.1	1.75	0.88	0.59	1.08

LSD1:among genotype LSD2:among N levels ns: non significant

Le Gouis et al. (2000) showed that increase of N doses increased GNY, while Lopez-Bellidio (2001), Huggins and Pan (2003), Haile et al. (2012) Van ginkel et al. (2001) found that increasing N rates decreased NUE. The reason of decrease of NUE in response to increasing N rates is explained with the less uptake of nitrogen by plants at the highest levels of N dose, in which much of applied N is lost by several factors such as denitrification, leaching and runoff (Dawson et al., 2008). In a similar study, Yildirim et al (2007) found GNY, NUEgy and NUEgn values, in parents and hybrids at low and high level of N doses (0 and 160 kg ha^{-1}), lesser than that of this study. As Ehdaie et al. (2001), whose study were carried out with five durum wheat cultivars at 105 and 170 kg N ha^{-1} doses, their NUEgy results were higher than that of this study. The differences of the results of these studies can be explained by the difference of N use efficiencies between varieties of the same plant or between plant species (Maizlish et al. 1980). Furthermore, timing of N application (Ehdaie et al. 2001), application rates (Ortiz-Monasterio et al. 1997) and application methods (Rahman et al. 2011) have been changing N use efficiency.

The ratio of GCA variance to SCA variance for all the studied traits was above one. This emphasized that especially additive gene action are important in the control of these traits, suggesting that the major portion of genetic variability in the base population was additive in nature. Yildirim et al. (2007) found similar result. However, Le Gouis et al. (2002) stated that NUE could be explained by both additive and non-additive gene effects. The fact that the traits were mediated by additive gene action showed that selection could be made early segregation progenies Due to the fact that Mersiniye and Menceki had the highest values at three level of N application among parents and showed the highest effects of GCA, both cultivars could be used in wheat breeding programs in order to increase GNY and NUE. The hybrid of Mersiniye x Spagetti among hybrid combination was unique with higher values for all traits and N doses.

5. Conclusion

Since GCA/SCA ratio was above one, it was determined that NUE was orginating from additive gene effect. Menceki and Mersiniye cultivars had higher NUEgn and NUEgy. Mersiniye x Spagetti hybrid combination showed high adaptation in terms of all traits. As a local variety Mersiniye and Menceki brought about increasing NUEgn and NUEgy, these cultivars can be used to increase variation and grain advantage in breeding programs. The results showed that it is possible to obtain high NUE fixed genotypes from segregation populations by altering nitrogen levels. Plant breeding research generates benefits only when the improved varieties are adopted by farmers. The genotypes have high NUE or high grain yield with low N input will be easily acceptable by worldwide wheat producer.

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