www.biodicon.com Biological Diversity and Conservation

ISSN 1308-8084 Online; ISSN 1308-5301 Print 10/2 (2017) 26-31

Research article/Araştırma makalesi

Nitrogen use efficiency of eleven triticale (x *Triticosecale* Wittmack) genotypes

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Abstract

A field experiment with eleven triticale genotypes was conducted to assess the grain yield, biomass yield, protein content, total nitrogen (N) uptake and various indexes (agronomic, physiological, agrophysiological, and apparent recovery efficiencies) of N use efficiency (NUE) using different levels of N fertilizer (0, 40, 80 and 160 kg N ha^{-1}) over two years. According to the results of this research, the grain yield and biomass yield were the highest with the N rate of 80 kg N ha^{-1}. While grain protein content and the total N accumulation of triticale increased with the N application rates, the NUE indexes decreased with increasing N rates. The TVD25 line had the highest in grain yield (3765 kg ha^{-1}), biomass yield (19418 kg ha^{-1}), grain protein content (16.3%) and total N uptake (178.8 kg ha^{-1}); the Mikham cultivar was the highest in agronomic efficiency (14.6 kg kg^{-1}), agrophysiological efficiency (19.3 kg kg^{-1}) and apparent recovery efficiency (70.4%) and the Samur sortu cultivar was the highest in physiological efficiency (63.4 kg kg^{-1}) based on the two-year-means. The low NUE index values were calculated from triticale genotypes having the highest yield and N accumulation. As a result, to reduce N losses from soil and increase the NUE indexes, N efficient genotypes in this study should be selected in breeding programs.

Key words: grain yield, nitrogen use efficiency, nitrogen uptake, triticale

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Onbir tritikale (x *Triticosecale* Wittmack) genotipinin azot kullanım etkinliği

Özet

Uygulanan dört azot (N) dozunun (0, 40, 80 and 160 kg N ha^{-1}), onbir tritikale genotipinin tane verimi, biyolojik verim, protein içeriği, toplam N alımı ve N kullanım etkinlik (NUE) indekslerine (agronomik, fizyolojik, agrofizyolojik, N değerlendirme ve N kullanım etkinliğine) etkileri iki yıl tarla koşullarında araştırılmıştır. Bu çalışmanın sonuçlarına göre, en yüksek tane ve biyolojik verimi, 80 kg N ha^{-1} doz uygulamasında olduğu belirlenmiştir. Tritikalenin tane protein içeriği ve toplam N alımı, uygulanan N dozlarıyla artarken, NUE indeksleri azalmıştır. TVD25 hattından en yüksek tane verimi (3765 kg ha^{-1}), biyolojik verim (19418 kg ha^{-1}), protein içeriği (%16.3) ve toplam N alımı (178.8 kg ha^{-1}), Mikham çeşidinden en yüksek agronomik (14.6 kg kg^{-1}), agrofizyolojik (19.3 kg kg^{-1}) ve N değerlendirme etkinliği (%70.4), Samur sortu çeşidinden ise en yüksek fizyolojik etkinlik (63.4 kg kg^{-1}) elde edilmiştir. Yüksek verimli ve toplam N alımına sahip tritikale genotiplerinden, en düşük NUE değerleri hesaplanmıştır. Sonuç olarak, belirlenen N etkin tritikale genotipleri, topraktan N kayıplarını azaltmak ve NUE indekslerini artırmak için yapılacak ıslah programlarında kullanılmalıdır.

Anahtar kelimeler: tane verimi, azot kullanım etkinliği, azot alımı, tritikale

1. Introduction

Crops can obtain nitrogen (N) from fertilizer, the soil N content or from both of them (Ladha et al., 2005). However, Craswell and Godwin (1984) stated that only approximately 50% of the N applied to soil is actually absorbed by crops, and the residual fertilizer N is lost via leaching, denitrification, volatilization and soil erosion and runoff. It is

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 BioDiCon. 657-0217

for this reason that increased production costs and environmental awareness (surface or ground water pollution from nitrates) promote the development of methods to increase the efficiency of applied fertilizer N. To determine the maximum grain and biomass production per unit of applied N, indexes of N use efficiency (NUE) are defined (Moll et al., 1982; Fageria and Baligar, 2001). However NUE by crop plants have been described using different methodology in the literature and the NUE indexes can be divided into two processes: biomass yield and economic yield (Ladha et al., 2005). The biomass yield can involve either the total aboveground plant dry matter or the total plant N, and the economic yield involves either the grain yield or the total grain N. That is to say, NUE indexes measure both uptake efficiency (uptake of N by plants from the soil) and utilization efficiency (using N to produce grain or total yield) (Hirel et al., 2007).

The change in the NUE among different crops has been investigated, and there is a large difference in the N accumulation of different species or genotypes of cereals such as wheat, barley and rice (Craswell and Godwin, 1984; Delogu et al., 1998; Zhao et al., 2007). Triticale (x *Triticosecale* Wittmack) is a successful synthetic cereal grain and it has potential in the production of bread and other food products, such as cookies, pasta, pizza dough and breakfast cereals. Conventional plant breeding has helped establish triticale as a valuable crop, especially under conditions that are less favorable for wheat cultivation (Varughese et al., 1996). A comparison study between triticale and wheat showed that triticale accumulates N to a much greater extent than wheat under lower levels of N application (Ortiz-Monasterio et al., 1993). Numerous studies have been conducted on the various aspects of using winter triticale. However, little research has been reported on the NUE of triticale. The main objective of this study was to assess the total N uptake and NUE indexes in eleven triticale genotypes grown under different levels of fertilizer N.

2. Materials and methods

1.1. Site description

The experiment was conducted in 2005/2006 and 2006/2007 at Agriculture Eskisehir Osmangazi University, Eskisehir (39º48′ N; 30º31′ E; 789 m elevation), Turkey. The average annual precipitation and temperature (from October to July) is 347 mm and 9.1ºC for the area over the last 60 year, 235 mm and 8.5ºC for 2005/06 (a dry year) and 301 mm and 9.2ºC for 2006/07 (a wet year), respectively. Precipitation distribution also differed between years. In 2006/07, a mean 50 % of total precipitation was recorded in the spring from April to June (during the grain filling period) whereas in 2005/06, a mean 16% of total precipitation was recorded during the same period. The weather data were different between the extended period and both study years. The soil samples (0-30 cm) were taken at sowing, air-dried, passed through a 2 mm sieve and analyzed for physical and chemical contents. The methods of soil analyses were similar in Kutlu and Gülmezoğlu (2017). The data were given with physical and chemical properties of soil in Table 1. The properties of the soils of experimental area had been conducted within two years and they were relatively similar, all being alkaline, low organic matter, moderate calcareous, insufficient Zn, Mn and sandy clay loam as in most soils in Central Anatolia where low in N supply to plants.

Table 1. Physical and chemical properties of soil of the experimental area

Parameter	Valu	Paramet
Sand	58.0	N
Silt	17.0	P
Clay	25.0	K
EC	0.22	Fe
pH	8.0	Mn
Lime	6.13	Cu
Organic	1.78	Zn

1.2. Experimental design

The eleven hexaploid winter triticale genotypes (six cultivars; Tatlıcak, Melez, Mikham, Presto, Karma, Samur sortu and five lines; TVD3, TVD4, KTVD9, TVD17, TVD25) were provided from Bahri Dagdas International Agricultural Research. The experimental design was a split-plot design with four replicates. The sowing was done in October (6th in 2005 and 10th in 2006). Each plot (7.5 m^2) was six rows and the space between the rows was 25 cm. The seeds were planted with 450 seed m^{-2}. The 60 kg P_2O_5 ha^{-1} as triple superphosphate was applied to all plots. The main plots consisted of four N levels and the subplots consisted of triticale genotypes. Control plots received no N (N0), while N fertilized plots were treated with 40 (N40), 80 (N80) and 160 (N160) kg ha^{-1} N. It was applied one-half of N fertilizer at planting as ammonium sulfate (26% N) and the rest of N was applied as topdressing at tillering time using ammonium nitrate (33% N). The plants were harvested in July (11th in 2006 and 09th in 2007).

1.3. Sampling and measurements

At harvest time, when the plants were completely dried, they were cut from aboveground in the middle of each plot (3 m x 1 m). The N concentration of grain and straw was separately determined using by the Kjeldahl digestion method after the plant samples were ground. Total N uptake was calculated by multiplying dry weight with N concentration in grain and straw. Biomass (straw + grain) and grain weight were measured.

1.4. Calculation

The NUE components are established as agronomic, physiological, agrophysiological, apparent recovery and utilization efficiencies were determined according to Fageria and Baligar (2003) and the following N efficiency parameters were calculated for each treatment:

Agronomic efficiency (kg kg^{-1}) = [(G*f* – G*u*) / N*a*]

where G*f* is the grain yield in the fertilized plot (kg), G*u* is the grain yield in the unfertilized plot (kg), and N*a* is the quantity of nutrient applied (kg).

Physiological efficiency (kg kg^{-1}) = [(Y*f* – Y*u*) / N*f* – N*u*)]

where Yf is the total biological yield (grain plus straw) of the fertilized plot (kg), Y*u* is the total biological yield in the unfertilized plot (kg), N*f* is the nutrient accumulation in the fertilized plot (kg), and N*u* is the nutrient accumulation in the unfertilized plot (kg).

Agrophysiological efficiency (NUE) (kg kg^{-1}) = [(G*f* – G*u*) / (N*f* – N*u*)],

where G*f* is the grain yield in the fertilized plot (kg), G*u* is the grain yield in the unfertilized plot (kg), N*f* is the nutrient accumulation by straw and grains in the fertilized plot (kg), and N*u* is the nutrient accumulation by straw and grains in the unfertilized plot (kg).

Apparent recovery efficiency (%) = [(N*f* – N*u*) / (N*a*) x 100],

where N*f* is the nutrient accumulation by the total biological yield (straw plus grain) in the fertilized plot (kg), N*u* is the nutrient accumulation by the total biological yield (straw plus grain) in the unfertilized plot (kg), and N*a* is the quantity of nutrient applied (kg).

Utilization efficiency (kg kg^{-1}) = Agrophysiological efficiency x Apparent recovery efficiency

1.5. Statistical analyses

The effects of the treatments on the measured variables were evaluated with analysis of variance (ANOVA) using general linear model (GLM) procedure. Treatment means were compared using the least significant difference (LSD) test at $P < 0.05$.

3. Results

1.1. Effect of N fertilization on triticale yields

The effect of N fertilizer application was significant ($P < 0.01$) for the triticale grain and biomass yields during both experimental years (Table 2). The triticale yield varied between both study years and the highest yields were recorded in 2005/2006 under four N fertilizer treatments (Table 2). Grain and biomass yields to applications of N showed high performance in each years and the highest yield was produced by 80 kg N ha^{-1} dose in both years, while the yield decreased at the 160 kg ha^{-1} dose of N. The lowest grain yield for two-year-mean was produced by KTVD9 (2263 kg ha^{-1}) and the highest grain yield was obtained by TVD25 (3765 kg ha^{-1}). TVD25 had the highest biomass yield (19418 kg ha^{-1}), and Tatlıcak produced the lowest biomass yield (16124 kg ha^{-1}) in two-year-mean.

1.2. *Grain protein and total N uptake of triticale*

The grain protein content and total N uptake increased in two years while the N rate increased. The highest protein content was recorded at the 160 kg N ha^{-1} rate (Table 2). The highest grain protein content (16%) and total N uptake (158.7 kg ha^{-1}) were determined in the second year. There was difference between the years with respect to protein content and N uptake. The highest protein content and total N uptake in means of two years were obtained from TVD25 (16.4%) and the lowest value (14.1%) was obtained from Tatlıcak.

1.3. Nitrogen use efficiency indexes

The genotypes, N and the interactions of the NUE indexes under different N doses each years were significant ($P < 0.01$) (Table 3). The increasing N rates decreased all NUE indexes. The five NUE index values varied between both years. The agronomic, physiological and agrophysiological efficiencies in the first year were higher than in the second year, while the apparent recovery and utilization efficiencies in the second year were higher than in the first year (Table 3). However, NUE indexes differed according to genotypes (Table 3). In the first year, the highest agronomic, physiological, agrophysiological, apparent recovery and utilization efficiencies were obtained from Mikham, Samur Sortu, TVD3, Mikham and Samur sortu, respectively. In second year, TVD3 had the highest apparent recovery and utilization efficiencies and Tatlıcak had the highest agronomic and agrophysiological efficiencies. Physiological efficiency was the highest in TVD17.

Table 2. The mean of grain yield (kg ha^{-1}), total biological yield (kg ha^{-1}), grain protein content (%), total nitrogen (N) accumulation (kg ha^{-1}) of triticale genotypes in two years.

	Grain yield			Total biological yield			Grain protein content			Total N accumulation		
Genotypes	2005 /2006	2006 /2007	Mean	2005 /2006	2006 /2007	Mean	2005 /2006	2006 /2007	Mean	2005 /2006	2006 /2007	Mean
TVD3	3171 e	3018 e	3095	17842 e	15580 j	16711	14.1 e	15.8 f	14.9	135.9 e	167.1 d	151.5
TVD4	3765 b	3249 c	3507	20971 b	17866 b	19418	14.9 b	17.1 b	16.0	153.0 b	153.2 g	153.1
KTVD9	2393 h	2132 j	2263	17187 g	16542 f	16865	14.8 b	16.7 c	15.7	129.2 f	135.5 i	132.3
TVD17	3773 b	3188 d	3481	18146 d	15994 g	17070	13.6 g	16.1 e	14.8	149.8 c	166.1 d	158.0
TVD25	4079 a	3450 a	3765	21366 a	17363 c	19364	14.5 d	18.3 a	16.3	163.2 a	194.4 a	178.8
Tatlıcak	3388 d	2770 h	3079	17395 f	14852 k	16124	14.4 d	13.8 i	14.1	134.9 e	122.6 j	128.8
Melez	3163 e	3196 d	3180	18180 d	17080 d	17630	14.6 c	14.7 h	14.7	147.5 d	178.2 b	162.8
Mikham	2939 f	2849 g	2894	18320 d	17017 e	17668	12.2 h	16.3 d	14.3	121.6 g	168.8 c	145.2
Presto	3489 c	2942 f	3216	17771 e	15970 h	16871	13.8 f	16.3 de	15.0	135.3 e	161.4 e	148.3
Karma	3153 e	2637 i	2896	17268 fg	15601 i	16434	14.1 e	15.1 g	14.6	136.1 e	141.9 h	139.0
S. Sortu	2812 g	3316 b	3064	19036 c	18105 a	18570	15.3 a	15.6 f	15.4	149.0 c	156.2 f	152.6
LSD 5%	*20.33***	*8.27***		*103.68***	*8.47***		*0.09***	*0.10***		*0.90***	*0.99***	
N doses												
0	2777 d	2558 d	2668	16347 d	14616 d	15481	12.7 d	14.4 d	13.5	103.7 d	122 d	112.9
40	3461 b	2904 c	3183	18210 c	16996 b	17603	13.5 c	15.5 c	14.5	132.5 c	152 c	142.3
80	3634 a	3298 a	3466	19967 a	17935 a	18951	14.8 b	16.6 b	15.7	161.8 b	181 a	171.7
160	3264 c	3147 b	3206	19470 b	16624 c	18047	15.9 a	17.5 a	16.7	167.7 a	178 b	173.3
LSD 5%	*9.92***	*7.97***		*97.22***	*20.42***		*0.05***	*0.05***		*0.65***	*0.85***	
Years	3284	2977	***3131***	18498	16543	***17521***	14.2	16.0	***15.1***	141.4	158.7	***150.1***

**, significant at *P*<0.01.

Table 3. The mean of agronomic efficiency (kg kg^{-1}), physiological efficiency (kg kg^{-1}), agrophysiological efficiency (kg kg^{-1}), apparent recovery efficiency (%), utilization efficiency (kg kg^{-1}) of triticale genotypes in two years.

	Agronomic eff.			Physiological eff.			Agrophysiological eff.			Apparent recovery eff.			Utilization eff.		
Genot.	2005 /2006	2006 /2007	Mean	2005 /2006	2006 /2007	Mean	2005 /2006	2006 /2007	Mean	2005 /2006	2006 /2007	Mean	2005 /2006	2006 /2007	Mean
TVD3	12.5 c	4.7 i	8.6	54.8 g	71.5 b	63.2	23.5 a	5.9 i	14.8	50.6 g	77.2 a	63.9	27.7 i	57.3 a	42.5
TVD4	12.7 b	5.9 h	9.3	61.6 f	30.1 k	45.9	18.0 c	10.2 g	14.1	68.3 b	56.1 g	62.2	44.6 d	17.1 i	30.8
KTVD9	6.9 h	0.8 k	3.9	76.8 b	41.0 j	58.9	10.1 h	2.4 k	6.3	62.3 d	37.7 h	50.1	46.4 c	20.6 h	33.6
TVD17	10.7 d	8.8 e	9.8	41.0 i	74.7 a	57.9	16.6 e	13.0 e	14.8	67.8 b	65.0 d	66.4	30.0 h	49.3 b	39.7
TVD25	5.7 i	9.4 d	7.6	67.4 d	57.8 e	62.6	8.2 i	14.5 d	11.4	60.0 e	62.2 e	61.1	41.1 e	36.1 f	38.6
Tatlıcak	8.6 fg	11.4 a	10.0	46.6 h	59.0 d	52.9	10.2 h	18.8 a	14.6	66.9 c	56.3 g	61.6	39.1 f	38.0 e	38.5
Melez	8.7 f	6.1 g	7.5	41.4 i	49.7 i	45.6	15.9 f	6.4 h	11.2	54.5 f	69.8 b	62.2	25.5 j	45.5 c	35.5
Mikham	17.9 a	11.3 b	14.6	64.7 e	61.9 c	63.4	22.5 b	16.1 c	19.3	70.5 a	70.3 b	70.4	48.3 b	45.2 c	46.8
Presto	8.5 g	10.2 c	9.4	69.6 c	50.9 h	60.3	17.4 d	17.3 b	17.4	44.9 h	59.1 f	52.0	30.6 g	32.4 g	31.6
Karma	10.8 d	2.9 j	6.9	29.0 j	52.9 g	41.0	14.6 g	5.4 j	10.0	67.6 bc	58.4 f	63.0	19.6 k	32.5 g	26.1
S. Sortu	9.9 e	7.2 f	8.6	86.7 a	54.1 f	70.4	14.5 g	10.7 f	12.6	62.4 d	66.5 c	64.5	55.1 a	42.2 d	48.6
LSD 5%	*0.09***	*0.06***		*0.46***	*0.44***		*0.12***	*0.08***		*0.47***	*0.46***		*0.29***	*0.32***	
N doses (kg ha^{-1})															
40	17.1 a	8.6 b	12.9	62.6 b	78.3 a	70.5	24.3 a	11.4 b	17.9	71.9 b	75.1 a	73.5	46.5 a	59.5 a	53.0
80	10.7 b	9.2 a	10.0	63.2 a	53.4 b	58.3	15.1 b	12.0 a	13.6	72.5 a	74.4 b	73.5	45.2 b	41.5 b	43.4
160	3.0 c	3.6 c	3.4	48.7 c	32.9 c	40.8	7.5 c	9.5 c	8.5	39.9 c	35.5 c	37.8	19.5 c	12.5 c	16.0
LSD 5%	*0.04***	*0.04***		*0.15***	*0.07***		*0.11***	*0.05***		*0.18***	*0.29***		*0.15***	*0.17***	
Years	10.3	7.2	***8.8***	58.2	54.9	***56.6***	15.6	11.0	***13.3***	61.5	61.7	***61.6***	37.1	37.9	***37.5***

**, significant at *P*<0.01.

4. Conclusions and discussion

1.1. Grain yield, biomass yield, protein and total N uptake of triticale genotypes differed by year

The 80 kg N ha^{-1} treatment resulted in significantly greater grain and biomass yields than the N40 and N160 treatments according to the average of the two years. Meanwhile, there were differences in the N applications among triticale genotypes. According to the two-year-means, TVD25 had both the highest grain and biomass yield while the lowest grain and biomass yield was obtained from KTVD9 and Tatlıcak, respectively. The effect of N fertilization on yield has been reported in various studies by Lewandowski and Kauter (2003) and Gulmezoglu and Kinaci (2005), who observed significant increases in the grain yield of triticale at increased N fertilizer levels, and their studies showed that 70 or 80 kg N ha^{-1} produced high grain yield.

The grain protein content and total N uptake increased in proportion to the N doses up to the highest N dose in this study. The total N uptake of triticale increased with the increasing N dose till the 160 kg N ha^{-1} dose. TVD25 had the highest grain protein content and total N uptake. Some researchers reported that increasing N levels raised in the protein content of the triticale grain (Knapowski et al., 2009; Gulmezoglu and Aytac, 2010; Janusauskaite, 2013).

4.2. *Effect of N levels on NUE indexe*s

The agronomic efficiency (the ratio of yield to N supply) was highest at the 40 kg N ha^{-1} application rate (12.9 kg kg^{-1}) and Mikham had the highest agronomic efficiency, while KTVD9 had the lowest. The average of agronomic efficiency was 8.8 kg kg^{-1}, which explained each kg N ha^{-1} produced 8.8 kg kg^{-1} grain. Janusauskaite (2013) found that the agronomic efficiency for spring triticale was 11.4 kg kg^{-1} for each kg N ha^{-1}. However, Sobkowicz and Sniady (2004) determined that the agronomic efficiency was 23.8 kg per kg N for triticale. All studies determined that increasing the N level decreases the agronomic efficiency. However, it was clear that agronomic efficiency could be significantly affected from climate, soil and genotype.

The physiological efficiency for mean of the years was 56.5 kg which defined that total yield per unit of N accumulated. Also, physiological efficiency indicates knowledge of the minimum N requirement for a given yield level. Knowledge of both soil factors and crop N requirements is a prerequisite to the development of management strategies to maximize the yield response to fertilizer N (Muchow, 1998). The physiological efficiency is little found in the literature. The physiological efficiency of Fageria and Baligar (2001) was 146 kg biomass yield per unit of accumulated N ha^{-1}. If the physiological efficiency of triticale in this study is compared with rice, the biomass yield per unit of N accumulation of triticale is lower than that of rice. The physiological efficiency was negatively affected by rising N levels, and it had the highest increase at the N40 application. Samur Sortu had the highest physiological efficiency of all triticale genotypes (70.4 kg kg-1) by the means of two years.

The agrophysiological efficiency of triticale genotypes for mean of two years was 13.3 kg grain produced per kg of N accumulated. The accumulated N was transformed into surplus grain yield in Mikham in all triticale genotypes. Fageria and Baligar (2001) determined an agrophysiological efficiency of 63 kg kg^{-1} for rice. The lowest agrophysiological efficiency in this study was in the highest N rate. Velasco et al. (2012) found that the agrophysiological efficiency of barley changed between 11.7 and 20.3 kg kg^{-1} and also indicated that the split N application decreased the agrophysiological efficiency of barley. Aynehband et al. (2012) reported that agrophysiological efficiency was decreased by increasing N fertilizer rates.

The apparent recovery efficiency was 61.6% on average over the trial years and Mikham had the highest efficiency. There is little information on the recovery of fertilizer N applied at different rates for triticale. Fageria and Baligar (2001) found 39% for rice and Ladha et al. (2005) mentioned a rate of 57% for wheat. The investigated triticale genotypes utilized N much more than rice and wheat. The apparent recovery efficiency value was the lowest at N160, while it was same at N40 and N80. Murphy et al. (2013) found that the low recovery was associated with high application rates of N. Indeed, it shows that the improved apparent recovery in crops can decrease N losses to the environment. Mineral N is mainly prone to losses through ammonia volatilization, leaching (i.e., removal in drainage water) and denitrification (i.e., transformations into gaseous forms) (Cameron et al., 2013). The application of fertilizer N in excess of crop requirements can increase the risk of N loss (Murphy et al., 2013). Therefore, the apparent recovery efficiency is an important NUE index.

Utilization efficiency for grain yield (defined as grain yield per unit N uptake) was 37.5 kg per kg N absorbed. Sobkowicz and Sniad (2004) was reported that utilization efficiency of triticale had 44.9 kg per kg N. This parameter is a sign of grain yield and N accumulation from fertilizer N. Fageria and Baligar (2001) found 58 kg kg^{-1} for rice. Compared to rice, triticale had quite low utilization efficiency.

Among 11 genotypes analyzed TVD25 lines and 80 kg N ha^{-1} had the highest yield, protein content and N uptake in two years. These results indicated that N application rate appears to be the key factor in comparison of the genetic expression of utilization and apparent recovery efficiencies in genotypes. Mikham for apparent recovery efficiency and Samur sortu for utilization efficiency was the highest by the means of two years. In conclusion, variability in triticale genotypes in NUE can be an important trait in breeding N efficient triticale genotypes under low N application rate.

Acknowledgements

This study was financially supported by the Research Fund of Eskisehir Osmangazi University (GR/200523005). The authors are thankful to all contributors.

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(Received for publication 20 February 2017; The date of publication 15 August 2017)