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Research Findings

Wheat experiment setup. Photo by authors.

Effects of Potassium and Nitrogen Applications on the Yield and Yield Components of Bread and Durum Wheat

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Abstract

This study reports on an investigation made at the Ege University experimental farm (Izmir, Turkey), with soil low in available potassium (K), on the effects of different rates of potassium (K_2O) and nitrogen (N) fertilization on two different wheat varieties, one bread wheat (Galil) and the other a durum wheat (Ege 88). Measurements were made on yield, yield components, elemental composition, N use efficiency (NUE %) and the N derived from the N fertilizer (Ndff %). In general, grain and straw yields were higher for the bread than the durum wheat for corresponding N and K applications. However, the highest yield was found at the highest N and K rates applied to durum wheat. NUE % was also high in the highest rate of K application, at 1% level in the bread wheat and 5% in the durum wheat. The N derived from the N fertilizers increased as the N and K rates increased. It can be concluded that the N_1 level (150 kg ha^{-1}) of the studied N doses can be accepted as the most economic dose for both bread and durum wheat varieties in terms of N fertilization. For the bread

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variety, the lowest dose of K fertilization (K_0), i.e. soil K, could be considered adequate under rainfed (244 mm) conditions in the Ege region of Turkey. On the other hand, the grain and straw yields of the durum wheat significantly increased with increasing doses of K up to $N_{1.5}$ (225 kg N ha^{-1}) application. The highest K fertilization level (225 kg K_2O ha^{-1}) at the highest N level (225 kg N ha^{-1}) can thus be recommended for this variety provided that it is economically viable.

Introduction

Bread is the main staple food in Turkey where both bread and durum wheat are cultivated. Durum wheat is used in the production of pasta and biscuits, which are consumed extensively. In all, about 22 million tons of wheat is produced annually (Anonymous, 2014a). The average yield of bread wheat is about 7 t ha^{-1} but under conditions of water shortage (150-200 mm), yield decreases greatly to less than 3 t ha^{-1}. In the case of durum wheat, yields of just over 3 MT ha^{-1} have been reported under 400 mm of rainfall conditions (Ayçiçek and Yıldırım, 2006). Most of the standard fertilizers are used in wheat production including: diammonium phosphate (DAP), NP (20:20:0), urea, calcium ammonium nitrate (CAN) or ammonium nitrate (AN). These are generally used under rainfed conditions. Above 500 mm precipitation, NPK (15:15:15 KCl based with or without Zn), and CAN fertilizers are also included in the fertilization recommendations.

The objective of this work was to study the effect of increasing rates of K supplied together with increasing rates of N application on the yield of two different wheat varieties (one bread wheat and the other durum wheat) on their main agronomic properties, including nutrient concentrations and N fertilizer use efficiencies (NUE).

Materials and methods

Two different N and K field experiments for bread and durum wheat varieties were established under rainfed conditions (244 mm) in the year 2012 at the Ege University experimental farm (38° N and 27° E; 44m above sea level). The soil was Typic Xerofluvent with the following characteristics: slightly alkaline reaction, sandy loam texture, rich in $CaCO_3$, poor in organic matter and without any problem of salinity. Regarding available plant nutrients, total-N was medium, K low and phosphorus (P) poor (Table 1).

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

	Unit	Value
Element		
Water soluble salts	%	0.027
pH		7.64
Organic matter	%	1.27
Texture		Sandy loam
$CaCO_3$	%	11.90
Total N	%	0.09
Available nutrients		
P	*mg kg^{-1}*	0.16
K	*mg kg^{-1}*	183
Na	*mg kg^{-1}*	71
Ca	*mg kg^{-1}*	2,802
Mg	*mg kg^{-1}*	186

The soil analytical methods used were as follow: pH (Jackson, 1967), water soluble salts (Anonymous, 2004), $CaCO_3$ (Çağlar, 1949), texture and organic matter (Black, 1965), total-N (Bremner, 1965), water extractable P (Bingham, 1949), exchangeable K (1 N NH_4OAc; pH=7), extractable K, calcium (Ca), sodium (Na) and magnesium (Mg) (Pratt, 1965; Thomas, 1982). The two varieties used in this experiment were Galil bread wheat and Ege 88 durum wheat. Galil has a mean 1,000 grain weight of 42 g, is resistant to drought, yields well and produces good quality bread. For Ege 88, the mean 1,000 grain weight is somewhat higher at 45-48 g, it is resistant to winter conditions, drought and lodging and is an early variety. It also responds well to fertilization and does not drop grains (Unsal *et al.*, 2009; Anonymous, 2014b).

The study was carried out with four replications using a random block design. The four N treatments were: N_0 (0), $N_{0.5}$ (75 kg ha^{-1}), N_1 (150 kg ha^{-1}) and $N_{1.5}$ (225 kg ha^{-1}). There were three rates of K: K_0 (0), K_1 (150 kg K_2O ha^{-1}) and $K_{1.5}$ (225 kg K_2O ha^{-1}). Fertilizers were applied in the form of ammonium sulfate ($(NH_4)_2SO_4$) and potassium sulfate (K_2SO_4). The N_1 and K_0 rates are the recommended doses according to soil analysis for wheat in this region. One third of the N was applied at sowing and two thirds at tillering. Phosphorus, together with K and with one third of N fertilizer, was given as 100 kg ha^{-1} P_2O_5 in the form of triple superphosphate (TSP) during soil preparation. In two of the treatments (75 and 225 kg ha^{-1} N) labelled $(NH_4)_2SO_4$ (^{15}N) was used to detect the NUE of the plants. Detailed findings can be found in the proceedings of the 2013 International Plant Nutrition Colloquium (IPNC) meeting (Çolak Esetlili *et al.*, 2013).

Grains were analyzed for their N, P, K and zinc (Zn) concentrations (Kacar, 1972). Crude protein concentrations were calculated according to the N concentration of the grains multiplied by the coefficient 6.25. Protein fractions were classified based on their differential solubility according to the MAES method (Maes, 1962). Estimation of NUE requires knowledge of the amount of plant N derived from the fertilizer. This was achieved using ^{15}N labeled nitrogen fertilizer; determination of ^{15}N in the dried plant material was determined by mass spectrometry after dry combustion (Axmann *et al.*, 1990; Halitligil *et al.*, 2009).

Statistical analyses were performed using SPSS 15.0 software for Windows.

Results and discussion

Yield and yield components

The lowest grain yield of Galil bread wheat variety (1,590 kg ha^{-1}) was found in the $N_0K_{1.0}$ treatment where no N was given and 150 kg ha^{-1} K_2O applied. The lowest straw yield (1,750 kg ha^{-1}) was also found in the same treatment (Table 2). The highest grain yield (4,610 kg ha^{-1}) of this variety was recorded in the $N_{1.5}K_0$ (225 kg ha^{-1} N and no K) treatment. Similarly, the highest straw yield (4,900 kg ha^{-1}) was also found in the same treatment ($N_{1.5}K_0$) as well as in the $N_{1.5}K_{1.0}$ treatment (Table 2). For the Ege 88 durum wheat variety, the lowest grain and straw yields were determined as 1,600 kg ha^{-1} in N_0K_0 treatments (Table 2). The highest grain yield was 4,690 kg ha^{-1} in the $N_{1.5}K_{1.5}$ application and the highest straw yield was 4,500 kg ha^{-1} in the same treatment (Table 2).

Table 2. Grain and straw yields of bread and durum wheat varieties.

N level	Grain			Straw		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	kg ha^{-1}					
	Bread wheat (*cv.* Galil)					
N_0	1,840 c	1,590 c	1,840 c	2,040 b	1,750 c	2,190 c
$N_{0.5}$	2,590 b	2,820 b	3,100 b	3,010 b	2,900 b	3,290 b
$N_{1.0}$	4,150 a	4,410 a	4,140 a	4,360 a	4820 a	4,330 ab
$N_{1.5}$	4,610 a	4,460 a	4,290 a	4,900 a	4,900 a	4,400 a
N_{LSD}	56.67$^{(2)}$			80.98$^{(2)}$		
K_{LSD}	ns$^{(3)}$			ns$^{(3)}$		
NxK_{LSD}	73.12$^{(1)}$			104.49$^{(1)}$		
	Triticum durum (*cv.* Ege 88)					
N_0	1,600 b	1,670 c	2,010 c	1,600 b	1,740 b	1,930 c
$N_{0.5}$	2,330 b	2,700 b	3,030 b	2,080 b	2,520 b	2,810 b
$N_{1.0}$	3,380 a	3,960 a	4,050 a	3,380 a	3,960 a	3,720 a
$N_{1.5}$	3,830 a B	4,320 a AB	4,690 a A	3,490 a B	4,110 a AB	4,500 a A
N_{LSD}	64.19$^{(2)}$			67.09$^{(2)}$		
K_{LSD}	55.59$^{(2)}$			43.28$^{(1)}$		
NxK_{LSD}	82.83$^{(1)}$			86.57$^{(1)}$		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
$^{(1)}P<0.05$; $^{(2)}P<0.01$; $^{(3)}$ns=not significant

Grain yields of both varieties increased in parallel with the increasing levels of N under all the increasing K levels and the differences between treatments were statistically significant. However, when yield results were examined in relation to increasing K levels under each of the increasing N applications the responses found in bread wheat were not statistically significant. In this regard, durum grain yield increased (Table 2). Our findings with respect to the yields of durum wheat were more or less similar to the reports of other scientists who studied the same variety in different localities of the same region (Dinçer, 1972; Alpaslan, M., 2001; Ünsal *et al.*, 2009). Therefore, to achieve higher grain and straw yields for bread wheat, 150 kg ha^{-1} ($N_{1.0}$ rate) can be recommended as the most economical dose in the Ege region. On the other hand, for durum wheat, since the yields responded to higher rates of N and K fertilization, higher doses should be considered.

Table 3. '000 grain weights of bread and durum wheat varieties.

N level	'000 grain weight					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	g					
N_0	42.8 c	42.7 b	43.4 a	47.4 b	49.3 b	48.2 c
$N_{0.5}$	43.3 bc B	46.6 a A	46.2 a B	53.0 a	52.0 ab	51.6 b
$N_{1.0}$	46.0 ab	48.1 a	45.6 a	53.7 a	55.1 a	55.0 a
$N_{1.5}$	47.1 a	45.2 ab	46.2 a	54.1 a	55.0 a	56.1 a
N_{LSD}	2.39$^{(2)}$			2.49$^{(2)}$		
K_{LSD}	ns$^{(3)}$			ns$^{(3)}$		
NxK_{LSD}	3.08$^{(1)}$			3.22$^{(1)}$		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
$^{(1)}P<0.05$; $^{(2)}P<0.01$; $^{(3)}$ns=not significant

Enhanced doses of N application increased the 1,000 grain weights under almost all of the K levels in both of the varieties. The effect of enhanced K rates was not so clear but the weights for the durum wheat were generally higher compared to the bread variety. In this respect the highest weight was obtained with the $N_{1.5}$ and $K_{1.5}$ treatment. The 1,000 grain weights ranged between 42.7-48.1 g for bread and 47.4-56.1 g for durum wheat (Table 3). Our findings indicate that the variety effect was more clearly expressed than N and K fertilization and these results are in agreement with other reports (Hussain *et al.*, 1996).

Crude protein concentrations in the grains of the bread wheat variety ranged between 11.8-13.2% and in durum wheat between 10.8-14.4%. In both varieties, no significant response to K fertilization was observed. However in the case of durum wheat, N fertilization was significantly effective in increasing the crude protein values (Table 4).

There is some indication that rates of N fertilization or high temperatures during growth can induce changes in the proportions of gliadins and glutenins in the grain but the reports are inconsistent and leave many unanswered questions

Table 4. Concentration (%) of crude protein in the grains of bread and durum wheat varieties.

N level	Crude protein					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	%					
N_0	12.2 ab	12.1	13.2 a	11.8 b	12.5 ab	12.3 ab
$N_{0.5}$	12.1 ab	11.8	11.6 b	11.7 b	11.0 b	10.7 b
$N_{1.0}$	11.2 b B	12.8 A	12.0 ab AB	13.4 ab	12.5 ab	12.4 ab
$N_{1.5}$	13.1 a	13.1	12.9 ab	14.2 a	13.8 a	14.4 a
N_{LSD}	0.88(1)			1.87(2)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	1.57(1)			2.41(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)$P<0.05$; (2)$P<0.01$; (3)ns=not significant

Table 5. Nitrogen concentration in bread and durum wheat varieties (N %).

N level	Nitrogen concentration					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	%					
N_0	1.95 ab	1.93	2.11 a	1.88 b	2.00 ab	1.97 ab
$N_{0.5}$	1.93 ab	1.88	1.86 b	1.87 b	1.76 b	1.72 b
$N_{1.0}$	1.80 b A	2.04 A	1.91 ab AB	2.15 ab	2.00 ab	1.98 ab
$N_{1.5}$	2.10 a	2.09	2.06 ab	2.28 a	2.21 a	2.30 a
N_{LSD}	0.14(1)			0.30(2)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	0.24(1)			0.38(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)$P<0.05$; (2)$P<0.01$; (3)ns=not significant

Table 6. Potassium concentration in bread and durum wheat varieties (K %).

N level	Potassium concentration					
	Bread wheat (*cv.* Galil)			*Triticum durum* (*cv.* Ege 88)		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	%					
N_0	0.34	0.33 b	0.33	0.37	0.37 b	0.38
$N_{0.5}$	0.32	0.32 b	0.32	0.39	0.40 ab	0.41
$N_{1.0}$	0.34 AB	0.36 a A	0.33 B	0.39	0.41 ab	0.41
$N_{1.5}$	0.32	0.33 ab	0.34	0.40	0.41 a	0.41
N_{LSD}	0.016(1)			0.021(1)		
K_{LSD}	ns(3)			ns(3)		
NxK_{LSD}	0.027(1)			0.037(1)		

Note: Lowercase letters refer to increasing N treatments; capital letters refer to K treatments.
(1)$P<0.05$; (2)$P<0.01$; (3)ns=not significant

(Dupont *et al.*, 2006). There is, however, good evidence that the proportion in which these two storage proteins are present in the endosperm does affect grain quality. The gliadins are low in molecular weight, do not possess di-sulphide bridges and engender a poor baking quality. By contrast, the glutenins are large heterogeneous molecules which contain many di-sulphide bridges which provide elasticity and resulting dough of high tenacity to improve baking quality (see Mengel and Kirkby, 2001).

Elemental composition

Nitrogen concentrations in the grain of bread wheat ranged between 1.80-2.11% and for durum wheat between 1.72-2.30%. Durum wheat crude protein concentrations increased in parallel with the N concentrations in the grain. However, no definite response to K fertilization was seen either in N concentrations of both varieties or in their crude protein concentrations (Table 4 and 5).

The P concentrations in the grain of both varieties declined with increasing N applications and the highest P concentration for durum wheat was observed in the N_0 plot. Phosphorus concentration in bread wheat grains ranged between 0.26-0.27% and of the durum wheat between 0.27-0.29%.

Potassium concentrations in durum wheat grain were enhanced by increasing doses of N as well as K applications. Results showed that K ranged between 0.32-0.36% in bread wheat and between 0.37-0.41% in durum wheat (Table 6). In general, the concentrations of K were greater in the grains of durum wheat and ran parallel with increasing grain yields.

Zinc concentrations generally decreased in relation to increasing N treatments and ranged between 23-61 mg kg^{-1} in the grain of bread wheat and 25-40 mg kg^{-1} in the grain of durum wheat. On the other hand, concentrations generally increased as the K rates were enhanced. It is important to record that all of the measurements were above the critical value of Zn (15 ppm) for wheat grain concentration (IPNI, 2014). This critical value relates to the important link between Zn grain concentration and the maintenance of human health because wheat is a major source of dietary Zn for human populations in large parts of the world, including Turkey.

Protein fractions

Results showed that in bread wheat, the albumin-N varied between 128-198 mg 100 g^{-1} flour, and in the durum wheat variety between 181-404 mg 100 g^{-1} flour. With respect to globulin-N, the range in bread wheat was between 70-287 mg 100 g^{-1} flour, and in durum wheat between 182-308 mg 100 g^{-1} flour (Table 7).

Table 7. Protein fractions of bread and durum grains (mg 100 g^{-1} flour).

N level	Albumin-N			Globulin-N		
	K_0	$K_{1.0}$	$K_{1.5}$	K_0	$K_{1.0}$	$K_{1.5}$
	---*mg 100 g^{-1} flour*---					
	Bread wheat (*cv.* Galil)					
N_0	128	152	140	70	189	196
$N_{0.5}$	187	163	169	140	196	224
$N_{1.0}$	187	198	198	266	161	189
$N_{1.5}$	146	187	175	252	259	287
	Triticum durum (*cv.* Ege 88)					
N_0	217	277	300	182	238	245
$N_{0.5}$	270	239	226	273	238	183
$N_{1.0}$	326	464	314	224	280	306
$N_{1.5}$	181	270	251	265	252	308

In general, no well defined steady responses in the protein fractions were observed in relation to increasing N and K fertilization. However, in both wheat varieties, globulin-N was found to be lowest in the K_0N_0 treatment and highest in $N_{1.5}K_{1.5}$. Here it is worth emphasizing that the highest yield in durum wheat was also obtained in the $N_{1.5}K_{1.5}$ treatment. Albumin-N was highest in the grains of the wheat of both varieties in the N_1K_1 treatment.

Table 8. Ndff (%) by the grain and straw of bread and durum wheat varieties and their NUE (%).

Treatments	Ndff		NUE
	---%---		
	Grain	Straw	
	Bread wheat (*cv.* Galil)		
$N_{0.5}K_0$	25.79 b	25.28 bc	19.20 bc
$N_{0.5}K_{1.0}$	26.38 b	28.03 ab	22.16 ab
$N_{0.5}K_{1.5}$	26.81 b	29.44 a	24.74 a
$N_{1.5}K_0$	29.68 a	19.97 d	15.20 cd
$N_{1.5}K_{1.0}$	29.84 a	23.19 cd	15.84 cd
$N_{1.5}K_{1.5}$	30.47a	22.41 cd	13.87 d
Treatments LSD	1.39$^{(2)}$	4.60$^{(2)}$	5.07$^{(2)}$
	Triticum durum (*cv.* Ege 88)		
$N_{0.5}K_0$	26.42 b	26.10 a	16.24 ab
$N_{0.5}K_{1.0}$	26.18 b	27.28 a	19.35 a
$N_{0.5}K_{1.5}$	24.84 bc	28.44 a	21.14 a
$N_{1.5}K_0$	22.48 c	20.13 b	9.61 c
$N_{1.5}K_{1.0}$	29.72 a	16.22 c	12.60 bc
$N_{1.5}K_{1.5}$	31.01 a	19.77 b	16.82 ab
Treatments LSD	2.86$^{(2)}$	2.48$^{(2)}$	6.00$^{(1)}$

Note: Lowercase letters refer to increasing N treatments.
$^{(1)}P<0.05$; $^{(2)}P<0.01$

Nitrogen fertilizer use efficiency and nitrogen derived from the fertilizer

NUE is defined as the ratio between the N derived from the fertilizer (Ndff) and the amount of N fertilizer applied to the crop. In the current study, NUE was found to be high under the low doses of N in both varieties. On the other hand, NUE increased in both varieties in parallel to the increasing doses of K fertilization. The highest NUE was obtained at 225 kg ha^{-1} K_2O (the highest dose of $K=K_{1.5}$) supplied with a low dose (75 kg ha^{-1}) of N fertilizer. As can be seen from Table 8, this result could be related to the low Ndff of the wheat straw because the Ndff of the grains were high and increased as the rate of N and K fertilization increased (Table 8). In this current study, even though different rates of fertilizers were supplied to the wheat in the treatments, NUE was generally higher in bread wheat than durum (Table 8).

As well as determining the levels of N crops require, the time and method of application should also be optimized (depending on rainfall conditions) to avoid nitrate leaching and to minimize environmental pollution (Limon-Ortega *et al.*, 2000; Velasco *et al.*, 2012; Silva *et al.*, 2014). It is thus important to increase the efficiency of N usage and the amount of N derived from the fertilizer (Kacar, 1984).

Potassium is an important essential primary plant nutrient which acts synergistically with N in various physiological processes, playing an outstanding role in water relationships as well as in stimulating the uptake and metabolism of both nutrients. If necessary, K should therefore be included in fertilizer recommendations according to soil analysis and crop requirements (Mengel and Kirkby, 2001).

Conclusion

It can be concluded that 150 kg ha^{-1} of N is the statistically significant economic dose for bread as well as durum wheat varieties in terms of N fertilization. For the K fertilization of the bread variety grown under Ege region's arid conditions, soil K could be considered as sufficient. On the other hand, since durum wheat yields significantly increased with increasing doses of K, higher K rates (150-225 kg ha^{-1} K_2O) could be recommended provided that this is economically viable. Results also showed that globulin-N was highest in this specified K dose. It is also worth stating that grains removed more from the fertilizer N (Ndff) compared to the straw and that the Ndff increased as the N and K rates increased.

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