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EFFECT OF LOW RATES OF MINERAL FERTILIZERS ON THE PRODUCTIVITY OF DURUM WHEAT (*Triticum durum* Desf.)

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Abstract

*The aim of the study was to determine the effect of nitrogen and phosphorus fertilization applied at low rates on grain yield and some physical and chemical parameters for the durum wheat variety Progress. Nitrogen and phosphorus fertilizers were applied given in doses of 0, 40 and 80 kg/ha alone and in various combinations. A stationary trial with fertilization has been carried out since 1966 in the experimental field of Field Crops Institute in town of Chirpan, Bulgaria. The study included 2016 and 2017 crop years. It was found that the fertilizer rate increase did not necessarily lead to an increase in the studied parameters. The highest values were reported as follows: grain yield at $N_{80}P_{80}$; thousand-kernel weight at N_{40}; test weight at $N_{40}P_{40}$; vitreous of grain at N_{80}; protein content at N_{80} and gluten at $N_{80}P_{40}$. Correlation analysis showed the strongest and most significant correlations between protein content and gluten (0.906**).*

Key words*: fertilization, grain yield, physical and chemical parameters, Triticum durum.*

INTRODUCTION

Durum wheat (*Triticum turgidum* L. var. *durum*) is the second most important wheat species grown in the world next to bread wheat (*Triticum aestivum* L.) (Gerba et al., 2013). In Bulgaria durum wheat is a traditional culture. The two top producing countries are Turkey and Canada with estimated 2 million ha each (USDA, 2015; Statistics Canada, 2017), followed by Algeria, Italy and India, each cultivating over 1.5 million ha (Nagarajan, 2006; Le Lamer & Rousellin, 2011).

Considering that world population is increasing day by day on one hand, and that the fields used for agriculture have reached its limits on the other hand, it is coming to light that increase of yield is required to continue also in the future (Yildiz & Beyaz, 2019). Low soil fertility is one of the constraints in durum wheat production (Teklu & Hailemariam, 2009). In order to increase soil fertility in the short run, nutrient have to be added to the soil (Getinet & Wassie, 2019). The use of nitrogen is normally considered a key factor in cereal crops and numerious studies on the best N fertilization rates (Rossini et al., 2018). Current research efforts, however, are trying to reduse the use of N fertilizer to avoid unfavorable environmental consequence due to its losses without affecting crop productivity (Ali et al., 2019). Moreover, the soil is nature resource whose exploitation should be seen through a conservative wise-use approach limiting all forms of degradation (Neffar et al., 2014). According to FAO data, global demand for mineral fertilizers increases every year. Chemical fertilizers, however, are expensive to purchase and for most small-scale farmers this is a problem (Gete et al., 2010; Getachew & Tilahum, 2017). On the other hand a high quality standard could be guaranteed with an increase in N input at rates often double those required to maximize grain yield (Gariddo-Lestache et al., 2005), but with a risk for the environment (i.e., nitrate pollution) (Ercoli et al., 2013).

Contrary to N, P is reasonable abundant in the Earth's crust (1.2 g kg^{-1} on average) (Hinsinger et al., 2011). However, with the formation of soil and weathering, the total P content vents with time and the content of organic P accumulates at the expense of inorganic (Richardson et al., 2004). However that Otiz-Monasterio et al. (2002) reported that phosphorus is the second most widely occurring nutrient deficiency in cereal system around the world, and Kizilgoz & Sakin (2010) defined phosphorus as a third most abundant macronutrients in plants after nitrogen and potassium, P is undoubtedly one of the main nutrients. Therefore, it is expected high-grade phosphate rockes are definitely expected to be exhausted within the next decades (Cordell et al., 2009), which calls in to question the sustainability of curret P fertilizer use in developed and emerging countries (Hinsinger et al., 2011).

It is well known, that the conciliation of performance improvement of wheat crops depends on maintaining the stock of nutrients in soil, which is essential for plant growth (Haung et al., 2005; Casado-Vela et al., 2006; Chennafi et al., 2011). Determining the optimum rate of N and P fertilizer rate is the key to maximize the economic yields (Dugassa et al., 2019). This requires detailed research on the impact of mineral fertilizers. The aim of our study was to determine the effect of nitrogen and phosphorous fertilizers applied alone and in various combinations at low rates on grain yield and some physical and chemical parameters.

MATERIALS AND METHODS

The experiment was performed of the Field Crops Institute in Chirpan, Bulgaria (42°11′58″N, 25°19'27″E). The experiment was a stationary fertilizer trial set up in 1966. The study included 2016 and 2017 crop years. The trial was conducted by the randomized complete block design in four replications in two-field crop system rotation of durum wheat and cotton in the experimental field of the Institute in Chirpan on soil type Pelic Vertisols (Kirchev et al., 2017).

Three N and P (alone) rates were applied - 0, 40 and 80 kg/ha and four NP fertilization combinations: $N_{40}P_{40}$; $N_{40}P_{80}$; $N_{80}P_{40}$ and $N_{80}P_{80}$ (kg/ha). N_0P_0 was taken as a control variant. The phosphorus fertilizer was incorporated during autumn with the deep plowing, the nitrogen in early spring at tillering stage of durum wheat.

The following traits were examined: grain yield (kg/ha); test weight (kg/hl); thousand-kernel weight (g); vitreous of grain (%), protein content (%) and gluten (%) of durum wheat.

According to Figure 1 precipitations were very unevenly distributed. In the harvest 2015/2016, the amount of precipitation in May was higher than in 2016/2017 and the multi-year period, and in June 2016 it was significantly less. In terms of temperature, the first harvest year was characterized by a mild winter and a warm spring. In the spring of 2017 the temperature curve was close to that of the climate norm.

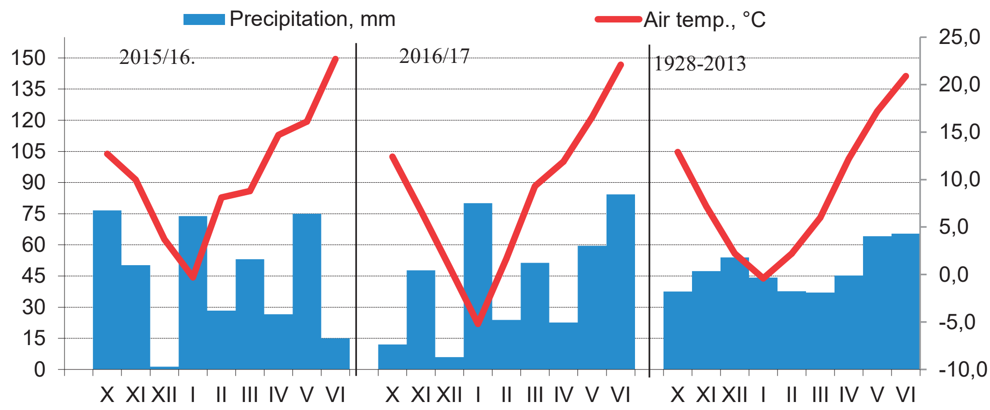

Figure 1. Precipitation and temperature security durum the durum wheat vegetation period

Variance (ANOVA) analysis was used to determine the significance of differences between the studied variants. Correlation relationships were established by applying the Statistics 13.0 software (TIBCO, Software, 2018).

Abbreviations: GY - grain yield; TW - test weight; TKW - thousand-kernel weight; GV - vitreous of grain; CP - protein content; G - gluten.

RESULTS AND DISCUSSION

Data in Table 1 showed that in 2016 GY was lower than in 2017. The lowest value in 2016 was observed for the variant without fertilization - 935.0 kg/ha. Nitrogen fertilization significantly increased the GY. With increasing the fertilizer rates GY values also increased. Of N_{40} was reported GY 1,737.5 kg/ha. When raised to N_{80}, GY increased by 162.6% compared to the untreated plot, reaching 2,455.0 kg/ha. The results of P fertilization showed little effect.

Table 1. Grain yield, kg/ha - 2016, 2017 and average

Fertilization rates, kg/ha		2016		2017		Average	
		kg/ha	% St	kg/ha	% St	kg/ha	% St
N_0P_0		935.0	100.0	3,255.3	100.0	2,095.2	100.0
N_{40}		1,737.5***	185.9	3,813.8**	117.2	2,775.7	132.5
N_{80}		2,455.0***	262.6	4,624.0***	142.1	3,539.5	168.9
P_{40}		1,005.0^{ns}	107.5	2,320.3^{ns}	71.3	1,662.7	79.4
P_{80}		1,067.5^{ns}	114.2	2,130.0^{ns}	65.4	1,598.8	76.3
$N_{40}P_{40}$		1,845.0***	197.3	4,258.8***	130.8	3,051.9	145.7
$N_{40}P_{80}$		2,045.0***	218.7	3,783.8**	116.2	2,914.4	139.1
$N_{80}P_{40}$		**2,485.0*** **	**265.8**	5,046.3***	155.0	3,765.7	179.7
$N_{80}P_{80}$		2,607.5***	278.9	**5,083.8*** **	**156.2**	**3,845.7**	**183.6**
LSD	*5%*	*337.4*	*36.1*	*371.7*	*11.4*	-	-
	1%	*455.6*	*48.7*	*501.9*	*15.4*	-	-
	0.1%	*606.8*	*64.9*	*668.3*	*20.5*	-	-

ns - no significant; *, **, ***significant at P = 5%, P = 1% and P = 0.1%

Attached low rate P_{40} exceeded the control plot by 7.5%. The P_{80} rate showed a slight increase in the value of the studied trait - by 14.2% above the control variant. Following these results, the differences were not be proved statistically.

Although self-P fertilization had no demonstrated effect in combination with N showed a good effect. The impact of $N_{40}P_{40}$ and $N_{40}P_{80}$ on GY statistically was confirmed in the highest degree. At fertilization with $N_{40}P_{40}$ GY was 1,845.0 kg/ha, and with an increase in the P rate ($N_{40}P_{80}$) GY increased by 200 kg/ha compared to the previous variant - 2,045.0 kg/ha.

At $N_{80}P_{40}$ GY was 2,485.0 kg/ha (165.8% over the control plot). It should be noted that the difference with N_{80} was only (30 kg/ha) i.e. 3.2%. This slight difference could not be taken as an argument for the imported P for the conditions of this year. At fertilization with $N_{80}P_{80}$ GY was 2,607.5 kg/ha, which was the highest GY reported in 2016. High values were statistically confirmed with high confidence.

Large amount of rainfall during the flowering (Figure 1) led to abnormal pollination of the flowers, which might explain the low GY in 2016. Kolev & Tahsin (2010) observed the same situation in a study with another cereal crop – triticale.

GY in 2017 without fertilizers was 3,255.3 kg/ha. Alone-application of N fertilization led to an increased in values. Of N_{40} GY of 3,813.8 kg/ha was reported. The GY was superior to control plot by 17.2%. The analysis of variance showed a high confidence for the effect of the N_{80} rate by raising the GY by 42.1% (4,624 kg/ha) over the non-fertilizing variant.

The lowest values were reported from P fertilization. At P_{40} GY was 2,320.3 kg/ha and when the rate increased to P_{80} the value of the trait decreased to 2,130.0 kg/ha. Both variants had a lower GY compared to the control plot, by 28.7% and 34.6%, respectively.

The combined fertilization $N_{40}P_{40}$ showed a higher GY of 4,258.8 kg/ha compared to $N_{40}P_{80}$ - 3,783.8 kg/ha. As a consequence, the $N_{40}P_{40}$ variant has a significantly higher statistical impact than the $N_{40}P_{80}$.

From the combined fertilization $N_{80}P_{40}$ and $N_{80}P_{80}$ similar results were reported for the GY achieving 5,046.3 kg/ha (155.0%) and 5,083.8 (156.2%) kg/ha. Maximum GY in 2017 was reported at $N_{80}P_{80}$. However, the 1.2% difference from the $N_{80}P_{40}$ variant did not justify its application.

The insufficient effect of P fertilization was due to the weather conditions in 2017. In October, when the P fertilizer was incorporated, the amount of rainfall was low, which prevented its absorption. As reported by Fricke et al. (1997) under soil moisture deficiency, nitrogen uptake from the roots was limited. It could be said that this effect was also valid for the other mineral fertilizers. Due to the large differences in GY during the two years of study statistical data processing was not carried out. However, the average data showed that the incorporated P had low effect. The P_{40} showed lower GY by 20.6% than the control. At the P_{80} rate GY was by 23.7% less than the variant without fertilizer. In contrast to our results, François et al. (2009) found higher but statistically unreliable values of GY under the impact of P. Grant and Bailey (1998) also reported an increase in GY under the impact of P, although in small quantities, even when the rate was increased.

The averaged data showed that N fertilization increased GY. With the application of N_{40} by 32.5% more grain was obtained compared to control plot. Higher than the N_{80} rate had a greater impact raising GY by 68.9% compared to without fertilizing. López-Bellido & López-Bellido (2001) confirmed an increase in GY due to an increase in the N rate (N_{50} - 2,548 kg/ha and N_{100} - 2,929 kg/ha). These results, however, contradicted the data of Ali et al. (2019), who find that the rate increased in the range 0, 30, 60 kg N/ha, grain yield decreased (4.4, 4.5, 4.1 t/ha - 4,400, 4,500, 4,100 kg/ha).

From the combined fertilization with $N_{40}P_{40}$ and $N_{40}P_{80}$ GY was lower than the single N fertilization at a dose of 80 kg/ha. The difference between N_{80} and $N_{40}P_{40}$ was 23.2% and the difference between N_{80} and $N_{40}P_{80}$ was 29.8%.

Fertilization with $N_{80}P_{40}$ GY was 3,765.7 kg/ha. This value exceeded the control plot by 79.7%. The highest GY reported for the average of the study was fertilization with $N_{80}P_{80}$ - 3,845.7 kg/ha, which was 83.6% above the non-fertilization variant. The effect of this fertilizer combination was confirmed in the study performed by Panayotova et al. (2018).

Table 2 presents the averaged values of the TW, TKW and GV grain properties.

Table 2. Test weight (kg/hl), thousand-kernel weight (g) and vitreous of grain (%) average for the period

Fertilization rates, kg/ha		TKW, g	% St	TW, kg/hl	% St	GV, %	% St
N_0P_0		58.70	100.00	77.28	100.00	60.4	100.0
N_{40}		**62.08*****	**105.76**	80.75***	104.49	68.4*	113.3
N_{80}		60.60*	103.24	80.50***	104.17	**72.5****	**120.0**
P_{40}		59.30^{ns}	101.02	80.43***	104.08	67.4*	111.6
P_{80}		58.38^{ns}	99.46	80.35***	103.97	68.2*	112.9
$N_{40}P_{40}$		61.28**	104.40	**80.95*****	**104.75**	69.9**	115.7
$N_{40}P_{80}$		60.75**	103.49	80.88***	104.66	70.4**	116.6
$N_{80}P_{40}$		61.00**	103.92	80.73***	104.46	71.1**	117.7
$N_{80}P_{80}$		60.23*	102.61	80.63***	104.34	72.4**	119.9
LSD	*5%*	*1.35*	*2.30*	*0.60*	*0.78*	*6.8*	*11.3*
	1%	*1.94*	*3.31*	*0.86*	*1.11*	*9.4*	*15.6*
	0.1%	*2.85*	*4.86*	*1.27*	*1.64*	*12.7*	*21.0*

ns - no significant; *, **, ***significant at P = 5%, P = 1% and P = 0.1%

Average for the two years of the study lowest TKW was under the control variant - 58.70 g. Nitrogen fertilization had a positive effect. However, the lower rate of N_{40} (62.08 g) showed a better result than N_{80} (60.60 g). The increasing of 5.76% over the control plot indicated that the N_{40} variant had the highest TKW and statistically significant effect of the highest degree. This result was at odds with that found by Woyema et al. (2012) and Iancu et al. (2019), and in both studies it was reported that when the N rate increased, TKW values also increased. The incorporation of P reduced the values of TKW. Increasing the rate had an adverse effect. At P_{40} fertilization values of 59.30 g were reported. Although the variant was superior in value this without fertilization by 1.02%, the difference was not statistically significant. At increase to P_{80} TKW was inferior to the control. The combination with low rates of fertilization ($N_{40}P_{40}$) showed TKW of 61.28 g, which was 4.40% more than without fertilization. As P, increased the value of the trait decreased ($N_{40}P_{80}$ - 60.75 g). Analysis of variance showed an average degree of impact of the factor in both variants.

The combination of a higher N rate and a low P ($N_{80}P_{40}$) increased the TKW value by 3.92% of the control plot. But with the increasing of P again negative effect was observed. Fertilization with $N_{80}P_{80}$ had a value of TKW 60.23 g, which exceeded the variant without fertilization by 2.61%.

The average data from the two years of study of Progress durum wheat showed high TW values. Without fertilization 77.28 kg/hl was reported. Application of N_{40} lead to an increase of 4.49% (80.75 kg/hl) compared to the control plot. However, when the rate was raised to N_{80} the value of the trait decreased to 80.50 kg/hl which was 4.17% compared to the control plot. Woyema et al. (2012) observed the same trend. Unlike our study, Ali et al. (2019) reported the same TW for the non-fertilizing variant and N_{30}, and when the norm increased to N_{60} the value decreased.

The lowest TW values for all variants tested were observed for P fertilization. At a rate of P_{40} TW was 80.43 kg/hl or 4.08% above the control plot. Again, when the rate was raised, the value of the trait decreased - P_{80} - 80.35 kg/hl.

The combined fertilization showed the same trend. The highest TW value over the study period was reported at $N_{40}P_{40}$ - 80.95 kg/hl. As the rates of combined fertilization increased, TW decreased. Thus, the lowest value for combined fertilization was observed at the highest rates - $N_{80}P_{80}$ - 80.63 kg/hl. Contrary to our results was the report of Makowska et al. (2008), where as the fertilizer rate increased, the test weight was increased.

The results for GV showed that the lowest value was reported from the version without fertilizer - 60.4%. The application of 40 kg N/ha increased GV by 13.3% and N_{80} by 20.0%, respectively, against the control plot. The resulting value of 72.5% GV from the N_{80} was the highest of the variants considered. However, the difference was not enough for a statistically significant influence of the highest rank. The increase of GV with the increase of N was confirmed by the study of Campiglia et al. (2014).

P fertilization showed a slight increase in GV. At P_{40}, GV was reported 67.4% and at 80 kg P/ha 68.2% or 12.9% above the control plot.

Fertilization with N and P led to a consistent increase with increasing fertilizer rate. Therefore, the lowest combination was the lowest value - $N_{40}P_{40}$ - 69.9%. The highest GV was observed the $N_{80}P_{80}$ variant - 72.4%. Although this was the highest GV at combination fertilization, it should be noted that GV had a similar value when applied N at a rate of 80 kg N/ha, although with a minimum difference of 0.1%. Compared to our study, Garrido-Lestache et al. (2005) also reported higher values of this property under the impact of self-fertilizing N in comparison with the combined NP fertilization.

Protein content and gluten strength are considered the most important features grain qualities needed for use in pasta (Rossini et al., 2018). In our study without fertilization and with fertilization P_{80} the lowest PC - 12.0% were accounted (Table 3).

Table 3. Protein content (%) and gluten (%) average for the test period

Fertilization rates, kg/ha		Average		Average	
		PC, %	% St	G, %	% St
N_0P_0		12.0	100.00	22.1	100.00
N_{40}		13.2*	110.0	25.8***	116.7
N_{80}		**15.1*****	**125.8**	30.5***	138.0
P_{40}		13.3**	110.8	25.5***	115.4
P_{80}		12.0^{ns}	100.0	23.5*	106.3
$N_{40}P_{40}$		13.4**	111.7	25.2***	114.0
$N_{40}P_{80}$		13.4**	111.7	24.7***	111.8
$N_{80}P_{40}$		14.6***	121.7	**30.7*****	**138.9**
$N_{80}P_{80}$		14.1***	117.5	28.0***	126.7
LSD	*5%*	*1.0*	*8.4*	*1.3*	*5.9*
	1%	*1.3*	*10.8*	*1.8*	*8.2*
	0.1%	*1.8*	*15.0*	*2.5*	*11.3*

ns - no significant; *, **, *** significant at P = 5%, P = 1% and P = 0.1%

N fertilization had a positive effect on PC. Similar results were reported by Ames et al. (2003). Several studies showed that application a significant increase in protein content (Lerner et al., 2006; Makowska et al., 2008). The highest content of 15.1% PC was observed when fertilizing with N_{80}. This variant showed high statistical significance of influence. Ierna et al. (2015) confirmed the positive effect of N fertilizers when the rate was raising. The combinations $N_{80}P_{40}$ (14.6%) and $N_{80}P_{80}$ (14.1%) had the same effect. Average for the years of studying 22.1% G was reported from the variant without fertilization. A minimal increase was observed at P_{80}, by 6.3% above the control. This rate remained statistically the least reliable for influence. Fertilization $N_{80}P_{40}$ showed the largest G - 30.7%. However, the difference with the application of N_{80} was minimal G - 0.2%. The increase at the low rates of combined fertilization was also small - $N_{40}P_{40}$ - 25.2% G. Gerba et al. (2013) confirned that with nitrogen increasing the content of gluten increased.

Of the correlation analysis performed (Table 4), the strongest significant relationship was between

CP and G (0.906**). A number of studies, such as those by Brites and Carrillo (2001), Bilgin et al. (2010), Sieber et al. (2015) and Fu et al. (2018) confirmed the positive relationship between CP and G. From the established interdependence between chemical and physical parameters, with the exception of TW and G (0.263^{ns}), good evidence of the yield values under the influence of applied mineral fertilization (Table 4) might suggest that the improved nutrition of durum wheat was from crucial for improving quality.

Table 4. Correlation coefficients between the studied traits

	TKW	*TW*	*GV*	*CP*	*G*
TKW	1				
TW	0.4713*	1			
GV	0.412*	0.598**	1		
CP	0.577**	0.391*	0.718**	1	
G	0.482*	0.263^{ns}	0.645**	**0.906****	1

*, **Significant at 5% and 1% level of probability

The presented data give reason to summarize that the low rates of alone fertilization with nitrogen and phosphorus, as well as their combined application, showed a favorable effect on TKW and TW, while an increase in the fertilizer rate positively affected GV. The impact of increasing rates of mineral fertilization was unidirectional on PC and G.

CONCLUSIONS

The highest GY of 3,845.7 kg/ha was found at fertilizing rate of $N_{80}P_{80}$ which was 83.6% over the control variant.

The highest TKW 62.08 g was found when fertilizing with N_{40}. All higher rates of self and combined fertilization had a weaker effect.

Fertilization had a statistically significant effect on TW at all variants. Although the differences were small the biggest effect was found at combined fertilization $N_{40}P_{40}$ – by 4.75% over the control.

The effect of the N_{80} was strongest on the GV trait. This rate was superior to all variants and was 20.0% more than the control.

The N_{80} rate increased the most CP by 25.8% compared to the non-fertilized control variant.

The best result on G was obtained at $N_{80}P_{40}$ - 30.7% G. However, the difference with the N_{80} was negligible - 0.2% G.

The highest and significant correlation was found between CP and G (0.906**).

Increasing rates of mineral fertilizers (N and P) did not necessarily increase the values of the studied traits. In some cases, the lower rates had a more favorable effect than the higher rates.

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