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RESPONSE OF DURUM WHEAT TO NITROGEN FERTILIZATION RATES

SUMMARY

The response of new Bulgarian durum wheat variety Predel to nitrogen fertilization was studied in a field fertilizing experiment with cotton – durum wheat crop rotation for the period 2008 – 2014, at the Institute of Field Crops – Chirpan, Bulgaria under rainy conditions. The studied nitrogen rates were 0; 60; 120 and 180 kg N.ha-1. The experimental design consisted of randomized block design with four replications. A tendency was found that nitrogen fertilization increased grain yield. The nitrogen rates N120 and N180 proved increased grain protein yield with 49.6 and 48.7 % compared to the control. The rate N180 decreased the harvest index. The highest agronomic efficiency of nitrogen for grain and grain protein were obtained with moderate rate N120 average for the period. Nitrogen fertilization decreased partially the factor of nitrogen productivity from 68 kg.kg-1 at rate N60 to 25 kg.kg-1 at rate N180. The highest concentration of grain protein - 15.97 % and vitreousness of the grain - 75.84 were obtained after applying N180. The content of wet and dry gluten slightly depended on nitrogen fertilization. A strong positive correlation was established between nitrogen fertilization and grain+straw yield (r=0.726**), grain protein concentration (r=0.862**), grain protein yield (r=0.635**) and vitreousness of the wheat grain (r=0.856**).

Keywords: Nitrogen rates, Durum wheat, Grain quality, Efficiency.

INTRODUCTION

Nitrogen fertilization is a major factor for high yields and grain quality of durum wheat (Panayotova, 2010; Ricciardi, 2001). Nitrogen has a strong influence on growth, but its impact on yield, quality and dry matter formation depends on the growing conditions. In meteorological terms, the favorable years strongly manifest the effect of higher nitrogen rate (Panayotova and Dechev, 2002; Rharrabti et al., 2003). According to Panayotova and Dechev (2003) the coefficient of yield variation of durum wheat from year to year is higher after fertilization with higher norms (N14P6). A number of studies (Hawkesford, 2012; López-Bellido and López-Bellido, 2001; Mohammadi and Amri, 2009; Panayotova, 1998) have established the fertilizing effectiveness of varieties with different genetic traits under different soil fertility was established. Durum wheat

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requires optimum fertilizer rates, consistent with the conditions of the area and the specifics of the field to increase the grain quality (Panayotova and Gorbanov, 1999). The main requirement for good quality of the grain is for the plant to obtain the optimal nitrogen amount during vegetation (Fixen, 2009). Nitrogen fertilization increases many of the quality indicators of durum wheat - crude protein content, wet and dry gluten, weight of 1000 grains, cooking properties of the pasta products (Panayotova and Gorbanov, 1999). The interaction between environmental conditions and nitrogen rates has a significant impact on grain quality (Sanjeev et al., 2000). According to Schulthess et al. (1993) the nitrogen content in the grain correlates significantly with the growing conditions. The yield is highest and of best quality when at the end of the grain filling stage begins slow drying and the temperature is raised gradually. The sharp temperature rise, coupled with rapid drought, leads to worse quality (Panayotova and Valkova, 2010).

The aim of the present study was to analyze the relationships between the main grain indicators of productivity and quality and the nitrogen fertilization rates for durum wheat Predel cultivar grown in southern Bulgaria over years of different meteorological conditions.

MATERIAL AND METHODS

The response of the new Bulgarian durum wheat cultivar Predel to nitrogen fertilization rates was studied in a field fertilizing experiment with cotton – durum wheat crop rotation during the period 2008 – 2014, at the Institute of Field Crops – Chirpan, Bulgaria, under rainy conditions. The experimental design consisted of randomized block design with four replications. The harvested size of the plots was 10 m^2. The studied fertilization rates were as follows: 0; 60; 120 and 180 kg $N.ha^{-1}$. Nitrogen fertilization in the form of NH_4NO_3 was applied before sowing (1/3 of the rate) and at early spring (2/3 of the rate). The phosphorus fertilization (P_{80}) was done before sowing in the form of triple superphosphate. The precursor crop was cotton fertilized by N_{80}. The soil type of the experimental field was *Pellic vertisols* (FAO), generally referred to as the so called Mediterranean chernozems. The soil type is one of the most generous and widely spread and significant in Bulgaria. It is suitable for growing most of the field crops and has a potential for high yield. The main parent materials were pliozen clay deposits. It has a high-powered humus horizon (70–80 cm), with a compact zone of the profile (united horizon). By humus content it belongs to the mean humus soils. It characterizes with high humidity capacity, caused by the high percentage of clay minerals, with clay soil texture, small water-permeability, bulk density of the arable soil layer - 1.2-1.3 $g.cm^{-3}$, with specific gravity 2.4-2.6 and low total porosity, neutral soil reaction and high cation exchange capacity (CEC) - 35-46 meq per 100 g soil, with a high degree of bases saturation (93.4-100.0 %), with total N in the arable layer ranging within 0.095-0.14 % and low content of total phosphorus (0.05-0.11 %), poor to medium supplied with hydrolyzed nitrogen, poorly supplied with available phosphorus and well-supplied with available potassium. Regarding the temperature during durum wheat vegetation, two of the experimental years were characterized as very warm, two as hot and two with values close to the multi-annual rate. In terms of precipitation one of the experimental years was wet, two years were dry, but in the three harvest years the rainfall values ware close to the norm. The productivity of durum wheat was determined by grain yield (kg.ha^{-1}), grain+straw yield (kg.ha^{-1}), grain protein yield (kg.ha^{-1}) and harvest index. The protein content in the grain (%) was determined by the Keldahl method (N, % x 5.7) according to BSS ISO 1871, and wet gluten content (%) - according to BSS 13375 by means of an automatic gluten-washable apparatus. The vitreousness of the grain (%) was determined by cutting the grains with pharynotom of Heinsdorf (standard ICC 129).

The main nitrogen use efficiency indicators of agronomic efficiency and partial factor productivity were used to assess the durum wheat response to nitrogen (Dobermann, 2007). agronomic efficiency (AE) and partial factor productivity (PFP) were calculated on dry weight basis using the following formulas: AE = $(Y-Y_0)/F$ (kg.kg^{-1}); and PFP = Y/F (kg.kg^{-1}), where Y and Y_0 were grain or grain protein yields from fertilized treatments and unfertilized control, respectively, and F - amount of N fertilizer applied (kg.ha^{-1}). The data were statistically analysed with the ANOVA procedure within the SPSS statistical program and Duncan’s multiple range test ($P = 0.05$) to find significant differences among means.

RESULTS AND DISCUSSION

A positive effect of nitrogen fertilization at rates 0 to 180 kg.ha^{-1} on grain yield of the Predel cultivar was found but the differences were not mathematically proven (Table 1). In years with different hydro-thermal conditions without nitrogen fertilization were obtained strongly variable yields - from 2790 to 4250 kg.ha^{-1}. With high nitrogen rate N_{180} the lowest average yield was 3850 kg.ha^{-1} and the highest registered grain yield was 5380 kg.ha^{-1}. These results confirmed that the nitrogen effect on grain yields of durum wheat was strongly dependent on the weather conditions during durum wheat vegetation (Modhej et al., 2008).

The total grain+straw yield increased significantly with the increase of nitrogen fertilization. It was highest at the rate of N_{180}, exceeding the unfertilized control with 46.3 %. Application of fertilizer rate N_{180} was proven to decrease the harvest yield index - with 15.3 % compared to the unfertilized plants. The low N_{60} and moderate N_{120} nitrogen rates had no significant effect on the harvest yield index and its values were close to the control. The yield of grain protein during the study period varied over a wide range - from 346 to 905 kg.ha^{-1}. Application of moderate and high nitrogen rates demonstrated proven increase of the grain protein yield with 49.6 and 48.9 %, respectively, compared to the variant without nitrogen fertilization. The results confirmed that the nitrogen fertilization is a factor that is of major importance for the protein concentration in the grain (Panayotova and Dechev, 2002).

Table 1. Productivity of durum wheat as dependent on nitrogen rates ($kg.ha^{-1}$)

Nitrogen rates	$\mathbf{N_0}$	$\mathbf{N_{60}}$	$\mathbf{N_{120}}$	$\mathbf{N_{180}}$
Grain yield	$3658^{ns} \pm 659$	4068 ± 724	4745 ± 925	4510 ± 636
% to N_0	100	111.2	129.7	123.3
Grain+straw yield	$9540^{c} \pm 1295$	$10883^{bc} \pm 1527$	$12728^{ab} \pm 2024$	$13958^{a} \pm 2328$
% to N_0	100	114.1	133.4	146.3
Harvest index	$0.383^{a} \pm 0.03$	$0.372^{a} \pm 0.022$	$0.372^{a} \pm 0.034$	$0.324^{b} \pm 0.009$
% to N_0	100	97.3	97.1	84.7
Grain protein yield	$486^{b} \pm 107$	$554^{ab} \pm 113$	$727^{a} \pm 168$	$723^{a} \pm 132$
% to N_0	100	113.9	149.6	148.7

Average for the period the cultivar Predel formed grain with crude protein content of 13.4 - 13.55 % without fertilization and after a low nitrogen rate of 6 kg $N.ha^{-1}$ (Table 2). The use of N_{120} and N_{180} showed an increase in protein concentration in the grain compared to the non-fertilized plants. The protein content of the grain after moderate and high nitrogen fertilization reached 15.20 - 15.97 % ensuring a high biological value of the grain and obtaining high-quality pasta.

Table 2. Grain quality of durum wheat as dependent on nitrogen rates

Quality parameters	$\mathbf{N_0}$	$\mathbf{N_{60}}$	$\mathbf{N_{120}}$	$\mathbf{N_{180}}$
Grain protein concentration	$13.40^{b} \pm 0.90$	$13.55^{b} \pm 0.57$	$15.20^{a} \pm 0.80$	$15.97^{a} \pm 0.78$
% to N_0	100	101.1	113.5	119.2
Wet gluten content, %	$25.82^{ns} \pm 5.90$	28.04 ± 5.43	30.32 ± 4.40	32.41 ± 3.38
% to N_0	100	108.6	117.4	125.5
Dry gluten content, %	$9.34^{ns} \pm 1.97$	10.07 ± 2.03	11.10 ± 1.59	11.93 ± 1.42
% to N_0	100	107.8	118.8	127.7
Vitreousness of the grain,%	$56.93^{c} \pm 6.02$	$60.24^{cb} \pm 5.7$	$67.45^{b} \pm 0.68$	$75.84^{a} \pm 4.52$
% to N_0	100	105.8	118.5	133.2

The standard requires that the content of wet gluten in the grain of strong and durum wheat is over 28 %, and dry gluten - over 10 %. The applied rates of nitrogen fertilization increased the content of wet and dry gluten in the grain of cultivar Predel and it met the quality requirements for wet and dry gluten content, unlike the unfertilized. Grain vitreousness is an important indicator for grain structure with proven impact on yield and quantity of the semolina. The high quality durum wheat has vitreousness of over 75-80 %. Grain of high quality in terms of vitreousness was obtained at fertilization with N_{180} - 75.84 % average for the period. The effect of the low rate N_{60} on grain vitreousness was not proven compared to the untreated variant.

Table 3. Agronomic efficiency and partial factor productivity of nitrogen in durum wheat, average for the period 2008-2014 ($kg.kg^{-1}$)

Nitrogen rates	**N_{60}**	**N_{120}**	**N_{180}**
AE-N for grain	$6.8^{ns} \pm 2.7$	9.1 ± 3.0	4.7 ± 2.7
% to N_0	100	133.8	69.1
AE-N for grain protein	$1.2^{ns} \pm 0.4$	1.9 ± 0.6	1.3 ± 0.4
% to N_0	100	158.3	108.3
PFP-N for grain	$68^{a} \pm 12$	$40^{b} \pm 8$	$25^{c} \pm 4$
% to N_0	100	58.8	36.8
PFP-N for grain protein	$9.5^{a} \pm 1.9$	$6.0^{b} \pm 1.4$	$4.0^{b} \pm 0.7$
% to N_0	100	63.2	42.1

The index of agronomic efficiency characterizes the ability of plants to increase grain yield in response to nitrogen fertilization (Craswell and Gowdin, 1984; Novoa and Loomis, 1981) and for wheat depends most heavily on nitrogen fertilization and climatic conditions (Delogua et al., 1998). The results indicated lack of proven differences in nitrogen agronomic efficiency for grain yield and grain protein, average for the period (Table 3). The values of nitrogen agronomic efficiency for grain yield ranged from 0.9 to 12.5 $kg.kg^{-1}$. The highest AE-N for grain - 9.1 $kg.kg^{-1}$ was established for moderate fertilization with N_{120}. The high nitrogen rate N_{180} led to decrease in the additional grain yield per one kilogram of nitrogen fertilizer, 31.9 % over the fertilizing rate N_{60}. The agronomic efficiency of nitrogen for grain protein - 1.2-1.9 $kg.kg^{-1}$ shifted slightly and decreased with the increase of the fertilizing rate over N_{120}. The partial factor productivity of nitrogen represents the kg of grain or grain protein harvested per kg of N fertilizer applied. It can be used as an index of total economic outputs relative to the use of all N sources (soil N and applied fertilizer). Typical levels of PFP for cereal crops are 40-80 units (Dobermann, 2007). The obtained values of the PFP reduced with the increase of the applied amount of nitrogen. The average values of PFP-N for grain yield and for grain protein for cultivar Predel fertilized at rate N_{60} were 68 and 9.5 $kg.kg^{-1}$, respectively. Application of three times more nitrogen fertilizer decreased PFP-N for grain and PFP-N for grain protein with 63.2 and 57.9 %, respectively.

A strong positive correlation was established between nitrogen fertilization and grain+straw yield ($r = 0.726$**), grain protein concentration ($r = 0.862$**), grain protein yield ($r = 0.635$**) and vitreousness of the grain ($r= 0.856$**) for durum wheat variety Predel (Table 4).

Regression analysis for the dependencies between the resulting parameters (grain yield, grain+straw yield, grain protein yield, grain protein concentration, wet gluten content, dry gluten content and vitreousness of the grain) and the factor nitrogen fertilization on durum wheat cultivar Predel indicated that correlations were represented by equations of the second degree (Table 5).

Table 4. Correlations between nitrogen fertilization, productivity and grain quality of durum wheat

Parameters	Nitrogen fertilization	Grain yield	Grai+straw yield	Grain protein yield	Grain protein, %
Wet gluten content	0.504*	-0.136	0.001	0.054	0.372
Dry gluten content	0.542*	0.037	0.145	0.221	0.492
Vitreousness of the grain	0.856**	0.123	0.435	0.328	0.667**
Grain protein concentration	0.862**	0.741**	0.852**	0.874*	
Grain protein yield	0.635**	0.970**	0.927**		
Grain+straw yield	0.726**	0.875**			
Grain yield	0.471				

Table 5. Regression models for dependence of productivity and grain quality (y) on nitrogen fertilization (x) for durum wheat

Relationships y /x	Equation	R^2
Grain yield	$y = 3598 + 13.4x - 0.0448x^2$	0.267
Grain+straw yield	$y = 9484 + 26.6x - 0.0078x^2$	0.528
Grain protein yield	$y = 471 + 2.4 - 0.0051x^2$	0.416
Grain protein concentration	$y = 13.2 + 0.0094x + 0.005x^2$	0.753
Wet gluten content	$y = 25.8 + 0.0385x + 0.002x^2$	0.254
Dry gluten content	$y = 9.3 + 0.0134x + 0.0001x^2$	0.291
Vitreousness of the grain	$y = 56.8 + 0.0431x + 0.0004x^2$	0.756

High values of coefficients of determination ($R^2 > 0.750$) were found for the grain protein concentration and grain vitreousness in dependence of nitrogen fertilization. The regression model indicated that the values of grain protein concentration, wet gluten content, dry gluten content and grain vitreousness significantly increased with the increase of applied nitrogen fertilization up to rate N_{180}.

CONCLUSIONS

The nitrogen rates N_{120} and N_{180} applied to durum wheat proved increased grain protein yield with 49.6 and 48.7 % compared to the control. The rate N_{180} decreased the harvest index. The highest agronomic efficiency of nitrogen for grain and grain protein were obtained with moderate rate N_{120} average for the experimental period. Nitrogen fertilization decreased partial factor productivity of nitrogen from 68 $kg.kg^{-1}$ at rate N_{60} to 25 $kg.kg^{-1}$ at rate N_{180}. The highest concentration of grain protein - 15.97 % and vitreousness of the grain - 75.84 were obtained after applying N_{180}. The content of wet and dry gluten slightly depended on nitrogen fertilization.

A strong positive correlation was established between nitrogen fertilization and grain+straw yield (r=0.726**), grain protein concentration (r=0.862**), grain protein yield (r=0.635**) and vitreousness of the wheat grain (r=0.856**).

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