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GRAIN QUALITY OF DURUM WHEAT AS AFFECTED BY PHOSPHORUS AND COMBINED NITROGEN-PHOSPHORUS FERTILIZATION

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Abstract

The influence of phosphorus and combined N-P fertilization on durum wheat grain quality under conditions of long term fertilizing experiment in cotton-durum wheat crop-rotation during the period 2011-2013 was studied. The treatments were: N_0P_0; N_0P_{80}; N_0P_{120}; N_0P_{160}; $N_{120}P_{80}$; $N_{120}P_{120}$; $N_{120}P_{160}$. The experimental design was the method of Latin square with trial plot size 50 m^2 in four replications. The test weight and 1000 kernel weight of durum wheat variety. Progress slightly depended on phosphorus fertilization at rates of P_{80-160}. Average for the period, the largest grain of 59.96 g was obtained after the high phosphorus rate of 160 kg.ha^{-1} and in years with favorable conditions during vegetation. With contents of mineral nitrogen in soil below 40 mg.kg^{-1}soil and phosphorus fertilization at rates P_{80-160} was obtained total vitreousness in the range of 49.20 - 53.0% and crude protein concentration within 12.37 - 12.60%. When N_{120} was added, vitreousness of grain increased to 79.38 - 84.52% and the protein concentration in the grain increased significantly to 14.95%. Combined fertilization $N_{120}P_{80}$ was the optimal system, wherein grain was obtained with the highest content of wet (34.07%) and dry (13.10%) gluten, while the combination of nitrogen rate N_{120} and higher than P_{80} tended to decrease the gluten content. Drought at the end of durum wheat vegetation in June led to grain with higher vitreousness and content of the wet and dry gluten.

Key words: *durum wheat, gluten, grain quality, phosphorus, protein.*

INTRODUCTION

The productivity and quality of durum wheat varies to a wide range in dependence of a number of factors: agroecological conditions, genetic potential of the cultivar, crop-rotation, soil fertility, applied fertilization, cultivation technology, etc. (Delchev, 2009; Delchev and Panayotova, 2010; Delchev and Petrova, 2012; Gerdzhikova et al., 2013; Lalev et al., 2000; Moral, 2003; Panayotova, 2001; Panayotova and Kostadinova, 2011; Petrova, 2009). Weather conditions in the years and applied fertilizers exert great influence on the grain yield and quality of durum wheat (Abad et al., 2004; Ammes et al., 2003; Koleva-Lizama and Panayotova, 2002; Panayotova and Dechev, 1997).

Optimizing the mineral nutrition is one of the most important conventions for a favorable growth, production and quality of the plants, for ensuring their need of nutrient elements, for increasing the soil fertility. The fertilization of durum wheat grown after cotton should be complied with the fact that a significant part of the nitrogen for cotton is not utilized by it, but remains in soil. The two crops are successfully developed in crop-rotation and when fertilized actively participate in the nutrient utilization (Panayotova, 1999). A number of studies (Pacucci et al., 2004; Panayotova and Yanev, 2001) establish fertilization efficiency for varieties with different genetic endowments in different soil fertility. Panayotova (2001) appoints a genotype specific in relation with grain yield depending on the nutrition level. It is generally acknowledged that the varieties vary in their responsiveness to nitrogen accumulation in the vegetative parts. In breeding rarely takes into account the specifics of output forms in terms of mineral nutrition and are predicted possible results. So in recent years, agrochemical assessment of varieties and hybrids are emerging as a component in modern selection (Johnson, 2004; Sylvester-Bradley and Kindred, 2009). Grain quality is the most important criterion in the breeding of durum wheat to produce high quality pasta.

Experimental data indicate that the new genotypes combine high productivity with good quality. The problems for genetically transmitted and improved grain quality under different varieties of durum wheat are the subject of extensive scientific work (Mariani, 1995; May et al., 2008; Panayotova and Gorbanov, 1999; Panayotova and Valkova, 2010; Rharrabti et al., 2003; Uppal et al., 2002). Many studies have been conducted to examine the effects of N fertilizers and pre-crop on cereal grain yield. Some authors (Bauer et al., 1987; Carcea, 2003; Kostadinova, 2000) reported that the increasing N rate and rich soil fertility enhanced the content of grain protein and N in the straw. The responsiveness of different cultivars to N accumulated in the vegetative plant parts was established (May et al., 2008; Panayotova, 2010).

The aim of this study was to investigate the influence of the long-term phosphorus fertilization and combined nitrogen-phosphorus fertilization on grain quality of durum wheat.

MATERIALS AND METHODS

The investigation was studied under conditions of long term fertilizing experiment. The standard variety Progress, selected in Institute of field crops - Chirpan, Bulgaria was grown in two field crops rotation cotton-durum wheat under rainfed conditions for the period of three growing seasons including years 2011 – 2013. The experimental design was the method of Latin square with trial plot size 50 m^2 in four replications. The treatments were as follows: N_0P_0; N_0P_{80}; N_0P_{120}; N_0P_{160}; $N_{120}P_{80}$; $N_{120}P_{120}$; $N_{120}P_{160}$. The phosphorus fertilization was applied before sowing as a triple superphosphate. The nitrogen as ammonium nitrate (34% N) for durum wheat was applied by hand two times: one third - at sowing, and the rest as a top dressing at the end of wheat tillering stage (Feekes stage 4-5). The seeds were sown on October 25-30 in a sowing rate of 450 germinated seeds per m^2. Weeds were controlled between the tillering and shoot elongation stages with herbicides. There were no pathogens and pests above the threshold of harm during the durum wheat vegetation period in the three growing years and chemicals praying was not carried out. The harvest with plot combine was occurred on July10-15.

The main quality parameters of grain were studied: test weight (kg.hl^{-1}) - determined with libra; 1000 kernel weight (g) – by weighting two samples with 500 kernels; total vitreousness (%) - by cutting with pharinotom of Heinsdorf; the content of crude protein – by Kjeldahl standard method after combustion with sulfuric acid and derived according to: Protein, %= N (% DM) x 5.7; and wet and dry gluten (%) - with Gluten washing apparatus and by drying.

In regard with the meteorological conditions on grain quality unfavorable influence had the high temperatures during the period April to June in the three years and heavy precipitation in May-June in 2012 and 2013. During the winter period were not counted critical negative temperatures and no frost bite of crop (Figures 1 and 2).

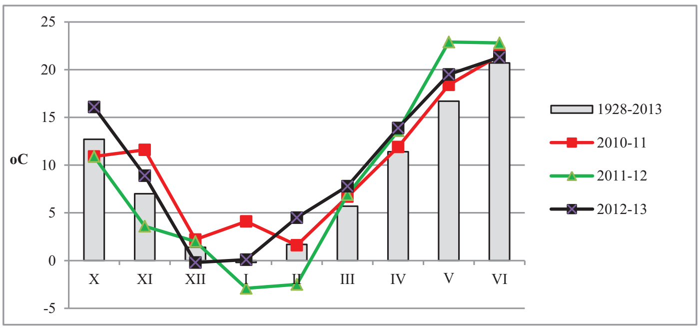

Figure 1. The average air temperatures during the vegetation period of durum wheat, 2011-2013

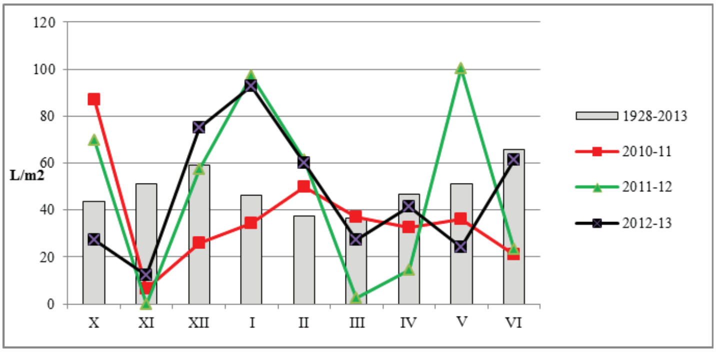

Figure 2. Sum of rainfall during the vegetation of durum wheat, 2011-2013

The soil in the field was *Pellic Vertisols* (FAO). It characterized with high humidity capacity and small water-permeability, defined by the sand-clay composition. The test field was with bulk weight of the plough soil layer 1.2 g/m^3 and specific gravity - 2.45. The sorbcium capacity was 35-50 mequ/100 g soil. The soil was of slightly acid soil reaction pH 6.2. The effect of different fertilizing systems on the contents of mineral nitrogen and the available forms of phosphorus and potassium in the soil is presented in Table 1.

Table 1. Content of mineral nitrogen and available phosphorus and potassium in the soil depends on fertilization

Fertilization	Depth, cm	N_{min}, mg.kg^{-1}	P_2O_5, mg.100g^{-1}	K_2O, mg.100g^{-1}
N_0P_0	0-20	19.63	3.3	17.9
	20-40	14.24	1.95	16.4
N_0P_{80}	0-20	20.02	18.6	18.2
	20-40	16.94	16.2	16.4
N_0P_{120}	0-20	19.74	19.7	18.4
	20-40	16.18	18.0	16.8
N_0P_{160}	0-20	21.56	21.6	18.6
	20-40	16.56	19.6	17.3
$N_{120}P_{80}$	0-20	43.12	19.9	20.1
	20-40	28.49	17.9	17.6
$N_{120}P_{120}$	0-20	43.82	19.8	19.4
	20-40	33.11	18.0	18.8
$N_{120}P_{160}$	0-20	44.34	21.2	19.2
	20-40	27.52	20.2	18.6

The content of mineral nitrogen as sum of NH_4-N and NO_3-N in the arable layer and in the 30-60 cm layer was 19.63-44.34 mg.kg^{-1} and 14.24 - 33.11 mg.kg^{-1}soil respectively, and the higher values were observed with nitrogen-phosphorus fertilization. Phosphorus fertilization led to enrichment with mobile phosphates. The soil in the plowing layer from low (3.3 mg/100 g soil at the unfertilized control) reached well-supplied with available phosphate (21.65 mg/100 g at P_{160}). The analyzes showed that the *Pellic Vertisols* was well supplied with mobile potassium - 17.95-20.1 mg/100 g soil in the plowing layer and 16.40-18.80 mg/100 g soil in layer 30-60 cm. Enrichment of plowing layer with phosphorus and potassium was more intense compared to that in 30-60 cm layer. Phosphorus fertilization enriched the subsoil with mobile phosphates - from 1.95 mg/100 g at P_0 to 18.02 mg at P_{120}, and to 19.65 mg/100 g at P_{160}. This is the result of long-term fertilization with phosphorus under a 50-years stationary fertilization trial.

RESULTS AND DISCUSSIONS

The test weight of grain during the period 2011-2013 had good values - more than 80.50 kg and conformity with the quality standard (Table 2). Different fertilizing systems influenced the test weight, and the differences were proven during the three analized years, despite their very close values. Average for the period, the highest proven test weight was reported as a result of natural soil fertility - 80.98 kg, and the lowest after phosphorous fertilization P_{120} - 80.50 kg (Table 2). In 2011, combined fertilization $N_{120}P_{160}$ formed a proven highest test weight of 81.15 kg, while the lowest was after fertilization with P_{120} - 80.05 kg. The highest values proven to exceed all systems of fertilization were reported in 2012 at unfertilized control - 81.20 kg, and were lowest at the high phosphorous rate of 160 kg P_2O_5.ha^{-1} and a background of N_{120} - 80.40 kg. In 2013, just like the previous year, a check had the highest values of the index, whereas the

lowest value of 80.45 kg was reported to the combined nitrogen-phosphorous fertilization at a rate of $N_{120}P_{80}$.
The test weight in 2011 increased by raising the level of combined fertilization, and in 2012 and 2013 had lower values as compared to control, which was associated with different precipitation and temperature supply at the end of the vegetation period when the qualitative parameters were being formed. In the different years, average for all fertilizing systems, the test weight was within very narrow limits and the differences were not proven mathematically (Table 2).
Average for the three analized statistically years, despite the proven differences between some of the variants, the 1000 kernel weight in variety Progress had similar values and was not strongly dependant on the system of fertilization (Table 3). The largest grain average for the period of study was established at the highest level of combined fertilization $N_{120}P_{160}$ - 55.52 g, which was 4 % more than the lowest 1000 kernel weight at high phosphorus fertilization P_{160} - 53.46 g. In 2011, the largest grain (similar to the average values for the whole period of study) was reported at the high phosphorus level of P_{160} and background of N_{120}- 59.96 g, which was proven to exceed all the other systems. The lowest values were at phosphorus fertilization P_{160}– 7% less than $N_{120}P_{160}$. In 2012, the 1000 kernel weight was highest compared to the other systems at $N_{120}P_{80}$ - 57.40 g, and it was lowest for the control - 55.00 g. In the last year of study, the strongest effect on size formation for wheat grain was observed with the combination $N_{120}P_{120}$ - 52.04 g, whereas the weakest was at N_0P_{160} - 48.38 g. The obtained higher values after combined NP fertilization could be explained by both manifested synergy between nitrogen and phosphorus in terms of assimilation by the wheat plants and increase in grain yield, and by their influence on the 1000 kernel weight. The average weight of 1000 kernels showed its highest values in 2011 - 57.34 g, which was more with 1.28 g than in 2012. The smallest grain was formed during the hot and dry year of 2013, which was characterized by insufficient rainfall during the ear formation – flowering period, which was an average of 14 % less than in 2011 (Table 3). Bozhanova et al. (2006) also reported a decreasing 1000 kernel weight in years of drought, and Abdullah (2009) found that the weight of grain was negatively affected by high temperatures and water deficit during filling and maturity of grain.
Average for the period, the total vitreousness after phosphorous fertilization on durum wheat was not high - 49.20-53.0%. According to some researchers, phosphorus fertilization decreased grain vitreousness, according to others – there was no effect on this parameter, and according to still others – it had positive effect. In the present study the increase of level of phosphorus fertilization from 80 to 160 $kg.ha^{-1}$ found that vitreousness increased with 2.53 to 6.33 points compared to the unfertilized check but it did not comply with the quality standard (Table 4). The values were proven higher after including nitrogen in the fertilization system, where vitreousness was 79.38 - 84.52% on average for the period and grain complied with the quality requirements. The differences were proven between all fertilization systems as average for the whole period.
In 2011, vitreousness for systems without nitrogen was low, whereas after combined fertilization the values significantly increased (72.35 - 75.35%). Higher grain vitreousness was obtained in 2012 for systems without nitrogen, where values reached 60.60 - 63.80% in dry conditions at the end of vegetation (June) and 88.60 - 90.0% after combined NP fertilization. In 2013, systems without nitrogen reached values of 45.60 - 50.80%, whereas adding nitrogen increased significantly the values (76.40 - 89.60%). Average for all systems of fertilization, vitreousness had proven and significantly higher values in 2012 - 73.87% due to drought at the end of the growing season (June), (respectively 17 and 36% more) compared to the values of this parameter in 2013 - 63.31% and in 2011 - 54.46% (Table 4).
The concentration of protein in durum wheat grain manifested slight changes after phosphorus fertilization. Average for the period of experiments, the lowest concentration of grain protein was established in check and after fertilization with P_{160} - 12.37%, and proven the highest was after combined phosphorous rate

P_{120} with 120 kg N.ha^{-1} (Table 5). The percentage of protein in the grain increased significantly after including nitrogen in the fertilization system, and the differences were proven against phosphorus fertilization. The highest proven values of the index were recorded for fertilization system $N_{120}P_{120}$ in each of the three years, and the lowest for unfertilized in 2011 and 2012 and at phosphorous fertilization P_{160} in 2013.

The year did not affect significantly the percentage of crude protein and average in all systems of fertilization, the values were very close – 13.12 to 13.58% and not cover statistically (Table 5).

Without nitrogen fertilization cannot be obtained durum wheat grain complying to the quality requirements for content of wet and dry gluten (Tables 6 and 7). The durum wheat requires nitrogen fertilization to obtain grain of good quality gluten. The annual nitrogen-phosphorous fertilization $N_{120}P_{80}$ on variety Progress and its cotton pre-crop was optimal out of the studied fertilizing systems, where grain was yield with the highest content of wet (34.07 %) and dry (13.10 %) gluten.

Table 2. Test weight of the wheat grain depends on fertilization (kg), 2011-2013

Factors	2011	2012	2013	Average	
				kg	%
A. Fertilization					
N_0P_0	80.80 c	81.20 a	80.95 a	80.98 a	100.0
N_0P_{80}	80.20 d	80.55 bc	80.90 a	80.55 cd	99.5
N_0P_{120}	80.05 e	80.75 b	80.70 b	80.50 d	99.4
N_0P_{160}	80.25 d	80.75 b	80.70 b	80.57 cd	99.5
$N_{120}P_{80}$	81.00 b	80.55 bc	80.45 c	80.67 bc	99.6
$N_{120}P_{120}$	80.95 b	80.45 bc	80.65 b	80.68 bc	99.6
$N_{120}P_{160}$	81.15 a	80.40 c	80.60 b	80.72 b	99.7
B. Year	80.63 ns	80.66	80.71		

Table 3. Weight of 1000 grains (g) in the wheat grain depends on fertilization, 2011-2013

Factors	2011	2012	2013	Average	
				g	%
A. Fertilization					
N_0P_0	56.68 bc	55.00 c	49.56 cd	53.75 cd	100.0
N_0P_{80}	57.32 b	55.80 bc	50.40 bc	54.51 bc	101.4
N_0P_{120}	56.84 bc	55.60 bc	49.53 cd	53.99 cd	100.4
N_0P_{160}	55.80 c	56.20 b	48.38 d	53.46 d	99.5
$N_{120}P_{80}$	57.28 b	57.40 a	51.24 ab	55.31 ab	102.9
$N_{120}P_{120}$	57.52 b	56.40 b	52.04 a	55.32 ab	102.9
$N_{120}P_{160}$	59.96 a	56.00 bc	50.61 abc	55.52 a	103.3
B. Year	57.34 a	56.06 b	50.25 c		

Table 4. Vitreousness (%) of durum wheat grain depends on fertilization, 2011-2013

Factors	2011	2012	2013	Average	
				%	% to N_0P_0
A. Fertilization					
N_0P_0	33.80 e	60.60 b	45.60 f	46.67 g	100.0
N_0P_{80}	40.00 d	61.00 b	46.60 ef	49.20 f	105.4
N_0P_{120}	41.20 d	63.70 b	48.20 e	51.03 e	109.3
N_0P_{160}	44.40 c	63.80 b	50.80 d	53.00 d	113.6
$N_{120}P_{80}$	72.35 b	89.40 a	76.40 c	79.38 c	170.1
$N_{120}P_{120}$	74.10 ab	90.00 a	86.00 b	83.37 b	178.6
$N_{120}P_{160}$	75.35 a	88.60 a	89.60 a	84.52 a	181.1
B. Year	54.46 b	73.87 a	63.31 b		

Table 5. Content of crude protein (%) in the grain of durum wheat depends on fertilization, 2011-2013

Factors	2011	2012	2013	Average	
				%	% to N_0P_0
A. Fertilization					
N_0P_0	12.51 e	12.20 f	12.39 de	12.37 f	100.0
N_0P_{80}	12.64 de	12.39 de	12.52 cd	12.52 e	101.2
N_0P_{120}	12.69 d	12.49 d	12.61 c	12.60 d	101.9
N_0P_{160}	12.52 e	12.26 ef	12.34 e	12.37 f	100.0
$N_{120}P_{80}$	14.86 b	14.07 b	14.44 b	14.46 b	116.9
$N_{120}P_{120}$	15.25 a	14.58 a	15.01 a	14.95 a	120.9
$N_{120}P_{160}$	14.62 c	13.87 c	14.30 b	14.26 c	115.3
B. Year	13.58 ns	13.12	13.37		

The combination of nitrogen rate N_{120} with higher than P_{80} showed a tendency to decrease the content of dry and wet gluten average for the period (Tables 6 and 7). In 2011 and 2012, the highest proven content of wet and dry gluten was reported after phosphorus rate of 80 $kg.ha^{-1}$ + N_{120} and the lowest after phosphorus fertilization P_{160}. In 2013 the highest content of gluten was for $N_{120}P_{160}$ (wet - 32.60% and dry - 12.00%) and lowest - for the unfertilized.

Average for the period for all fertilization systems the gluten content was highest in 2012 due to high temperatures in the period May-June, reaching 33.81% for wet and 13.33% for dry gluten. Gluten content was lowest in 2013 due to precipitation during the grain filling (June) (Tables 6 and 7).

Table 6. Concentration of wet gluten (%) in the grain of durum wheat depends on fertilization, 2011-2013

Factors	2011	2012	2013	Average	
				%	% to N_0P_0
A. Fertilization					
N_0P_0	26.40 d	31.00 f	12.60 f	23.33 f	100
N_0P_{80}	24.20 e	31.50 e	16.60 e	24.10 e	103.3
N_0P_{120}	24.00 f	31.80 d	16.80 d	24.20 d	103.7
N_0P_{160}	22.60 g	29.90 g	16.80 d	23.10 g	99.0
$N_{120}P_{80}$	33.50 a	37.80 a	30.90 c	34.07 a	146.0
$N_{120}P_{120}$	31.40 b	37.00 c	32.00 b	33.47 c	143.5
$N_{120}P_{160}$	31.20 c	37.70 b	32.60 a	33.83 b	145.0
B. Year	27.61 b	33.81 a	22.61 c		

Table 7. Concentration of dry gluten (%) in the grain of durum wheat depends on fertilization, 2011-2013

Factors	2011	2012	2013	Average	
				%	% to N_0P_0
A. Fertilization					
N_0P_0	9.60 d	12.60 d	4.20 g	8.80 f	100
N_0P_{80}	8.70 e	12.80 c	5.70 f	9.07 e	103.1
N_0P_{120}	8.60 f	12.80 c	5.90 d	9.10 d	103.4
N_0P_{160}	8.00 g	10.60 e	5.80 e	8.13 g	92.4
$N_{120}P_{80}$	13.20 a	14.90 a	11.20 c	13.10 a	148.9
$N_{120}P_{120}$	11.40 b	14.80 b	11.70 b	12.63 c	143.5
$N_{120}P_{160}$	11.20 c	14.80 b	12.00 a	12.67 b	144.0
B. Year	10.10 b	13.33 a	8.07 c		

CONCLUSIONS

The test weight and 1000 kernel weight of durum wheat variety Progress slightly depended on phosphorus fertilization at rates of 80-160 kg $P_2O_5.ha^{-1}$. Average for the studied period, the largest grain of 59.96 g was obtained after the high phosphorus fertilizer rate of 160 $kg.ha^{-1}$ against background of N_{120} and in years with favorable hydrothermal conditions during the vegetation of durum wheat. With contents of mineral nitrogen in soil below 40 $mg.kg^{-1}$soil and phosphorus fertilization at rates 80-160 kg $P_2O_5.ha^{-1}$ was obtained total grain vitreousness in the range of 49.20 - 53.0% and crude protein content within 12.37 - 12.60%.

When N_{120} was added, vitreousness of grain increased to 79.38 - 84.52% and the protein concentration in the grain increased significantly to 14.95%. To obtain grain with good quality gluten, durum wheat requires nitrogen fertilization. Combined fertilization $N_{120}P_{80}$ was the optimal system, wherein grain was obtained with the highest content of wet (34.07%) and dry (13.10%) gluten, while the combination of nitrogen rate N_{120} and higher than P_{80} tended to decrease the gluten content. Drought at the end of durum wheat vegetation in June led to grain with higher vitreousness and content of the wet and dry gluten.

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