THE EFFECT OF FERTILIZATION ON GRAIN YIELD AND PROTEIN CONTENT IN THE GRAINS OF SEVERAL WINTER WHEAT GENOTYPES

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Abstract: *Mineral nutrition of wheat crops grown on acid soils is specific. Well-balanced nutrition with nitrogen and phosphorus is crucial, the latter nutrient having a higher impact. Studies of fertilization effects were conducted in a stationary field trial on a degrading vertisol soil with low pH (pH < 5.0). Six variants of mineral nutrition (N, NP_1K_1, NP_2K_1, NP_1, NP_2 and NK_1) and untreated control (without nutrition) were tested in the experiment. The rates of nitrogen application were 80 and 120 kg N/ha, and they were applied either individually or in combination with two phosphorus rates and a potassium fertilizer. Grain yields and protein contents in seven genetically divergent cultivars of winter wheat (Takovčanka, Ana Morava, KG–100, Lazarica, KG–56S, KG–4 and KG–5) were analyzed. The investigation displayed considerable variation in the cultivars grain yields and grain protein contents depending on mineral nutrition. The cultivars Ana Morava and Takovčanka achieved the highest grain yields under mineral nutrition involving a combination of three mineral elements: N, P and K (120 kg N, 100 kg P_2O_5 and 60 kg K_2O), and under NP treatment at a rate of 120 kg N and 60 kg P_2O_5. The cultivar KG–56 S had the highest protein content, while the lowest was achieved by KG–5. The highest increase in grain protein content was achieved by applying NP nutrition at the rates of 120 kg N and 60 kg P_2O_5, as well as by NK nutrition at 120 kg N and 60 kg K_2O.*

Rezime: *Mineralna ishrana pšenice na zemljištima kisele reakcije pokazuje izvesne specifičnosti. Pri tome, presudan značaj ima izbalansirana ishrana azotom i fosforom, gde je znatno povećan udeo fosfornog hraniva. Ispitivanja su izvedena na stacionarnom poljskom ogledu sa đubrenjem, na zemljištu tipa vertisol u procesu degradacije. Zemljište na kome je ogled izveden odlikuje se niskom pH vrednošću (pH < 5,0). Ogled je obuhvatao kontrolu i šest varijanti mineralne ishrane (N, NP_1K_1, NP_2K_1, NP_1, NP_2 i NK_1). Doze upotrebljenog azota su bile 80 i 120 kg N/ha, koje su primenjivane pojedinačno i u kombinaciji sa dva nivoa fosfornih i kalijumovih đubriva. Ispitivan je prinos zrna i sadržaj proteina kod sedam različitih genotipova ozime pšenice (Takovčanka, Ana Morava, KG–100, Lazarica, KG–56S, KG–4 i KG–5). Ispitivanja su pokazala znatno variranje prinosa zrna i sadržaja proteina u njemu i to u zavisnosti od mineralne ishrane i uzgajanog genotipa. Najviši prinos zrna dobijen je sa sortama ozime pšenice Ana Morava i Takovčanka i to pri ishrani sa tri hranljiva elementa N, P i K (120 kg N,100 kg P_2O_5 i 60 kg K_2O), kao i sa primenom NP u količini od 120 kg N i 100 kg P_2O_5). Najveći sadržaj sirovih proteina u zrnu ostvaren je sa sortom pšenice KG–56S, a najniži sa sortom KG–5. Upotrebom NP hraniva u količinama od 120 kg N i 60 kg P_2O_5, kao i NK (120 kg N i 60 kg K_2O) postignut je najveći efekat u povećanju udela proteina u zrnu biljaka kod svih ispitivanih genotipova ozime pšenice.*

Key words: *mineral nutrition, wheat, cultivar, proteins, grain yield*
Ključne reči: *mineralna ishrana, pšenica, sorta, proteini, prinos zrna.*

INTRODUCTION

Wheat is one of the principle field crops in Serbia, as well as worldwide. In terms of acrage under wheat crops, it is currently ranked third internationally with its 220 million hectares, and the trend is rising. Regarding the volume of produce, its 510 million tonnes annually make it the first most important crop (DENČIĆ *et al*., 2004). Over the 2002–2004 period, wheat was cultivated in our country on an average of 664.000 ha, producing average yields of 3.28 t/ha (MLADENOV *et al*., 2005). Several factors are decisive in increasing wheat yields: the cultivar, cultural practices, agroecological conditions, local climatic and soil

characteristics, mineral nutrition and adequate protection from plant diseases, pests and weeds (MALEŠEVIĆ *et al*., 1997; MLADENOV *et al*., 2005).

High quality and high yields of wheat grains cannot be achieved without providing an adequately balanced mineral nutrition. Wheat fertilization is therefore primarily based on the crop's needs for NPK nutrients and their dynamic of uptake. Knowing the plants' requirements, the dynamic of uptake of certain nutrients during vegetation and their role in the formation of plant organs is crucial for determining the time and manner of application of fertilizers (MENGEL *and* KIRKBY, 2001). It is also important to know the crucial periods during vegetation when nutrient requirements are highest and their possible deficiencies affect the yield. However, an optimal effect of NPK fertilization can only be achieved if other factors influencing the yield have been optimized as well (JELIĆ *et al*., 2007; MALEŠEVIĆ, 2008). This especially concerns nitrogen due to its effect on the yield and quality of grains, but also because of its high mobility in soil (BEDÖ *et al*., 2001). Besides nitrogen, phosphorus fertilizers also have an important role, their effect being especially evident in acid or degraded soils (KOSTIĆ *et al*., 1991; TYRONE, 2002; JELIĆ *et al*., 2004). Protein content in wheat grains is an important parameter of quality, which depends on several factors: soil fertility, weather factors, cultural technology, etc. Elevated nitrogen supplies increase the accumulation of proteins in the grains, while its low rates, or poorly balanced nutrition lead to decreased protein contents (JELIĆ *and* LOMOVIĆ, 1993). Protein contents in the grain also depend on nutrient ratios in the fertilizers applied. Crude proteins have been found to increase under fertilization, especially in the later stages of wheat development (earing, blooming) (ĐOKIĆ *and* KOSTIĆ, 1996).

This study aimed at investigating the effect of different rates and ratios of mineral fertilizers on the yield and content of proteins in the grains of several winter wheat genotypes.

MATERIAL AND METHODS

The study was carried out in a stationary field trial involving fertilization over a three–year period from 2003 to 2006. Trials were first set up in the experimental fields of the Small Grains Research Centre in Kragujevac in 1970. This investigation included an untreated control and six variants of fertilization: N (80 and 120 kg N/ha), NP_1K_1 (80 and 120 kg N/ha, 60 kg P_2O_5/ha, 60 kg K_2O/ha), NP_2K_1 (80 and 120 kg N/ha, 100 kg P_2O_5/ha, 60 kg K_2O/ha), NP_1 (80 and 120 kg N/ha, 60 kg P_2O_5/ha), NP_2 (80 and 120 kg N/ha, 100 kg P_2O_5/ha) and NK_1 (80 and 120 kg N/ha, 60 kg K_2O/ha). The trial was set up in a randomized block design with five replications. Plot size was 50 m^2. Fertilization was regular and followed a long–time scheme. Total amounts of phosphorus and potassium fertilizers and half the nitrogen rate are regularly applied during pre–sowing cultivation of soil. The remaining amount of nitrogen fertilizer is applied in a single treatment at the height of tilling towards the end of winter. Seven wheat cultivars were tested in the trial: Takovčanka, Ana Morava, KG–100, Lazarica, KG–56S, KG 4 and KG 5. They were cultivated in rotation with millet. Sowing was carried out at optimal time with 700 germinable grains per m^2. The rest of the production technology was standard. The crop was harvested in the stage of full maturity, and the yield was measured and adjusted for 14% moisture. Immediately before harvest, samples were taken for analysis from 50 plants. Total nitrogen in wheat grains was determined according to Kjeldahl, while protein content was computed by multiplying total nitrogen concentration in the grains with coefficient 5.7. The data were tested and processed using the appropriate mathematical and statistical methods and the analysis of variance (*Mead et al.*, 1996).

Agroecologial conditions

The trial was set up on a vertisol soil in a process of degradation, with heavy texture and very coarse and unstable structure. Soil pH indicates high acidity ($pH_{(KCl)}$ 3.92–4.27), nitrogen content in soil is medium (0.12–0.15%), while the content of available phosphorus ranges from

very low (1.7–2.9 mg/100 g soil) in the N and NK trial variants to very high (26.9 mg P_2O_5/100 g soil) in the NPK variants of fertilization. Available potassium contents are high, ranging from 19.5 to 21.0 mg K_2O/100 g soil.

Meteorological conditions over the trial seasons (precipitation and temperatures) were very changeable (Tab. 1).

Table 1.

Average monthly air temperatures and precipitation during the growing seasons of winter wheat

Year	Month									Average
	X	XI	XII	I	II	III	IV	V	VI	
Air temperature (^{0}C)										
2003/04	13.5	10.8	4.9	3.9	4.2	11.0	10.8	17.4	18.5	10.6
2004/05	13.8	4.6	–2.4	–0.3	6.2	9.0	10.7	18.4	21.6	9.1
2005/06	12.3	9.7	1.3	0.6	–2.3	5.7	10.8	19.9	23.3	9.0
LTM	12.4	8.0	1.2	–0.2	0.8	5.8	11.6	16.3	20.1	8.4
Precipitation (mm)										Total
2003/04	8.0	24.0	24.6	20.7	32.7	36.8	155.3	43.7	104.9	450.07
2004/05	10.4	64.1	20.4	17.2	20.1	26.0	63.7	40.7	57.1	319.7
2005/06	65.5	31.5	39.4	59.0	19.8	2.8	37.2	42.5	47.7	345.4
LTM	60.8	47.3	54.7	42.4	32.8	54.6	59.3	99.2	84.8	529.2

Compared to a previous several–year average, monthly temperature means were higher, while precipitation was significantly lower in all of the three trial years. Compared to the several–year average, total precipitation decreased most in the second, and least in the first year of investigation. A significant decrease in total precipation, compared to the several-year average, was observed in the month of May, in addition to irregularity of precipation throughout the vegetation period.

RESULTS AND DISCUSSION

Good quality and high yield of wheat grains are not possible to achieve without adequately balanced mineral nutrition. Knowing the plants' requirements, the dynamic of nutrient uptake during vegetation and their role in the formation of plant organs is crucial for determining the appropriate time and method of fertilization (*Mengel and Kirkby*, 2001). It is also important to know the critical periods during vegetation when nutrient requirements are highest and possible deficiencies affect the yield and quality of grains (*Malešević*, 2008).

In the three–year period, the highest average grain yield of all winter wheat cultivars investigated was achieved in the NPK variant with the higher phosphorus rate (6.02 t ha^{-1}) (Tab. 2). Differences between grain yields of the untreated control and variants with fertilization were statistically highly significant. Fertilization with nitrogen alone resulted in a statistically highly significant increase in grain yield, compared to the untreated control, but further increase when nitrogen was applied in combination with P and K fertilizers was no longer statistically highly significant. Grain yield was higher when the higher nitrogen rate of 120 kg ha^{-1} was applied than it was under the lower rate of 80 ha^{-1}. The study showed that most investigated wheat cultivars achieved their highest grain yields less than 120 kg ha^{-1} nitrogen rate, phosphorus rate of 100 kg ha^{-1} P_2O_5 and potassium rate of 60 kg ha^{-1} K_2O.

The significantly lower wheat grain yields achieved in the N and NK trial variants than in the NPK and NP variants resulted from the existing phosphorus deficit in soil, and low pH and high content of mobile Al in soil solution (*Jelić et al*., 2003). Previously, *Jelić* (1996) and *Jelić et al*. (2003) had found that a significant increase in wheat grain yield on acid soils with low production capacity can be achieved using NPK fertilizers with a heightened portion of P nutrient. The investigated wheat cultivars reacted differently to the applied nutrients and their

rates, as well as to different nutrient ratios in the applied fertilizers. The highest average wheat grain yield was achieved by the cultivar *Ana Morava* (5.68 t ha^{-1}), and the lowest by KG–5 (4.36 t ha^{-1}). Considering the trial variants, the highest grain yield was achieved by *Ana Morava* in the variant of NP_1 nutrition (6.90 t ha^{-1}), and the lowest by the cultivar KG–100 in the control (1.79 t ha^{-1}). The investigated wheat cultivars reacted positively to the applied fertilizers, especially to the NPK fertilizer with increased portions of N and P nutrients. Corresponding findings had been reported by *Malešević and Bogdanović* (1987); *Jelić and Lomović* (1993), etc.

Table 2.

Grain yield of winter wheat (t ha^{-1})

Variant of fertilization		Cultivar							Average	
		Takovčanka	Ana Morava	KG–100	Lazarica	KG–56S	KG 4	KG 5		
Control		2.14	2.02	1.79	2.21	2.06	1.81	2.33	2.05	2.05
N	N_1	4.20	4.19	3.82	3.69	4.02	3.17	4.00	3.87	4.04
	N_2	4.64	5.14	4.31	3.68	4.07	3.84	3.79	4.21	
NP_1K	N_1	5.37	6.45	5.57	5.44	4.99	4.59	4.88	5.33	5.55
	N_2	5.72	6.32	6.27	6.27	5.43	5.51	4.93	5.78	
NP_2K	N_1	6.72	6.63	5.83	5.09	6.06	5.16	4.92	5.77	6.02
	N_2	6.85	6.77	6.03	6.68	5.66	6.05	5.91	6.28	
NP_1	N_1	6.44	6.90	5.87	5.11	5.44	4.40	3.84	5.43	5.64
	N_2	6.48	6.51	5.55	6.47	5.57	5.30	5.15	5.86	
NP_2	N_1	5.84	6.26	5.61	5.37	5.33	4.55	4.25	5.31	5.52
	N_2	6.66	6.39	5.92	5.61	5.39	5.33	4.79	5.73	
NK	N_1	4.74	4.99	4.32	4.20	4.19	3.60	3.73	4.25	4.43
	N_2	5.18	5.22	4.63	4.75	4.30	4.14	4.15	4.62	
Average		5.46	5.68	5.04	4.97	4.81	4.42	4.36	4.96	

LSD	A	B	AB	C	AC	BC	ABC
0.05	0.183	0.183	0.486	0.098	0.260	0.260	0.687
0.01	0.242	0.242	0.641	0.129	0.342	0.342	0.906

A–fertilization variant; B–nitrogen rate; C–year, AB–, AC–, BC–, ABC–interaction

Protein content in wheat grains is an important parameter of quality, which depends on several factors: soil fertility, weather factors, cultivation technology applied, etc. Higher nitrogen rates intensify protein accumulation in the grains, while lower rates or unbalance of mineral nutrients result in lower protein contents (*Jelić and Lomović*, 1993; *Malešević et al*., 1997). Protein content in the grains also depends on the ratio of nutrients in a fertilizer applied. It has also been found that the content of crude proteins in wheat grains has a rising trend under fertilization, especially in the later stages of plant growth (during earing or blooming) (*Malešević et al*., 2005).

In this investigation, protein contents in winter wheat grains varied depending on the variant of mineral nutrition and genotype investigated (Table 3).

The highest average content of proteins in wheat grains was achieved in the NP_1 and NK variants of fertilization (11.8% and 11.8%, respectively), and the lowest in the untreated control (10.0%). The increase in protein contents in the former variants of fertilization was statistically significant against the untreated control, while differences in protein contents among the variants NP_2K, NP_1 and NK had no statistical significance. Corresponding data had been reported by *Tyrone* (2002). The investigated wheat cultivars were found to have different contents of crude proteins. Among the genotypes investigated, the highest average protein content was achieved by the cultivar KG–56S (12.8%), and the lowest by KG–5 (10.7%). Regarding the fertilizers applied, the highest protein content was achieved by the cultivar KG–

56S in the variants involving NP_1 and NK fertilizers (14.4%), and the lowest by the cultivar Lazarica in the NP_1K variant of fertilization.

Table 3.

Average protein contents in winter wheat grains (%)

Variant of fertilization		Cultivar							Average	
		Takovčanka	Ana Morava	KG–100	Lazarica	KG–56S	KG 4	KG 5		
Control		9.7	9.8	10.1	9.5	10.7	10.2	10.3	10.0	10.0
N	N_1	11.8	11.6	9.8	11.4	11.6	12.2	12.3	11.5	11.5
	N_2	11.1	10.5	11.1	11.4	13.9	12.6	10.2	11.5	
NP_1K	N_1	10.6	9.8	10.6	9.1	12.6	10.9	10.3	10.5	10.9
	N_2	10.8	9.9	11.3	11.6	12.1	11.4	11.9	11.3	
NP_2K	N_1	10.7	12.1	9.5	11.9	13.6	11.3	9.7	11.2	11.3
	N_2	11.3	11.0	10.8	12.6	13.6	11.1	9.9	11.5	
NP_1	N_1	10.7	12.5	10.7	11.6	12.8	13.1	10.4	11.7	11.8
	N_2	12.6	11.2	11.2	10.4	14.4	13.3	10.6	11.9	
NP_2	N_1	10.4	9.9	11.5	9.5	13.4	10.9	10.4	10.8	11.0
	N_2	10.2	11.3	11.2	10.8	11.9	13.6	10.1	11.3	
NK	N_1	10.8	10.3	10.8	11.6	11.6	12.3	11.4	11.2	11.8
	N_2	12.5	11.9	12.4	13.0	14.4	11.4	11.9	12.5	
Average		11.0	10.9	10.8	11.1	12.8	11.9	10.7	11.3	

LSD	A	B	AB	C	AC	BC	ABC
0.05	0.222	0.222	0.587	0.119	0.314	0.314	0.830
0.01	0.293	0.293	0.774	0.156	0.414	0.414	1.095

A–fertilization variant; B–nitrogen rate; C–year, AB–, AC–, BC–, ABC–interaction

CONCLUSIONS

The results of this investigation of effects of different rates and ratios of mineral fertilizers on grain yields and protein contents of different genotypes of winter wheat suggest the following conclusions:

- Over the three-year period, all investigated cultivars of winter wheat achieved the highest average grain yield in the NPK variant of fertilization with the higher rate of phosphorus (6.02 t ha^{-1}). The difference between grain yields in the control and fertilization variants were statistically highly significant;
- The investigated wheat cultivars reacted differently to the applied types and rates of fertilizers, as well as to different nutrient ratios in the fertilizers applied. The cultivar *Ana Morava* achieved the highest average grain yield (5.68 t ha^{-1}), and the cultivar KG–5 the lowest yield (4.36 t ha^{-1});
- The highest average protein content in wheat grains was found in the variants involving NP_1 and NK fertilizers (11.8% and 11.8%, respectively), while the lowest content was found in the control variant (10.0%). The achieved increase in protein contents under fertilization was statistically significant against the untreated control, while the differences among protein contents in the NP_2K, NP_1 and NK variants were statistically insignificant.

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