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Impacts of NPK fertilization on chemical composition of wheat grain

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Abstract
The field experiment with NPK-fertilization rates was conducted on acid soil in spring 2008 as follows: a) 103 N + 52 P_2O_5+ 52 K_2O b) 133 N + 182 P_2O_5+ 182 K_2O; c) 183 N + 312 P_2O_5 + 312 K_2O.Each treatment plot measured 1008 $m^2$and it was divided in four 252 m^2 sub-plots (replicates). Winter wheat (cultivar *Renata*) was sown in the growing season 2010/2011. Grain yields of wheat were as follows: 7.44 t ha^{-1} (a), 8.74 t ha^{-1} (b) and 8.43 t ha^{-1} (c). As affected by the highest fertilizer rate, significantly were increased concentrations in wheat grain of P for 11%, Mg for 20%, Zn for 15%, Mn for 34%, Fe for 33%, B for 34%, Cd for 75%, and Sr for 67%. Cd concentrations were acceptable with aspects of human health (wheat grain: below 0.2 mg Cd kg^{-1}).

Key words: acid soil, grain yield, NPK-fertilization, winter wheat, grain composition

Introduction
Wheat is after maize, main field crop on arable lands in Croatia. According the data of the State Bureau for Statistics in the five-year period (2006-2010) wheat was grown in Croatia on 176794 ha/year or about 20% of used arable land in the country (867123 ha). Majority of wheat growing area of wheat (about 75%) is situated in five counties covering the region Eastern Croatia, which occupies about 22% of the state territory. In general, high wheat yield variation among years was found in the eastern Croatia, mainly as result of less or more favourable weather characteristics (Kovačević 2005; Marijanović et al., 2010). We presume that by adequate soil and crop management practice is possible to alleviate yield variation among years. Aim of this study was testing residual effects of increasing rates of NPK-fertilization on grain composition of winter wheat.

Material and methods
The field experiment
The field trial with three rates of NPK 8:26:26 (product of Petrokemija Fertilizer Factory Kutina, Croatia) fertilization was started on Gorjani (Osijek-Barannya County) acid soil (pH in 1nKCl = 4.13) in April 2008 as follows (kg ha^{-1}): a) 103 N + 52 P_2O_5+ 52 K_2O (200 kg ha^{-1} NPK 8:26:26 ploughed in autumn + 100 kg ha^{-1} urea 46% N applied before sowing + top-dressing with 150 kg ha^{-1} calcium ammonium nitrate or CAN 27% N); b) 133 N + 182 P_2O_5+ 182 K_2O (F-1 + 500 kg ha^{-1} NPK before sowing); c) 183 N + 312 P_2O_5 + 312 K_2O (F-1 + 1000 kg ha^{-1} NPK before sowing). The fertilization were made in three successive plots each of 1008 m^2 area. These plots were divided in four 252 m^2 of sub-plots (replicates).
In the next years residual effects of the fertilization were tested and the experiment was fertilized uniformly as basic fertilization. Crop rotation was as follows: maize (2008) – maize (2009) – maize (2010) – winter wheat (2010/2011). Response of maize (yields) and wheat (yields and grain quality) were elaborated in the previous study (Kovačević et al. 2012).

Winter wheat (cultivar *Renata*) was used in the experiment. The experiment was fertilized only with 150 kg N ha^{-1}, because of adequete P and K reserves. Urea (46% N) in amount 170 kg ha^{-1} incorporated in soil by presowing soil tillage and CAN (calcium ammonium nitrate: 27% N) applied in total amount of 260 kg ha^{-1} by two top-dressings in tillering and stem elongation stages. Wheat was sown in October 8, 2010 and harvested in June 28, 2011 (4 x $1m^2$ of area from each fertilization treatment). Ear were enumerated and harvested by special treshing mashine. Mass of grains were waighed by Kern electronic balance (d = 5 g). Grain yields were calculated on 14% grain moisture basis. Total mass of grain from individual plot used as sample for determination grain quality parameters and grain composition.

The total amount s of individual elements (phosphorus, potassium, magnesium, zinc, iron, manganese, copper, boron, cadmium and strontium) in grain samples, after microwave digestion using concentrated HNO_3+H_2O_2,was measured by the ICP-AES technique by Jobin-Yvon Ultrace 238 ICP-OES spectrometer in the laboratory of the Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of Hungarian Academy of Science and Arts in Budapest, Hungary.

Weather characteristics

Weather data (precipitatin and mean air-temperatures) were collected from The State Hydrometeorological Institute Zagreb were (Osijek Weather Bureau: about 30 km air-distance from Gorjani in NE direction).

In general, the growing season 2010/2011 could be characterized as favorable for wheat growing. Precipitation in n October-June period were 426 mm or for 13% lower in comparison with the long-term average. At the same period, average air-temperature was 8.6 °C or 1.7 °C higher. Precipitation were moderate but good distributed. Water deficite in the March-April period was compensated with adequate precipitation in May-June period. Winter was mild because mean Januar and Februar air-temperature was 0.9 °C or for 0.7 °C higher compared to the long-term average (Table 1).

Table 1. Precipitation and mean air-temperatures in Osijek Weather Bureau

	Osijek Weather Bureau: precipitation (mm) and mean-air-temperature (°C) during										
	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	Total	Mean
	The 2010/2011 growing season										
mm	67	56	73	24	18	37	20	81	50	*426*	
°C	9.1	8.9	0.3	1.1	0.7	6.4	13.2	16.7	20.8		*8.6*
	Long-term (30-y) averages (1931-1960)										
mm	68	70	57	47	53	45	54	71	83	*548*	
°C	11.3	6.0	1.6	-1.0	1.0	5.9	11.7	16.6	20.0		*8.1*
	Long-term (30-y) averages (1961-1990)										
mm	41	57	52	47	40	45	54	58	88	*492*	
°C	11.2	5.4	0.9	-1.2	1.6	6.1	11.3	16.5	19.5		*7.9*

Sampling, chemical and statistical analysis

Ten maize cobs from of each basic plot was taken for determinations of grain moisture and shelling percentage. Total mass of wheat grain collected from 1 m^2 harvested area in level of basic plot were used as samples for grain yield and quality parameters determinations.

The total content of the elements (P, K, Mg, Zn, Mn, Fe, Cu, B, Cd and Sr) inwheat grain samples were determined using ICP (Jobin-Yvon Ultrace 238 ICP-OES spectrometer) after their microwave digestion by conc. HNO_3 + H_2O_2. In the laboratory of RISSAC,

Budapest. The data were statistically analyzed by ANOVA and treatment means were compared using t-test and LSD at 5% and 1% probability levels.

Results and discussion

As affected by application the highest fertilizer rate, significantly were increased in wheat grain concentrations of phosphorus for 11% (4370 mg P kg^{-1}), magnesium for 20% (1360 mg Mg kg^{-1}), zinc for 15% (35.3 mg Zn kg^{-1}), manganese for 34% (72.3 mg Mn kg^{-1}), iron for 33% (58.9 mg Fe kg^{-1}), boron for 34% (0.94 mg B kg^{-1}), cadmium for 75% (0.14 mg Cd kg^{-1}), and strontium for 67% (1.14 mg Sr kg^{-1}), in comparison to the control. However, grain K and Cu status was independent on the fertilization (Table 2). Concentrations of Cd were in range of acceptable quantities with aspects of human health. According Decreeof The Commision of the European Communities, tolerable concentrations of Cd in grains of wheat are maximal 0.2 mg kg^{-1}, while tolerable daily intake of Cd is 1 μg Cd kg^{-1} body $weight^{-1}$ (FAO/WHO, 1989).

In general, soil pollutions by Cd in Croatia are low and Cd concentrations in the field crops are in acceptable levels with aspects of food security (Kovačević et al., 2011).Also, low quantities of Cd were found in maize grain and production of healthy food is possible on the most part of arable lands in Croatia. Excessive concentrations of Cd and other heavy metals were found mainly in soils of urban areas (Lončarić et al., 2012).

Table 2. Impacts of fertilization on composition of wheat grain (cultivar *Renata*)

Fertilization kg ha^{-1} (April 5, 2008)				Residual effects of fertilization on wheat grain composition (the growing season 2010/2011): mg kg^{-1} on dry matter basis								
	N	P_2O_5	K_2O	P	K	Mg	Zn	Mn	Fe	Cu	B	Cd	Sr
a	103	52	52	3950	4590	1130	31.5	53.8	44.4	3.28	0.70	0.08	0.68
b	133	182	182	4000	4610	1260	33.4	75.0	52.5	3.54	0.82	0.15	0.78
c	183	312	312	4370	4870	1360	35.3	72.3	58.9	3.51	0.94	0.14	1.14
Average				4110	4690	1250	33.4	67.0	52.0	3.44	0.82	0.12	0.53
LSD-test: LSD 5%				1903	n.s.	160	2.6	11.0	12.5	n.s.	0.17	0.02	0.25
LSD 1%				320		n.s.	n.s.	n.s.	n.s.		n.s.	0.03	n.s

In our investigations, high yield of wheat were found as result of especially favourable weather conditions. Moderate and good distributed precipitation as well as mild winter is more favourable for wheat, in comparison with excess of precipitation, especially in autumn/winter period, and cold winter. Wheat yield differences among years in the 1996-2007 period were from 3.62 to 5.00 t ha^{-1}. Precipitation quantities for Osijek in the period October-June were 606 and 382 mm, for unfavourable and favourable year, respectively (Kovačević, 2005; Josipović et al., 2005; Marijanović et al., 2010). However, drought stress and high air-temperature frequently limiting wheat yield in semiaride areas of Hungary (Pepo and Kovačević, 2011).

In our study, considerable residual effects of applied fertilization on wheat yield were found (Table 3) because wheat yield was increased for 17% in comparison to the control. However, maize (the 2008 – 2009 growing seasons) responded to the applied fertilization by yield decreases for 7% (Kovačević et al., 2012).

Table 3. Response of wheat (cultivar *Renata*) to the fertilization (Kovačević et al., 2012)

The stationary field experiment Gorjani 2011											
Fertilization kg ha^{-1} (April 5, 2008)				Effect of the fertilization on wheat (the growing season 2010/2011)							
				Ears per m^2	Grain characteristics						
					Yield	TKW	TW	Percent			ml
	N	P_2O_5	K_2O		t ha^{-1}	g	kg	Protein	Starch	WG	Sed.
a	103	52	52	680	7.44	50.20	83.4	11.8	68.2	30.3	33.2
b	133	182	182	713	8.74	48.40	83.6	13.1	67.0	34.0	43.2
c	183	312	312	706	8.43	47.58	84.6	13.6	66.4	35.5	50.0
Average				699	8.20	48.73	83.9	12.8	67.2	33.2	42.1
LSD-test: LSD 5%				31	0.55	n.s.	n.s.	0.6	0.9	1.9	4.1
LSD 1%				n.s.	0.83			1.0	1.3	2.8	6.2

Abreviations: TKW (thousand-kernel weight), TW (test weight), WG (wet gluten), sedimentation (Sed.)

Kirchmann et al., (2009) were analysed concentrations of trace elements in wheat grain samples from the Swedish long-term soil fertility experiments. Concentrations of Cu and Fe declined in NPK-fertilized wheat as compared to unfertilized wheat. Very low concentrations of Se and Co and low concentrations of Fe and Cu require attention to counteract risks for deficiencies.No samples had sufficiently high Se concentrations for human (0.05 mg Se kg^{-1}) or animal demand (0.1 mg Se kg^{-1}). Concentrations of Co in wheat grain were extremely low, 0.002–0.005 mg Co kg^{-1} grain dry weight, and far below the minimum levels required by animals. Sameen et al., (2002) tested impacts of NPK fertilization on chemical composition of wheat genotypes in Pakistan. Fertilization significantly affected ash and crude protein contents and moist absorption by wheat flour.Malghani et al., (2010) analysed response of wheat to NPK fertilization on sandy loam alkaline (pH 8.5) low in organic matter (0.41%) Layyah soil in Pakistan. The highest grain yield of 5.17 t ha^{-1}was recorded with the application (kg ha^{-1}) of 175 N + 150 P_2O_5 + 125 K_2O and it was 52% higher in comparison to the unfertilized plot (2.50 t ha^{-1}). Kaniuczak et al., (2011) reported results of the long-term liming and mineral fertilization effects on Cd contents in grain of spring barley and winter wheat on loessial soil in Poland. Liming did not prove to have any significant effect on Cd contents in spring barley and winter wheat grain, although the latter tended to decline in response to the treatment. Mineral NPK fertilization, significantly raised Cd contents especially in barley grain.

Conclusions

As affected by increasing NPK fertilization wheat yields were increased for 17%. At the same time, significantly were increased grain concentrations of phosphorus, magnesium, zinc, manganese, iron,boron, cadmium and strontium. However,grain K and Cu status was independent on the fertilization (Table 2). Grain Cd were in acceptable amounts with aspects of human health.

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Utjecaj NPK gnojidbe na kemijski sastav zrna pšenice

Sažetak

Poljski pokus NPK gnojidbe postavljen je na kiselom tlu u proljeće 2008.: a) 103 N + 52 P_2O_5+ 52 K_2O b) 133 N + 182 P_2O_5+ 182 K_2O; c) 183 N + 312 P_2O_5 + 312 K_2O.Površina svakog tretmana iznosila je 1008 m^2 i kasnije je podijeljena na četiri ponavljanja (252 m^2). Ozima pšenica (sorta *Renata*) uzgajana je na pokusnoj parceli tijekom vegetacije 2010/2011. Pšenica je posijana 8. listopada 2010., a požnjevena 26. lipnja 2011. Prinosi pšenice bili su slijedeći: 7,44 t ha^{-1} (a), 8,74 t ha^{-1} (b) i 8,43 t ha^{-1} (c). Primjenom najveće količine gnojiva su signifikantno povećane koncentracije u zrnu (u zagradi:mg kg^{-1}) P za 11%, Mg za 20%, Zn za 15%, Mn za 34%, Fe za 33%, B za 34%, Cd za 75% i Sr za 67%. Koncentracije Cd bile su u prihvatljivim vrijednostima sa stajališta ludskog zdravlja (zrno pšenice: ispod 0.2 mg Cd kg^{-1}).

Klučne riječi: kiselo tlo, prinos zrna, NPK gnojidba, elementarni sastav