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ISSN 1330-7142
UDK = 633.15+633.11:631.83'4'5

RESPONSE OF MAIZE AND WHEAT TO INCREASING RATES OF NPK-FERTILIZATION

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Original scientific paper
Izvorni znanstveni članak

SUMMARY

The stationary field experiment with increasing rates of NPK 8:26:26 fertilization was conducted on acid soil. Three steps of NPK-fertilization were applied (kg ha^{-1}) as follows: F-1 = 103 N + 52 P_2O_5 + 52 K_2O, F-2 = 133 N + 182 P_2O_5+ 182 K_2O and F-3 = 183 N + 312 P_2O_5+ 312 K_2O. Six hybrids of maize (the growing seasons 2008-2010) and winter wheat (2010/2011) cultivar Renata were grown in crop rotation. In our study, considerable subsequent effects of applied fertilization on wheat yields were found as follows: 7.44 t ha^{-1} (F-1), 8.74 t ha^{-1} (F-2) and 8.43 t ha^{-1} (F-3). However, maize responded by yield decreases up to 7% (3-year means: 10.76, 10,50 and 10.02 t ha^{-1}, for F-1, F-2 and F-3, respectively).

Key-words: acid soil, NPK-fertilization, yield, maize, wheat

INTRODUCTION

Maize and wheat are main field crops on arable lands in Croatia. According to the data of the State Bureau for Statistics (Statistical Yearbook 2011) in the five-year period (2006-2010) mean used agricultural land in the category arable land and gardens in Croatia was 867123 ha. Mean harvested areas of maize (298412 ha) and wheat (176794 ha) occupied 55% of used arable land of the country. Majority of maize and wheat growing areas are situated in the five counties of the eastern Croatia region. In general, high variation annually yields of maize and wheat in short period (for example from 4. 9 to 8.0 t ha^{-1} for maize and from 4.0 to 5.5 t ha^{-1} for wheat in the period 2006-2010) are mainly result of less or more favourable weather characteristics in the individual growing season (Josipović et al., 2005; Kovačević, 2009b; Marijanović et al., 2010). We presume that by adequate soil and crop management practice it is possible to alleviate yield variation among years. Aim of this study was testing subsequent effects of increasing rates of NPK-fertilization on maize and winter wheat yields.

MATERIAL AND METHODS

The field experiment

The stationary field experiment with increasing rates of NPK-fertilization was conducted on Gorjani (Osijek-Barannya County) acid soil (Ivan Pribanic Agricultural Family Farm) on April 5, 2008 (pH in 1nKCl = 4.13; hydrolitical acidity 6.78 cmol kg^{-1}). Three steps of NPK 8:26.26 fertilization were applied (kg ha^{-1}) as follows: F-1 = 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); F-2 = 133 N + 182 P_2O_5+ 182 K_2O (F-1 + 500 kg ha^{-1} NPK 8:26:26 applied before sowing; F-3 = 183 N + 312 P_2O_5 + 312 K_2O (F-1 + 1000 kg ha^{-1} NPK 8:26:26 applied before sowing). The fertilizers have been produced in Petrokemija Fertilizer Factory Kutina, Croatia. Each fertilizer treatment was appeared 1008 m^2 (30m longitude and 33.6 m width) of area.

These plots were divided into four 252 m^2 areas of sub-plots (replicates). In the next years subsequent effects of applied fertilization were tested and the experiment was fertilized uniformly at basic fertilization level. Crop rotation was as follows: maize (2008-2010) – winter wheat (2010/2011).

Six maize (Zea mays L.) domestic hybrids originating from Agricultural Institute Osijek (H-1=OsSK430, H-2=OsSK444, H-3=OsSK494, H-4=OsSK499, H-5=OsSK515 and H-6=OsSK552) were grown in the

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experiment for three growing seasons. The trial was designed as 2-factorial experiment (A: fertilization; B: hybrid) in four replicates. Two 4-rows replications of each hybrid distributed in form of reflection in mirror were sown in the second half of April (interrow spacing 70 cm and distance in row 20.0 cm: theoretical plant density 71428 plants ha^{-1}). Each fertilization treatment was divided at early growth stage of maize in two 15m-long plots for receiving four replicates at the hybrids level. Two internal rows (basic plot) of each replicates were harvested manually at end of October. Mass of cob was weighed by Kern electronic balance (d = 50 g). Grain yields were calculated on the average realized plant density at the hybrid level (because of similar plant density among fertilization treatments) and 14% grain moisture basis. Grain moisture were determined by Dicky-John grain moisture determination instrument.

Winter wheat (cultivar *Renata*) was sown in the fourth year of testing (the growing season 2010/2011) and subsequent effects of the fertilization were tested. Wheat was sown in October 8, 2010. The experiment was fertilized uniformly as follows (kg ha^{-1}): 150 N + 0 P_2O_5 + 0 K_2O (ploughed before sowing 170 kg urea 46% N ha^{-1} and two top-dressings with total 260 kg CAN ha^{-1}). Wheat was harvested in term June 28, 2011. Ears of wheat crop were taken from 4 x 1m^2 of area from each fertilization treatment for determination of yield and ears quantities per unit of area. Ear were enumerated and harvested by special small harvesting machine used for the field experiments. Mass of grains were weighed by Kern electronic balance (d = 5 g). Grain yields were calculated on 14% grain moisture basis.

Weather characteristics

The meteorological data of The State Hydrometeorological Institute Zagreb were used (Osijek Weather Bureau: about 30 km air-distance from Gorjani in NE direction) for characterization of weather properties (Tables 1 and 2).

The growing seasons 2008 and 2010 were more favorable for maize growing in comparison to the 2009 mainly because of adequate precipitation, especially in July and August. However, the growing season 2009 was unfavorable for maize. For example, in the two-month period April-May 2009 precipitation were inadequate, only 58 mm i.e. only 40% of long-term average. Additional aggravating circumstance was moderate soil reserves of water in the presowing period. Under these conditions there were difficulties in emergence of maize and reduction of plant density realization by about 25% compared to the planned plant density (Table 3). Also, drought in July (about 20% precipitation compared to the long-term mean) was accompanied with 23.2ºC monthly air-temperatures or by 2.2ºC higher in comparison to the usual value (Table 1). In general, the higher yields of maize found in the growing seasons characterized the higher precipitation and the lower temperatures, especially in two summer months July and August (Shaw, 1988; Kovačević et al., 2009a, 2009b; Maklenović et al., 2009; Markulj et al., 2010).

The growing season 2010/2011 was favorable for wheat growing. Precipitation in the October-June period were 426 mm or by 13% lower in comparison with the long-term average 1961-1990. At the same period, average air-temperature was 8.6 °C or by 1.7 °C higher. Precipitation were moderate but well distributed. Water deficit in the March-April period was compensated with adequate precipitation in May-June period. Winter was mild because mean January and February air-temperature was 0.9 °C or by 0.7°C higher compared to 30-y mean 1961-1990 (Table 2). In general, according to our experiences (Kovačević and Josipović, 1995; Kovačević, 2005; Josipović et al., 2005; Kovačević et al., 2009a, 2009b; Iljkić et al., 2010; Marijanović et al., 2010) moderate and well distributed precipitation as well as mild winter are more favourable for wheat in comparison with excess of precipitation, especially in autumn/winter period and cold winter. However, drought stress and high air-temperature more frequently limited wheat yield under semiaride climate in the eastern Hungary, compared to in the eastern Croatia (Pepo and Kovačević, 2011).

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

Tablica 1. Oborine i srednje temperature zraka (Meteorološka postaja Osijek)

Period *Razdoblje*	Osijek Weather Bureau (LTM = long-term means 1961-1990) *Meteorološka postaja Osijek (LTM = višegodišnji prosjeci 1961.-1990.)*							April – September *Travanj - Rujan*	
	Jan.-March *Sij.-ožujak*	April *Travanj*	May *Svibanj*	June *Lipanj*	July *Srpanj*	Aug. *Kolovoz*	Sept. *Rujan*	Total *Ukupno*	Mean *Prosjek*
	Precipitation (mm) / *Oborne (mm)*							mm	ºC
2008	123	50	67	76	79	46	86	404	
2009	115	19	39	63	14	61	10	206	
2010	165	71	121	234	32	111	108	677	
LTM	132	87	58	88	65	59	45	402	
	Mean air-temperature (ºC) / *Srednja temperatura zraka (ºC)*								
2008	4.6	12.5	18.1	21.5	21.8	21.8	15.7		18.6
2009	2.7	14.6	18.3	19.2	23.2	22.9	19.1		19.6
2010	2.5	12.4	16.5	20.4	23.1	21.7	15.6		18.3
LTM	2.2	12.7	16.5	19.5	21.0	20.3	16.6		17.8

Table 2. Precipitation and mean air-temperatures (Osijek Weather Bureau)

Tablica 2. Oborine i srednje temperature zraka (Meteorološka postaja Osijek)

	Osijek Weather Bureau: monthly precipitation (mm) and mean-air-temperature (°C) *Meteorološka postaja Osijek: mjesečne vrijednosti oborina (mm) i srednjih temperatura zraka (ºC)*										
	Oct. *List.*	Nov. *Stud.*	Dec. *Pros.*	Jan. *Sij.*	Feb. *Velj.*	March *Ožujak*	Apr. *Trav.*	May *Svib.*	June *Lipanj*	Total *Ukupno*	Mean *Prosjek*
	The 2010/2011 growing season / *Vegetacija 2010./2011.*										
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) means (1961-1990) / *Višegodišnji prosjeci (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 were taken for determination of grain moisture and shelling percentage. Total mass of wheat grain collected from 1 m^2 harvested area at basic plot level were used as samples for grain yield and quality parameters determinations.

Protein content, starch content, wet gluten and sedimentation value in the grain were determined by Near Infrared Transmittance spectroscopic method on Grain Analyzer (Infratec 1241, Foss Tecator) in the Agrochemical laboratory of Agricultural Institute Osijek.

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

By testing three factors (year, fertilization and hybrids) different degrees of their influence on maize yield were found. Regarding the aforesaid the most influencing factor was hybrid because differences of yields among the hybrids (3-year means) ranged from 8.94 t ha^{-1} (OsSK444) to 11.53 t ha^{-1} (OsSK440). The first-ranged hybrid yield was by 29% higher than the one from the last-ranged hybrid (Table 3). The second-ranged factor of yield was the growing season ("year") because under especially favorable weather conditions of the 2010 growing season maize grain yield was by 17% higher in comparison with less favourable 2009. The highest rate of NPK-fertilization resulted in moderate yield reduction of maize by 7% (3-year mean 10.02 t ha^{-1}) compared to the control (10.76 t ha^{-1}), while in the first-step of increasing NPK-fertilization maize yield was 10.50 t ha^{-1} or at the control level. We presume that additional soil acidification by addition of the high quantity of NPK-fertilizer could be the reason for this yield reduction. This hypothesis is supported by the fact that under more dry conditions of the 2009 growing season differences of maize yields among the fertilization treatments were non-significant and in narrow range from 9.70 to 9.97 t ha^{-1} (Table 3). For this reason, liming of acid soil could have priority in comparison to NPK-fertilization (Antunović, 2008; Kovačević and Rastija, 2010). However, specific response of individual hybrids to NPK-fertilization increasing was found. For example, based on 3-year means, yield of OsSK494 hybrid (B-3) was decreased BY 11% compared to the control, whereas yields of the hybrids OsSK499 (B-4) and Os515 (B-5) were practically independent on the fertilization, while yield losses of remaining three hybrids were between 7 and 8%. Also, specific response of maize to fertilization were found in the individual growing season. Taking this into account, yields were independent on the fertilization in 2009, while in the remaining two years yield reductions in A-3 treatment were 8% and 10%, respectively (Table 3).

In our investigations, very high yield of wheat (mean 8.20 t ha^{-1}) were found (Table 4), as a result of especially favourable weather conditions. In contrast with maize, considerable subsequent effects of conducted fertilization were found because wheat yield was increased by 17% in comparison to the control (7.44 and 8.74 t ha^{-1}, for F-1 and F-3, respectively). Regarding the aforesaid, application of the lower rate was adequate for significant yield increase (Table 4).

Increasing NPK-fertilization affected significantly improvements of wheat grain quality parameters, such as protein and wet-gluten contents as well as sedimentation while differences of thousand-kernel weight and test weight were non-significant (Table 4).

Komljenović et al. (2010) examined in a four years experiment the effect of four rates of phosphorus fertilization up to 1750 P_2O_5 kg ha^{-1} in the form of triple superphosphate on maize grain yields and maize nutrient status. P fertilization resulted mainly in considerable yield increase at 17% level (4-year means 2005-2008: 4.30 and 5.02 t ha^{-1}, for control and three ameliorative P-fertilized treatments, respectively). The experiment was conducted on the hydromprhic soil of the northern Bosnia in Gradiska municipality. In the second experiment on Knespolje soil (Kozarska Dubica municipality) application of P rates up to 1500 kg P_2O_5 ha^{-1} resulted in yield increase compared to the control being up to 32%, 17% and 20%, for the growing seasons 2004, 2005 and 2007, respectively. However, under drought conditions of the 2007 growing season yield was up to 60%

Table 3. Response of maize hybrids to fertilization

Tablica 3. Reakcija hibrida kukuruza na gnojidbu

The stationary field experiment Gorjani 2008 - 2010 / *Stacionirani poljski pokus Gorjani 2008. – 2010.g*										
Fertilization (April 5, 2008) *Gnojidba (5. travnja 2008.)*				Maize hybrid (factor B) *Hibrid kukuruza (faktor B)*						Average Prosjek
	kg ha^{-1}			B-1	B-2	B-3	B-4	B-5	B-6	A
	N	P_2O_5	K_2O	OsSK430	OsSK444	OsSK494	OsSK499	OsSK515	OsSK552	
				Grain yield of maize (t ha^{-1}): the 2008 growing season *Prinos zrna kukuruza (t ha^{-1}): vegetacija 2008.*						
A-1	103	52	52	12.74	9.32	10.39	10.75	11.64	9.51	10.72
A-2	133	182	182	11.68	8.96	9.45	10.99	11.67	9.58	10.39
A-3	183	312	312	11.36	8.14	9.08	11.17	10.87	9.24	9.81
Average B / Prosjek B				11.92	8.81	9.64	10.63	11.40	9.44	
				Grain yield of maize (t ha^{-1}): the 2009 growing season – subsequent effects *Prinos zrna kukuruza (t ha^{-1}): vegetacija 2009. – naknadni učinci*						
A-1	103	52	52	10.85	7.40	10.49	10.00	10.43	9.68	9.81
A-2	133	182	182	11.55	8.08	10.31	10.42	10.13	9.32	9.97
A-3	183	312	312	10.56	7.47	10.33	10.28	10.03	9.54	9.70
Average B / Prosjek B				10.99	7.65	10.38	10.23	10.20	9.52	
				Grain yield (t ha^{-1}): the 2010 growing season – subsequent effects *Prinos zrna kukuruza (t ha^{-1}): vegetacija 2010. – naknadni učinci*						
A-1	103	52	52	12.41	10.80	12.77	10.90	10.96	12.67	11.75
A-2	133	182	182	11.27	10.58	11.84	11.13	10.77	11.19	11.13
A-3	183	312	312	11.40	9.74	10.49	10.04	11.13	10.53	10.56
Average B / Prosjek B				11.69	10.37	11.70	10.69	10.95	11.46	

Statistical analysis (LSD-test) for grain yield (n.s. = non-significant) *Statistička analiza (LSD-test) za prinos zrna (n.s. = nesignifikantno)*									
	The growing season 2008			The growing season 2009			The growing season 2010		
	A	B	AB	A	B	AB	A	B	AB
LSD 5%	0.36	0.51	n.s.	n.s.	0.54	n.s.	0.51	0.37	0.9
LSD 1%	0.48	0.68			0.71		0.70	0.49	n.s.

Plant density realization (PDR) in % (100% = 71428 plants ha^{-1}) and grain moisture at the hybrids level (omissioned fertilization treatments because of similar values) for three tested growing seasons *Ostvareni sklop (PDR) u % (100% = 71428 biljaka ha^{-1}) i vlaga zrna na razini hibrida (izostavljene vrijednosti za tretmane gnojidbe zbog sličnih vrijednosti) za tri analizirane sezone vegetacije*								
		B-1	B-2	B-3	B-4	B-5	B-6	Average
PDR (%) *Ostvareni sklop (%)*	2008	93.5	91.2	94.0	96.3	93.5	90.3	93.1
	2009	81.8	63.7	71.3	72.4	82.0	72.9	74.0
	2010	95.5	89.2	92.2	92.4	91.8	91.0	92.0
Grain moisture (%) *Vlaga zrna (%)*	2008	18.4	18.9	20.0	21.6	18.8	21.6	19.9
	2009	16.9	17.0	17.6	16.9	16.5	16.9	17.0
	2010	19.8	19.5	20.1	20.6	19.9	22.6	20.4

Table 4. Response of wheat (cultivar *Renata*) to the fertilization

Tablica 4. Reakcija pšenice (sorta Renata) na oplodnju

The stationary field experiment Gorjani 2011 / *Stacionirani poljski pokus Gorjani 2011. g*											
Fertilization kg ha^{-1} Gnojidba kg ha^{-1}				Subsequent effect of the fertilization 2008 on wheat (the growing season 2010/2011) *Naknadni učinak gnojidbe 2008. na pšenicu (vegetacija 2010./2011.)*							
					Grain caharacteristics / *Svojstva zrna*						
								Percent / *Postotak*			ml
	N	P_2O_5	K_2O	Ears per m^2 *Klasovi po m^2*	Yield Prinos t ha^{-1}	TKW g	TW kg	Protein *Protein*	Starch *Škrob*	WG	Sed.
A-1	103	52	52	680	7.44	50.20	83.4	11.8	68.2	30.3	33.2
A-2	133	182	182	713	8.74	48.40	83.6	13.1	67.0	34.0	43.2
A-3	183	312	312	706	8.43	47.58	84.6	13.6	66.4	35.5	50.0
Average / Prosjek				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: *Kratice:*	TKW (thousand-kernel weight), TW (test weight), WG (wet gluten), sedimentation (Sed.) *TKW (masa 1000 zrna), TW (hektolitarska masa), WG (vlažni gluten), sedimentacija (Sed.)*										

lower and yields were similar to the P rates treatments (Komljenović et al., 2006, 2008).

Rastija et al. (2006) found positive response of maize to increasing rates of NPK-fertilization on acid soil of Bjelovar-Bilogora County because maize yields were increased up to 14%. However, soybean responded to this fertilization by yield increased up to 32%.

Liming of acid soil is mainly useful soil management practice for improvement of soil fertility. Marković et al. (2008) applied hydratized dolomite meal rates up to 20 t ha^{-1} on Gradiska hydromorphic soil in the northern Bosnia. By applying 20 t ha^{-1} lime maize yield increased close to 50%. Antunović (2008) tested response of maize and sugar beet to liming up to 60 t ha^{-1} with by-product of sugar factory (carbocalk) on acid soil of Slatina area. As affected by liming maize yields for four years of testing increased, depending on year, from 7% to 50%. Sugar beet responded to liming by root yield increases up to 43%.

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}).

CONCLUSION

Growing season characteristics, hybrid and fertilization were considerable factors of maize yields. Regarding, genotype was the most effective factor. Maize responded to the highest rate of NPK-fertilization by moderate yield loss to 7% level of probably because of additional acidification of acid soil. However, wheat responded to the fertilization by yield increases up to 17%. We recommend first of all liming of acid soil and then increasing NPK fertilization, especially for low supplied soils with P and K.

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REAKCIJA KUKURUZA I PŠENICE NA RASTUĆU NPK-GNOJIDBU

SAŽETAK

Stacionirani poljski pokus s rastućim količinama gnojiva NPK 8:26:26 postavljen je na kiselome tlu u travnju 2008. Primijenjene su tri stepenice gnojidbe (kg ha^{-1}): F-1 = 103 N + 52 P_2O_5 + 52 K_2O, F-2 = 133 N + 182 P_2O_5+ 182 K_2O i F-3 = 183 N + 312 P_2O_5+ 312 K_2O. Šest hibrida kukuruza uzgajano je tri godine (2008.-2010.), a nakon toga je na pokusnom polju uzgajana pšenica (sorta Renata). U našim istraživanjima ustanovljen je značajan naknadni učinak gnojidbe na prinos pšenice: 7,44 t ha^{-1} (F-1), 8,74 t ha^{-1} (F-2) i 8,43 t ha^{-1} (F-3). Međutim, kukuruz je reagirao nižim prinosom do 7% (3-god. prosjeci: 10,76; 10,50 i 10,02 t ha^{-1}, za F-1, F-2, odnosno F-3).

Ključne riječi: kiselo tlo, NPK-gnojidba, prinos zrna, kukuruz, pšenica

(Received on 1 October 2012; accepted on 29 November 2012 - *Primljeno 01. listopada 2012.; prihvaćeno 29. studenoga 2012.)*