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IMPACTS OF LIMING BY DOLOMITE ON THE MAIZE AND BARLEY GRAIN YIELDS

V. Kovačević[(1)], Mirta Rastija[(1)]

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SUMMARY

In a five year experiment the effect of liming on maize and spring barley grain yields and maize nutrient status were examined. The field trial with application of increasing rates of dolomite (0, 5, 10 and 15 t ha^{-1}) containing 56% CaO and 40% MgO was conducted on the very acid soil with pH (KCl) 3.78 on the location in the central Croatia (45°30' N, 17°11' E). Maize crops were grown during 2003-2005 and 2007, whereas spring barley was grown in 2006. Soil chemical properties and maize leaf nutrient concentrations were evaluated after the second year of trial. Liming raised the soil pH by 2.62 pH units and AL-P_2O_5 by 5.65 mg 100 g^{-1} and increased crops yield in all years. There were no statistically confirmed differences between treatments with 10 and 15 t ha^{-1} dolomite for maize yields, while barley grain yield significantly increased only at the highest dolomite rate. Liming also improved maize nutritional status and increased P, Ca, Mg and Mo concentration and decreased high Mn content to the adequate range.

Key-words: liming, maize, barley, grain yield, maize leaf nutrients

INTRODUCTION

Soil acidity and elemental toxicities or deficiencies associated with it, affects crops growth and restricts yields throughout the world (Eswaran et al., 1997; Rengel et al., 2003). Acid soil with a pH lower than 5.50 are widespread in Croatia and cover a large area of arable land (Kovacevic et al., 1993; Loncaric et al., 2005). Amelioration of acid soil by different liming materials can raise soil pH, benefiting soil properties and plant growth and liming is widely practiced for improving the acid soils productivity (Adams, 1984; Edmeades and Ridley, 2003; Conyers, 2006). There are plenty of liming materials that can be used to neutralize soil acidity, but majority of them comes from ground limestone such as calcite ($CaCO_3$) and dolomite ($CaCO_3$, $MgCO_3$). Numerous researches have confirmed positive effect of liming on crops grain yield in Croatia (Kovacevic et al., 1993, 2006a; Antunovic, 2008; Rastija et al., 2010). Acid soils are usually excessive in soluble Al and Mn and deficient in P, Ca, Mg and Mo, that may cause their reduced uptake and lead to nutrient imbalances in plants (Foy, 1984; Clark and Baligar, 2000). The present study aimed to investigate the effect of lime application on maize and barley grain yield during five year period, as well as on soil status and maize leaf nutrients.

MATERIAL AND METHODS

The liming field trial with application of dolomite containing 56% CaO and 40% MgO was conducted in the spring of 2003 on the very acid soil with pH (KCl) 3.78 in the Badljevina (Pakrac municipality, Pozega-Slavonia County). The trial was set up in a randomized complete block design with four repetitions and the size of basic plot was 92.4 m^2. Liming treatments consisted of three rates of dolomite including the control as follows: 0 (control), 5, 10 and 15 t ha^{-1}. The experimental plot was fertilized uniformly at a level of the ordinary fertilization (160 N + 150 P_2O_5+ 100 K_2O). The cropping sequence in the five year period was: maize (2003 – 2005) – spring barley (2006) – maize (2007).

The maize was sown at the end of April at different plant densities, depending on hybrid FAO group: OSSK617 at 52000 plants/ha for 2003, OSSK552 at 60000 for 2004 and 2005, and OSSK373 at 72000 plants/ha for 2007. Four rows from each plot were harvested manually at the end of September or the first half of October. Grain yields of different maize hybrids were evaluated and calculated on the 14% moisture basis and realized plant density.

(1) Prof.dr.sc. Vlado Kovačević, doc.dr.sc. Mirta Rastija (mrastija@pfos.hr) – Sveučilište Josipa Jurja Strossmayera u Osijeku, Poljoprivredni fakultet u Osijeku, Trg Svetog Trojstva 3, 31000 Osijek

Spring barley was sown in the middle of March. Total area of 1.0 m^2 was harvested manually from each plot for grain yield and ears number determination.

Choice of the experimental plot was made based on the previous soil analysis performed as a part of international project of war affected communities revitalization supported by USA (International Rescue Committee) in cooperation with Croatian Co-operative Association and Croatian Agricultural Extension Service (Kovacevic et al., 2005). Identical field experiment was conducted on the soil of somewhat less acid reaction (pH_{KCl} 4.30) about 2 km air-line apart, which results were shown by the earlier studies (Kovacevic et al., 2010; Rastija et al., 2010). Soil samples (0-30 cm) were taken from each basic plot, after maize harvesting in 2004. Soil pH (H_2O and M KCl,) was determined according to ISO (1994), humus content by sulfocromic oxidation (ISO, 1998) and plant available phosphorus and potassium by ammonium-lactate extraction (Egner et al., 1960). The samples of maize ear-leaves for nutritional status determination were taken at the beginning of silking stage in 2004. The concentrations of elements were measured by ICP technique followed by microwave digestion procedure with $HNO_3+H_2O_2$.

Data were statistically analyzed by ANOVA and treatment means were compared using t-test and LSD at 0.05 probability level. Weather data were collected from Meteorological station Daruvar, 10 km toward N-direction from the experimental field.

Weather conditions were differed during experimental period, especially concerning monthly rainfall amount. The 2003 was exceptionally warm and dry and very unsuitable for maze growing, while the rainy summer months is the main feature of 2005 (Table 1). Other maize vegetation seasons were generally favourable concerning rainfall and air temperature regimes. Lack of water and somewhat higher air temperatures were characteristic of 2007, too. The 2006 was favourable for spring barley growing, as air temperatures were in the range of long term mean, and higher amount of rainfall in April and May were recorded (Table 2).

Table 1. Weather characteristics for maize growing seasons and long-term means

Tablica 1. Vremenske prilike tijekom vegetacijskih razdoblja kukuruza i višegodišnje prosječne vrijednosti

Year	Monthly amount of precipitation (mm) *Mjesečne količine oborina (mm)*						Mean air-temperatures (°C) *Srednje temperature zraka (°C)*					
	May	June	July	Aug.	Sept.	Total	May	June	July	Aug.	Sept.	Mean
2003	35	36	38	46	111	266	18.5	23.6	22.2	23.7	15.0	20.6
2004	55	97	65	63	103	383	14.2	18.7	20.4	20.2	14.9	17.7
2005	69	45	106	166	110	496	15.9	18.9	20.8	18.5	16.1	18.0
2007	95	62	29	100	146	432	17.5	21.5	22.5	21.1	13.7	19.3
LTM#	86	99	86	91	65	427	15.7	18.9	20.6	19.7	16.1	18.2

#LTM – Long-term mean (1961-1990)/ *višegodišnji prosjek (1961.-1990.)*

Table 2. Weather characteristics for spring barley growing season and long-term means

Tablica 2. Vremenske prilike tijekom vegetacijskoga razdoblja jarog ječma i višegodišnje prosječne vrijednosti

Year	Monthly amount of precipitation (mm) *Mjesečne količine oborina (mm)*						Mean air-temperatures (°C) *Srednje temperature zraka (°C)*					
	Feb.	March	April	May	June	Total	Feb.	March	April	May	June	Mean
2006	26	59	117	106	95	403	1.2	5.1	11.6	15.2	19.1	10.4
LTM#	49	58	77	86	99	369	2.1	6.2	11.0	15.7	18.9	10.8

#LTM – Long-term mean (1961-1990)/ *višegodišnji prosjek (1961.-1990.)*

RESULTS AND DISCUSSION

Liming with dolomite significantly influenced the soil pH and phosphorus availability. After the second maize growing season (autumn 2004), soil pH gradually raised from initial very acid reaction measured on the control to the low acid soil reaction. Application of 15 t ha^{-1} dolomite raised pH(KCl) value by 2.62 pH units, indicating a considerable changes of chemical soil properties (Table 3).

Although lack of phosphorus could be expected in such an acidic soil, probably due to prior adequate fertilization, its content wasn't in the range of insufficient supply. However, significant increase of plant available phosphorus was achieved by the application of 10 and 15 t ha^{-1} dolomite, respectively (Table 3). It is generally known that reducing of soil acidity leads to increased phosphorus availability (Gaume et al., 2001) Liming didn't affect potassium availability, being in the optimal range. In the identical experiment, Kovacevic et al. (2010) didn't find the effect of liming on potassium content either, while the application of 10 and 15 t dolomite ha^{-1} significantly increased phosphorus content. Similar effects regarding AL-soluble phosphorus and potassium

Table 3. Liming effects on the soil properties (0-30 cm depth), 2004

Tablica 3. Utjecaj kalcizacije na svojstva tla (0-30 cm dubine), 2004. godine

Dolomite	pH		Humus	P_2O_5	K_2O
t ha^{-1}	H_2O	KCl	%	mg 100 g^{-1}	
0	4.50 d	3.74 d	2.75	17.18 b	21.65
5	5.68 c	4.90 c	2.67	17.73 b	21.80
10	6.29 b	5.71 b	2.88	21.20 a	23.20
15	6.86 a	6.36 a	2.78	22.83 a	23.15
Mean	5.83	5.18	2.77	19.73	22.45
$LSD_{0,05}$	0.27	0.37	ns	2.99	ns

Values followed by the different letters within each column are significantly different ($P \leq 0.05$)

Vrijednosti označene različitim slovima unutar kolone signifikantno su različite ($P \leq 0,05$)

were observed by Zhang et al. (2004) and Lončarić et al. (2007).

On the average, appropriate plant density for maize hybrids was achieved, but in dryer 2003 and 2007 vegetation seasons realized plant density was somewhat lower than in 2004 and 2005 (Table 4). Moreover, a greater contribution of sterile plants in control treatments was recorded in 2005. Especially high percent of plants without ears was observed in the last year of liming experiment, when maize hybrid from earlier FAO group was growing. Dry June and particularly July of 2007 (Table 2), and hybrid susceptibility could be the cause of this case. Kovačević and Josipović (1998) have reported that lower maize yields in Croatia are usually related to lack of rainfall and higher air temperatures during July and August.

The highest average maize grain yield (11.47 t ha^{-1}) was achieved in 2004 which was characterized by an adequate amount of evenly distributed rainfall and somewhat lower air temperatures during the growing season. On the contrary, in the last year of field trial, the average maize grain yield was only 4.44 t ha^{-1}. Such a low yield is probably more a result of adverse weather conditions and great proportion of sterile plants than reduced liming effect after five years. Some studies have indicated that effects of lower liming rates are short termed (Rastija et al., 2008).

Table 4. Response of maize hybrids to liming - realized plant density (% RPD) and share of sterile plants (% SP)

Tablica 4. Reakcija hibrida kukuruza na kalcizaciju - ostvareni sklop (% RPD) i udjel sterilnih biljaka (% FSP)

Dolomite t ha^{-1}	Year/ hybrid – *Godina/hibrid*							
	2003/OSSK617		2004/OSSK552		2005/OSSK552		2007/OSSK373	
	RPD	SP	RPD	SP	RPD	SP	RPD	SP
0	92.3	4.3	90.9	3.2	96.4	27.3	84.9	44.5
5	93.0	3.9	89.8	2.4	99.0	0	89.8	40.3
10	86.3	0	92.4	2.3	101.4	0	90.3	32.1
15	80.3	0	90.7	1.3	94.1	0	83.5	24.7
Mean	88.0	2.0	91.0	2.3	97.7	6.8	87.1	35.4

Table 5. Response of maize hybrids to liming - grain yield

Tablica 5. Reakcija hibrida kukuruza na kalcizaciju - prinos zrna

Dolomite t ha^{-1}	Year/ hybrid - *Godina/hibrid*			
	2003/OSSK617	2004/OSSK552	2005/OSSK552	2007/OSSK373
	Grain yield (t ha^{-1}) - *Prinos zrna (t ha^{-1})*			
0	6.75 b	9.82 b	3.72 c	3.60 c
5	7.49 ab	11.76 a	8.05 b	4.04 bc
10	7.53 ab	12.29 a	9.35 a	4.72 ab
15	7.76 a	12.01 a	8.72 ab	5.40 a
Mean	7.38	11.47	7.46	4.44
$LSD_{0,05}$	0.93	0.68	0.90	0.72

Values followed by the same letters within each column are not significantly different ($P \leq 0.05$)

Vrijednosti označene istim slovima unutar kolone nisu signifikantno različite ($P \leq 0,05$)

The grain yield of maize was influenced by liming in all four years and yield was significantly increased at all liming treatments compared with control. However, between rates of 15 and 10 t ha^{-1} dolomite no significant difference was found (Table 5). In the first year of the research maize responded to lime application by increasing the grain yield by 15%, and in the second year by 25%. The best response was observed in 2005 and 2007 when grain yields increased by 50%. As share of sterile plants on the control treatments was 27% and 44% in 2005 and 2007, respectively (Table 4), such a considerable increase compared to the control can be attributed to the influence of liming on the reduction of sterile plant.

Table 6. Liming impact on concentrations of elements in maize ear-leaf in growing season 2004

Tablica 6. Utjecaj kalcizacije na koncentraciju elemenata u listu ispod klipa 2004. godine

Dolomite t ha^{-1}	Concentration of macroelements (g kg^{-1}) *Koncentracija makroelemenata*				Concentration of microelements (mg kg^{-1}) *Koncentracija mikroelemenata*			
	P	K	Ca	Mg	Fe	Mn	Zn	Mo
0	3.38 c	25.2	4.79 b	1.62 c	132	256 a	44.3	0.06 d
5	3.61 b	25.6	5.19 a	2.42 b	122	152 b	47.8	0.29 c
10	3.70 ab	26.1	5.09 ab	2.56 ab	130	127 c	46.6	0.49 b
15	3.78 a	25.4	5.03 ab	2.70 a	137	122 c	45.7	0.59 a
Mean	3.61	25.6	5.02	2.33	131	164	46.1	0.36
$LSD_{0,05}$	0.16	ns	0.38	0.28	14	24	ns	0.06

As expected, liming significantly increased P, Ca and Mg concentrations in the maize ear-leaves. Overall, the highest values were realised with the highest dolomite rate, but without significant difference in comparison with 10 t ha^{-1} dolomite (Table 6). Leaf P, K and Ca status was in an adequate range, but low Mg concentration (1.62 g kg^{-1}) in the control treatment was found, as range from 2.5 to 5.0 g kg^{-1} reported to be optimal (Bergmann, 1992). Liming improved leaf Mg concentration to 2.70 g kg^{-1} or by 44% compared to the control. In liming experiments at 19 sites, Aitken et al. (1998) reported that lime significantly increased maize leaf tissue P concentrations at 6 sites, whereas Zn and Mn concentrations were decreased at 7 and 10 sites, respectively. Jurković et al. (2008) also found the increased concentrations of P, Mg and Ca in maize ear leaf, as well as significant decrease for Mn and Zn concentrations, six years after liming.

Surprisingly, liming didn't affect maize Zn status, although it is well known that lime application considerably reduces its availability in soil and may induce plant Zn deficiency (Brallier et al., 1996, Rochayati et al., 2010). We presume that this effect would be likely to appear in the following years. However, ear leaf Zn concentration of about 45 mg kg^{-1} is in the quite optimal range. Irrespective of Zn, concentration of Mn in maize leaf considerably decreased from high value of 256 mg kg^{-1} to 122 mg kg^{-1} Mn as a result of liming (Table 6). Although the upper critical level of Mn concentration is not clearly limited, Mengel and Kirkby (2001) notified that the value of 200 mg Mn kg^{-1} could be responsible for dry matter yield reduction, while Zorn and Prausse (1993) found out that Mn concentrations above 350 mg kg^{-1} in the young maize plants is associated with symptoms of Mn excess. It seems that Mn concentration in maize leaves above 200 mg kg^{-1} is not unusual for very acid soil as in this research. Molybdenum concentration is considerably increased with dolomite rates. It is known that Mo in acid soils tends to be unavailable to plants but it could be released by liming (Kaiser, 2005).

Table 7. Response of spring barley to liming (2006)

Tablica 7. Reakcija jaroga ječma na kalcizaciju 2006. godine

Dolomite t ha^{-1}	Ears density per m^2	Grain yield t ha^{-1}	Test weight (kg)	Proteins (%)	Starch (%)
0	505 b	2.70 b	72.0	13.4	52.7
5	457 c	2.94 b	72.2	12.6	53.9
10	450 c	2.86 b	70.9	12.2	53.1
15	615 a	3.24 a	70.8	12.9	53.2
Mean	507	2.94	71.5	12.8	53.2
$LSD_{0,05}$	33	0.30	ns	ns	ns

Values followed by the different letter within each column are significantly different ($P<0.05$)

Vrijednosti označene različitim slovima unutar kolone signifikantno su različite (P<0,05)

Liming significantly affected barley ears number and grain yield four years after dolomite application, but only at the highest rate, where yield increase by 20% was achieved. Barley is particularly sensitive to soil acidity. A number of authors reported about positive effect of liming on barley growth and grain yield (Tang et al., 2003.; Kovacevic et al., 2006b). However, no impact on the test weight and contents of proteins and starch in the grain was observed (Table 7).

CONCLUSION

Liming considerably affected the soil pH and plant available P status, as pH(KCl) raised by 2.62 pH units and AL-P_2O_5 by 5.65 mg 100 g^{-1} at the highest dolomite rate two years after application. Liming also increased crops yield in all years, but there were no significant differences between treatments with 10 and 15 t ha^{-1} dolomite for maize yield, implying that effect of liming with lower dose could last for several years. However, barley grain yield significantly increased only at the highest dolomite rate. The results also showed that liming effect on grain yield is influenced by environmental conditions. Liming improved maize nutritional status and increased P, Ca, Mg and Mo concentration and decreased high Mn to the adequate range.

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UTJECAJ KALCIZACIJE S DOLOMITOM NA PRINOSE ZRNA KUKURUZA I JEČMA

SAŽETAK

Utjecaj kalcizacije na prinose zrna kukuruza i jaroga ječma te na nutritivni sastav lista kukuruza istraživan je tijekom pet godina. Poljski pokus s primjenom dolomita (0, 5, 10 i 15 t ha^{-1}) koji sadržava 56% Cao i 40% MgO postavljen je na vrlo kiselome tlu s pH(KCl) 3,78 na lokaciji u središnjoj Hrvatskoj. Kukuruz je uzgajan tijekom 2003.-2005. i 2007. godine, a ječam 2006. godine. Kemijska svojstva tla i koncentracija elemenata u listu kukuruza analizirani su nakon druge godine pokusa. Kalcizacija je povisila pH vrijednost tla za 2,62 pH jedinice, a sadržaj AL-P_2O_5 za 5,65 mg 100 g^{-1} tla te povećala prinose zrna u svim godinama. Između tretmana s 10 i 15 t ha^{-1} dolomita nisu utvrđene statistički opravdane razlike za prinose zrna kukuruza, dok je prinos zrna ječma bio signifikantno viši samo uz najvišu dozu dolomita. Kalcizacija je, također, povećala koncentracije P, Ca, Mg i Mo u listu kukuruza te smanjila visoki sadržaj Mn do normalne vrijednosti.

Ključne riječi: kalcizacija, kukuruz, ječam, prinos zrna, hraniva u listu kukuruza

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