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SUBSEQUENT EFFECTS OF LIMING WITH CARBOCALK ON MAIZE GRAIN YIELDS

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SUMMARY

The aim of this study was to examine subsequent effects of carbocalk liming on soil characteristic, maize yield components and grain yield. For this study the field experiment (Sopje, Virovitica-Podravina County) was established on an acidic planosol (pH(KCl)=3.42) amended once in 2000 with increasing rates of air–dried carbocalk (0, 15, 30, 45 and 60 t ha^{-1}). Even though liming in 2000 increased maize grain yield in 2013 growing season as compared to the control, the highest maize grain yield of 5.42 t ha^{-1} was achived with liming at 30 t ha^{-1} carbocalk, whereas the lowest maize grain yield (4.39 t ha^{-1}) of limed treatments was at 60 t ha^{-1} carbocalk. The highest decrease of soil acidity in 2013 for 3.41 pH units as compared to the control, was at 60 t ha^{-1} carbocalk in 2000. Increasing carbocalk doses in 2000 had a subsequent effect on increase of P and decrease of K availability in 2013.

Key-words: liming, carbocalk, maize, pH, yield

INTRODUCTION

Soil acidity has been a major constraint to crop production over the world. The primary limitations on acid soils are toxic levels of soluble Al^{3+} and Mn^{2+} which cause reduction of root mass and deficiency of P, Mg and Ca (Kochian et al., 2004; Manna et al., 2007). Therefore, soil acidity correction is essential for appropriate crop development. Various authors suggested liming, as the most widely used treatment, for ameliorating soil acidity (Nohrstedt, 2002; Tang et al., 2003; Kemmitt et al., 2006; Rastija et al., 2007; Antunovic et al., 2008; Caires et al., 2008; Kovačević and Rastija, 2010; Rastija et al., 2010; Saarsalmi et al., 2011).

Applying lime as limestone ($CaCO_3$), quicklime (CaO) or hydrated lime ($Ca(OH)_2$) to soil raise its pH and adjust soil pH to the levels needed by the crop to be grown (Rastija et al., 2008; Kovačević et al., 2009; Karalić et al., 2013). Although Ca is the main base cation used, materials containing some Mg such as dolomitic limestone are often used to ensure an adequate supply of Mg to crops. In Croatia carbocalk is often used material for amelioration soil acidity by liming. Carbocalk is lime–based (39% CaO and 15% H_2O) waste product of sugar beet processing from Osijek Sugar Factory.

Liming has long-term effect on soil properties but beneficial effects of liming can fade under appropriate rainfall conditions. Lime loss increases with rainfall becouse the high annual rainfall can increase the leaching of cations such as Ca^{2+} and Mg^{2+}, allowing the soil exchange complex to become dominated by H^+ and Al^+, which can result in phytotoxicity.

The pH value is dominant factor regulating soil nutrient bioavailability. Applying lime increases the availability of essential plant nutrients like P (Chang and Sung, 2004; Rastija et al., 2007; Rastija et al., 2008; Kovačević and Rastija, 2010; Rastija et al., 2012), N, C (Kemmitt et al., 2006; Manna et al., 2007; Saarsalmi et al., 2011) but also, liming can decrease the apparent availability of several nutrients like K, S, Na, (Nohrstedt, 2002; Rastija et al., 2007; Kovačević and Rastija, 2010; Kovačević et al., 2012; Kowalenko and Ihnat, 2013) Fe, Mg and Zn (Christenson et al., 2000; Kovačević et al., 2009; Karalić et al., 2013), which could reduce the intended benefit of applying lime.

Even though tolerance to soil acidity may be variable for each genotype, many studies have demonstrated that soil correction increases yield of maize, wheat and other cereales (Tang et al., 2003; Antunovic et al., 2008; Caires et al., 2008; Farhoodi and Coventry, 2008; Rastija et al., 2008; Andric et al., 2012; Iljkić and Kovačević, 2012; Kovačević and Rastija, 2010; Castro and Crusciol,

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2013), sugar beet (Antunović et al., 2002; Windles et al., 2006; Windles et al., 2007; Antunovic et al., 2008) and various other crops (Chang and Sung, 2004; Popović et al., 2009).

There is relatively less information on the long term effectiveness of soil correction with carbocalk in Croatia. This study aimed to examine subsequent effects of carbocalk liming on maize yield components and final maize grain yield.

MATERIAL AND METHODS

The field experiment and sample collections

The field experiment with increasing rates of air–dried carbocalk (waste of Osijek Sugar Factory, about 15% H_2O, 39% CaO) was started at the beginning of November 2000 in Sopje (Virovitica-Podravina County) planosol (pH in 1n KCl = 3.42) in the amounts as follows: 0, 15, 30, 45 and 60 t ha^{-1}. The treatments were distributed in four blocks, each of 350 m^2 area. Each block was divided in four sub–pots (87.5 m^2) at the early stage of crops aiming to receive four replicates. The experiment covered 1750 m^2 of visual homogenous soil area without depression and incline. Results of the previous investigations were shown in the earlier studies: Antunovic et al. (2008) and Rastija et al. (2012).

Maize hybrid OSSK 444 (FAO 450; Agricultural Institute Osijek) was sown on April 26th, 2013, by pneumatic sowing machine at planned (theoretical) plant density (TPD) 59524 plants ha^{-1} (distance in row 24.0 cm; interrow spacing 70.0 cm).

Maize was harvested in October 8th, 2013. Two 10–m rows were harvested manualy. Maize ears weight was determinated by Kern electronic balance (d=50 g). Five ears from each basic plot were used for determination of grain moisture and grain share in each ear. Weighing of ears and grain was made by Kern electronic balance (d=10 g). Grain moisture was determined by electronic grain moisture instrument (WILE–55, Agroelectronics, Finland). Grain yields were calculated on the realized plant density and 14% grain moisture basis. The realized plant density (RPD) per hectare was calculated in level of treatment as a result of multiplication of sum of plants number from each of four replicates with the factor 178.4. Barren plants contribution was calculate as difference of plant and ear amounts in level of the treatment. Grain yields of maize were calculated on the realized plant density (RPD) and 14% grain moisture basis.

Weather characteristics

The weather conditions for maize vegetation in 2013 are shown in Table 1. In July and August when maize water needs are largest, due to flowering and grain formation, the rainfall was less than long-term mean by 40% and 26%, respectively, whereas mean air-temperatures were higher by 2.2°C and 2.1°C, respectively from long-term mean.

Table 1. Weather characteristics in 2013 of maize growing season *(Meteorological and hydrological institute of Croatia – DHMZ)*

Tablica 1. Vremenske prilike u vegetaciji kukuruza 2013. godine (Državni hidrometeorološki zavod - DHMZ, Republika Hrvatska)

Virovitica Weather Bureau (LTM=long-term mean 1971-1990) *Klimatološka postaja Virovitica (višegodišnji prosjek 1971.-1990.)*												
Year *Godina*	Rainfall (mm) *Oborine (mm)*						Mean air-temperatures (°C) *Prosječna temperatura zraka (°C)*					
	May	June	July	Aug.	Sept.	Sum	May	June	July	Aug.	Sept.	Mean
2013	59	75	46	56	110	346	16.4	19.6	22.5	21.7	15.5	*19,1*
LTM	72	87	76	75	55	365	15.6	18.3	20.3	19.6	15.7	17.9
* air–distances from Sopje (the experiment location): Virovitica=20 km in W direction												

RESULTS AND DISCUSSION

In our study previous carbocalk application generally increased maize grain yield and realized plant density (Table 2). Grain moisture at harvest was on the average 23.56% and realized plant density was on the average 90.6% of theoretical plant density.

Liming with 30 t ha^{-1} carbocalk in 2000 has the highest positive subsequent effect on maize grain yield in 2013. Even though realized plant density (%) was higher at liming with 45 and 60 t ha^{-1} carbocalk, a higher percentage of barren plants (17.1 and 23.8, respectively) resulted in lower grain yield. Castro and Crusciol (2013) reported that limestone application (36% CaO and 12% MgO) at 3.8 Mg ha^{-1} increased maize population (hybrid 2B570) from 56 207 plants ha^{-1} (control) to 60 680 plants ha^{-1} (limestone).

Lime applied on the soil surface has brought about a short–term and a long–term decrease in soil acidity. After maize harvest in October 2013 the soil status was analyzed (Table 3). Soil pH increased most with the highest carbocalk application rate (60 t ha^{-1}). Saarsalmi et al. (2011) reported that increase in the pH (0–10 cm soil layer) after 21 years was, on the average, 0.4 and 0.5 pH units, with doses of limestone 2 and 4 Mg ha^{-1}, respectively and that liming increased amounts of soil exchangeable Ca and Mg, but had no effect on the amounts of total N and NH_4 acetate extractable K and P.

Table 2. Response of maize yield components (the growing season 2013) to liming with carbocalk

Tablica 2. Utjecaj kalcizacije karbokalkom na komponente prinosa kukuruza (vegetacija 2013.)

The experiment Sopje (Virovitica-Podravina County) *Lokacija Sopje (Virovitičko-podravska županija)*					
Maize yield components *Komponente prinosa kukuruza*	Liming with carbocalk (t ha^{-1}): November 2000 *Kalcizacija karbokalkom (t ha^{-1}): studeni 2000.*				
	0	15	30	45	60
	Maize (the hybrid OSSK 444): the growing season 2013 *Kukuruz (hibrid OSSK 444): vegetacija 2013.*				
Grain yield (t ha^{-1})/*prinos zrna kukuruza (t ha^{-1})*	3.71 Aa	4.52 B	5.42 C	4.52 B	4.39 Bb
Grain moisture at harvest (%)/*vlaga zrna u berbi (%)*	25.8 n.s.	22.0	23.8	22.0	24.2
Realized plant density (% of TPD[1])/*ostvareni sklop (%TPD)*	85.8	86.9	90.7	95.9	93.7
Barren plants contribution (%)/*jalove biljke (%)*	31.1	10.8	12.8	17.1	23.8
[1] TPD = theoretical plant density 59524 plants ha^{-1} (distance of plants in row=24.0 cm; interrow spacing=70.0 cm)/*teoretska gustoća sklopa 59524 biljaka ha^{-1} (razmak u redu=24 cm, međuredni razmak=70 cm)*					

Means with the same letter are not significantly different from each other: acb at $P \leq 0.05$ level and ABC at $P \leq 0.01$

Vrijednosti iste slovne oznake nisu statistički značajne: acb razina $P \leq 0.05$ i ABC razina $P \leq 0.01$

Table 3. The effect of carbocalk liming in November 2000 on soil status (0-30 cm depth) of the experiment Sopje in October 2013.

Tablica 3. Utjecaj kalcizacije karbokalkom u studenome 2000. na karakteristike tla (0-30 cm dubine) pokusa Sopje u listopadu 2013. godine.

Soil status (0-30 cm depth) in October 2013 *Kemijske karakteristike tla (0-30 cm) u listopadu 2013. godine*					
	Liming with carbocalk (t ha^{-1}): November 2000 *Kalcizacija karbokalkom (t ha^{-1}): studeni 2000.*				
	0	15	30	45	60
pH in H_2O	4.55 E	6.11 D b	6.98 B a	6.93 C a	7.78 A b
pH in 1n KCl	3.56 E	4.89 D a	5.88 B b	5.81 C b	6.97 A a
Phosphorus (mg P_2O_5 kg^{-1})*	17.42 a	15.15 b	18.31 a	22.33 a	24.17 a
Potassium (mg K_2O kg^{-1})*	26.72 a	17.72 b	20.27 b	23.56 a	20.88 a
% humus	1.55 a	1.70 a	1.61 a	1.63 a	1.49 b
* NH_4 Acetate + EDTA (pH 4.65) extraction (Lakanen and Ervio, 1971)					

Means with the same letter are not significantly different from each other: acb at $P \leq 0.05$ level and ABC at $P \leq 0.01$

Vrijednosti iste slovne oznake nisu statistički značajne: acb razina $P \leq 0.05$ i ABC razina $P \leq 0.01$

In the previous studies of the Sopje experiment, Antunovic et al. (2008) and Rastija et al. (2012) were elaborated response of maize (2001–2003 and 2005), sugar beet (2004) and winter wheat (2006/2007) to carbocalk applicaton (Table 4). Antunovic et al. (2008) reported that increasing carbocalk rates (up to 60 t ha^{-1}) considerably increase maize yields up to 26% (4 year mean) and sugar beet yield up to 43% (30 and 43 t ha^{-1}, for 0 and 30 t ha^{-1} of lime, respectively). For winter wheat growing season Rastija et al. (2012) found that carbocalk application (up to 60 t ha^{-1}) have residual effect of liming on winter wheat yield and breadmaking quality parameters, but overliming (60 t ha^{-1}) drastically decreased winter wheat yield to the control level (3.8 t ha^{-1}). Furthermore, the elevation in soil pH through liming of the experiment Sopje increased availability of P, Ca and Mg.

Applying lime has long–term effect on crops yield. In their study Tang et al. (2003) sowed barley in 2000 on soil which was previously limed in 1984 (2.5 t ha^{-1} fresh lime). Barley grain yield increased from 1.40 t ha^{-1} (control) to 1.74 t ha^{-1} (2.5 t ha^{-1} fresh lime) and based on the results of their research authors suggested that benefit of liming at 2.5 t ha^{-1} lasted at least 17 years. Similar findings of long–term liming benefits were obtained by Manna et al. (2007) with increasing soybean and wheat yields at liming rate of 2.5 Mg ha^{-1} once in 4 years through 30–years period (1971–2001). Caires et al. (2008) reported that re–liming with dolomitic lime in 2000 with 3 t ha^{-1} (176 g kg^{-1} Ca and 136 g kg^{-1} Mg) of previously limed soil in 1993 with 6 t ha^{-1} (196 g kg^{-1} Ca and 130 g kg^{-1} Mg) increased maize yield (2001 growing season) from 9.29 t ha^{-1} (control) to 9.64 t ha^{-1} and wheat yield (2003 growing season) from 1.29 t ha^{-1} (control) to 4.03 t ha^{-1}. Besides that, authors found out that 10 years after applying dolomitic lime (1993) wheat yield increased by 220% (2003).

Kovačević and Rastija (2010) reported that application of dolomite (56% CaO and 40% MgO) on acid soil (pH(KCl)=3.78) in rates of 5, 10 and 15 t ha^{-1} can increase maize grain yield over 50%. Farhoodi and Coventry (2008) found out that liming in rates 1.2 and 4 t ha^{-1} (40% Ca and 0.3% Mg) can increase wheat yield over 70%.

Table 4. Survey of the previous studies of the experiment Sopje (Antunovic et al., 2008; Rastija et al., 2012).

Tablica 4. Pregled prethodnih istraživanja pokusa Sopje (Antunovic i sur., 2008.; Rastija i sur., 2012.).

The experiment Sopje: selected results from the previous studies Antunovic et al., 2008; Rastija et al., 2012/ *Pokus Sopje: Izabrani rezultati prethodnih istraživanja Antunovic i sur., 2008.; Rastija et al., 2012.*							
The crop and year *Usjev i godina*		Liming with carbocalk (t ha^{-1}): November 2000/ *Kalcizacija karbokalkom (t ha^{-1}): studeni 2000.*					
		0	15	30	45	60	Mean A
Maize 2001	Grain yield (t ha^{-1})	7.36	10.2	10.3	11.2	10.3	9.87
Maize 2002		9.89	10.5	10.7	11.2	12.5	10.96
Maize 2003		4.42	5.14	5.81	6.63	5.53	5.51
Maize 2005		7.48	7.96	7.66	7.80	8.00	7.78
Mean B		7.29	8.46	8.62	9.20	9.08	
		LSD 5%	A: 0.33	B: 0.38		AB: 0.77	*LSD 5%*
Sugar beet 2004 (root yield t ha^{-1})		30.0		43.0		34.0	6.6
Sugar beet 2004 (sugar yield t ha^{-1})		4.4		5.9		4.5	0.9
Sugar beet 2004 (sucrose %)		14.6		13.7		13.4	0.5
Winter wheat 2006/2007 (grain yield t ha^{-1})		3.84	4.63	4.99	4.52	3.80	0.51
Winter wheat 2006/2007 (grain protein %)		10.8	11.0	12.3	12.6	12.7	1.3
Soil status (0-30 cm depth) in November 2002 *Kemijske karakteristike tla (0-30 cm) u studenome 2002.*							*LSD 5%*
pH in H_2O		4.52	6.34	7.12	7.39	7.82	0.49
pH in 1n KCl		3.42	5.65	6.41	6.65	6.87	0.49
Calcium (mg Ca kg^{-1})*		873	1434	2418	4494	7122	1006
Magnesium (mg Mg kg^{-1})*		95.7	160.7	137.3	224.3	195.0	30.0
Phosphorus (mg P_2O_5 kg^{-1})*		72.4	88.9	144.4	211.0	210.0	21.6
Potassium (mg K_2O kg^{-1})*		103.1	97.6	96.1	94.4	76.1	16.3
Zinc (mg Zn kg^{-1})*		5.30	2.85	2.95	1.31	1.22	0.63
		* NH_4 Acetate + EDTA (pH 4.65) extraction (Lakanen and Ervio, 1971)					

Similar results were obtained in other corresponding experiments in Croatia. In Pozega–Slavonia County Jurkovic et al. (2008) 6 years after carbocalk application (up to 90 t ha^{-1}) got similar response with liming at 45 t ha^{-1}, which increased maize yield from 7.28 t ha^{-1} (control) to 8.26 t ha^{-1} and 7 years after liming wheat yield inceased from 5042 kg ha^{-1} (control) to 7251 kg ha^{-1}. On the same experiment Kovačević et al. (2012) reported that 10 years after carbocalk liming (up to 60 t ha^{-1}) maize grain yield was increased up to 18% as compared to the control.

Kovačević and Rastija (2010) reported that application of dolomite (56% CaO and 40% MgO) on acid soil (pH(KCl)=3.78) in rates of 5, 10 and 15 t ha^{-1} can increase maize grain yield over 50%.

Based od their research in Osijek–Baranja County (Podgorač) Andric et al. (2012) reported that one year after liming with 20 t ha^{-1} hydratized calcite (73% CaO) soil pH(KCl) increased from 4.47 to 6.68 and maize grain yield from 7.91 t ha^{-1} to 10.50 t ha^{-1}. Moreover, authors concluded that 3 years after liming soybean yield increase up to 44% as compared to the control. In order to determine micronutrients status in soil Lončarić at al. (2008) analyzed 40 soil samples of continental part of Croatia and reported that acid soils (the lowest pH(KCl)=3.80) had a higher EDTA (Ethylenediaminetetraacetic acid) plant available Zn and Mn as compared to calcareous soil (the highest pH(KCl)=7.83).

CONCLUSION

This study showed subsequent benefits of liming with carbocalk. Lime applied on the soil surface has brought about a short–term and a long–term decrease in soil acidity. Carbocalk corrected soil acidity and increased maize grain yield. Results showed that 13 years after application of carbocalk soil pH increased by more than 3 pH units and at the same time available P and maize grain yield increased while available K decreased.

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NAKNADNI UČINAK KALCIZACIJE KARBOKALKOM NA PRINOS ZRNA KUKURUZA

SAŽETAK

Cilj ovog istraživanja bio je ispitati naknadni učinak kalcizacije karbokalkom na karakteristike tla, komponente prinosa kukuruza i prinos zrna kukuruza. Za ovo istraživanje postavljen je poljski pokus na lokaciji Sopje (Virovitičko-podravska županija) na tipu kiseloga tla, pseudogleju (pH(KCl)=3,42). Tlo je kalcizirano u 2000. godini različitim dozama zrako-sušenoga karbokalka: 0, 15, 30, 45 i 60 t ha^{-1}. Kalcizacija u 2000. godini pozitivno je djelovala na povećanje prinosa zrna kukuruza u vegetaciji 2013., u odnosu na kontrolu, te je najviši prinos zrna kukuruza od 5,42 t ha^{-1} ostvaren pri aplikaciji 30 t ha^{-1} karbokalka, dok je najmanji prinos kukuruza (4,39 t ha^{-1}) od svih kalciziranih površina ostvaren s 60 t ha^{-1} karbokalka. Kiselost tla u 2013. godini najviše je smanjena pri najvećoj dozi karbokalka (60 t ha^{-1}) u 2000. godini te je povećanje pH(KCl) u 2013. godini iznosilo 3,41 pH jedinica u odnosu na kontrolu. Povećanje doze karbokalka u 2000. godini imalo je naknadni učinak na povećanje pristupačnoga P i smanjenje pristupačnoga K u tlu u 2013. godini.

Ključne riječi: kalcizacija, karbokalk, kukuruz, pH, prinos

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