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Response of maize and soybeans to liming

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Abstract: A field trial with the application of 3 rates (0, 5, and 20 t ha^{-1}) of hydratized calcite (73% CaO + 2%-3% MgO + 21% H_2O) was set up in the spring of 2006. The experiment area had 3 plots of 630 m^2. Each plot was divided into 4 subplots for replications. Over the next 2 years, the residual effects of liming on plant yield and nutrient uptake were investigated using maize hybrid OsSK499 in 2006 and 2007 and soybean variety *Ika* in 2008. The ear leaves of maize at flowering (mid-July 2006 and 2007) were analyzed for P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, Mo, and B concentrations in leaf dry matter. In general, liming was more effective in 2007 than in 2006, based on the significant influence on Mg (+34%), Ca (+10%), Mo (+24%), K (−13%), B (−20%), Mn (−68%), and Zn (−19%) concentrations in the leaves. Liming increased maize yield up to 33% and 35% in 2006 and 2007, respectively. In the third year of testing, soybean responded with a considerable yield increase of up to 44%. A very high soybean yield might be the result of the high yield capacity of the *Ika* cultivar and favorable weather conditions. However, based on leaf analysis, the nutritional status of soybean was unbalanced because of inadequate concentrations of K, Mg, and Mo. Additionally, P, Cu, and B concentrations were at the lowest limit of an adequate status. However, the leaf nutrient status of Ca, Zn, and Mn could be defined as adequate.

Key words: Liming, maize, nutritional status, soybean, yield

Introduction

A deficiency or an excess of nutrients limits agricultural production in 23% of world soils (Blair 1983). According to von Uexkull and Mutert (1995), acid soils occupy about 30% (3.95 b ha) of the world's ice-free land area. Plant growth-limiting factors in acid soils include N, P, Ca, Mg, Mo, and Zn deficiencies and/or Al, Mn, Fe, and H toxicities. Mengel and Kirkby (2001) reported that the efficiency of added N, P, and K fertilizers was very low in acid soils. Vago et al. (2011) reported that in Hungary more than half of the land is prone to acidification. Moniz et al. (1997) recommend a combination of soil management practices as way to improve crop production in acid soils: liming in combination with corrective levels of P and the use of crop cultivars developed for low pH conditions. Naturally occurring minerals that are commonly used to raise soil pH are limestone and dolomite. In addition, waste products from manufacturing processes using limestone or similar raw materials can be used for neutralizing soil acidity. Liming and increased P fertilization are common recommendations for improvement of pseudogley soils in Croatia (Kisic et al. 2002; Petosic et al. 2003; Komljenovic et al. 2006, 2008; Kovacevic et al. 2006, 2007, 2008; Rastija et al. 2006; Antunovic 2008). Markovic et al. (2006, 2008) reported on P and

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acid soil nutritional problems in northern Bosnia. To successfully grow field crops on acid soils, liming, alone or in combination with mineral and organic fertilization, is recommended worldwide (Ciecko et al. 2000; Anetor and Akinrinde 2006; Onwonga 2006; Hassan et al. 2007; Onwuka et al. 2009; Omenyo et al. 2010; Uzoho et al. 2010; Ayalew 2011). The aim of this study was to test the influences of liming on grain yield and nutritional status of maize and soybean.

Material and methods

The field experiment and soil and weather characteristics

The field experiment, with an application of hydratized calcite (73% CaO + 2%-3% MgO + 21% of bound water; Kamen Sirac d.d., Croatia) at 0, 5.0, and 20.0 t ha^{-1} followed by the usual fertilization (kg ha^{-1}: 180 N + 80 P_2O_5 + 100 K_2O), was initiated on acid soil in Podgorac (Osijek, Barannya County) in 2006 (Table 1). The applied lime quantities were chosen with the aim of increasing soil pH values (1 N KCl) up to 5.5 and 7.0, respectively. The usual experimental fertilization was used for maize in 2007 and soybean in 2008, whereas only 80 kg N ha^{-1} for soybean was applied. Soybean was used as a model crop in the third year of the research, as soybean is commonly grown after maize in Croatia; it was also chosen to test the prolonged effect of liming on soybean growth. The experiment was set up on 3 plots of 630 m^2. Each plot was divided into 4 subplots for replications. Maize hybrid OsSK 499 (Agricultural Institute, Osijek, Croatia) was grown in 2006 and 2007. Maize was sown at the beginning of May by pneumatic sowing machine and harvested manually in the second half of October. From each treatment, 10 cobs were used for determination of grain moisture and grain share in cob. Grain moisture was determined by electronic grain moisture instrument (WILE-55, Agroelectronics, Finland). Yields were calculated on a 14% grain moisture basis, taking into account crop densities. Soybean (cultivar *Ika*) was grown in 2008, sown on 21 April and harvested on 2 October; it was grown on 3 m^2 of each subplot area.

Both maize growing seasons were characterized by lower precipitation and higher air temperatures as compared to the 30-year mean. However, in terms of precipitation distribution and temperature regime, growth conditions were more favorable in 2006. The 2008 growing season was characterized by 15% higher precipitation in comparison with the 30-year mean. During the same period, the air temperature was 1 °C higher (Table 2).

Sampling and chemical and statistical analysis

Soil sampling (depth: 0-30 cm) was done at the beginning of the experiment as well as after maize harvest in the second year of the experiment (Table 1). Mobile fractions of nutrients in the soil were extracted by acid solution NH_4-acetate + EDTA (pH 4.65) (Lakanen and Ervio 1971). The ear leaf at flowering (mid-July 2006 and 2007; about 20 leaves in the mean sample) and grain at maturity (5 cobs in mean sample) was taken from each subplot for chemical analysis.

Table 1. Soil characteristics in the experimental area.

Soil properties (0-30 cm depth)												
Lime	pH	NH_4-acetate + EDTA (pH 4.6) extraction (mg kg^{-1})										
(t ha^{-1})	(KCl)	P_2O_5	K_2O	Ca	Mg	S	Zn	Mn	Fe	Cu	Mo	B
Before starting the experiment (1 March 2006)												
	4.47	181	310	4333	1111	19.7	1.44	135	1240	8.5	0.01	0.09
After maize harvesting (end of October 2007)												
0	4.75	176	263	4211	1072	18.1	1.71	142	1280	7.9	0.01	0.14
5	5.28	212	293	6450	1575	19.5	1.79	116	1180	7.0	0.01	0.23
20	6.86	253	303	6670	1869	21.9	1.74	96	917	6.7	0.02	0.26

Table 2. Weather characteristics for the maize and soybean growing seasons.

Osijek*: weather data for 2006, 2007, 2008, and long-term mean (LTM: 1961-1990)												
Year	Precipitation (mm)						Mean air temperatures (°C)					
	May	Jun	Jul	Aug	Sep	*Total*	May	Jun	Jul	Aug	Sep	*Mean*
2006	79	93	15	123	9	*319*	16.4	20.5	24.0	19.6	17.9	*19.7*
2007	56	33	27	45	65	*226*	18.2	22.3	23.9	22.2	14.5	*20.2*
2008	67	76	79	46	86	*354*	18.1	21.5	21.8	21.8	15.7	*19.8*
LTM	59	88	65	58	45	*315*	16.5	19.5	21.1	20.3	16.6	*18.8*

* Experiment location, about 35 km northwest of Osijek.

The uppermost fully developed leaf of soybean was taken at the beginning of anthesis (mid-July 2008; about 50 leaves) from each subplot.

Total element content (P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, Mo, and B) in maize and soybean leaves was determined using inductively coupled plasma (ICP) spectroscopy (Jobin-Yvon Ultrace 238 ICP-OES spectrometer) after microwave digestion by concentrated HNO_3 + H_2O_2.

Data were statistically analyzed by single-factor ANOVA using SAS software (SAS Institute, Cary, NC, USA; PROC ANOVA), and the effects of liming on tested parameters were evaluated by t-test and least significant difference (LSD) at 0.05 and 0.01 probability levels.

Results

As a result of liming, soil pH increased from 4.75 to 5.28 and was close to neutral after application of 5 t ha^{-1} and 20 t ha^{-1} of lime, respectively. Liming also considerably affected soil nutrient availability because of increases in P (+44%), Ca (+58%), Mg (+74%), and B (+86%) and decreases in Mn (−33%) and Fe (−28%), compared to the control (Table 1). These findings are mainly in accordance with the literature (Bergman 1992; Mengel and Kirkby 2001; Kovacevic et al. 2011).

Maize yield in 2007 was 20% lower (mean: 7.19 t ha^{-1}) than in 2006 (mean: 9.04 t ha^{-1}), probably because of drought stress (Table 2). Liming resulted in grain yield increases of up to 33% in 2006 and 35% in 2007 (Table 3).

Drought stress was the main characteristic of the 2007 growing season; precipitation levels in the 3-month period (June-August) were 50% lower than the 30-year mean. At the same time, air temperatures were 2.5 °C higher (Table 2). In general, low maize yields are connected with drought and high air temperatures, especially in July and August (Josipovic et al. 2005). The 2008 growing season could be described as favorable for soybean growth (Vrataric and Sudaric 2008) because of adequate precipitation and temperature regimes (Table 2).

According to Christensen, as cited by Gollmick et al. (1970), on a dry matter basis, adequate nutrient status in the ear leaf of maize at the flowering stage is as follows: P: 0.2%-0.50%, K: 1.5%-3.0%, Ca: 0.20%-1.0%, Mg: 0.20%-1.0%, Zn: 20-70 mg kg^{-1}, Mn: 20-200 mg kg^{-1}, Fe: 10-300 mg kg^{-1}, Cu: 6-50 mg kg^{-1}, and B: 6-40 mg kg^{-1}. Bergmann (1992) reported that adequate Mo status in maize leaf at flowering is in the range of 0.15-0.50 mg Mo kg^{-1}, whereas the common content of S in plants is in the range of 0.1-0.5% in dry matter. According to these criteria, the nutritional status of maize was in adequate range in our study in both years and all applied treatments (Table 3). In general, liming influence on leaf composition was more pronounced in 2007 than in 2006 because of the significant increase in Mg (+34%), Ca (+10%), and Mo (+24%) and decreases in K (−13%), Mn (−72%), and Zn (−19%) concentrations in leaves.

Bergmann (1992) reported adequate ranges of mineral nutrient content in fully developed leaves at the top of the plant and at the end of the blossom (on a dry matter basis) as follows: 0.35%-0.60% P, 2.50%-

Table 3. Response of maize (hybrid OsSK499) to liming.

Liming (30 Mar 2006) by calcite (73% CaO + 2%-3% MgO + 21% of bound water)												
Lime	Grain yield (t ha^{-1}) and leaf composition and LSD test (5% and 1% significance)											
(t ha^{-1})	Yield	Percent in dry matter					mg kg^{-1} in dry matter					
	t ha^{-1}	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	Mo	B
2006 growing season												
0	7.91	0.273	2.36	0.76	0.287	0.172	19.7	32.5	267	16.2	0.56	15.2
5	8.70	0.275	2.43	0.81	0.303	0.195	24.4	36.1	258	16.6	0.46	18.5
20	10.50	0.296	2.30	0.81	0.383	0.200	21.1	27.6	330	19.9	1.32	15.2
Mean	9.04	0.281	2.36	0.79	0.324	0.189	21.7	32.1	285	17.6	0.78	16.3
Statistical significance (LSD values)												
$P_{0.05}$	0.67	ns	ns	ns	0.075	0.020	2.4	ns	ns	3.6	0.19	ns
$P_{0.01}$	0.97				ns	ns	ns			ns	0.32	
2007 growing season (residual effects of liming)												
0	5.97	0.312	1.98	0.59	0.269	0.192	57.4	64.8	119	16.3	0.57	11.1
5	7.55	0.308	2.03	0.59	0.281	0.197	56.4	36.3	153	16.0	0.47	11.4
20	8.05	0.302	1.72	0.65	0.362	0.196	46.6	18.1	126	14.7	0.71	8.9
Mean	7.19	0.307	1.91	0.61	0.304	0.195	53.5	39.7	133	15.7	0.58	10.5
Statistical significance (LSD values)												
$P_{0.05}$	0.89	ns	0.09	0.05	0.04	ns	3.9	16.5	ns	ns	0.13	ns
$P_{0.01}$	1.33		0.15	ns	0.06		6.2	ns			ns	

3.70% K, 0.60%-1.5% Ca, 0.30%-0.70% Mg, 25-60 mg Zn kg^{-1}, 30-100 mg Mn kg^{-1}, 10-20 mg Cu kg^{-1}, 25-60 mg B kg^{-1}, and 0.50-1.0 mg Mo kg^{-1}. According to these criteria, soybean showed unbalanced nutritional status due to inadequate concentrations of K (mean: 1.93% K), Mg (mean: 0.23% Mg), and Mo (mean: 0.05 mg Mo kg^{-1}). In addition, P (mean: 0.35% P), Cu (mean: 9.7 mg Cu kg^{-1}), and B (mean: 24 mg B kg^{-1}) concentrations were at the lowest level of the adequate status cited above. Adequate nutrient status was found in Ca (mean: 1.24% Ca), Zn (mean: 47 mg Zn kg^{-1}), and Mn (mean: 140 mg Mn kg^{-1}) (Table 4). Significant effects of liming on soybean nutritional status were found for Mg, Mn, and Zn (decreasing trends) and for Mo (increasing trend).

In the third year of testing, soybean responded with a considerable grain yield increase of up to 44%, with 3.90 and 5.63 t ha^{-1} at 0 and 20 t ha^{-1} lime, respectively (Table 4). A very high soybean yield might be the result of the high yield capacity of *Ika* cultivar and favorable weather conditions (Table 2). Similar positive effects of liming on soybean yield were observed in the research of Kovacevic et al. (2011), who applied liming with 10 t ha^{-1} of granulated fertdolomite (24.0% CaO + 16.0% MgO + 3.0% N + 2.5% P_2O_5 + 3.0% K_2O) in the autumn of 2007. As a result of liming, soybean yields increased by 18% (3.28 and 3.85 t ha^{-1}, respectively). Grain quality parameters improved (1000-grain weight = 151.8 and 168.3 g; protein content = 35.24% and 39.06%, respectively), while oil content decreased (23.84% and 22.62%, respectively).

Discussion

In our study, liming increased grain yields of maize by up to 34% and soybean by up to 44%. Based on leaf analyses, the nutritional status of maize was in the adequate range for both years in all applied treatments. However, nutritional status of soybeans

Table 4. Response of soybean (cultivar *Ika*) to liming.

Liming (30 Mar 2006) by calcite (73% CaO + 2%-3% MgO + 21% of bound water)												
Lime	Grain yield (t ha^{-1}) and composition of the uppermost fully-developed 3-foliate leaf before anthesis (LSD test on 5% and 1% significances)											
(t ha^{-1})	Yield	Percent in dry matter					mg kg^{-1} in dry matter					
	(t ha^{-1})	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	Mo	B
2008 growing season (residual effects of liming)												
0	3.90	0.342	1.97	1.22	0.262	0.247	47.7	171.0	110	9.3	0.03	24.3
5	5.53	0.359	1.92	1.24	0.226	0.260	49.8	130.3	123	10.7	0.04	25.1
20	5.63	0.333	1.89	1.25	0.207	0.250	43.3	119.3	115	9.0	0.09	23.8
Mean	5.02	0.345	1.93	1.24	0.232	0.252	46.9	140.2	116	9.7	0.05	24.4
Statistical significance (LSD values)												
$P_{0.05}$	0.306	ns	ns	ns	0.024	ns	3.0	13.6	ns	1.4	0.03	ns
$P_{0.01}$	0.464				ns		ns	22.5		ns	ns	

was unbalanced due to inadequate concentrations of K, Mg, and Mo in leaf dry matter. The P, Cu, and B concentrations were at the lowest level of adequate status, whereas adequate concentrations of Ca, Zn, and Mn were found. Significant effects of liming on soybean nutritional status were found in terms of Mg, Mn, and Zn. It is feasible that large amounts of Ca in the soil, as a consequence of liming, might interfere with Mg uptake in soybean; a significant decrease in Mg concentrations in leaves was obtained when high liming treatment was applied.

The nutritional status of a plant is responsible for yield and quality as well as resistance to abiotic stress. In general, fertilization by N, P, and K is adequate, but in some cases using Mg and S (Zengin et al. 2009) or Zn (Tavallali et al. 2010) fertilizers is useful. Through plant breeding programs, it is also possible to improve plant genetic potential under different environmental conditions (Zdunic et al. 2008).

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