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Effect of Zinc and Dolomite Treatments on the Chemical Composition of Acid Sandy Soil and Bean Crop

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The impact of the application of 4,500 kg ha^{-1} dolomite with or without 40 kg ha^{-1} $ZnSO_4$ $7H_2O$ on the elemental composition of bean and soil as well as on agronomic properties of the crop were examined in a pot experiment. The application of dolomite increased soil ammonium lactate–extractable magnesium content threefold and that of calcium by 80%. Application of zinc increased ammonium lactate–extractable zinc content by 100%. The increase of 0.8 pH unit from 5.4 (Ø-Ø) to pH 6.2 (Ø-dolomite) was accompanied by a significantly lower zinc, manganese, and potassium content of the plant material. Magnesium and potassium antagonistic effects manifest in plant composition and soil–plant relationships but not in soil. Magnesium and phosphorus show contradictory relationships: negative in soil and plant but positive in soil–plant relationship. The dry mass of bean shows the order of $ZnSO_4$-dolomite > $ZnSO_4$-Ø > Ø-dolomite > Ø-Ø.

Keywords Acidity, ANOVA, antagonism, brown forest soil, correlation matrix, pot experiment

Introduction

Soil acidification is an important degradation form worldwide (Adams 1984). Due to the (hydro)geological and, most important, climatic conditions, Hungary lies in a transitional zone where liming is requested or not depending on the region. As can be predicted from soil analysis (Rékási and Filep 2007), the smallest acidity-buffering capacity is typical in soils containing low ratios of colloids (mostly clay and soil organic matter), such as the acid sandy soils of northeastern Hungary. In these areas, the application of dolomite has been suggested. Dolomite is beneficial to correct the acidity and also to provide necessary magnesium to the plants. But there can be conflicts due to the sudden decrease in soil acidity (Blaylock 1995).

Inside Hungary, the lowest zinc (Zn) content can be found in the sandy soils (Győri 1984). An increase in the pH is known to limit the Zn adsorption of plants (Wear 1956; Pais 1980; Loch and Nosticzius 1983; Havlin et al. 2005).

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Several plants are known to show sensitivity for soil Zn content (Blaylock 1995); bean is a representative of them and is sensitive for magnesium (Mg) as well (Kamprath and Foy 1985; Oliveira et al. 2000). On the other hand, soybean is less sensitive to soil zinc contents (Franzen 1999).

Our objective was to compare the effect of separate and combined applications of dolomite as an acidity-correcting material and of zinc sulfate as a Zn fertilizer on beans and the soil in a pot experiment. Besides comparing soil and plant composition, the biomass of the plants was also evaluated. Our specific goal was to test whether the combined application of dolomite and zinc sulfate would be beneficial for soil and plant Zn contents as well as for the plant dry matter.

Material and Methods

Soil

The soil was collected from the study site of the research plot of the Karcag Research Institute of the Debrecen University located close to the settlement of Tornyospálca in northeastern Hungary (48°15′ N, 22°8′ E) from a depth of 0–20 cm. The soil is a brown forest soil with clay illuviation in the Hungarian soil classification (Szabolcs 1966); the approximate equivalent is Kandiustalf in soil taxonomy. Characteristic properties of the soil are as follows: hydrolytic acidity (y_1) according to Kappen (1929) was 2.5 cmol kg^{-1} soil, total fraction of particles less than 0.01 mm is 47.7%, texture class is sandy loam, and soil organic matter is 0.83% (soil analytical methods are described in detail by Buzás [1988]).

Treatments

In each pot there was 2.5 kg soil and the following treatments were utilized: zero or 40 kg ha^{-1} $ZnSO_4 \times 7H_2O$, combined with zero or 4,500 kg ha^{-1} dolomite, resulting in four treatments.

The dosage calculations were made by considering a 20-cm layer of soil with the typical bulk density of 1.5 kg dm^{-3} (Research Report 1985), which is equivalent to 3 million kg soil in one hectare. The coefficient of 1,200,000, that is the ratio of the mass of the topsoil of one hectare and the soil in one pot, 3,000,000 kg:2.5 kg was used to convert dosage from kg ha^{-1} to kg pot^{-1}.

The $ZnSO_4$ treatment required 33 mg of $ZnSO_4 \times 7H_2O$; to apply it, first a solution was prepared: 0.33 g $ZnSO_4 \times 7H_2O$ was dissolved in 3 L of distilled water and for each of the 10 pots receiving the $ZnSO_4$ treatment, 300 mL of this solution was used as prewetting media. The other 10 pots received the same amount of water for prewetting.

The dolomite treatment was realized by mixing 3.78 g dolomite with the soil from the pots. The most important technical criteria for the applied friable dolomite were described by Ministry of Agriculture and Regional Development (2001) as not less than 80% equivalent calcium carbonate content, not less than 16% calcium, not less than 10% magnesium, the amount of fraction falling through 0.1-mm mesh must be not less than 20%, and the amount of fraction falling through 0.25-mm mesh must be not less than 80%.

Pot Culture

There were five replicates of each treatment. In each pot 12 seeds of bean (*Phaseolus vulgaris* L. cv. Yellowstar) were seeded. Every other day the pots were wetted to the initial total weight on a balance scale. After 3 weeks the number of plants was reduced to five and after 7 weeks the beans were harvested and soil samples were collected for analysis. After the bean, soybean (*Glycine max* [L.] Merr. cv. Evans) was planted with the same number of seeds in pots, which were harvested at the age of 6 weeks.

Soil and Plant Analysis

The soil was sampled and analyzed according to the methods described by Buzás (1988). The ammonium lactate–extractable nutrient contents (AL-extractable) were determined with the application of the mixture of 0.1 M ammonium lactate and 0.4 M acetic acid (at pH 3.75) at the ratio of 5 g of air-dried soil to 100 mL extractant. Plant analysis was carried out according to National Standard (1985) with concentrated sulfuric acid.

Statistical Analysis

The analytical results were evaluated with analysis of variance (ANOVA) according to SPSS (1999). First a two-way ANOVA was calculated and the effect of the main terms of zinc sulfate and dolomite treatments was evaluated. For those variables, in the case of which there was a significant interaction, a one-way ANOVA was calculated and the four combinations of the two main treatments (zinc sulfate and dolomite) were compared based on the least significant difference (LSD) with SPSS (SPSS 1999; general linear model). In order to elucidate the relationship between the properties the correlation matrix was calculated.

Results and Discussion

Soil properties are shown in Table 1. Based on the general purpose agronomic rating of the original soil, according to Buzás (1983), the supply of nitrogen is evaluated as intermediate, the supply of phosphorus is very good, the supply of potassium is very good, the supply of magnesium is intermediate, but needs liming, and has a low supply of zinc. After the application of the combined zinc sulfate and dolomite treatment the supply of zinc and magnesium was good and the necessity of liming decreased.

From the point of AL-extractable nutrient content (Table 1) the soil acidity is decisive. Since the solution of zinc sulfate is acidic, this treatment increases the soil hydrolytic acidity and contributes to an increase of AL-extractable zinc content in the soil. The dolomite treatment increases pH values and decreases hydrolytic acidity, and increases the AL-extractable calcium and magnesium content but decreases the AL-extractable content of potassium. Bohn, McNeal, and O'Connor (2001) suggested that the adsorption of potassium on the carbonates can be a mechanism explaining the antagonism between liming material and potassium. Kozlowski, Alekseyev, and Churikov (1983) also reported an inverse relationship between plant potassium and calcium and a decrease in the availability of manganese and zinc due to liming. Our data do not show a significant change in soil manganese contents as a consequence of the treatments. In the case of phosphorus, there was a significant interaction, and in a second step the LSD was compared with the differences. Both treatments of zinc sulfate (only and with a combination of dolomite) showed a significantly higher phosphorus content. This observation was contrary to the predictions regarding the effect of liming on the mobilization of phosphorus (Győri 1984) but agreed with the suggestion of Buzás (1983). The latter author stated that in soils containing carbonates these can fix phosphorus and therefore decrease phosphorous availability. Haynes (1982) suggested that in soils with high exchangeable aluminum there

Table 1
Average soil properties of the soil after the cultivation of bean (n = 5) and the significance of the treatments and their interaction

Soil parameter	pH_H_2O	pH_KCl	y_1 (cmol kg^{-1} soil)	AL-P_2O_5 (mg 100 g^{-1} soil)	AL-K_2O	AL-Ca	AL-Mg	AL-Mn (ppm)	AL-Zn
Treatment									
Ø-Ø	5.40a	4.51	2.51	21.7aef	30.72	24	6	139.2	0.8
$ZnSO_4$-Ø	5.26b	4.37	2.63	28.66b	44.12	25.6	5	52.8	1.6
Ø-dolomite	6.23c	5.72	1.37	20.68ce	28	43.2	19.4	152	0.8
$ZnSO_4$-dolomite	6.25c	5.75	1.40	24.04df	36.6	43.2	19	178	1.6
Significance of $ZnSO_4$ treatment, main effect	0.275	0.185	0.039	0.000	0.000	0.668	0.264	0.187	0.002
Significance of dolomite, main effect	0.000	0.000	0.000	0.003	0.008	0.000	0.000	0.204	1.000
Significance of interaction effect	0.044	0.075	0.077	0.038	0.170	0.668	0.626	0.671	1.000
Least significant difference of one-way ANOVA when interaction is significant at $p < 0.05$. Means followed by the same letter are not significantly different	0.123	NA	NA	2.37	NA	NA	NA	NA	NA

Note. y_1 is hydrolytic acidity; AL is ammonium lactate–acetate extractant; NA means not applicable.

Table 2

Correlation matrix of soil (columns 1 to 9 and rows) and bean composition (columns 10 to 16 and rows) and bean growth parameters (columns 17 and 18 and rows) showing only correlation coefficients more significant than 1%

		pH H_2O 1	pH KCl 2	y_1 3	AL-P_2O_5 4	AL-K_2O 5	AL-Ca 6	AL-Mg 7	AL-Mn 8	AL-Zn 9	Plant N% 10	Plant P_2O_5% 11	Plant K_2O% 12	Plant Ca 13	Plant Mg 14	Plant Mn 15	Plant Zn 16	Bean Height 17	Bean Mass 18
1	pH_{H2O}	1	$+^{***}$	$-^{***}$			$+^{***}$	$+^{***}$				$-^{***}$	$-^{***}$	$+^{***}$	$+^{***}$	$-^{***}$	$-^{**}$		
2	pH_{KCl}	$+^{***}$	1	$-^{***}$			$+^{***}$	$+^{***}$				$-^{**}$	$-^{***}$	$+^{***}$	$+^{***}$	$-^{***}$	$-^{**}$		
3	y_1	$-^{***}$	$-^{***}$	1			$-^{***}$	$-^{***}$				$+^{***}$	$+^{***}$	$-^{***}$	$-^{***}$	$+^{***}$	$+^{***}$		
4	P_2O_5				1	$+^{***}$		$-$				$+^{***}$					$+^{***}$		
5	K_2O				$+^{***}$	1						$+^{***}$					$+^{***}$		
6	Ca	$+^{***}$	$+^{***}$	$-^{***}$			1	$+^{***}$				$-^{**}$	$-^{**}$	$+^{***}$	$+^{***}$	$-^{***}$			
7	Mg	$+^{***}$	$+^{***}$	$-^{***}$	$-$		$+^{***}$	1					$-^{***}$	$+^{***}$	$+^{***}$	$-^{***}$	$-^{**}$		
8	Mn								1										
9	Zn									1							$+^{**}$		
10	N%										1								$-^{***}$
11	P_2O_5%	$-^{***}$	$-^{**}$	$+^{***}$	$+^{***}$	$+^{***}$	$-^{**}$					1			$-^{**}$		$+^{***}$		
12	K_2O%	$-^{***}$	$-^{***}$	$+^{***}$			$-^{**}$	$-^{***}$					1		$-^{***}$	$+^{***}$			
13	Ca	$+^{***}$	$+^{***}$	$-^{***}$			$+^{***}$	$+^{***}$						1	$+^{***}$	$-^{***}$			
14	Mg	$+^{***}$	$+^{***}$	$-^{***}$			$+^{***}$	$+^{***}$				$-^{**}$	$-^{***}$	$+^{***}$	1	$-^{***}$	$-^{**}$		
15	Mn	$-^{***}$	$-^{***}$	$+^{***}$			$-^{***}$	$-^{***}$					$+^{***}$	$-^{***}$	$-^{***}$	1			
16	Zn	$-^{**}$	$-^{**}$	$+^{***}$	$+^{***}$	$+^{***}$		$-^{**}$		$+^{**}$		$+^{***}$			$-^{**}$		1		
17	Bean height																	1	$+^{***}$
18	Bean mass										$-^{***}$							$+^{***}$	1

Note. In the cells the sign of correlation coefficient and the level of significance are shown.
**Significant at 1%. ***Signficant at 0.1%.
N = 20.

are phosphate-adsorbing surfaces formed upon liming. The correlations between soil calcium and magnesium content and soil P_2O_5 and plant P_2O_5 in Table 2 seem to support this hypothesis. Data in Table 1 show that after the application of dolomite the original acidic soil became vulnerable to zinc deficiency. In a previous electro-ultrafiltration experiment (Research Report 1985), in the ultrafiltrates the dolomite treatment resulted in the lowest potassium content but the highest content of phosphorus among the three treatments of soil studied (liming with calcite, liming with dolomite, and unlimed). Friesen, Juo, and Miller (1980) showed that intermediate liming caused a decrease of phosphorus content in the soil solution in a coarse textured Ultisol, and only large liming dosage caused an increase in phosphorus contents. Our contradictory results show that the effect of dolomite on the phosphorus content of the soil is a complex phenomenon.

The zinc sulfate treatment only significantly affected the zinc content of bean (Table 3), with a large increase. The lowest zinc content of Ø-dolomite treatment approached the threshold value of 20 ppm, at which deficiency was appearing according

Table 3
Average composition of bean tissues (n = 5) and the significance of the treatments and their interaction

	N	P_2O_5	K_2O	Ca	Mg	Mn	Zn
Plant composition	(%)			(g kg^{-1})		(ppm)	
Treatment							
Ø-Ø	3.55	0.89a	5.18	5.26	1.50	1206.4a	33
$ZnSO_4$-Ø	3.51	1.12b	5.03	5.70	1.40	899.6b	43.6
Ø-dolomite	3.58	0.83a	4.30	7.78	2.66	306.8c	25.2
$ZnSO_4$-dolomite	3.22	0.80a	4.39	8.54	2.84	447.2c	31.2
Significance of $ZnSO_4$ treatment, main effect	0.268	0.008	0.868	0.123	0.780	0.261	0.001
Significance of dolomite, main effect	0.449	0.000	0.001	0.000	0.000	0.000	0.000
Significance of interaction effect	0.362	0.001	0.510	0.670	0.335	0.006	0.250
Least significant difference of one-way ANOVA when interaction is significant at $p < 0.05$. Means followed by the same letter are not significantly different.	NA	0.094	NA	NA	NA	212.2	NA

Note. NA means not applicable.

to Vitosh, Warncke, and Lucas (1994). The dolomite treatment has an effect on the phosphorus, potassium, calcium, magnesium, manganese, and zinc contents of the bean plant (this negative effect of liming on the zinc content was reported by Chowdhury, McLaren, and Swift [1997]). Smirnov and Muravin (1984) denied that liming increased the calcium–potassium antagonism. Nevertheless in this study there was strong negative correlation found between calcium, magnesium versus potassium, showing clear antagonistic effects (Table 2). The decrease in availability of manganese after liming was also suggested by Marschner (1997).

Zinc sulfate treatment has a significant increasing effect on the green and dry mass of bean plants (Table 4). The greatest biomass and plant height were achieved in the combined treatment of $ZnSO_4$-dolomite, the second greatest was $ZnSO_4$-Ø, and the third was Ø-dolomite treatment, with 147, 128, and 111% biomass of the Ø-Ø treatment, respectively. In the case of soybean, only marginally higher biomass was shown by the Ø-dolomite and $ZnSO_4$-dolomite treatments and the differences were not statistically significant.

By separating Table 2 into three blocks, the strength of the correlation between the groups of variables (among soil variables, among plant variables, and between soil and plant variables) can be evaluated. The variables pH, hydrolytic acidity, AL-extractable calcium, and magnesium show the usual relationships. The demonstrated antagonism between potassium and magnesium in magnesium-deficient soils is well known (Welte and Werner 1963).

Among soil and plant variables there are positive correlations between soil and plant phosphorus, calcium, magnesium, and zinc contents. Soil pH and acidity has the

Table 4
Average growth parameters of plants (n = 5) and the significance of the treatments and their interaction

	Experiment with bean			Experiment with soybean		
Plant composition	Plant height (cm)	Green mass (g)	Dry mass (g)	Plant height (cm)	Green mass (g)	Dry mass (g)
Treatment						
Ø-Ø	33.6	18.73	2.71	22.46	4.60	0.73
$ZnSO_4$-Ø	34.46	23.82	3.47	22.06	4.71	0.69
Ø-dolomite	34.35	19.86	3.0	23.68	4.55	0.75
$ZnSO_4$-dolomite	35.38	25.93	3.92	24.16	4.73	0.74
Significance of $ZnSO_4$ treatment, main effect	0.255	0.008	0.024	0.963	0.558	0.475
Significance of dolomite, main effect	0.309	0.394	0.286	0.067	0.955	0.249
Significance of interaction effect	0.914	0.793	0.814	0.613	0.891	0.648

expected effect on plant calcium and magnesium, manganese, and zinc content. Soil magnesium content showed a negative correlation with plant potassium, manganese, and zinc content.

Among the plant variables the negative correlation between the nitrogen content and the bean mass shows that total plant nitrogen was diluted by the increase of plant mass. Between plant calcium and magnesium content there was a positive correlation due to the application of dolomite. Plant magnesium content showed a negative correlation with potassium, as was expected from the antagonism (Welte and Werner 1963). Plant manganese content showed a positive correlation with potassium and negative with calcium and magnesium. This latter was known already as a consequence of acidity reduction in soils with low colloid content (Helyar and Anderson 1971; Marschner 1997). The negative correlation between zinc and magnesium was already demonstrated by several authors (Loch and Nosticzius 1983; Marschner 1997). Bean height and mass show a positive correlation.

These results suggest that in the acidic sandy soils of Hungary the application of zinc can contribute to a higher yield and more balanced plant composition.

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