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The effect of liming on the acidity level of *Dystric cambisol* and the content of available forms of some microelements

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Abstract

Limited acid soil fertility is caused by a high concentration of H^+ and Al^{3+}, some organic acids and heavy metals, but also by a small accessibility of some nutrients (P, Ca, Mg, B, Zn, particularly Mo) and a small microbiological activity. This study has been conducted to determine the effect of three levels of liming (partial – 1/3 Y1, half – 1/2 Y1, and complete liming) on the neutralization of the acid reaction, a high content of mobile Al^{3+}, and changes in the concentrations of available forms of Fe, Zn, and Cu in Dystric cambisol soil. The complete liming has almost completely neutralized the acid reaction, and decreased the level of mobile Al^{3+} below 1.0 mg kg^{-1}. There has been a satisfactory degree of decrease in pH and Al^{3+} in partial (1/3 of Y1) and half (1/2 of Y1) liming. No level of liming has had a significant influence on the content of available forms of Fe and Cu, while the content of Zn has decreased in accordance with the level of entered lime material and has been the lowest at the maximum doses of CaO applied. The level of changes caused by partial and halh-liming has justified these levels of acid repairing, which can be a great ecological and economic importance.

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Introduction

Acid soils create a number of difficulties in agriculture, especially in the production of good-quality and biologically valuable food. There are numerous factors that limit the fertility of these soils. High concentrations of H and Al ions, of some organic acids and heavy metals, as well as low accessibility of nutrients (P, Ca, Mg, B, Zn, particularly Mo) are just some of them. However, Al-toxicity is a major stress factor for plants on soils whose pH ≤ 5.5 (Poschenrieder *et al.,* 2008; Merino-Gergichevich *et al.,* 2010), and in these conditions, the prevailing pressure for the adaptation of cultivated plants is attributed to it (Ryan and Delhaize, 2010). The acidic environment serves to increase the presence of trivalent aluminum cations – Al^{3+} (Lidon and Barreiro, 2002; Kochian *et al.,* 2005), which is the most poisonous of all kinds of Al. More recognizable effects of Al-toxicity have been observed and well-described on the root (Barceló and Poschenrieder 2002; Ma, 2007; Panda and Matsumoto, 2007). However, damages may be present even on the upper parts of the plants (Merino-Gergichevich *et al.,* 2010), especially on the leaves, about which little is known. Today, there is growing evidence of the negative impact of aluminum on the light absorption, photosynthetic electron transport, gas exchange (Chen *et al.,* 2005a; Chen *et al.,* 2005b; Chen, 2006), photoprotective systems (Chen *et al.,* 2005a; Ali *et al.,* 2008), pigments (Chen *et al.,* 2005a; Mihailovic *et al.,* 2008; Milivojević *et al.,* 2000), as well as on other elements related to the structure or function of the photosynthetic apparatus. In addition to the direct effect, Al also affects plants indirectly, in such a way that aluminum ions, among other things, block the adsorption of phosphorus and potassium, thus disrupting the growth and development of crops (Zheng, 2010).

The availability of microelements in different soils, apart from the presence of phosphorus and organic matter, is significantly conditioned by their pH value (Wei *et al.,* 2006; Li *et al.,* 2007; Asadu *et al.,* 2014). Thus, the availability of micronutrients and toxic ions, as cations (e.g. Al^{3+}, Fe^{3+}, Mn^{2+}), increases with an increase of soil acidity (Porter *et al.,* 2004; Khabaz-Saberi and Rengel, 2010). After Al, an excess of Mn is the greatest factor of limited plant growth on acid soils (Rengel, 2000). Like Al, when manganese reaches the level of toxicity, it also limits the growth and function of plant roots, reduces the absorption of nutrients and water.

Liming acid soils is one of the key measures that can preserve or increase their productivity (Mao *et al.,* 2008; Repšiene and Skuodiene, 2010). Quantitative evidence on the effect of soil acidity on yield are unknown, but some controlled experiments on the effects of the treatment of acid soil with lime, and a combination of triple super phosphate and living mulch, have shown a yield increase for about three times (Uexkül and Mutert, 1995). That is why this research aimed to, by applying different levels of liming on Dystric cambisol in the year of application, define their effect on the rate of change of acidity, the content of mobile Al, and some micronutrients (Fe, Zn, Cu) as important factors in fertility.

Material and methods

Experimental sites

The research was conducted in 2010 and 2011 on an experimental field near the town of Leposavic (43° 16' N; 20° 36' E), belonging to the southern and central part of the Ibar-Kopaonik region, and located in southwestern Serbia. Leposavic is located at an altitude of 545 m, and is characterized by a temperate continental climate.

Agrochemical soil characteristics

The soil on which the research was performed belonged to the Dystric cambisol type and the basic agrochemical characteristics of the sites on which the experiments were placed in 2010 and 2011 are shown in Table 1. Dystric cambisol was characterized by the acid reaction, a low content of organic matter and available phosphorus, a high concentration of exchangeable aluminum, and a medium quantity of available potassium. The content of the analyzed microelements was high and very high.

Table 1. Agrochemical characteristics of Dystric cambisol.

Year	pH		Y1	OM	Al	P	K	Fe	Zn	Cu
	H_2O	KCl	cm^3	%	------- mg 100 g^{-1} -----			------- mg kg-1 -------		
2010	5.45	4.85	14.52	2.09	12.26	2.24	18.7	19.2	6.65	2.72
2011	5.52	4.87	13.95	2.33	13.86	2.94	15.10	26.6	4.05	3.63

Experimental design

Before the establishment of the experimental field, average soil samples had been collected for analysis to determine the level of liming in order to eliminate the excess acidity. CaO of high degree of fineness was used for liming. In both years, the material was applied in September, more precisely before basic processing, by being properly distributed over the surface and entered into the soil by plowing.

The applied rates of CaO were calculated according to the value of Y1 in the soil and the size of the experimental site (50 m^2). Three variants of liming were determined and applied: 1/3 Y1 CaO (V-3), 1/2 Y1 CaO (V-4), and Y1 CaO (V-5); as well as two variants without liming: the version with only the application of NPK (V-2), and the version without liming and fertilizer application – control (V-1). Fertilizers were also applied in the versions where liming was performed. In all cases, the doses of active compounds of nitrogen, phosphorus, and potassium were for N 120 kg ha^{-1}, and for P and K per 90 kg ha^{-1}. Fertilization was performed according to the standard technology for the wheat production. The experiment was set up as a random complete block design (RCBD) in four replications. The size of the base experimental site was 50 m^2, and the crop was wheat, Pobeda cultivar.

Soil laboratory analysis

In both years of research, during the stage of wheat tillering (T), 5 months since the liming and after the harvest (A. H.), 10 months since the liming, the pH was determined on a pH meter with a glass electrode in a 1: 2.5 suspension with water and 1 M KCl. At the same time, the content of exchangeable or mobile Al was determined by using Sokolov's method on a soil extract with 1M KCl by first determining the total substitutional acidity, and then by a deposition of aluminum with NaF and the share of Al^{3+} in the formation of substitutional acidity. Hydrolytic acidity, that is, Y1, was determined only after the harvest and by Kappen's method by treating a soil sample with $(CH_3COO)_2Ca$, and then the neutralization of excess acid was performed with 0.1 M NaOH. The content of available forms of soil microelements (Fe, Cu, and Zn) was determined by atomic absorption spectrophotometry, using Carl Zeiss Jena apparatus – AAS-1, Analityk Jena, Jena, Germany. The content of available Fe was determined after the extraction into a solution of 1M CH_3COONH_4 (pH 7) in the stage of wheat tillering (T) and after the harvest (A.H.), and for the available Cu and Zn, only after the harvest, upon the extraction (A.H.) in 0.1 M HCl.

Statistical analyses

Statistical analyses were performed on SPSS software, variant 16. The effects of the treatment on all variants were tested by ANOVA. Statistical differences between the treatments were determined by using the t-test (95 and 99%) by Pearson for Fisher's LSD (SPSS, 2007).

Results and discussion

The effect of three levels of liming on active, substitutional, and hydrolytic acidity has been in accordance with the applied dose of CaO (Table 2), the highest in the variants with complete liming (V-5), and the lowest in partial liming (V-3). The soil quickly reacted to entered CaO, and changes were obvious and complete already at the first check, 5 months after liming, i.e. in the stage of wheat tillering.

The differences between the treatments where CaO has not been used (V-1 and V-2) and the treatments in which CaO has been used (V-3, V-4, and V-5) are highly significant. The differences between the variants in which liming has been performed can clearly be observed. All the differences are highly significant ($p < 0.01$), except for the changes in active acidity in the tillering stage (T) in 2010, when a difference in the level of statistical significance ($p < 0.05$) has been found between the first (V-3) and the second level (V-4) of partial liming. The resulting changes, both in active and substitutional acidity, are in favor of the claims of the need for liming acid soils (Busari *et al.,* 2008; Jelić *et al.,* 2011; Mao *et al.,* 2008; Repšiene and Skuodiene, 2010), in order to perform the neutralization and create favorable conditions for smooth growth and development of plants. It particularly refers to a group of plants that are insufficiently tolerant to soil acidity.

Table 2. The change in pH (H_2O and KCl) and Y1 after liming.

Variants	pH H_2O				pH KCl				Y1	
	2010		2011		2010		2011			
	T	AH	T	AH	T	AH	T	AH	2010	2011
V-1	5.45	5.43	5.42	5.50	4.83	4.83	4.84	4,83	16.32	14.12
V-2	5.50	5.51	5.41	5.47	4.75	4.79	4.79	4.82	14.32	14.56
V-3	5.92	5.89	5.90	5.84	5.23	5.30	5.29	5.24	7.76	7.66
V-4	6.17	6.15	6.18	6.14	5.57	5.56	5.60	5.58	5.21	5.38
V-5	6.79	6.77	6.87	6.73	6.24	6.20	6.24	6.19	3.00	3.45
Lsd 0.05	0.243	0.081	0.098	0.094	0.120	0.099	0.136	0.086	1.69	1.565
Lsd 0.01	0.349	0.117	0.141	0.135	0.173	0.143	0.196	0.124	2.430	2.248

The observed changes in pH during one growing season should be emphasized. Namely, in the period between the first (tillering stage) and the second checks (after the harvest), there was a small decline in pH. This trend was expected because numerous processes in the soil, primarily flushing, as well as the adoption of Ca by the plants, led to losses of liming material, which inevitably led to a decrease in pH. For this reason, it is often talked about a time-limited (fixed-term) effect of this measure, which has to be repeated after a while for these reasons. Since the problem with acidity cannot be definitely resolved, a practical approach consisting of a regular application of moderate amounts of lime material, with which soil acidity would be maintained at an acceptable level, is completely acceptable (Garscho and Parker, 2001). In this way, the benefits would be multiple. Smaller quantities of lime material would be, on the one hand, economically justified, and on the other hand, they would enable a better availability of nutrients, as well as a more favorable environment for the growth and development of crops.

Mobile aluminum, as one of the limiting factors of crop production in acid soils, was in Dystric cambisol at the level at which its depressing effect on crops was expected. However, in all the years of research and at all levels of repair, liming radically changed the image of mobile Al content, and the results are shown in Table 3.

Table 3. The changes in mobile Al content ($mg \cdot 100\ g^{-1}$) after liming.

Variant	2010.		2011.	
	T	AH	T	AH
V-1	12.28	12.21	13.62	13.80
V-2	12.32	12.54	13.92	13.87
V-3	5.26	5.56	6.25	6.39
V-4	2.17	2.37	2.44	2.62
V-5	0.48	0.40	0.47	0.42
Lsd 0.05	0.346	0.277	0.346	0.072
Lsd 0,01	0.497	0.398	0.497	0.104

The content of mobile Al^{3+}, in both years of research, was strongly changed in all the variants where CaO was applied. Thus, trace aluminum content was found in the first measuring, in the stage of wheat tillering, in the complete liming variant. According to the results of other authors, liming had the same effect on other soil types, such as pseudogley (Dugalić *et al.,* 2002; Jelić *et al.,* 2011), Dystric albeluvisol (Repšiene and Skuodiene, 2010), Lessivated Cambisol and pseudogley (Pivić *et al.,* 2011). At the same time, also in the variants of partial (V-3) and particularly half-liming, the content of mobile aluminum was reduced to a level at which the risk of its toxic effect on the crops was significantly reduced. In V-3 and V-4 variants, a slight increase in the content of mobile Al was found during the growing season.

Despite an obvious improvement in the reaction of Dystric cambisol, liming has not had a major effect on the content of available forms of Fe and Cu (Table 4). Namely, the content of Cu per variants, in both years of research, has not indicated any effect of entrained lime material, and the differences between the liming treatment and the control variant are not statistically significant. On the other hand, the content of Fe in the tillering stage, in the part of the experiment when amelioration was performed, did not sufficiently clearly indicate the real impact of lime. In particular, it was because the differences, in the part of the experiment when liming was performed and in the part without liming, almost entirely disappeared when the content of the element was measured after the wheat harvest. The observed difference in available Fe concentration during the growing season was most likely the result of changes in oxidation-reduction conditions, on which numerous processes that transform Fe into available forms and vice versa depend.

Table 4. The changes in the content of available forms of Fe, Zn, and Cu (mg kg^{-1}) after liming.

Variants	Fe				Zn		Cu	
	2010		2011		2010	2011	2010	2011
	T	AH	T	AH				
V-1	17.43	9.73	33.48	21.28	3.78	3.18	2.40	3.65
V-2	14.78	12.30	30.15	19.20	3.30	3.75	2.49	3.69
V-3	14.45	9.78	30.18	20.40	3.13	2.83	2.49	3.66
V-4	14.61	10.05	30.25	20.21	3.05	2.75	2.51	3.64
V-5	14.50	10.78	30.60	19.55	2.95	2.55	2.55	3.62
Lsd 0.05	3.49	3.89	3.90	1.99	0.39	0.18	0.46	0.13
Lsd 0,01	5.01	5.59	5.61	2.86	0.56	0.26	0.66	0.19

The effect of liming has been observed only on the content of available Zn. Namely, lime material and an increase of pH have caused a decrease in the amount of available forms of this element. The differences of all the variants with liming, in both years of research, have been highly significant ($p < 0.01$) as compared to the control variant. Also, the amount of applied lime material has had an effect on the content of Zn. Thus, the lowest content, in both years, has been found in the variant where complete liming was applied (V-5), and the differences compared to the other two levels of liming (V-3 and V-4) had a statistical significance only in 2011. There is no complete consensus regarding the concentrations of mobile fractions of Zn after liming, so there are opinions that it is being reduced (Lalljee and Facknath, 2001; Kovačević *et al.,* 2009), or that the entered lime does not influence its content (Bošković-Rakočević and Bokan, 2005).

Conclusion

Liming has caused significant changes in Dystric cambisol, and the changes were rapid and in proportion to the rates of applied CaO. Soon after the introduction, already in the stage of tillering, a decrease in acidity and in the content of mobile aluminum occurred, and of the analyzed microelements, only Zn reacted to entered lime material in such a manner that the content of its available forms was reduced. The degree of achieved changes was adequate to the level of applied liming. Complete liming almost completely neutralized the acid reaction, in traces it brought the content of mobile Al, but it also significantly reduced the availability of Zn, thus jeopardizing the regular supply of plants with this microelement. On the other hand, the level of changes caused by partial (1/3 Y_1) and half-liming (1/2 Y_1) has justified and promoted these levels of acid soil repairing. The main benefits of lower levels of liming are lower investments in liming material, satisfactory pH neutralization, a reduction in mobile Al below the toxicity level and a lower risk of bringing some microelements to the deficit limits, which is of great ecological and economic importance.

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