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Macronutrient contents in the leaves and fruits of red raspberry as affected by liming in an extremely acid soil

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ABSTRACT

The study evaluates the effect of liming materials application in combination with NPK fertilizer and borax on macronutrient contents (nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg)), in an extremely acid soil and raspberry leaves and fruits during a two-year period. Liming increased soil pH, N mineral content, P, Ca and Mg soil content, while K content either increased (dolomite and borax application), or decreased (lime application). The N and P contents in raspberry leaves after liming increased significantly, but P content remained below the optimal values. Some treatments with lime caused a decrease in K content in leaves, while dolomite and borax application increased K content. Initially optimal Ca content in leaves increased significantly in the treatments with lime, but decreased after dolomite application. The Mg content in leaves increased after dolomite and borax application, but mainly remained below optimal values. Liming either did not alter or only slightly altered macronutrient contents in raspberry fruits.

Keywords: raspberry nutrition; amelioration of acid soils; macronutrient concentration; *Rubus idaeus*; Dystric Cambisol

The Republic of Serbia is at the top of the world's commercial raspberry (*Rubus idaeus* L.) production at the moment. Numerous raspberry plantations in intensive production have been established on extremely acid soils. The raspberry nutrition in this soil type is of particular significance when it comes to obtaining high, stable yield and high quality crop, especially after a serious problem of raspberry plantation drying up in such soil. Besides the pathogenic causes, it is believed that soil conditions, especially low pH, can be a considerable reason for raspberry drying up. In addition, in acid soils plant growth could be limited because of Al, Fe and Mn toxic concentrations and the deficit of biogenic elements P, Zn, Ca, Mg, B and Mo (von Uexküll and Mutert 1995).

Improvement of acid soil fertility was usually performed by liming. However, the addition of greater amounts of Ca or Mg via liming, besides its advantages, can also result in the lack of certain micronutrients (Fageria et al. 1995). Furthermore, the antagonism between the ions has a great practical significance, both in terms of their accessibility in the soil and their uptake (Ca/NH_4, K, Mg; Mg/NH_4, K, Ca) (Jakobsen 1993).

Therefore, it is of great significance to explore how liming, except soil acidity, affects nutrient contents in the soil and plant. The object of this study was to determine the influence of different lime and dolomite rates on macronutrient contents (N, P, K, Ca and Mg) in soil, as well as in raspberry leaves and fruits, grown in extremely acid soil.

MATERIAL AND METHODS

The experiment was set up in 2002, on a 4-year old raspberry plantation, established on an ex-

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tremely acid soil (Dystric Cambisol) in West Serbia (43°51'2.00''N, 20°4'9.39''E). The treatments were: 2 and 4 t lime/ha; 2 and 4 t dolomite/ha, 2 t lime/ha + 50 kg borax/ha and 2 t dolomite/ha + 50 kg borax/ha. Lime (with 98.5% of $CaCO_3$), dolomite (with 97% of $CaCO_3 \times MgCO_3$ in 1:1 ratio), and borax ($Na_2B_4O_2 \cdot 10\ H_2O$), were applied once in autumn of 2002 and their effect was observed in the two following growing seasons (2003 and 2004). In early spring, 1 t/ha of NPK fertilizer (15% N, 6.54% P, and 12.45% K) was added to each treatment of the experiment, including the control. Soil characteristics before the experiment was set up are presented in Table 1. Soil samples for analysis and plant material samples (leaves) were taken in mid-June.

Soil pH was determined with a glass electrode pH meter in 1 mol/L KCl and in H_2O (in ratio soil:KCl or H_2O 1:2.5). Hydrolytic acidity (H) and the sum of exchangeable basis (S) were determined following Kappen (1929). Cation exchange capacity (CEC) was determined using 1 mol/L ammonium acetate (NH_4OAc), pH 7, and base saturation (BS) was calculated. The N mineral forms in the soil (NH_4^+-N, NO_3^--N) were determined by steam distillation method by Bremner (1965). Available P and K in soil were determined by the AL-method (Egnér et al. 1960). Soil Ca and Mg were extracted by ammonium acetate and determined with a SensAA dual atomic absorption spectrophotometer (Dandenong, Australia). Soil organic C and total N (in soil and plant) were measured with an elemental CNS analyzer, Vario EL III (Hanau, Germany). In order to determine plant K, P, Mg and Ca, leaves and fruit samples were burned to ash and acid digestion with HCl was performed according to Chapman and Pratt (1961). Phosphorus was measured by the colorimetric ammonium vanadate method, K by flame photometry (Egnér et al. 1960), while Ca and Mg by atomic absorption spectroscopy (Chapman and Pratt 1961).

The effect of the treatments was evaluated using the analysis of variance (SPSS 16.0, Chicago, USA), and significant differences between means were tested by the Duncan's multiple range test.

Table 1. Soil characteristics at the study site

Parameter		Parameter	
pH_{KCl}	3.60	NH_4^+-N (mg/kg)	24.9
pH_{H_2O}	4.35	NO_3^--N (mg/kg)	30.1
S ($mmol_+$/kg)	3.20	P (mg/kg)	50.6
H ($mmol_+$/kg)	140.8	K (mg/kg)	129.5
CEC ($mmol_+$/kg)	180.0	Mg (mg/kg)	94.0
BS (%)	17.8	Ca (mg/kg)	670.0
C_{org} (%)	2.115	Ca/Mg	4.35/1
N_{tot} (%)	0.228		

S – sum of exchangeable basis; H – hydrolytic acidity; CEC – cation exchange capacity; BS – base saturation

RESULTS AND DISCUSSION

Soil pH increased significantly (by 0.85 units), only in the treatment with 4 t/ha of lime (Table 2).

Table 2. Soil acidity and soil adsorptive complex

	pH_{KCl}		pH_{H_2O}		H ($mmol_+$/kg)		S ($mmol_+$/kg)		CEC ($mmol_+$/kg)		BS (%)	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Control	3.50^{bc}	3.55^{b}	4.40^{bc}	4.50^{b}	147^{a}	145^{a}	30^{c}	30^{bc}	177^{ab}	175	20.4	17.2
2 t/ha $CaCO_3$	3.60^{bc}	3.70^{b}	4.45^{bc}	4.60^{b}	146^{a}	139^{a}	61^{b}	50^{ab}	207^{a}	189	29.0	26.4
4 t/ha $CaCO_3$	4.10^{a}	4.20^{a}	4.89^{a}	5.05^{a}	98^{b}	82^{b}	98^{a}	78^{a}	196^{a}	160	50.1	48.8
2 t/ha $MgCaCO_3$	3.30^{d}	3.40^{b}	4.25^{c}	4.30^{b}	145^{a}	130^{a}	31^{c}	46^{b}	176^{ab}	176	17.1	26.1
4 t/ha $MgCaCO_3$	3.45^{c}	3.65^{b}	4.35^{bc}	4.60^{b}	130^{a}	98^{b}	30^{c}	50^{b}	160^{b}	148	18.8	33.9
2 t/ha $CaCO_3$ + 50 kg/ha borax	3.70^{b}	3.55^{b}	4.50^{bc}	4.40^{b}	120^{ab}	140^{a}	28^{c}	30^{bc}	148^{b}	170	18.9	17.6
2 t/ha $MgCaCO_3$ +50 kg/ha borax	3.70^{b}	3.60^{b}	4.55^{bc}	4.40^{b}	115^{ab}	132^{a}	29^{c}	30^{bc}	144^{b}	162	20.1	18.6
$LSD_{0.05}$	0.18	0.25	0.21	0.23	20.5	17.0	7.0	14.0	19.0	15.0^{ns}		

^{ns}statistically not significant, values followed by the same letter in a column are not significantly different ($P \leq 0.05$). H – hydrolytic acidity; S – sum of exchangeable basis; CEC – cation exchange capacity; BS – base saturation

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Table 3. Effect of liming materials on mineral N content (mg/kg) in soil

Treatment	NH_4^+-N		NO_3^--N		NH_4^+-N + NO_3^--N	
	2003	2004	2003	2004	2003	2004
Control	23.1^e	31.5^d	20.2^d	26.3^e	43.3	57.8
2 t/ha $CaCO_3$	33.2^b	48.1^c	24.4^d	37.5^c	57.6	85.6
4 t/ha $CaCO_3$	44.3^a	79.5^b	42.4^b	83.3^a	86.7	162.8
2 t/ha $MgCaCO_3$	32.0^{bc}	51.5^c	22.5^d	32.3^d	54.5	83.8
4 t/ha $MgCaCO_3$	30.2^c	88.8^a	30.1^c	59.0^b	60.3	147.8
2 t/ha $CaCO_3$ + 50 kg/ha borax	34.3^b	37.8^d	53.6^a	34.3^{cd}	87.9	72.1
2 t/ha $MgCaCO_3$ + 50 kg/ha borax	26.3^d	35.0^d	41.1^b	31.6^d	67.4	66.6
$LSD_{0.05}$	2.06	5.54	4.13	3.69		

Values followed by the same letter in a column are not significantly different ($P \leq 0.05$)

However, the obtained pH value of 5.05 (in H_2O) was still below the optimal values for raspberry cultivation (pH 5.6–6.2). In the same treatment, the highest decrease in hydrolytic activity and the highest increase in the sum of bases and base saturation were obtained, while CEC slightly increased. Similar effects of lime on soil properties were reported by Kadar and Rekasi (2008).

In general, a significant increase of NH_4^+-N and NO_3^--N contents in all treatments was detected in both years (Table 3). Liming causes faster mineralization of organic matter, influencing higher concentrations of N mineral forms in soil (Bailey 1995). However, higher concentrations of NH_4^+-N in relation to NO_3^--N, indicate that even after the liming, the nitrification conditions were still unfavourable.

In the first year, all treatments caused a significant increase in N content in raspberry leaves, compared to the control, and N concentrations were above optimal (except with 2 t/h of lime and dolomite) (Bergmann 1986). Liming by increasing Ca availability in the rhizosphere improves the ability of plants to uptake N (Bailey 1995). However, in the second year, even though N mineral content increased in the soil, N content in leaves decreased (under the optimal values). Bigger plant growth and higher organic matter production can cause the dilution effect of N and its decrease in leaves. In both years, in all treatments N content in raspberry fruits did not differ significantly, compared to the control, and the obtained values (0.72–1.11% N of dry matter), were lower than those reported by Džamić and Stevanović (2000) (1.45% N of dry matter) (Table 4). Mineral nutrient contents in berry fruits depend on plant genotype (cultivars), and to a lesser extent, on mineral nutrition and ecological factors.

The available P content in the control soil, despite regular addition of 1 t/ha NPK was low in both years (Table 5). In all treatments, soil P content significantly increased and in the second year medium supply with P was obtained. Increased soil pH influenced the release of one part of bound P from Al- and Fe-phosphate in acid soils (Iyamuremye et al. 1996).

In the first year, P content in raspberry leaves was not significantly changed, while in the second year, a significant increase was detected in all treatments (except in the 2 t/ha of lime) (Table 4). However, P content in all treatments (0.11–0.18% P) was still below the optimal values (0.3–0.5% P) according to Bergmann (1986). Increased P content in leaves after liming may be a result of its increased content in the soil. In addition, increased soil pH could improve ability of the plant to uptake P, mainly by reducing the toxic level of mobile Al, which negatively influences the root development and nutrient elements uptake in very acid soils (Haynes and Mokolobate 2001, Jakovljević et al. 2005). Possibly, low soil pH even after the liming (the highest pH 5.05 in H_2O), did not reduce Al toxicity sufficiently and P content in leaves did not reach the optimal level (Sikirić et al. 2009). Lower P content in leaves can also be influenced by the antagonism between P and Ca, whose concentration in leaves was high (Järvan and Poldma 2004). The P content in fruits in the second year increased significantly and values were similar to Tešović (1988) (0.22–0.31% P).

The content of available K in the control soil was at the medium level (Table 5) (Džamić and Stevanović 2000). The K available content in soil in the first year after liming did not significantly

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Table 4. Effect of liming materials on macronutrient contents in raspberry leaves and fruits (% of dry weight)

Treatment		Leaf		Fruit	
		2003	2004	2003	2004
N (%)	control	3.05^{d}	2.87^{a}	0.86	0.98^{ab}
	2 t/ha $CaCO_3$	3.55^{bc}	2.80^{a}	0.75	0.80^{b}
	4 t/ha $CaCO_3$	4.20^{a}	2.51^{ab}	0.72	0.87^{ab}
	2 t/ha $MgCaCO_3$	3.40^{b}	2.13^{c}	0.80	0.94^{ab}
	4 t/ha $MgCaCO_3$	3.60^{bc}	2.27^{bc}	0.86	1.11^{a}
	2 t/ha $CaCO_3$ + 50 kg/ha borax	3.90^{ab}	2.13^{c}	0.88	0.98^{ab}
	2 t/ha $MgCaCO_3$ + 50 kg/ha borax	3.80^{b}	2.06^{c}	0.86	0.98^{ab}
	$LSD_{0.05}$	0.32	0.33	0.18^{ns}	0.17
P (%)	control	0.11	0.13^{b}	0.14	0.20^{d}
	2 t/ha $CaCO_3$	0.13	0.14^{b}	0.17	0.22^{cd}
	4 t/ha $CaCO_3$	0.14	0.16^{a}	0.18	0.22^{cd}
	2 t/ha $MgCaCO_3$	0.13	0.17^{a}	0.16	0.24^{bc}
	4 t/ha $MgCaCO_3$	0.14	0.16^{a}	0.17	0.22^{cd}
	2 t/ha $CaCO_3$ + 50 kg/ha borax	0.13	0.17^{a}	0.19	0.27^{a}
	2 t/ha $MgCaCO_3$ + 50 kg/ha borax	0.13	0.18^{a}	0.18	0.25^{ab}
	$LSD_{0.05}$	0.023^{ns}	0.019	0.054^{ns}	0.041
K (%)	control	1.62^{b}	1.64^{a}	1.08^{b}	1.14^{bc}
	2 t/ha $CaCO_3$	1.49^{bc}	1.33^{b}	1.06^{b}	0.83^{d}
	4 t/ha $CaCO_3$	1.33^{c}	1.14^{b}	1.11^{b}	0.97^{cd}
	2 t/ha $MgCaCO_3$	1.58^{b}	1.62^{a}	1.06^{b}	1.08^{bc}
	4 t/ha $MgCaCO_3$	1.80^{a}	1.74^{a}	1.26^{a}	1.33^{a}
	2 t/ha $CaCO_3$ + 50 kg/ha borax	1.97^{a}	1.97^{a}	1.13^{b}	1.20^{ab}
	2 t/ha $MgCaCO_3$ + 50 kg/ha borax	1.91^{a}	1.72^{a}	1.11^{b}	0.97^{cd}
	$LSD_{0.05}$	0.17	0.27	0.12	0.20
Ca (%)	control	1.45^{cd}	1.60^{ab}	0.10	0.11
	2 t/ha $CaCO_3$	1.60^{ab}	1.70^{ab}	0.11	0.11
	4 t/ha $CaCO_3$	1.64^{a}	1.69^{ab}	0.11	0.12
	2 t/ha $MgCaCO_3$	1.40^{cd}	1.28^{c}	0.12	0.11
	4 t/ha $MgCaCO_3$	1.50^{bc}	1.46^{bc}	0.11	0.11
	2 t/ha $CaCO_3$ + 50 kg/ha borax	1.70^{a}	1.81^{a}	0.11	0.12
	2 t/ha $MgCaCO_3$ + 50 kg/ha borax	1.35^{d}	1.30^{c}	0.12	0.12
	$LSD_{0.05}$	0.102	0.23	0.020^{ns}	0.021^{ns}
Mg (%)	control	0.20^{c}	0.18^{bc}	0.09	0.10
	2 t/ha $CaCO_3$	0.20^{c}	0.18^{bc}	0.09	0.11
	4 t/ha $CaCO_3$	0.21^{c}	0.16^{c}	0.09	0.11
	2 t/ha $MgCaCO_3$	0.23^{bc}	0.19^{b}	0.10	0.12
	4 t/ha $MgCaCO_3$	0.25^{b}	0.20^{b}	0.10	0.12
	2 t/ha $CaCO_3$ + 50 kg/ha borax	0.30^{a}	0.23^{a}	0.10	0.11
	2 t/ha $MgCaCO_3$ + 50 kg/ha borax	0.31^{a}	0.24^{a}	0.11	0.12
	$LSD_{0.05}$	0.026	0.024	0.019^{ns}	0.020^{ns}

^{ns}statistically not significant. Values followed by the same letter in a column are not significantly different ($P \leq 0.05$)

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Table 5. Effect of liming materials on macronutrient contents (mg/kg) in soil

Treatment	P		K		Ca		Mg		Ca/Mg	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Control	22.9[e]	37.0[d]	136.1	151.9[bc]	890[c]	890[e]	97[c]	90[e]	5.6:1	6:1
2 t/ha $CaCO_3$	34.8[c]	55.9[b]	136.9	139.4[cd]	1640[b]	1390[a]	116[c]	113[d]	8.6:1	9.2:1
4 t/ha $CaCO_3$	55.9[a]	67.8[a]	160.9	122.8[d]	2310[a]	1930[b]	137[b]	142[c]	10.4:1	7.8:1
2 t/ha $MgCaCO_3$	28.6[d]	45.3[c]	131.1	171.0[ab]	920[c]	1000[de]	136[b]	184[b]	4.2:1	3.3:1
4 t/ha $MgCaCO_3$	37.4[c]	56.8[b]	136.1	180.1[a]	960[c]	1110[cd]	164[a]	228[a]	3.6:1	2.9:1
2 t/ha $CaCO_3$ + 50 kg/ha borax	44.9[b]	66.9[a]	156.0	178.4[a]	1060[c]	1230[c]	110[c]	175[b]	5.9:1	4.3:1
2 t/ha $MgCaCO_3$ + 50 kg/ha borax	39.2[c]	66.4[a]	156.0	191.7[a]	1010[c]	1170[c]	115[c]	182[b]	4.7:1	3.9:1
$LSD_{0.05}$	3.9	3.9	21.3[ns]	19.1	140.4	128.6	14.4	17.3		

[ns]statistically not significant. Values followed by the same letter in a column are not significantly different ($P \leq 0.05$)

change (Michalk and Huang 1992, Järvan and Poldma 2004). However, in the second year, K content significantly increased in the treatment with 4 t/ha of dolomite and both treatments with borax, while K content significantly decreased in the treatment with 4 t/ha of lime.

Content of K in raspberry leaves (1.14–1.97%), was mainly below the optimal values (1.80–2.50%) (Bergmann 1986) or within the range of sufficient values (1.0–2.0%) (Kessel 2003). Compared to the control, in both years, lime application significantly decreased K content in leaves (up to 31%), possibly due to the antagonism in Ca and K uptake from soil solution (Weis et al. 2009). In the first year, in treatments with 4 t/ha of dolomite and borax, K content in leaves increased, possibly due to the antagonism of Ca and Mg, which can influence the weakness of antagonism between Ca and K (particularly in the second year, when the dolomite solubility was higher). Boron could be indirectly involved in the increased accumulation of K by plants, since the addition of B in the nutrient solution enhanced the K concentration of plants, possibly because B depressed the concentration of Ca due to antagonism (Tariq and Mott 2006).

In fruits, K content (0.83–1.33% K) was similar to previously reported values (0.77–1.15% K) (Tešović 1988). Application of 4 t/ha of dolomite increased K content in both years (on average 17%, compared to the controls), but 2 t/ha of lime decreased K content in the second year, similar to the treatment effect in soil and leaves.

In the control treatment, Ca content in the soil was deficient in both years (Table 5) (Džamić and Stevanović 2000). In the first year, only lime application increased Ca content in soil, while in the second year, Ca content significantly increased in all treatments. Lower Ca content in lime treatments in the second year compared to the first, was mainly caused by its easy rinsing.

Content of Ca in the leaves in lime treatments was either optimal (Kessel 2003) or above optimal (Bergmann 1986). In lime treatments, Ca content in the raspberry leaves significantly increased only in the first year (up to 13%), similar to the previous findings (Fystro and Bakken 2005). Although dolomite application significantly increased Ca content in soil, its content in leaves was not affected in the first year, but significantly decreased in the second (up to 20%). Dolomite caused changes in Ca/Mg ratio, and their antagonistic relationship influenced a lower adsorption of Ca and its decrease in leaves (Michalk and Huang 1992, Järvan and Poldma 2004).

The Ca concentrations in fruits (0.09–0.14%) were lower, compared to the previous report (Tešović 1988) (0.14–0.15% Ca), and there were no differences in all treatments in both years.

In the control soil, content of available Mg was at medium level, but it was in unfavourable ratio with Ca (Table 5) (Džamić and Stevanović 2000). In the first year, dolomite significantly increased Mg content, as well as 4 t/ha of lime, while in the second year, all treatments significantly increased Mg content (except 2 t/ha of lime). During the two years, the unfavourable ratio of Ca/Mg in control soil (higher than 5:1) has become more unfavourable due to the lime application, while dolomite application influenced Ca:Mg ratio positively.

Compared to the control, Mg content in leaves increased in treatments with 4 t/ha of dolomite (first year), as well as in both treatments with borax (in both years). Only in these treatments,

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Mg content was optimal in the first year (0.30–0.60%; 0.25–0.50%) (Bergmann 1986, Kessel 2003). Application of dolomite caused higher Mg content by increasing pH values and by direct Mg input in soil. Borax can depress the concentration of Ca due to antagonism and consequently easier and higher adsorption of Mg by plants (Tariq and Mott 2006). In our experiment, Mg content in fruits did not change after liming and it was lower (0.09–0.012) compared to Tešović (1988) (0.12–0.16% Mg), except in all treatments with dolomite.

Taking into account the leaf analysis as the most common method for determining nutrient deficiency in fruit plants, it can be concluded that after liming and NPK fertilization, the P and Mg contents in leaves were still below the optimal values, indicating a need for the combination of higher rates of organic or mineral fertilizers with lime and particularly dolomite, in raspberry cultivation in extremely acid soils.

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