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Full Length Research Paper

Effect of liming on the molybdenum content in the root and leaf of tomato grown on pseudogley under controlled conditions

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Pseudogley is a typical type of acid soils predominating in both Serbia and the wider region. Acid soils are not suitable for the cultivation of agricultural crops due to the hampered uptake of most nutrients as induced by increased levels of hydrogen ions. In order to make pseudogley soil suitable for crop production, pH improvement measures should be employed. The objective of this study was to use liming to neutralise soil acidity and evaluate the effect of soil pH improvement measures on the Mo content in both root and leaf of the Dutch tomato (*Lycopericon esculentum* Mill.) hybrid Belle planted under controlled conditions on pseudogley soil. Molybdenum was studied in this paper due to its role in plant nitrogen metabolism. Moreover, the determination of molybdenum presence in the root and leaf is a sure indicator of successful liming effects. Three liming treatments were employed (1, 3 and 4 t/ha $CaCO_3$). The liming operation used on pseudogley induced a statistically significant increase in molybdenum ion absorption into the root system of tomato. Independently from the aforementioned, the values for the root and leaf molybdenum content of tomato in each treatment were very low and insufficient for successful growth of this plant. In order to make pseudogley suitable for successful development of agricultural production, it is necessary to increase both soil pH and the content of available molybdenum in the soil.

Key words: Liming, pseudogley, molybdenum, leaf, root, tomato.

INTRODUCTION

Long-term research reveals that Serbia has over 60% of acid soils that are a major constraint to crop production due to their low productivity (Bošković-Rakočević et al., 2004; Dalović et al., 2010). Acid soils limit crop production on 30 to 40% of the world's arable land and up to 70% of the world's potentially arable land (Von Uexkull and Murtert, 1995). A continuous increase in the land area under such soils is the result of the effect of a multitude of factors including intensification of plant production involving the uncontrolled use of soil acidifying fertilisers, the effect of acid rains resulting from acid emissions from industrial plants and urban areas, and nutrient depletion in soils occurring through nutrient removal by crops. Acid soils are not suitable for the cultivation of agricultural crops due to the absence or decreased level of availability of the macronutrients P, Ca and Mg and some micronutrients most notably molybdenum as induced by increased levels of hydrogen ions. Although, plant molybdenum requirements are very low; molybdenum is vital for the regulation of certain physiological processes within the plant, primarily

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nitrogen uptake (Gupta and Lipsett, 1981; Kaiser et al., 2005). The lack of Mo in the plant leads to decreased activities of nitrate reductase and nitrogenase which results in reduced protein synthesis and increased content of amides and other soluble non-protein forms of nitrogen (Nicholas and Nason, 1954; Randall, 1969; Jones et al., 1976; Zhao and Bai, 2001). Another adverse effect of soil acidity increase is the release of toxic Al, Mn and Fe forms from the soil adsorption complex and, accordingly, an increase in their concentration in the soil solution and the plant (Rao et al., 1993; Samac and Tesfaye, 2003). This induces a decrease in both yield and quality of plants grown on such soils. Pseudogley is a typical type of acid soils predominating in both Serbia and the wider region. In order to make this soil suitable for plant production, pH improvement measures should be employed. The operation used most commonly to this end is liming which involves the introduction of adequate rates of calcium fertilisers into the soil in order to achieve neutral or mildly acid pH and, hence, create a suitable environment for the nutrient uptake by the plant.

The objective of this study was to use liming to neutralise soil acidity and evaluate the effect of soil pH improvement measures on the Mo content in both root and leaf of the Dutch tomato (*Lycopericon esculentum* Mill.) hybrid Belle planted under controlled conditions on pseudogley soil. Molybdenum was studied in this paper due to its importance for plant development (Williams and Silva, 2002). Moreover, the determination of molybdenum presence in the root and leaf is a sure indicator of successful liming effects. Molybdenum is uptaken by the plant from the soil solution in the form of highly oxidised molybdate (MoO_4^-) that exists in the plant as an anion, its availability increasing with increasing alkalinity as opposed to any other micronutrient.

MATERIALS AND METHODS

Studies were conducted in 2008 and 2009 under controlled greenhouse conditions at the Faculty of Agronomy, Čačak. The material used included vessels containing pseudogley, the Dutch tomato hybrid Belle plants and ground calcium carbonate. The pseudogley soil used in the trial was taken from the experimental plot located in Gornji Milanovac. It was sampled from different plot zones up to a depth of 40 cm and mixed thereafter to obtain uniformity. Active acidity of the soil was 5.01 pH units as determined by a pH metre. In order to improve the physical properties and mechanical composition of the soil used in the experiment performed under controlled conditions, the soil was ground and mixed with sand at a ratio of 3:1 on 18 March 2008 at the greenhouse of the Faculty of Agronomy, Čačak. Immediately thereafter, soil pH improvement operations were carried out using liming applied at three different treatments that were compared to the non-treated control. Liming involved the use of ground calcium carbonate ($CaCO_3$) uniformly dispersed over the soil surface at adequate rates depending on the treatment. The material employed was powdered (particle size 0.2 mm) so as to enhance dilution and, hence, increase the effect of liming. The following treatments were employed:

i) V_1 – 1t/ha,
ii) V_2 – 3t/ha,
iii) V_3 – 4t/ha,
iv) V_4 - control (without liming).

The aforementioned rates were calculated and applied relative to the area treated. Three weeks after the liming operation, tomato plants were transplanted into 11 L vessels containing the previously treated pseudogley soil. The Dutch tomato hybrid Belle plants used in this study were produced at a certified nursery located near the Faculty of Agronomy. The trial involving evaluation of the effect of liming on the Mo content of both root and leaf of tomato grown under controlled conditions was set up at the greenhouse of the Faculty of Agronomy, Čačak as a randomised block design in five replications and under four treatments. Each liming treatment included ten tomato plants which made up a total of 200 plants. The trial scheme was identical in both years of the study. The cultivation, transplanting, fertilisation and other cultural operations vital for successful tomato growth were used in all plants during the experiment. Fertilisation was performed through the soil using mineral fertilisers in the following manner depending on the plot treated: the fertilisers applied had a high content of nitrogen (CAN) at the beginning of the growing season of tomato, an identical content of nitrogen, phosphorus and potassium (20-20-20) in the middle of the experiment and a higher potassium content (50-20-30) at the end of the growing season.

The Mo content in both leaf and root of the test tomato plants was determined during the phenostages of flowering and full maturity using atomic absorption spectrophotometry (Black et al., 1965). The results obtained were subjected to standard statistical methods of analysis of variance (ANOVA) and multiple tests (Dunnett's test) using Microsoft Excel 2003 and Statistica 5.0 programmes. The data analysed were used to interpret the results and draw conclusions .

RESULTS AND DISCUSSION

The root molybdenum content of tomato at different stages of plant development as dependent upon pseudogley liming rate during the years of study is given in Tables 1 and 2. The analysis of variance of the average root molybdenum content in tomato plants as dependent upon liming rate, stage of plant development and year showed that soil liming rate and plant development stage had a statistically highly significant effect on the root molybdenum content. Furthermore, the analysis of variance revealed random that is statistically non-significant differences in the test parameter across the years. These results comply with those of many authors who confirmed the positive effect of liming in terms of increasing the molybdenum content in tomato plants (Graves et al., 1978; Asiegbu and Uzo, 1983; Pierce and Warncke, 2000). As compared to the available literature data, the average values for the molybdenum content of the tomato root in this study were quite low, irrespective of the treatment employed. The values reported in the literature ranged from 0.5 to 1 mg/g dry matter (Gowaricer et al., 2009). Conversely, the highest value of the root molybdenum content in this study was as low as 0.138 mg/g dry matter. As confirmed by a number of studies, Jones reports a minimum molybdenum requirement of at least 0.2 mg/g dry matter

Table 1. Average content of Mo in tomato root (ppm).

Liming treatment	Stage of development			
	Flowering		Full maturity	
	2008	2009	2008	2009
V_1	0.105[abc]	0.101[abc]	0.0483[c]	0.0449[c]
V_2	0.134[ab]	0.133[ab]	0.0683[abc]	0.0666[bc]
V_3	0.138[a]	0.128[ab]	0.0850[abc]	0.0833[abc]
V_4 (control)	0.085[abc]	0.0816[abc]	0.0366[c]	0.0400[c]
F - Test	Significant			
$D_{0.05}$ = 0.074				

Table 2. Analysis of variance of the average content of Mo in tomato root.

Sources of variation	Degrees of freedom	Mean square	F- exp.	Significance
Liming (A)	3	0.0119	321.513	**
Stage of development (B)	1	0.0709	1912.095	**
Year (C)	1	0.000176	4.744	ns
Interaction AB	3	0.000542	14.624	**
Interaction AC	3	0.0000371	8.000	ns
Interaction BC	1	0.0000843	2.273	ns
Interaction ABC	3	0.0000288	0.776	ns
Error	75	0.0000371		

ns = non-significant; ** = highly significant.

Table 3. Average content of Mo in tomato leaf (ppm).

Liming treatment	Stage of development			
	Flowering		Full maturity	
	2008	2009	2008	2009
V_1	0.221[bc]	0.225[bc]	0.153[c]	0.153[c]
V_2	0.296[ab]	0.311[a]	0.183[c]	0.173[c]
V_3	0.301[ab]	0.319[a]	0.165[c]	0.178[c]
V_4 (control)	0.204[c]	0.198[c]	0.156[c]	0.144[c]
F - test	Significant			
$D_{0.05}$ = 0.084				

in the plant for successful plant nitrogen metabolism. Given the fact that no treatment in this study resulted in a value higher than the aforementioned value, the liming operations performed on the pseudogley soil under controlled conditions were not sufficient to obtain an optimal content of molybdenum in the plant. This is due to biological reasons associated with the parent substrate the pseudogley soil developed from. In pseudogley soils, molybdenum content is very low (below 2 ppm) and cannot be absorbed by the plant root system due to the extreme acidity of these soils (Gerloff et al., 1959). Therefore, an increase in the molybdenum content of the pseudogley solution can be achieved using not only liming but also molybdenum fertilisation. To this end, the molybdenum form used should be ammonium molybdate rather than ammonium nitrate as the latter form induces additional soil acidity. Moreover, when employing molybdenum fertilisation, the manganese content of the soil solution should be also considered, given the antagonistic relationship between the two nutrients (Liu, 2002).

The leaf molybdenum content of tomato as dependent upon soil liming treatment and stage of plant development during the years of the study is presented in Tables 3 and 4. During the flowering stage, a statistically significant increase in the leaf molybdenum content of tomato plants was obtained with treatments 2 and 3 using higher rates of $CaCO_3$ (3 and 4 t/ha) as compared to treatment 4 (control) regardless of the year. Treatment 1 involving lower $CaCO_3$ rates (1 t/ha) did not show

Table 4. Analysis of variance of the average content of Mo in tomato leaf.

Sources of variation	Degrees of freedom	Mean squares	F- exp.	Significance
Liming (A)	3	0.0283	136.357	**
Stage of development (B)	1	0.223	1072.413	**
Year (C)	1	0.000176	0.846	ns
Interaction AB	3	0.0109	52.525	**
Interaction AC	3	0.000628	3.019	ns
Interaction BC	1	0.000550	2.644	ns
Interaction ABC	3	0.000159	0.765	ns
Error	75	0.000208		

ns = non-significant; ** = highly significant.

statistically significant differences in the test parameter in either year as compared to treatment 4 (control). During full maturity, in both years, the leaf molybdenum content was also highest in treatments 2 and 3, but the differences were not statistically significant as compared to the other treatments. The data outlined in Table 3 suggested that the leaf molybdenum content during full maturity was significantly lower than that during the flowering stage, which can be attributed to the fact that towards the end of the growing season nutrients are mostly translocated to the tomato crop, thus leading to a decreased content of all nutrients and, hence, molybdenum in senescent leaves (Abbasi et al., 2010). Tables 3 and 4 also show that the differences in the leaf molybdenum content of tomato across the years were statistically non-significant. The molybdenum content of tomato leaves as dependent upon soil liming, plant development stage and year was completely analogous to that of the tomato roots dependent upon the same factors. This finding was due to the following quite simple reason: the liming operation applied increased soil pH, thus enabling molybdenum ions to translocate from the soil solution into the root and, consequently, into other plant parts (Hepler and Wayne, 1985; Mandal and Mandal, 1998). There is another analogy between the molybdenum content in the leaf and that in the root.

As compared to the scientific literature, the average values for the leaf molybdenum content in this study were very low, regardless of treatment. These data serve as additional confirmation of the thesis that successful agricultural production on pseudogley soil is governed not only by liming but also by molybdenum fertilisation focused on providing the most favourable conditions for plant development.

Conclusion

This study on the molybdenum content in the leaf and root of tomato as dependent upon soil liming, plant development stage and year suggests the following: the pseudogley liming operation had a highly positive effect in terms of increasing the absorption of molybdenum ions into the root system of tomato plants. Increasing rates of $CaCO_3$ induced an increase in molybdenum levels in tomato plant parts. Independently from the aforementioned, the measured values for the molybdenum content in the root and leaf of tomato in each treatment were very low and insufficient for successful plant development. In order to make pseudogley soil suitable for successful development of agricultural production, it is necessary to increase not only soil pH but also the content of available molybdenum in the soil through adequate fertilisation. Importantly, fertilisers containing both molybdenum and nitrates should not be used as they may lead to an additional increase in soil acidity and, hence, hamper the absorption of P, Ca and Mg by the root system of the plant. Furthermore, additional molybdenum amounts should not be too high to produce problems with Mn supply to the plants due to the antagonistic relationships between the aforementioned nutrients.

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