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Full Length Research Paper

Aluminium content in leaf and root of oat (*Avena sativa* L.) grown on pseudogley soil

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Acid soils are not suitable for cultivation of agricultural crops as increased concentrations of hydrogen ions hinder the uptake of most nutrients. The adverse effects of increased soil acidity also include release of aluminium (Al) ions from the adsorption complex and hence, an increase in their concentration in the soil solution and plants. Aluminium ions block phosphorus and potassium uptake by the crop, thus leading to disturbance of plant growth and development, as well as to a substantial decline in crop yield and quality. This suggests that the use of such soils is not justified in terms of successful plant production. The objective of this study was to use liming to neutralise excess acidity of pseudogley soil under oat crop and evaluate the effect of soil pH improvement measures on the aluminium content of both the leaf and root of oat (*Avena sativa* L.) cv. Mediteran. Three liming treatments were employed [1.0, 3.0 and 4.0 t ha^{-1} calcium carbonate ($CaCO_3$)]. The treatments with 3.0 and 4.0 t ha^{-1} $CaCO_3$ induced no Al presence in oat plants, suggesting that liming in these treatments was successful in terms of aluminium content.

Key words: Aluminium, leaf, oat, pseudogley, root.

INTRODUCTION

Acid soils are characterised by a large accumulation of hydrogen ions. They are not suitable for cultivation of agricultural crops as they considerably hinder the uptake of most nutrients (Kochian et al., 2004). An increase in soil acidity facilitates the release of aluminium (Al) ions from the adsorption complex, thereby resulting in an elevated concentration of aluminium ions both in the soil solution and the plant (Mladkova et al., 2006). The aluminium present in the soil solution restrains plant growth on acidic soils since aluminium ions block phosphorus and potassium uptake, thereby inducing disturbance of crop growth and development (Zheng, 2010).

Soil acidity can increase for a number of reasons. The first one is biological in nature, being associated with the parent material the soil developed from ("acid rock"). Two additional factors contributing largely to an increase in soil acidity include: intensive plant production that involves nitrogen fertilisation that has a strong acidifying effect on the soil, and soil impoverishment induced by nutrient removal with the harvested portion of the crop (Winch, 2007). Other causal agents of soil acidification are acid rains resulting from the emission of acid compounds from industrial facilities, traffic and urban areas (Krug and Frinck, 1983).

In order to be used for plant production purposes, acid soils should undergo pH amelioration measures. Liming is among the commonest cultural operations used in soil pH improvement (Oguntoynbo et al., 1991). It involves incorporation of calcium based fertilisers (as a rule, lime material, calcium oxide (CaO) or calcium carbonate ($CaCO_3$) aimed at producing neutral or slightly acid pH and, hence, creating a more favourable environment for plant nutrient uptake (Tisdale and Nelson, 1975). Once

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Table 1. Average Al content of oat leaf.

Liming treatment	Average Al content of oat leaf (ppm)			
	Flowering		Full maturity	
	2007	2008	2007	2008
T_1	38.59	38.90	26.76	26.41
T_2	0.00	0.00	0.00	0.00
T_3	0.00	0.00	0.00	0.00
T_4 (Control)	101.67	102.54	91.90	92.49
F test	**	**	**	**
$d'_{0.05}$ = 0.873				
$d'_{0.01}$ = 1.187				

**Significant at $d' \leq 0.01$ by Dunett's test.

introduced into the soil, $CaCO_3$ dissolves into calcium (Ca), hydrogen carbonate (HCO_3^-) and hydroxyl ions (OH^-). Hydroxyl ions neutralise soil acidity by binding H^+ ions, thus forming water (H_2O). This leads to a decrease in the concentration of H^+ ions and a concurrent increase in soil pH value:

$$CaCO_3 + H_2O \rightarrow Ca^{2+} + HCO_3^- + OH^-$$
$$OH^- + 2H^+ \rightarrow H_2O$$

The role of calcium is also important in terms of soil structure maintenance. Along with humus substances, calcium binds particles together into structural aggregates, thus regulating the water to air relationship in the soil (Muneer and Oades, 1989). Small grains show different tolerance to soil acidity and increased Al content of the soil solution. The highest susceptibility is exhibited by barley, followed by wheat and the three more tolerant species, viz. oats, triticale and rye (Djalović et al*.,* 2010).

The objective of this study was to use liming to neutralise excess acidity of pseudogley soil under oat crop and evaluate the effect of soil pH improvement measures on aluminium content of the leaf and root of oat (*A. sativa* L.) cv. Mediteran. Aluminium toxicity is the critical factor hindering plant development (Delhaize and Ryan, 1995); therefore, its content has been determined in this study.

MATERIALS AND METHODS

Field trial, plant material and experimental design

This study was conducted in oat cv. Mediteran grown on pseudogley (USDA Soil Taxnomy) near Gornji Milanovac (44°02'N; 20°29'E), Western Serbia during two successive years (2007 to 2008). Prior to trial establishment, soil samples were collected for the analysis of soil chemical properties. Soil samples were taken using a soil probe and brought in paper bags into the laboratory of the Faculty of Agronomy, Cacak where soil reaction in H_2O (pH value) and soil Al content were analysed.

Soil pH was measured in distilled water using a pH metre Cyber Scan 510 (Nijkerk, Netherlands) (Schofield and Taylor, 1955), whereas aluminium content was determined by atomic absorption spectrophotometry (Pye Unicam SP 191, UK) preceded by sample digestion in aqua regia (Black et al., 1965). Data are given as ppm.

The obtained data were used to set up the trial so as to eliminate excess acidity in the soil and assess the effect of soil pH improvement on aluminium content in oat leaf and root.

Soil pH was improved by liming; incorporation of ground calcium carbonate into the soil under three different treatments. The untreated control without liming was also employed. The ground calcium carbonate was uniformly sprayed over the soil surface prior to sowing and subsequently ploughed into the soil. The material used had a high degree of fineness (a particle size of 0.2 mm), which enabled better dissolution and, hence, the enhanced liming effect. Liming treatments were as follows: T_1 - 1.0 t ha^{-1}, T_2 - 3.0 t ha^{-1}, T_3 - 4.0 t ha^{-1}, T_4 - control (without liming).

The fertiliser rates applied were calculated according to the size of the experimental plot. Apart from the effect of liming on the Al content of oat leaf and root, an evaluation of the effect of additional two factors (plant development stage and year of the study) was made. A three-factor trial was established in a Latin square design in five replications. The size of the elementary plot was 70 m^2.

In both years, following the liming operations, aluminium content was determined in average leaf and root samples of the oat crop during the flowering and full maturity phenophases. The Al content of oat leaf and root was determined by atomic absorption spectrophotometer.

Data analysis

The data were subjected to standard statistical methods of analysis of variance (ANOVA) and multiple *d'* tests (Dunett's test) using Microsoft Excel 2003 and Statistical 5.0 programmes. The analysis of data was used to interpret the results and draw conclusions.

RESULTS AND DISCUSSION

Evaluation of oat leaf Al

Aluminium content of oat leaf as dependent upon soil liming treatments and stage of plant development during the years is outlined in Tables 1 and 2. The data in Tables 1 and 2 suggest that highest leaf Al content of oat grown on pseudogley was found in the T_4 (control), and the lowest in T_2 and T_3 using $CaCO_3$ at a rate of 3.0 and 4.0 t ha^{-1},

Table 2. Analysis of variance of Al content of oat leaf.

Sources of variation	Degrees of freedom	Mean square	*F* exp	Significance
Liming (A)	1	49903.04	84770.91	**
Development stage (B)	1	1461.61	2482.86	**
Year (C)	1	1.53	2.60	ns
Interaction A×B	1	15.01	25.50	**
Interaction A×C	1	1.67	2.84	ns
Interaction B×C	1	0.65	1.10	ns
Interaction A×B×C	1	0.14	0.23	ns
Error	35	0.59		

A, B and C represent 'liming', 'development stage' and 'Year' treatment, respectively. ** Significant at $d' \leq 0.01$ by Dunett's test; ns, non-significant.

Table 3. Average Al content of oat root.

Liming treatment	Average Al content of oat root (ppm)			
	Flowering		Full maturity	
	2007	2008	2007	2008
T_1	35.94	35.90	42.97	43.26
T_2	0.00	0.00	0.00	0.00
T_3	0.00	0.00	0.00	0.00
T_4 (Control)	106.61	106.46	108.05	108.88
F test	**	**	**	**
$d'_{0.05} = 0.598$				
$d'_{0.01} = 0.812$				

**Significant at $d' \leq 0.01$ by Dunett's test.

respectively. The higher content of Ca ions inactivated Al ions and prevented their translocation from the soil solution through the root into the leaf. These results are similar to those obtained by Dugalić et al. (2002), who reported positive effects of liming on Al ion inactivation on the same soil type. Also, a similar pattern was observed by Jelić et al. (1995), on vertisol.

The Al content in oat leaf from the flowering phenophase and all through to the maturity phenophase in T_1 and the T_4 (control) decreased significantly, which was anticipated given the gradual effect of the liming material applied. This was not observed in T_2 and T_3 involving the use of higher $CaCO_3$ rates. Increased Ca rates were found to have evidently improved soil pH more rapidly, leading to immediate inactivation of Al ions. However, the use of higher Ca rates can induce soil alkalinity, thus adversely affecting the plant uptake of boron (Kizilgoz and Sakin, 2010), manganese (Kazda and Zvacek, 1989) and potassium (Foy, 1992). In addition, differences in Al content of oat leaf across years were non-significant, which means that weather conditions prevailing in the studied area during the implementation of the experiment, did not significantly affect the studied parameters.

Evaluation of oat root Al

Aluminium content of oat root as dependent upon soil liming treatments and plant development stage in the years of observation is given in Tables 3 and 4. The data in these tables suggested that Al content of oat root, as dependent upon soil liming, plant development stage and year of study, followed almost the similar pattern as that of Al content of oat leaf. The only difference between the two contents was that, in case of the Al content of the root, interaction was observed between plant development stage and year of observation, and mutual interaction was found among the three factors tested. Similarity between Al content of the leaf and that of the root was clearly due to the fact that liming induced an increase in soil pH, which reduced the release of Al ions from the adsorption complex of soil and their entry into the root of plants, and consequently the leaf of the oat plant. The positive effect of liming on the reduction of the concentration of Al ions in soil solution and thus on the reduction of the possibility of entry Al ions in plant roots were determine in the works of many other scientists (Blevins et al., 1978; Brady et al., 1993; Caires et al., 2005).

Table 4. Analysis of variance of average Al content of oat root.

Sources of variation	Degrees of freedom	Mean square	*F* exp	Significance
Liming (A)	1	55481.86	200342.88	**
Development stage (B)	1	248.09	895.86	**
Year (C)	1	0.72	2.60	ns
Interaction A×B	1	82.11	296.49	**
Interaction A×C	1	0.14	0.49	ns
Interaction B×C	1	1.41	5.08	*
Interaction A×B×C	1	0.22	0.79	ns
Error	35	0.28		

A, B and C represent 'liming', 'development stage' and 'year' treatment, respectively. ** Significant at *d'* ≤ 0.01 by Dunett's test; ns, non-significant.

Conclusion

This study on aluminium content of both oat leaf and root governed by soil liming, plant development stage and year of study suggests the following: liming applied on acid pseudogley soil has a very positive effect. It prevents aluminium ions from entering the root system of oat plants and exhibiting their adverse effect. The higher the $CaCO_3$ concentration applied, the lower the aluminium concentration of the oat plant. Nevertheless, extreme care should be taken during liming so as not to introduce excess calcium that is likely to prevent the plant uptake of boron, manganese and some other biogenic elements. Moreover, excess calcium leads to changes in soil fertility by increasing soil mineralization, which subsequently results in soil impoverishment. The following parameters are recommended for the determination of calcium requirements for soil pH improvement: current soil pH and tolerance of the plant (to be grown) to soil acidity. An example of a simple method of determination of calcium requirements for liming purposes is illustrated by the Schatschabel method (Hanić et al., 2009).

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