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THE INFLUENCE OF SOIL ACIDITY ON ALUMINIUM AND MINERAL NUTRIENTS CONCENTRATIONS IN SOLUTIONS FROM SOIL AT DIFFERENT WATER POTENTIALS

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Abstract. The aim of the research was to analyse the impact of soil water potential on the concentration of aluminium and selected mineral nutrients in soil solution. Soil acidification is a natural process accelerated by agriculture, and one of the most important factors limiting crop production worldwide. Concentrations of aluminium and selected mineral nutrients in solutions obtained from soil at initial pH 4.2 and after liming at various soil water potential were measured in centrifuged soil solution. Our results showed a significant gradual increase in the concentration of Al and most of mineral nutrients (Ca, Mg and P) with decreasing soil water potential from −3.5 kPa to −0.205 MPa. The results are important in the evaluation and interpretation of plant response to aluminium toxicity when accompanied by changes in water availability.

Keywords: soil solution, aluminium, drought, soil water potential, mineral nutrients

INTRODUCTION

Approximately 30% of the world's total land area and as much as 50% of the world's potentially arable lands (Yang *et al*. 2013) are affected by soil acidification. Many soil properties are affected by changes of soil acidity. In very acid soils (pH < 4.5) all the major plant nutrients (nitrogen, phosphorus, potassium, sulphur, calcium, manganese and also the trace element molybdenum) are unavailable, or available in insufficient quantities for most crop plants. In spite of the application of fertilisers at high doses, plants can show symptoms of deficiency in acid soils. High concentrations of the toxic Al^{3+} ion in acid soils retard root growth, restricting access to water and nutrients.

The overall response of crops to Al toxicity is usually altered by the co-occurrence of other abiotic stresses. Among these stresses, soil water deficit is one of the most important. Soil water potential affects many properties of soils as it influences soil chemistry. At the same time, soil water potential fluctuations affect the toxicity of aluminium and the availability of nutrients for plants (Anderson *et al*. 2013), however, it is dependent on soil type and specific plant characteristic (phenotype).

It has been demonstrated that a decrease in soil water content may increase Al concentration in the soil solution, thus enhancing Al toxicity in plants (Schier and McQuattie 2000). However, there are some reports with opposite conclusions (Slugenowa *et al*. 2011). That contradiction comes from the complex plant response to both simultaneous stresses.

The aim of the research was to analyse the impact of decreasing soil water potential on the concentration of Al and selected mineral nutrients (Ca, Mg and P) in soil solution in acid and limed soil.

MATERIALS AND METHODS

Soil preparation

Samples of the acid loamy sand soil (Table 1) were obtained from the 0-20 cm layer of an arable field located in the south-eastern region of Poland (51°26′34.5″N, 23°06′31.4″E). The soil particle size fractions were determined by a Mastersizer 2000 (Malvern, UK) laser diffractometer (Ryżak and Bieganowski, 2011). The pH of the soil was 4.2 as determined in 1M KCl. Half of the collected soil was limed by addition of calcium powder containing 93-98% $CaCO_3$ (PolCalc, Poland) to reach pH 6.5.

Table 1. Particle size distribution of the soil

	Fraction (%, w/w)	
< 0.002 mm	0.002-0.05 mm	0.05-2.0 mm
1.62	21.44	76.94

Extraction of soil solutions

Initially air dry soil was moistened by adding demineralised water to specified soil water contents: 6, 7, 8, 10, 12 and 14% (w/w). The soil water potentials ranging from −1.53 to −0.12 MPa in soil samples with soil moisture of 2 to 8% w/w was measured using a WP4C Water Potential Meter (Decagon Devices, USA) in precise measuring mode in cylindrical sample holders filled with approximately 5 g of soil (Fig. 1). The soil water potentials ranging from −19.0 to −2.3 kPa of soil samples moistened from 10 to 14% w/w were measured using a Tensimeter with porous tensiometer (Soil Measurement System, Arizona, USA) placed in the middle of 100 cm^3 steel cylinders filled with soil packed to density equal to 1.4 Mg m^{-3}. It was impossible to obtain soil solution from soil samples at potentials below −1.53 MPa using this method.

The modified method for the collection of soil solution (Reynolds 1984) was used. A modified sample holder and different centrifugation speeds were used in the analysis.

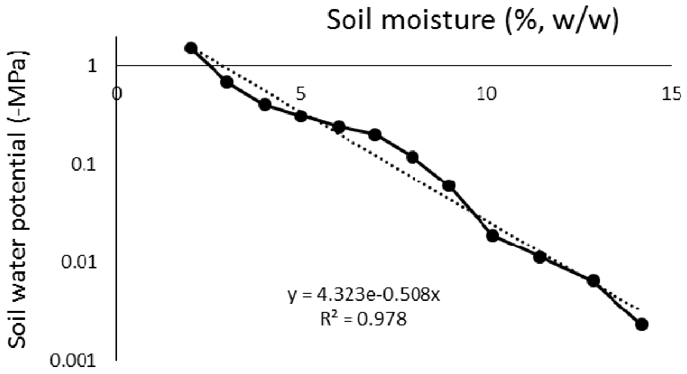

Fig. 1. Soil moisture – soil water potential characteristic of loamy sand soil

70 g of soil at specified moisture was placed into 15 ml specially prepared weighed sample holders with water-permeable bottom. The weighed sample holders were inserted into 50 ml collection cups and centrifuged at a speed of 9500 rpm for 15 min using a Rotanta 460RS centrifuge. After centrifugation, the extracted solution was transferred from the collection cups to small vials using a pipette. The soil solution samples obtained were centrifuged again at 14000 rpm for 15 min in a MiniSpin Eppendorf centrifuge to remove soil debris. The procedure was repeated for both soil pH values and all soil water potentials. It was not possible to obtain soil solution from soil samples at soil moisture below 6% w/w for all centrifugation parameters described above.

Concentrations of soil mineral nutrients in soil solution

The soil solutions were analysed by means of an ICP-OES (Thermo Scientific iCAP Series 6500), equipped with a charge injection device (CID), detector and TEVA software. A multi-element standard solution for ICP-OES containing 6 elements: Cu, Fe, Mg, P, K, and Na in 5% HNO_3 (1000 ppm, Analityk-46) and a multi-element standard solution containing elements: Al, As, Cd, Cr, Pb, Mn, Hg, Ni, Sc, Se, Sr, V, Zn in 10% HNO_3 (100 ppm, Analityk-47) obtained from Inorganic Ventures (US, Virginia) were used for standardisation.

Each of the measurements was conducted in at least three replications. The mean and the standard error of the mean were used to compare the data. Microsoft Excel 2013 (Microsoft Inc., Redmond, Washington) was used to fit curves to the data.

RESULTS AND DISCUSSION

The composition of soil solution was influenced by the soil water potetial content and pH. Our results demonstrated that the concentration of nutrients in soil solution varies significantly with changes in soil moisture. Decreasing soil moisture content resulted in a gradual increase of the concentration of almost all analysed inorganic ions.

Calcium was affected the most by changes in soil moisture. In acid soils the bioavailability of calcium decreases with decreasing soil pH (Haynes and Ludecke, 1981). The increase in the concentration of this cation with soil drying was 2.6 and 3.3 times in acid and in limed soil, respectively. The concentration of calcium was higher in soil at pH 6.5 as a result of calcium powder application (Fig. 2).

The concentration of calcium in soil solution was up to 1.64 times higher in limed than in acid soil; this ratio was noted at soil water potential equal to −0.205 MPa. This ratio decreased with increasing soil water potential, and at soil water potential of −3.5 kPa the concentration of calcium in soil solution of limed soil was close to that measured in soil solution of acid soil. These results are in agreement with the results of Yang *et al.* (2012) on acid Oxisol and indicate that the concentration of calcium in soil solution can vary considerably with changes in soil moisture.

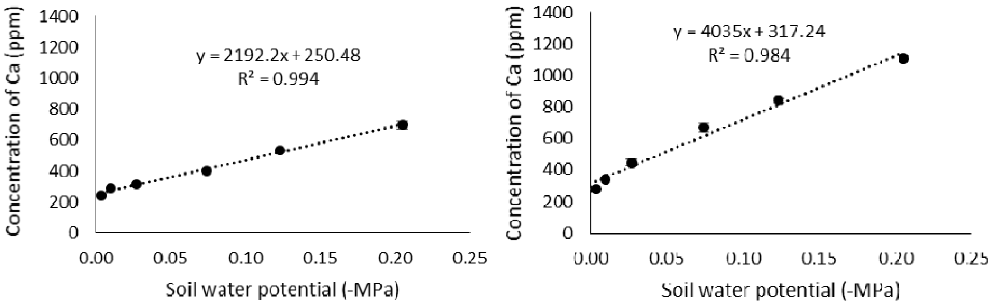

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Fig. 2. The effect of soil water potential on the concentration of calcium in soil solutions at pH 4.2 (a) and 6.5 (b). Average values (n = 3) with standard errors are presented

The decrease observed in Mg concentration in extracts with increasing soil moisture in both acid and limed soil was less steep than that of Ca, as indicated by the coefficients of fitted equations in Figures 2 and 3. The concentration of magnesium in soil solution of acid soil at soil water potential of −0.205 MPa was up to 1.4 times higher than in soil solution of limed soil. This ratio increased with increasing soil water potential, and the concentration of magnesium in soil solution of acid soil at soil water potential of −3.5 kPa was 2.5 times higher than in soil solution of limed soil at the same soil water potential. However, at all soil moisture levels, magnesium concentration was lower in limed than in acid soil as a possible result of Mg immobilisation by e.g. phosphorous ions. Magnesium becomes significantly less exchangeable at soil pH above 6.5 (Lityński and Jurkowska 1982). Moreover, many authors (Grove and Sumner 1985, Meyers *et al.* 1988, Miyazawa *et al.* 2001) found that liming reduced exchangeable magnesium in the soil as a consequence of magnesium adsorption in the interlayers of $Al(OH)_3$, coprecipitation of Mg and adsorption of MgOH in the stern layer.

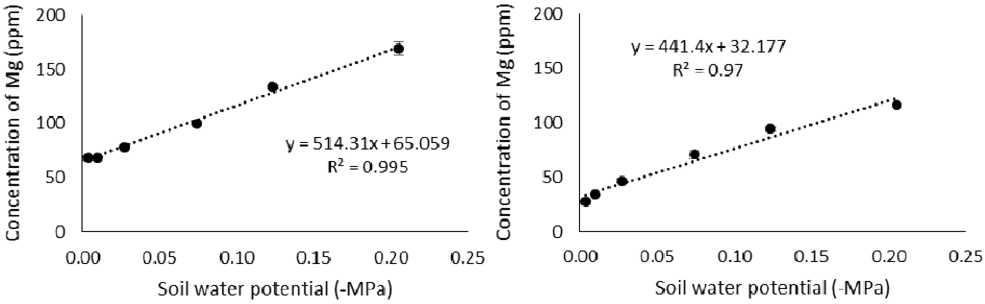

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Fig. 3. The effect of soil water potential on the concentration of magnesium in soil solutions at 4.2 (a) and 6.5 pH (b). Average values (n = 3) with standard error are presented

The concentration of total soluble aluminium (Fig. 4) in the soil solutions increased significantly with decreasing soil moisture of acid soil. The concentration of aluminium in soil solution of acid soil at soil water potential of −0.205 MPa was 104 times higher than in soil solution of limed soil at the same soil water potential. This ratio decreased with increasing soil moisture. The concentration of aluminium in soil solution of acid soil at soil water potential of −0.205 MPa was almost 7 times higher than in soil solution of limed soil. As expected, in limed soil the concentrations of total soluble Al were very low and did not differ significantly at various soil water potentials (Fig. 4b).

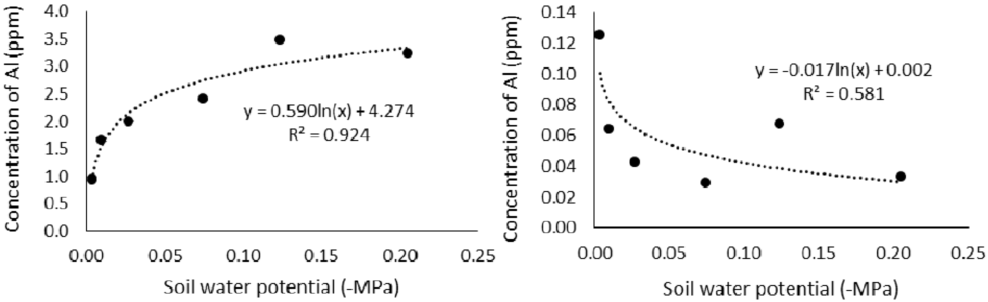

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Fig. 4. The effect of soil water potential on the concentration of aluminium in soil solutions at pH 4.2 (a) and 6.5 (b). Average values (n = 3) with standard error are presented

Phosphorus is an essential macroelement and occurs in soil in both organic and inorganic forms, nevertheless the amount of soluble phosphorus is often very low compared with the total amount of phosphorus in soils (Haynes 1982). The concentration of P in soil solution displayed only slight changes with decreasing soil water potential as it is indicated by low values of the coefficients of fitted equations (Fig. 5). This was possibly caused by very low concentration of this nutrient in soil solution.

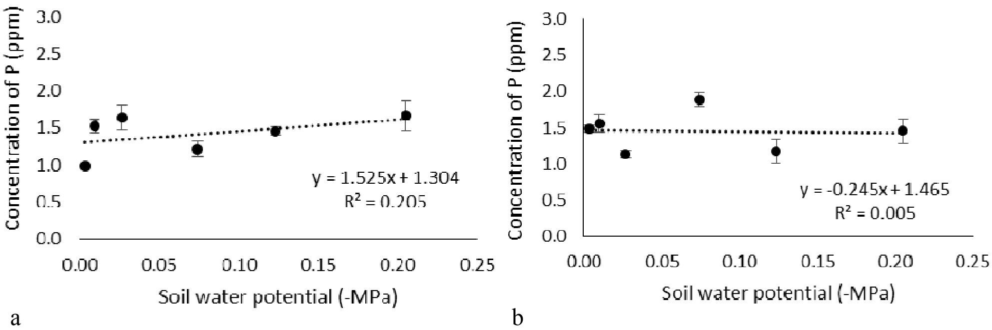

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Fig. 5. The effect of soil water potential on the concentration of phosphorous in soil solutions at pH 4.2 (a) and 6.5 (b). Average values (n = 3) with standard error are presented

CONCLUSIONS

The results indicate the importance of taking into account an increase of the concentration of Al with decrease of soil moisture when evaluating the potential toxicity of Al to crop plants. It is especially important in acid soils susceptible to drought (e.g. sandy soils). Soil water potential changes are also accompanied by alterations in the availability of mineral nutrients, depending on soil pH. Our results support the hypothesis that soil moisture has an important effect on aluminium concentration and, in consequence, on its possible toxicity to plants. The changes observed in the concentration of analysed elements with soil drying could become both beneficial (decreasing passive uptake of Al by roots and increasing concentration of Ca and Mg in soil solution) and harmful (increasing concentration of Al in soil solution and complex interactions between Al toxicity at drought stress) to the nutrition of plants.

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WPŁYW KWASOWOŚCI GLEBY NA ZAWARTOŚĆ GLINU ORAZ WYBRANYCH SKŁADNIKÓW MINERALNYCH W ROZTWORZE GLEBOWYM PRZY RÓŻNYCH POTENCJAŁACH WODY GLEBOWEJ

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Streszczenie: Celem badań była analiza wpływu potencjału wody glebowej na stężenie glinu i wybranych składników mineralnych w roztworze glebowym gleby kwaśnej i wapnowanej. Wzrost kwasowości gleb jest naturalnym procesem, jednym z najważniejszych czynników ograniczających produkcję roślinną na świecie. Może on ulec przyspieszeniu przez środki stosowane w rolnictwie. Pomiarami objęto zmiany stężenia glinu oraz wybranych składników mineralnych w roztworach glebowych z gleby o pH 4.2 oraz gleby wapnowanej, otrzymanych przy różnych potencjałach wody glebowej. Nasze wyniki wskazują na znaczący wzrost stężenia glinu i większości składników mineralnych (Ca, Mg i P) wraz ze spadkiem potencjału wody glebowej z −3.5 kPa do – 0.205 MPa. Uzyskane wyniki są ważne w ocenie i interpretacji odpowiedzi roślin na toksyczność glinu, w warunkach zróżnicowanego uwilgotnienia gleby.

Słowa kluczowe: roztwór glebowy, glin, susza, potencjał wody glebowej, składniki mineralne