

Effect of gypsum application rate and leaching regime on wheat growth in a highly acidic subsoil

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Abstract

A glasshouse experiment was conducted to investigate gypsum application and leaching on the amelioration of an aluminium (Al) toxic subsoil for wheat growth. Treatments included different rates of gypsum application and amount of leaching prior to wheat being grown. Wheat shoot growth increased when gypsum was applied in both the presence and absence of leaching, but growth was higher with leaching. Gypsum application led to a decrease in toxic Al as a result of a higher ionic strength and activity of AlSO_4^+ ion pairs in the soil solution, and increased Al leached from the soil. Root growth may not be a good bioassay for predicting wheat shoot responses to gypsum applications on acidic subsoils.

Introduction

Gypsum applied to the soil surface has often been observed to be more effective than surface applied lime at improving crop yields on soils which have acidic subsoils (Shainberg et al., 1989). The difference in responses to lime and gypsum has generally been related to movement through the soil profile. Gypsum is rapidly leached to the depth of soil where acidity is limiting growth whereas lime movement into the subsoil is generally very slow. A number of mechanisms have been proposed by which gypsum may ameliorate aluminium toxicity in acidic subsoils (Shainberg et al., 1989), although the actual mechanism(s) which operate in different soils remains poorly understood. In some studies, it has been suggested that calcium (Ca) ions displaced Al ions off soil surfaces and therefore cause Al to be leached from the soil in the drainage water (Kotzé and Deist, 1975; Oates and Caldwell, 1985). Other studies however have not reported changes in the concentration of total Al in the subsoil, and have suggested that an increase in the concentration of Ca or SO_4 ions decreases the toxicity of Al to plants.

In Western Australia, a large area of deep yellow sandplain soils, which occur in a region of low rainfall (c. 300 mm annum⁻¹), have been shown to have toxic concentrations of Al which decrease wheat yields (Carr et al., 1991). If leaching of Al from the soil profile was essential for gypsum to effect amelioration, it is uncertain whether there would be sufficient rainfall in the environment where yellow sandplain soils occur for gypsum to be effective. The aim of the experiment, therefore, was to establish whether leaching of Al was an essential mechanism for gypsum to decrease Al toxicity and improve wheat growth in the subsoil of a yellow sandplain soil.

Materials and methods

A factorial pot experiment was designed with three gypsum rates (0 g gypsum kg⁻¹ - G0; 0.142 g gypsum kg⁻¹ - G1; 0.567 g gypsum kg⁻¹ - G2) and three leaching regimes (unleached - L0; 250 mm drainage (equivalent to one winter's rainfall) in five daily leaching events of 50 mm each - L1; and 500 mm drainage in five leaching events of 100 mm each - L2). Soil was incubated overnight at 40 °C between each leaching

event. Soil was collected at a depth of 15–40 cm from a deep yellow sandplain soil in the eastern wheatbelt of Western Australia (117 °E., 32 °S.) which had previously been shown to contain concentrations of Al in the subsoil solution which decreased wheat yields in the field (Carr et al., 1991). The soil is a sandy clay loam with kaolinite as the major clay mineral. The soil solution had a pH of 3.92 and total Al concentration of 76.9 μM . Other properties of the soil have been given by Carr et al. (1991).

The soil was air-dried, sieved (<2 mm) and weighed (3 kg) into polythene bags. Gypsum treatments were added to the soil in solid form and thoroughly mixed before adding water to bring the soil to 80% of field capacity moisture content. All treatments were prepared in triplicate and incubated at 40 °C for one week to enable reaction of the gypsum with the soil. Soil for the unleached treatment (L0) was then air-dried. Soil for the other leaching treatments was added to 3 kg pots which had drainage holes at the base and were lined with muslin cloth to prevent soil falling out. Leaching treatments were imposed by adding de-ionised water to the soil surface, at a rate that prevented ponding, until the required amount of daily drainage was collected. Leachate was retained for chemical analysis.

At the completion of leaching, the soil was returned to polythene bags and air-dried. Basal nutrients (100 mL) were then added to soil in all treatments at the following rates (mg pot^{-1}): KH_2PO_4 , 1200; $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 200; H_3BO_3 , 2; $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, 10; $\text{ZnSO}_4 \cdot 2\text{H}_2\text{O}$, 15; $\text{MnSO}_4 \cdot 2\text{H}_2\text{O}$, 10; $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$, 1; NH_4NO_3 , 160, Na_2SO_4 , 30. $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 200 and K_2SO_4 , 200 were also added to the control treatment to prevent Ca or S deficiency limiting plant growth. After drying, the soils were thoroughly mixed, watered to 80% of field capacity moisture content, and placed in non-draining 3 kg plastic pots lined with polythene in a root cooling tank maintained at 18 °C. Fifteen evenly sized seeds of wheat (*Triticum aestivum* cv. Gutha) were placed in each pot at a depth of 10 mm. The pots were weighed daily and water added to maintain the moisture content. Ten d after sowing, the seedlings were thinned to 10 per pot. Every 10 d, pots received an additional 100 mg^{-1} pot NH_4NO_3 to prevent nitrogen deficiency.

The plants in all treatments were harvested after 32 d when it became apparent that the plants grown in pots of the control treatment were suffering Al toxicity symptoms to an extent that they would not survive much longer. Shoot dry weight (SDW) and root dry weight (RDW) were recorded after oven-drying at 70

°C. Root length (RL) was measured using a Comair root length scanner (Aerospace Industries Ltd.). Soil solution was removed by centrifugation (Gillman and Bell, 1978) and analysed for pH, electrical conductivity (EC), total Al (Al_T) using a colorimetric method (Dougan and Wilson, 1974), cations (Na^+ , K^+ , Mg^{2+} , Ca^{2+}) by atomic absorption spectrophotometry and anions (SO_4^{2-} , NO_3^- and Cl^-) by ion-exchange chromatography. Ionic strength was calculated from EC using the equation of Gillman and Bell (1978). The activities of various aluminium species in the soil solution were estimated using the chemical speciation program TITRATOR (Cabaniss, 1987). The activity of total monomeric aluminium ($\Sigma\text{Al}_{\text{mono}}$) was calculated as the sum of the activities of Al^{3+} , $\text{Al}(\text{OH})^{2+}$ and $\text{Al}(\text{OH})_2^+$ in the solution.

Results

Considerable leaching losses of most elements occurred from the soil (Table 1). The total amount of H and Al ions leached increased as both the gypsum application rate and amount of leachate collected increased. The total amount of Ca, SO_4 and Mg ions leached from the soil also increased ($p < 0.001$) with both the rate of gypsum application and amount of leaching (Table 1), but only small differences in the amount of K, Na, NO_3 or Cl ions were generally recorded between either gypsum application rate or leaching regime (data not presented).

Plant growth was affected by both gypsum application rate and leaching regime. In unleached soil, SDW increased with gypsum application rate ($p < 0.001$) and was approximately double the SDW of the control at the highest rate (Fig. 1a). In soil which did not receive gypsum, SDW was approximately 50% higher ($p < 0.001$) in leached than unleached soil. The highest SDW was recorded for the highest gypsum application rates in leached soil, with no difference ($p < 0.05$) in SDW recorded between the L1 and L2 treatments at the highest gypsum rate. In contrast to shoot growth, no differences ($p < 0.05$) in RDW were recorded between the rates of gypsum application (Fig. 1b), although leaching increased RDW ($p < 0.001$). Root length responses were similar to RDW (data not presented). A poor and non-significant ($p < 0.05$) correlation ($r^2 = 0.31$) existed for the relationship between SDW and RDW.

Differences in soil solution chemical properties at the completion of the pot experiment were recorded

Table 1. Total amount of selected elements leached from soil in pre-leaching, and pH, concentration of total Al and activity of monomeric Al and AlSO_4^+ (as calculated using chemical speciation program) in soil solution at completion of pot experiment

Treatment	Leached					Soil solution			
	H^+ (mmoles)	Total Al	Ca^{2+}	Mg^{2+}	SO_4^{2-}	pH	total Al (μM)	(ΣAlmono)	(AlSO_4^+)
<i>L0</i>									
G0	N.A.	N.A.	N.A.	N.A.	N.A.	3.77	323.3	98.5	5.6
G1	N.A.	N.A.	N.A.	N.A.	N.A.	3.81	283.3	63.3	8.5
G2	N.A.	N.A.	N.A.	N.A.	N.A.	3.81	277.5	32.2	100.4
<i>L1</i>									
G0	0.218	0.055	0.558	0.243	0.817	3.99	171.0	74.3	20.2
G1	0.250	0.130	1.709	0.296	2.124	3.88	144.0	48.2	31.0
G2	0.313	0.480	5.125	0.344	6.707	3.92	171.3	50.6	43.9
<i>L2</i>									
G0	0.360	0.078	0.849	0.392	1.560	3.88	134.7	56.5	19.6
G1	0.447	0.185	2.581	0.481	3.341	3.90	135.7	51.7	28.5
G2	0.521	0.574	7.744	0.566	10.092	3.95	97.7	34.6	24.8
LSD _(0.05)	0.040	0.043	0.391	0.054	0.420	0.15	68.4	N.A. ^a	N.A. ^a

N.A. not applicable

^a activity estimated from mean concentration of other ions in soil solution, therefore LSD not calculated

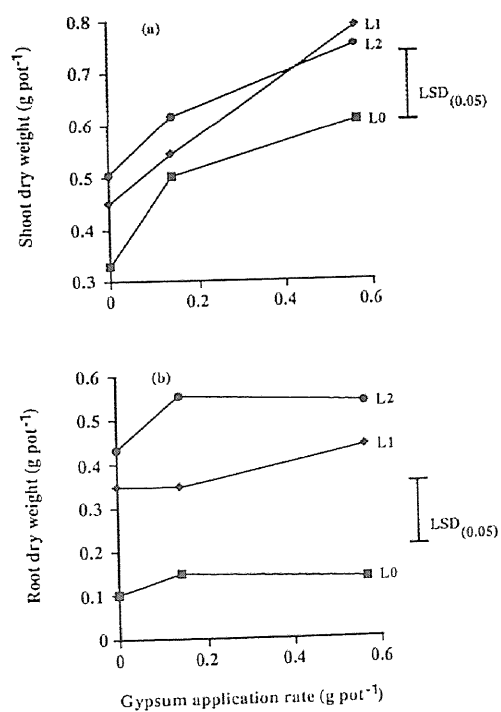


Fig. 1. Wheat shoot (a) and root (b) response to different gypsum application and leaching rates.

between both gypsum application rate and leaching regime. Soil pH was not affected by the rate of gypsum application but was slightly higher in leached soil than unleached soil (Table 1). The concentration of total Al was not affected ($p < 0.05$) by gypsum application rate. However, the amount of Al as monomeric Al decreased and the amount as the AlSO_4^+ ion pair increased substantially as the gypsum rate increased (Table 1). The concentration of total Al decreased as the amount of leaching increased and Al concentrations were less than half of the control soil at the highest leaching rate. The ionic strength, and concentration of Ca and SO_4 ions in the soil solution were all higher as the rate of gypsum application increased, but were lower as the amount of leaching increased. The relationship between ionic strength and total Al in the soil solution was asymptotic (Eq. 1):

$$\text{Total Al} = 410.7 (\log \text{ Ionic strength}) + 934.2 r^2 = 0.79 \quad (1)$$

Mg was lower in leached soil than unleached soil, but was not generally affected by gypsum application rate. The concentrations of the monovalent ions measured were also lower ($p < 0.05$) in leached than unleached soil, but unaffected by gypsum application

rate (data not presented). No significant correlations were recorded between shoot or root dry weight of wheat and the concentration of any ions in the soil solution at the completion of the pot experiment (data not presented). Shoot dry weight (SDW) was best correlated ($p < 0.05$) with the concentration of monomeric Al in the soil solution (Eq. 2) :

$$\text{SDW} = -0.005 \Sigma(\text{Al}_{\text{mono}}) + 0.881 r^2 = 0.60 \quad (2)$$

Discussion

The increase in wheat shoot growth with higher gypsum application rates in both leached and unleached soil indicated that leaching of Al from the soil is not essential for gypsum to decrease Al toxicity and effect amelioration for wheat. Gypsum therefore could potentially increase wheat yields as long as the dissolution products can reach the 15–25 cm depth where acidity has been shown to limit wheat growth in the yellow sandplain soils (Carr et al., 1991). The increase in wheat shoot growth in the presence of gypsum coincided with the decrease in monomeric Al and increase in amount of AlSO_4^+ ion pairs present in the soil solution. These observations support previous suggestions that mechanisms such as an increase in ionic strength (Carr et al., 1991; Ritchie 1989) or formation of AlSO_4^+ ion pairs (Pavan et al., 1982) can decrease the toxicity of Al in the soil solution and therefore increase plant growth.

The Al concentrations recorded in the soil solution of all treatments at the completion of the pot experiment are higher than normally measured in the soil and may be attributed to the higher ionic strength of the soil solution as a result of application of basal nutrients for plant growth. A high ionic strength has previously been shown to increase soluble Al in soils which have large amounts of exchangeable Al (Bruce et al., 1989). However, the asymptotic relationship between total Al and ionic strength suggests that in the presence of gypsum there was either a limit to the amount of Al that could be displaced from exchange sites or an Al-SO_4 compound was precipitating.

Leaching of Al from the soil was also effective at improving wheat growth since shoot growth as the total

amount of leaching increased, both in the presence and absence of gypsum. Amelioration of Al toxicity to wheat by gypsum application is likely to be most effective in soils which have considerable drainage of water through the profile to leach Al ions which have been displaced off soil colloids beyond the rooting zone.

Root growth in soils has frequently been reported to be adversely affected by Al toxicity and root bioassays are therefore commonly conducted to predict the effects of Al toxicity on plant growth. In the presence of gypsum, however, we observed that the relative increase in either root weight or root length was considerably less than the relative increase in wheat shoot weight as the rate of gypsum application increased. Therefore, root bioassays may not be suitable for predicting the magnitude of wheat shoot responses to gypsum applications on acidic subsoils.

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