Cereal crop emergence and early root establishment in acidic sandy subsoil ameliorated with lime and gypsum

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Key messages

- Lime application on its own had no effect on crop emergence but high rates of gypsum slowed plant emergence by 2 days. Application of lime with gypsum, however, eliminated the negative emergence impact of gypsum by reducing the number of days required to achieve 75% plant emergence which could be an advantage especially in farming areas that are sown dry and/or receive a small rainfall event during sowing.
- Increasing the lime rate increased total root length by up to 14-fold through the production of secondary and fine root systems which may allow young seedlings to grow their roots into comparatively moist subsoil. This can be advantage where the crop experiences a dry spell following germination.
- Early seedling emergence and enhanced root growth were achieved due to an increase in soil pH and a decrease in Al concentration where lime increased pH of acidic subsoil but gypsum did not. Combined application of lime and gypsum was found to be more efficient than applying either lime or gypsum alone.

Introduction

Subsoil acidity is one of the major soil constraints in the Western Australian grain belt. Conventional application of surface applied lime takes a number of years to treat acidity deeper in the soil profile (Whitten, 2002) and often too little lime is applied (Gazey et al., 2014). As growers are looking for a 'quick fix' to the subsurface soil acidity problem, GRDC has recently funded a number of projects researching innovative approaches to manage subsoil acidity.

Current literature suggests that physical incorporation of lime through tillage operations to an acidic soil is the most effective way of improving soil pH. Research shows incorporation of lime by one-way plough made large and quick improvements in soil pH up to 20-30cm depth and subsequent yield improvements especially from the second year post trial set up. In some instances, however, a negative yield response has been reported especially in the establishment year. This is probably due to an unsettled and unsuitable seedbed with lifted hostile subsoil (as a result of ploughing) which has not been ameliorated up to the target pH level, resulting in poor crop emergence. However, we have limited knowledge on how crop emergence is affected as a result of such lime incorporation practices.

There has also been a growing interest in gypsum application as an alternative method (without physical disturbance of soil profile) for rapidly fixing subsoil acidity or to enhance the movement of alkalinity from lime application at the surface (Sumner, 1995). However, we have very limited knowledge on how gypsum changes soil pH, aluminium toxicity, electrical conductivity (as a function of osmotic potential) in the seedbed (Zoca and Penn, 2017). All these factors affect seed germination, plant emergence and early root growth.

We conducted a lime rate by gypsum rate experiment in the glasshouse and measured the interactive contribution of the ameliorants in improving soil pH, aluminium and other relevant chemical properties as well as their consequent effects on crop emergence and early growth of barley roots.

Methods

Soil collection and preparation

Subsoil from 20-40cm depth was collected from a continuously cropped paddock near Kalannie, Western Australia (35°42'S, 117°29'E). Soil was a loamy sand (particle size distribution: 87% sand, 3% silt and 10% clay). The soil was very acidic (pH_{Ca} 3.95) and contained high levels of toxic aluminium (22 mg kg^{-1}). It had sufficient levels of P, K and S. The soil was first air-dried and sieved though a 2mm mesh before it was used for growing barley seedlings in a pot experiment under a controlled environment.

Experimental design

A randomised block design was used with a complete factorial of lime rate by gypsum rate. Five rates of lime (95% neutralising value, almost 100% limesand had particle size of <1mm where 90% lime fell within 0-0.25mm particle size distribution, limesand contained 35.4% calcium and 1.6% magnesium), namely 0, 0.53, 1.06, 1.59 and 2.65g lime per kg soil were applied (equivalent rates in the field of 0, 2.5, 5.0, 7.5 and 12.5 t/ha per 40cm depth). There were also five rates of gypsum (96% pure gypsum that contained 22.4% calcium and 17.8% sulphur), i.e., 0, 0.27, 0.53, 0.80 and 1.33g gypsum per kg soil (equivalent rates in the field of 0, 1.25, 2.50, 3.75 and 6.25 t/ha per 40cm depth).

Initially all lime rates were added to the soil and mixed using a rotary mixer. Lime incorporated soils were then packed into tapered pots (953ml capacity, 10cm height, 12cm top diameter, 10 cm basal diameter). Gypsum treatments were then applied to the surface of the packed soils. All pots were watered with deionised water to field capacity – so there was no drainage loss of water through the bottom of the pots. There were 3 replicated pots for each treatment.

Management and data collection

Five barley cv. *La Trobe* seeds were sown in each pot and placed in growth room (controlled environment) for germination and then moved to a controlled glasshouse 5 days after sowing (DAS). All pots were regularly weighed and watered to the original weight. During the second week, when seeds were germinated, soil surfaces were mulched with 5mm of polyethylene beads (Alkathene™). No fertiliser was applied to the pots as the experiment was run for a very short period of time. However, all lime treated soils received additional Ca and Mg and all gypsum treated soils received additional Ca and S from the application of soil ameliorant.

Plant emergence was counted every day from 5 DAS until no further emergence was recorded. Plants were clipped at their bases 26 DAS. A representative soil sample was collected from each pot, air-dried at 40ºC in a forced-drought oven and passed through a 2mm sieve and later used for measuring pH in 1:5 0.01M $CaCl_2$ extract, EC in 1:5 water extract and $CaCl_2$- extractable total aluminium. All exchangeable cations were also measured with 0.1M NH_4Cl–0.1M $BaCl_2$. Roots were separated from the soil using a gentle jet of water over a 0.5mm sieve. All roots from each pot were then scanned using a high-resolution scanner (600 dpi). Total root lengths and mean root diameter were estimated using WinRhizo image analysis software (v. 2005c; Régent Instruments Inc., Quebec, Canada).

Statistical analyses

A linear model was fitted to each of the measurements, i.e., soil pH, [Al], EC, CEC, using the ANOVA procedure in GenStat statistical package (version 18.1, VSN International, Oxford, UK) to compare the factorial treatments of lime by gypsum with polynomial contrasts. For non-normal data, a log-transformation (log_{10}) was performed to stabilise the variance. For the plant emergence data, we estimated the time to reach 75% seedling emergence (ED75) using a logistic curve with the 'drc' package in R Statistical System (https://www.R-project.org) for each pot. These data were then examined with an analysis of variance with the same model as above. For confirming any statistically significant differences between treatment means, Fisher's protected least significant difference (LSD) was applied at the 0.05 significance level.

Results

The interaction of lime and gypsum had no significant effect on the number of estimated days required to emerge 75% (ED75) seedlings (Table 1). Lime treated soils required same number of days for ED75 as in control, however, gypsum treated soils took significantly longer time to achieve ED75. Combined application of lime and gypsum were able to eliminate the negative effects of gypsum on ED75. The final count of emerged seedlings did not differ for any lime or gypsum application.

Table 1: Effect of lime and gypsum application on ED75 of barley seedling. Statistics: LSD of means (5% level) of ED75 for lime rates (P= 0.03) = 0.80; for gypsum rates (P=0.11) =0.80 and for lime x gypsum rates (P=0.11) = 1.80.

Lime(g per kg soil)	Gypsum (g per kg soil)				
	0	0.27	0.53	0.80	1.33
0	5.0	6.2	6.0	6.7	7.6
0.53	5.1	6.0	6.3	3.4	5.0
1.06	5.4	5.5	6.1	5.5	5.6
1.59	4.9	4.1	6.0	5.7	4.9
2.65	5.9	5.1	6.0	4.3	5.9

Increasing lime rates increased total root length of barley plant but no effect was found for the gypsum rates (Figure 1 and 2a). When lime was applied alone there was a linear increase in root length at the lower lime application rates (0.53 and 1.06g per kg soil) but thereafter the response plateaued. There was a 6-fold increase in total root length when 0.53g lime (per kg soil) was added and a 14-fold increase in total root length when 1.06g lime (per kg soil) was added. In general when any gypsum was added in combination with ≤1.06g of lime (per kg soil) the effect on total root length was negative compared to the lime rates alone. However, when incorporated in combination with higher rates of lime (≥1.59g per kg soil) gypsum had an additive effect on total root length.

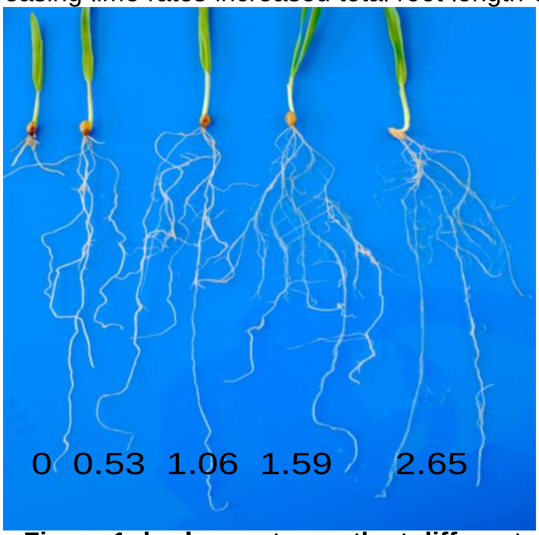

Figure 1: barley root growth at different rates of lime (0-2.65g/kg)

Increasing lime rates also reduced the average diameter of barley roots but gypsum had no effect (Figure 2b). When 0.53g of lime (per kg soil) was added it had very limited effect in reducing average root diameter but addition of 1.06g of lime (per kg soil) almost halved the average root diameter. No further significant reduction occurred at two higher rates of lime.

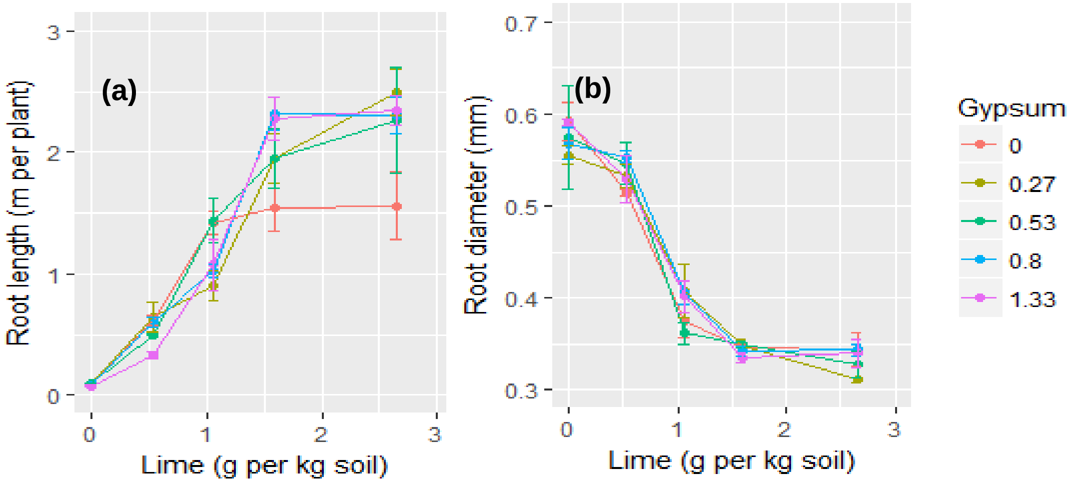

Figure 2: Effect of lime and gypsum application on (a) total root length and (b) mean root diameter of barley seedling. Vertical bars represent ± standard error of the means. Statistics: LSD of means (5% level) of total root length: for lime rates ($P<0.001$) = 0.21, for gypsum rates ($P=0.222$) = 0.21 and for lime x gypsum rates ($P=0.007$) = 0.46; LSD of means (5% level) of root diameter: for lime rates ($P<0.001$) = 0.023, for gypsum rates ($P=0.81$) = 0.023 and for lime x gypsum rates ($P=0.70$) = 0.051.

The interactive effect of lime x gypsum to change soil pH was significant. Increasing lime rates increased soil pH. There was a linear increase in soil pH at the lower range of soil pH (pH between 4.0 and 6.0) and the rate of change pH decreased when pH was above 6.0 (Figure 3). In general gypsum rates did not affect soil pH when applied on its own but at the lower range of soil pH there was a negative effect of gypsum application. Gypsum had a positive effect on changing soil pH when it was added with higher rates of lime (≥1.59g per kg soil).

The interaction of lime level by gypsum level significantly affected soil [Al]. With increasing lime rates [Al] decreased logarithmically and addition of 0.53g of lime decreased [Al] by 20 fold. When lime was added at ≥1.06g (per kg soil) the [Al] was almost undetectable (Table 2). In absence of lime there was a reduction in [Al] when gypsum was added at 0.53 and 0.80g (per kg soil) rates but the [Al] levels were still toxic especially for growing an aluminium sensitive barley. The lowest and the highest rates of gypsum had no effect in changing [Al]. In presence of lime the effect of gypsum rates on [Al] was almost nil.

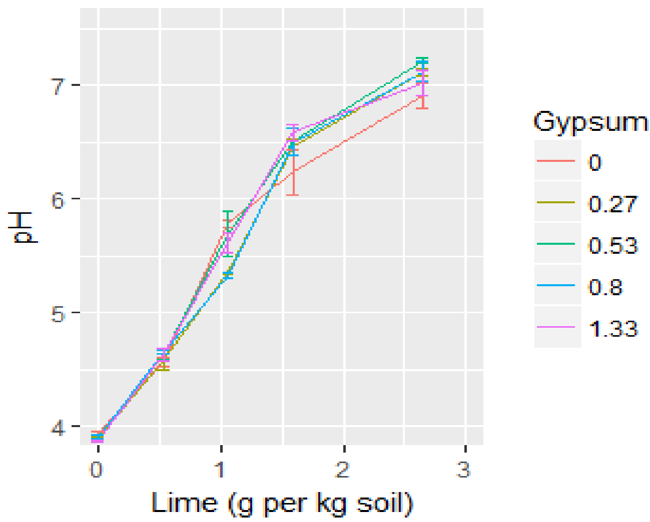

Figure 3: Effect of lime and gypsum application on subsoil pH (measured in 0.01 M $CaCl_2$ extract). Vertical bars represent ± standard error of the mean soil pH. Statistics: LSD of means (5% level) of pH for lime rates x gypsum rates ($P=0.015$) = 0.241.

Table 2: Effect of lime and gypsum on total aluminium (μM, log-transformed), measured in 0.01 M $CaCl_2$ extract. Original mean values are presented in the parenthesis. Statistics: LSD of means (5% level) of [Al] for lime rates x gypsum rates (P 0.004) = 0.19.

Lime(g per kg soil)	Gypsum (g per kg soil)				
	0	0.27	0.53	0.80	1.33
0	2.3 (194.1)	2.3 (184.9)	2.1 (125.6)	2.1 (112.5)	2.3 (192.8)
0.53	0.8 (6)	1 (9.4)	0.8 (5.6)	0.9 (7.2)	0.9 (7.3)
1.06	-0.6 (0.3)	-0.5 (0.3)	-0.6 (0.3)	-0.5 (0.3)	-0.5 (0.3)
1.59	-0.6 (0.3)	-0.6 (0.2)	-0.5 (0.3)	-0.4 (0.4)	-0.6 (0.3)
2.65	-0.6 (0.3)	-0.7 (0.2)	-0.7 (0.2)	-0.7 (0.2)	-0.5 (0.3)

Table 3: Summary of the responses due to lime and gypsum application

Parameter	Lime only	Gypsum only	Lime plus gypsum
Soil pH	Increased	No change	Increased only when pH exceeded 6 due to lime
Soil Al	Decreased	Variable – small reduction	No benefit over lime only
Soil EC and ECE	Increased	Increased	Increased
Plant emergence	No change	Decreased	No change
Root length	Increased – more secondary and fine roots	Small decrease	Increased only when gypsum added with adequate lime
Root diameter	Decreased	No change	No change over lime only

Increasing soil pH (due to addition of lime) showed positive and exponential relations with both EC and CEC under all gypsum application rates (data not presented). Greater rates of change were observed when soil pH was 6 or more especially when pH was achieved with the combined application of lime and gypsum. In general, gypsum contributed more to change EC than lime. For example, 1.33g gypsum (per kg soil) increased EC by 0.50 units and by comparison 2.66g lime (per kg soil) increased EC by 0.35 units. When lime and gypsum were combined at two highest rates there was an increase of 1.77 units. Lime and gypsum contributed equally to change CEC, however, at higher soil pH gypsum had stronger effect to change CEC than lime.

Implications and conclusions

Liming on its own did not improve emergence of barley seedling on acidic subsoil but gypsum application at higher rates significantly delayed plant emergence. Combining lime with gypsum eliminated negative effects of gypsum on the number of days required to achieve ED75. A reduction in early seedling emergence time of two days could be an advantage in farming areas that receive small amounts of rainfall during sowing and there is only a small window for young seedlings to grow roots into comparatively moist subsoil. This was proven as we found that increasing lime rates resulted in an enormous increase in total root length and decreased average root diameter due to enhanced production of secondary and fine roots. Application of gypsum only did not affect root characteristics, however, when gypsum was added with higher rates of lime, it enhanced the positive effect of lime on total root length.

The benefits of ameliorating acid subsoil are achieved due to an increase in soil pH and hence a decrease in [Al]. Lime was more effective in increasing soil pH and decreasing [Al] than gypsum, which was ineffective when applied on its own to more strongly acid soil in the absence of lime. Gypsum application may decrease soil pH if it is applied alone to an acidic soil but may increase pH of a soil that is not so acidic due to addition of lime.

Our findings show that the application of lime is essential to correct soil acidity and aluminium toxicity. Applying gypsum on its own does not ameliorate soil acidity but it may supply S nutrition where it is deficient. Combining gypsum with lime may bring additional benefits but only where adequate rates of lime are applied to address the soil acidity present.

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Key words

Soil pH, lime, gypsum, subsoil acidity

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