Quantifying the effectiveness of prilled lime and liquid lime for neutralising soil acidity in the glasshouse

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Key messages

- Liquid lime, prilled lime slurry and limesand had a similar effect on soil solution pH and Al concentration and the growth of wheat roots when mixed through subsoil at the same $CaCO_3$-equivalent rate.
- Pelletising fine lime in prilled granules reduced its effectiveness by affecting the distribution of lime in soil.
- The Al concentration [Al] in soil solution was strongly correlated with pH, and lime treatment effects on root proliferation in the subsoil horizon were consistent with changes in the pH and [Al] of the subsoil solution.

Aims

A glasshouse study was conducted to assess two novel lime materials (a liquid suspension of fine lime and a prilled fine lime) for their capacity to ameliorate subsoil acidity and associated aluminium toxicity to wheat plants.

Method

Two relatively novel formulations for processed, high purity, fine lime were assessed: a liquid fine lime suspension and prilled (pelletised) fine lime. The prilled lime material was assessed in its granular form, and also as a suspension of its constituent particles after disintegration of the granules in water (prilled lime slurry). The manufactured lime materials were compared to a high quality limesand from the mid-west region of Western Australia, as well as an unamended control. Two experiments were conducted in acidic soil profiles representative of the acidic yellow sands of the eastern wheatbelt of WA. Four lime materials were assessed by 4 application treatments and 3 experimental replicates.

Application of treatments

The amount of lime required to raise soil pH by 0.5 units (low rate) or 2 units (high rate) was estimated from Dunn Titration Curves constructed for topsoil and subsoil horizons of the Merredin and South Carrabin soils. Rates of application of each lime material were derived based on the liming efficiency of the material (Scott, Conyers, Fisher, & Lill 1992). However, in Experiment 1 (South Carabin soil) limesand was more effective than predicted under the study conditions; hence, rates were calculated based on physical effectiveness of 100 % for Experiment 2 (Merredin soil).

Based on the results of our previous experiments, lime materials were applied by 4 different application methods; a low rate (calculated to raise soil pH by 0.5 units) or a high rate (to raise soil pH by 2.0 units) mixed thoroughly through the top 10 cm of the subsoil horizon, a high rate mixed through the top 10 cm of the topsoil horizon or the high rate banded (at 4 cm from the surface) in the topsoil horizon.

Table 1: The chemical and physical efficiency values for the lime materials employed to calculate rates of application.

Material	Chemical Efficiency[a]	Physical Efficiency[a]	Liming Efficiency[a]
limesand (kg^{-1})	95	53 / 100[b]	51 / 95[b]
liquid lime (L^{-1})	120	100	120
prilled lime (kg^{-1})	99	98	97

[a] Calculated from the model presented by Scott et al. (1992).[b] Preliminary results in Experiment 1 (South Carabin soil) indicated the physical efficiency of the limesand was near 100 % under the study conditions, hence rates were calculated based on physical efficiency of 100 % for Experiment 2 (Merredin soil).

Plant culture

The experiments were conducted in the glasshouse in 23 cm deep, 8.5 cm diameter pots with free drainage. Rates of application for basal nutrients and treatments were calculated on the basis of soil surface area of the pot ($6.4x10^{-7}$ ha pot^{-1}). Pots were filled with acidic subsoil (13 cm deep) and then less acidic topsoil (10 cm deep).

Basal N and P fertiliser (prilled mono-ammonium phosphate (MAP) at 200 kg ha^{-1} and sodium molybdate at 126 g Mo ha^{-1}) was placed into a 4 cm deep, 8 cm long slot across the centre of each pot. Urea-ammonium nitrate liquid was applied to the soil surface at 100 L ha^{-1} at sowing and again 5 weeks later. Wheat seed (*Triticum aestivum* L. genotype ES8, a known Al-sensitive line) was sown into a 1.5 cm deep slot directly above the fertiliser band at 5 seeds per pot. Pots were brought to 75 % of water holding capacity with deionised water and arranged in a randomised block design in a glasshouse.

130 mL of deionised water per pot was applied to the soil surface on a weekly basis (1/3 of water holding capacity) for the first 8 weeks, and then 260 mL (2/3 of water holding capacity) onwards to harvest, inducing partial leaching of the columns. The watering regime was chosen to demonstrate any potential for downward migration of alkalinity in the soil profile, and ensure that all pots were at water holding capacity at the time of sampling soil solution, but without excessive leaching from the soil profile.

Sample collection and analysis

Soil solution was extracted *in situ* from the topsoil (at 7 cm deep) and subsoil (at 17 cm deep) horizons of each pot using ‘Rhizon MOM’ soil moisture samplers at 5, 11, 21, 42 and 89 days after sowing (Experiment 1; South Carrabin soil) or 6, 13, 22, 42 and 70 days after sowing (Experiment 2; Merredin soil). Extraction of soil solution from the soil columns commenced 16 h after watering to allow equilibration between soil solution and solid phases at field capacity. Soil solution was analysed for pH and total Al concentration.

The experiment was terminated 91 or 71 days after sowing for South Carrabin or Merredin soil, respectively, when plants were at the anthesis growth stage. Soil columns were dissected at the boundary of the topsoil and subsoil horizons, and roots from each soil horizon were collected to measure root length.

All data were subjected to 2-way ANOVA with application treatment and lime material as the treatment factors. Where the lime material x application interaction was significant, 1-way ANOVA was conducted for each application method with lime materials as the treatment factor. Where treatment effects were significant, mean values were ranked by Tukey’s HSD test at the 5 % significance level (GenStat 14th Edition).

Results

The response to the treatments was generally consistent for both the South Carrabin and Merredin soil. To avoid repetition, soil chemistry data are presented for the Merredin soil only, although results in both soils are discussed.

Root growth in the acidic subsoil

The liquid lime, prilled lime slurry, and limesand materials were generally similar in terms of their effect on root proliferation in the subsoil horizon, with prilled lime material consistently less effective (Figure 1). In the Merredin soil (Figure 2), liquid lime, prilled lime slurry, and limesand significantly increased root proliferation in the subsoil horizon when mixed through the subsoil at a low or high rate. In the South Carrabin soil, the effect of liquid lime was significant only at the high rate (Figure 1), and limesand was the most effective due to its rate of application based on 53% physical efficiency (which was later estimated to be 100%) (Table 1). In contrast, the prilled lime material did not significantly influence root length in the subsoil under any of the scenarios examined. The contrasting effect of the prilled lime and prilled lime slurry can be attributed to the contrasting distribution of the fine lime particles in soil after incorporation. Visual observations of soil and roots at the time of harvest indicated that, whilst prilled lime granules placed in the subsoil remained largely intact, prilled lime granules placed in the topsoil had partially dispersed; creating a small sphere of visually altered soil that was permeated by a dense mass of fine roots. Hence, it appears that the prilled lime granules did not behave as large particles, as previously reported, but as poorly dispersed fine lime particles.

Application method was a significant factor influencing root length in the subsoil horizon. The greatest response of root proliferation to the lime materials occurred where they were mixed through the subsoil at a high rate (Figures 1d & 2d), with the average total length of subsoil roots at least 10 times greater where liquid lime, prilled lime slurry, or limesand were applied, compared to the unamended control, in both soil types. When mixed through subsoil at a low rate, the lime materials consistently increased root length in the subsoil, albeit to a lesser extent. Liquid lime (in Merredin soil) and prilled lime slurry (in South Carrabin soil) induced a small but significant increase in root length in the subsoil when mixed through the topsoil at a high rate, indicating a greater potential of the fine limes than limesand when applied to topsoil to enhance growth of subsoil roots. None of the lime materials had any effect on root length in the subsoil when banded in the topsoil at a high rate (Figures 1a, 2a), suggesting limited, if any, capacity for the downward movement of alkalinity from the topsoil to the subsoil horizon. Furthermore, a presumed localised zone of amelioration in the topsoil horizon did not impart any systemic benefit to the plant to enhance the capacity of roots to tolerate the hostile acidic subsoil.

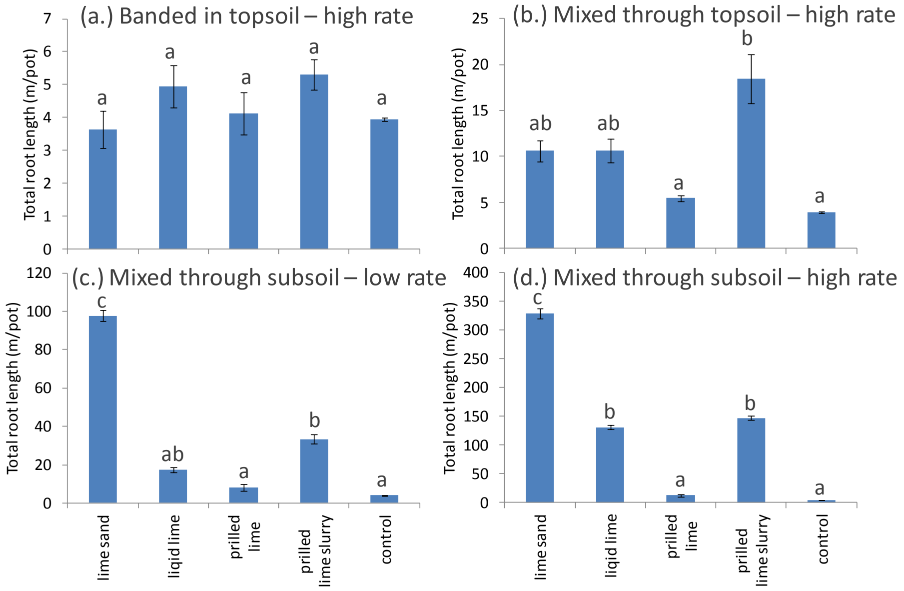

Figure 1: Total root length in the acidic subsoil horizon of South Carrabin soil with wheat plants grown to anthesis. Note the differences in the Y-axis scale.
Means ± standard errors (n=3). Letters above columns denote significant difference of mean values at p = 0.05

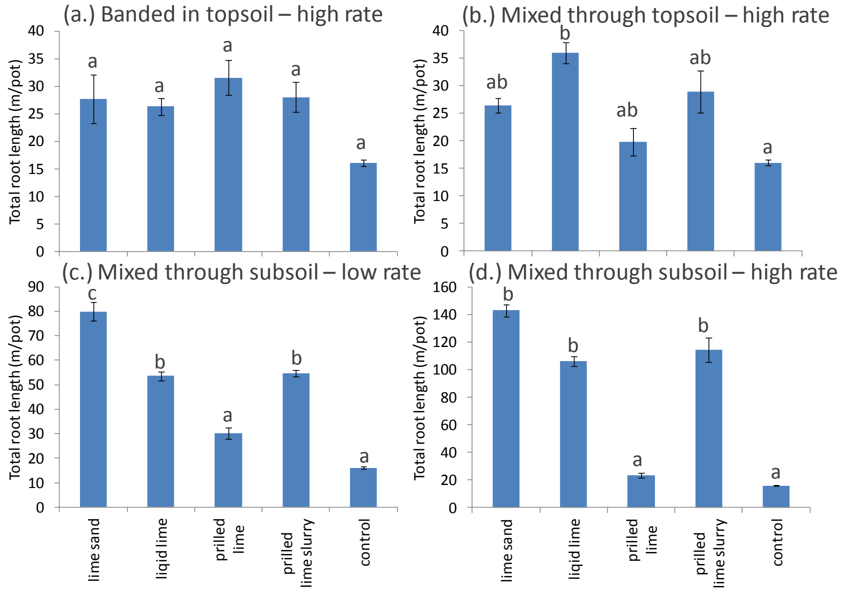

Figure 2: Total root length in the acidic subsoil horizon of Merredin soil with wheat plants grown to anthesis.
Means ± standard errors (n=3). Letters above columns denote significant difference of mean values at p = 0.05

pH and Al concentration of soil solution

The Al concentration in soil solution was strongly related to the pH across all treatments and sampling times in both soils. The pH and Al concentration in the topsoil and subsoil horizons were significantly influenced by the lime amendments, with the effects dependent on both the lime material and the application method (Figures 3 & 4, data shown only for the Merredin soil, but the treatment effects and the relationships were similar (except where stated otherwise) in the South Carrabin soil as well).

When applied to the Merredin (Figures 3c, 3d) or South Carrabin subsoil at a low or high rate, limesand, liquid lime, or prilled lime slurry significantly increased the pH and decreased the Al concentration of subsoil solution compared to the unamended control at all sampling times. When mixed through the topsoil at a high rate, the pH was increased and the Al concentration decreased in the topsoil solution (Figure 3b). When banded in the topsoil, however, none of the lime materials was associated with a significant increase in the pH of the soil solution collected 1–2 cm below the amended band in the Merredin soil (Figure 3a). However, in the South Carrabin soil (data not shown), on sampling days 42 and 89, liquid lime banded in the topsoil was associated with a small but significant increase (0.5 and 0.3

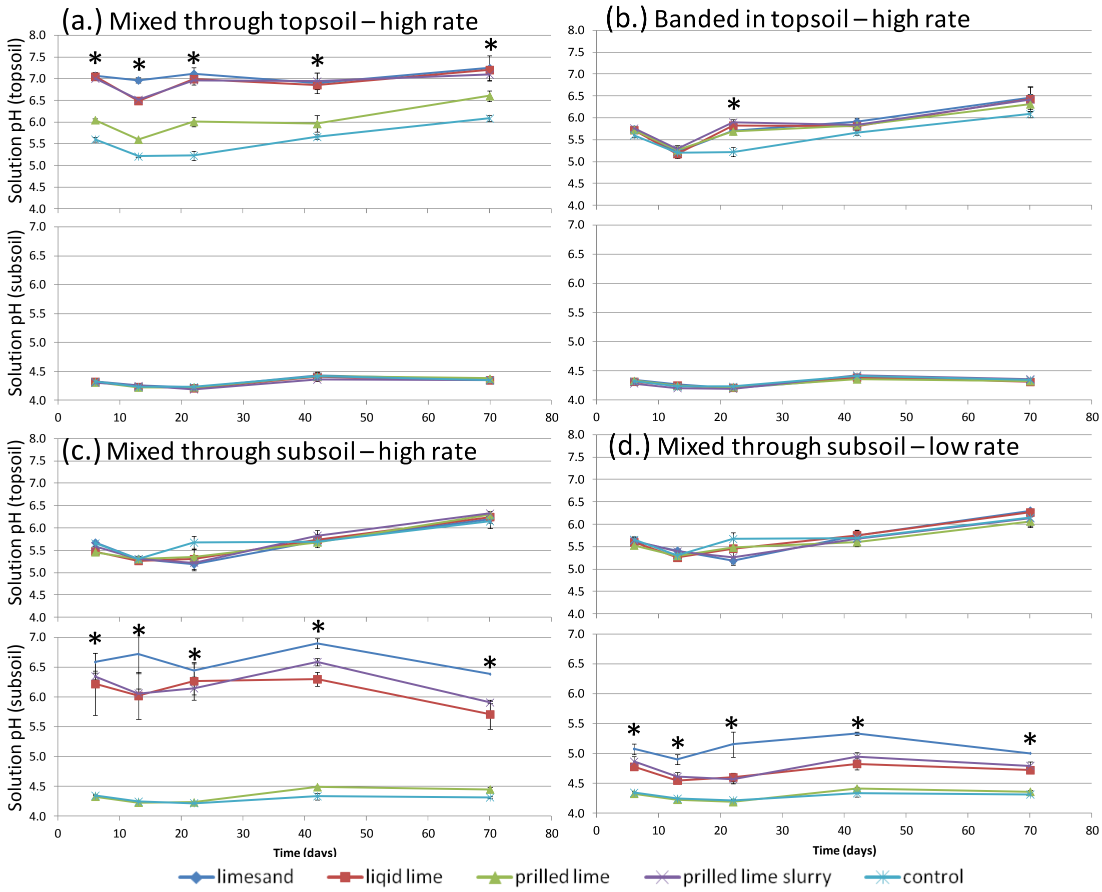

Figure 3: pH of solution extracted from Merredin soil *in situ* during the growth of wheat plants. Means ± standard error (n=3). The asterisks indicate significant differences among mean values at p = 0.05.

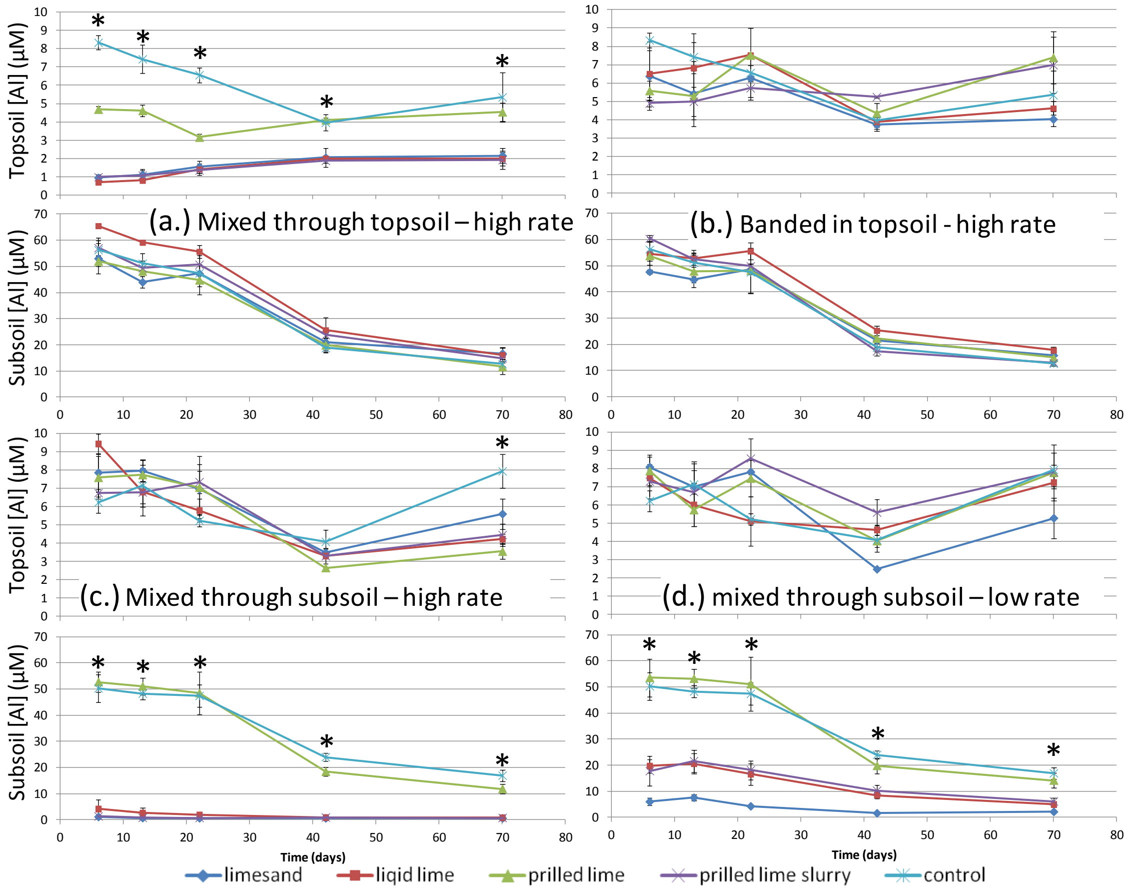

Figure 4: The total Al concentration [Al] in solution extracted from Merredin soil during the growth of wheat plants. Means ± standard error (n=3). The asterisks indicate significant differences among mean values at p = 0.05.

units, respectively) in the pH of topsoil solution collected 1–2 cm below the amended band. These results indicate that liquid lime may have had greater downward mobility in the topsoil than the other lime materials.

The prilled lime amendment applied to the subsoil typically had no significant effect on the pH of topsoil or subsoil solution.

Under the controlled experimental conditions of optimal soil moisture content and thorough incorporation of amendments, liquid lime, prilled lime slurry and limesand reacted rapidly in soil, even though 100 % of the particles were larger than 75 µm. However, under field conditions of transient, heterogeneous soil moisture with imperfect (at best) incorporation of amendments, lime particle size greater than 75 µm has been shown to be a significant factor in hampering lime effectiveness in the short term, and the fine lime materials may be up to twice as effective as the limesand material.

Conclusions

When applied at the equivalent rate, liquid lime, prilled lime slurry and limesand, but not prilled lime, increased the pH of soil solution in the Merredin and South Carrabin soils, when mixed through either the topsoil or subsoil horizon.

While the liquid lime, prilled lime slurry and limesand had a similar effect on the soil solution pH, Al concentration and root length, prilled lime was less effective, having little or no effect on root length or the pH and Al concentration of soil solution when mixed through the topsoil or subsoil. The relatively low effectiveness of the prilled lime was attributed to the pelletised formation of the material, and subsequent effects on particle distribution in soil, because its effectiveness was similar to the other lime materials where the granules were disintegrated and their constituent particles uniformly distributed through the soil (prilled lime slurry).

Mixing liquid lime, prilled lime slurry, or limesand through the subsoil at a low or high rate was more effective than mixing through the topsoil at a high rate in terms of influencing pH and Al concentration in the subsoil solution and root proliferation in the subsoil. Banding these lime materials in the topsoil generally did not influence the pH of the soil solution collected 1–2 cm below the lime-amended band, nor did it effect root proliferation in the subsoil.

The Al concentration in soil solution was strongly correlated with the pH. The lime treatment effects on root proliferation in the subsoil horizon were largely consistent with changes in the pH and Al concentration in the subsoil solution.

Further work is required to test these liming materials under field conditions of transient, heterogeneous soil moisture and with imperfect incorporation of amendments.

Key words

prilled, pelletised, liquid, lime, acid soil.

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References

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