Evaluating novel materials for ameliorating Al toxicity in acidic subsoils

Paul Damon[a], Zed Rengel[a], Gaus Azam[b], Chris Gazey[b], Craig Scanlan[b], Daron Malinowski[b]

[a] UWA School of Agriculture and Environment, The University of Western Australia, Crawley, WA

[b] Department of Primary Industries and Regional Development, Govt of Western Australia, Northam, WA.

Key messages

- Neutralisation of acidic subsoil is the most effective way to reduce aluminium toxicity to plant roots.
- Root proliferation in the acidic subsoil was increased by soil amendments only where they were incorporated into the subsoil, but not when applied to the topsoil.
- High rates of biochar mixed through the subsoil were effective in neutralising acidity, reducing aluminium toxicity, and increasing root proliferation in the subsoil.
- Liquid limes, prilled limes, and diatomaceous earths demonstrated poor capacity to neutralise soil acidity at the rates assessed in this study, but may be effective at higher rates.
- Banding the amendments with fertiliser had no effect on root growth in the acidic subsoil for any of the materials.

Background and Aims

New technologies in the formulation of liming materials and liquid delivery systems present potentially viable alternatives to the incorporation of agricultural lime. However, there is a lack of quantitative, objective evaluation for many of the novel materials, particularly for acidic soils of the WA wheatbelt.

Our objective was to investigate a range of novel, commercially-available products for their capacity to ameliorate acidic subsoil toxicity to wheat roots, specifically in terms of root proliferation in the acidic subsoil.

Method

An array of novel materials comprising limes, organics, diatomaceous earths, gypsum and Epsom salt were assessed for their effect on the capacity of wheat roots to grow in acidic, Al-toxic subsoil. The materials assessed were diverse, as were their proposed modes of action and strategies for application. Therefore, all materials were initially assessed by four different methods of application. At this initial screening stage, detailed characterisation of the treatment materials was not conducted. The rates of application (Table 1) were based on independent trial-based recommendations, manufacturer recommendations, or other parallel farm trials.

Experimental setup

The materials were assessed under glasshouse conditions at The University of Western Australia in constructed acidic soil profiles from 2 sandy, acidic soils. The soils were chosen to represent the yellow, sandy soils that are widespread in the WA wheatbelt and have acidic, Al-toxic subsoils associated with yield reductions. For Experiment 1, acidic (pH_{Ca} = 4.9), brown, sandy topsoil was collected from the 0-7 cm (A11) horizon, and strongly acidic (pH_{Ca} = 4.0), yellow, loamy sand subsoil from the 15-30 cm (B1) horizon of a paddock under long term cereal/canola rotation at the Department of Primary Industries and Regional Development's Research Facility, Merredin, Western Australia. Experiment 2 was conducted in a wodjil soil collected from South Carrabin, WA, within a paddock under long-term wheat cultivation, and previously characterised as having extremely high Al toxicity in the subsoil. Brown, sandy, acidic (pH_{Ca} = 4.2) topsoil from the 0-7 cm (A11) horizon and yellow, loamy sand, highly acidic (pH_{Ca} = 3.8) subsoil from the 15-30 cm (B1) horizon were collected separately. The topsoil and subsoil horizons of the constructed profiles represent the contrasting properties of the relatively fertile topsoil, in which seeds germinate, and the Al-toxic subsoil that inhibits root proliferation at depth, respectively.

Plastic bag-lined pots, 8 cm square and 16 cm deep, were packed with variously treated topsoil and subsoil layers (Figure 1). Basal fertiliser (prilled mono-ammonium phosphate at 100 kg ha^{-1}) was placed into a 4 cm deep, 8 cm long slot across the centre of each pot. Application rates for basal nutrients and treatments were calculated on the basis of soil surface area of the pot (6.4×10^{-7} ha pot^{-1}). For Experiment 1, the subsoil band was located at the top of the subsoil horizon (5-6 cm from the soil surface), whereas for Experiment 2, the subsoil band was placed at a depth of 5 cm into the acidic subsoil horizon (10 cm from the soil surface). Epsom salt ($MgSO_4.7H_2O$) was not assessed in Experiment 1.

Four application methods were intended to expose, and differentiate between, potential mechanisms for the amelioration of Al toxicity in the subsoil, and do not specifically represent methods of application that may be employed on-farm. For example, mixing thoroughly through the subsoil at a high rate is unlikely to be an economically viable option, but may demonstrate the maximum potential effectiveness of materials to be flagged for further assessment. In contrast, banding a low rate of material at a locally-high rate, with much of the soil left unamended, assesses mobility in soil or systemic plant effects. Each material was assessed under all application scenarios.

Table 1: List of the materials assessed, and the amount applied to soil (per ha) for the low and high rate of application

Material	**Low Rate**	**High Rate**	**Material**	**Low Rate**	**High Rate**
Prilled limes	75 kg	375 kg	Biochars	2 t	10 t
Liquid Limes	5 L	100 L	Gypsum	1 t	5 t
Diatomaceous Earths	1 t	5 t	Epsom Salt	100 kg	250 kg
Humates	20 kg	100 kg	Limesand	1 t	5 t

Plant culture

Wheat seed (*Triticum aestivum* L. genotype ES8, a known aluminium sensitive line) was sown into a 1.5 cm deep slot directly above the fertiliser band at five seeds per pot. Pots were maintained near 75 % of water holding capacity (WHC; assessed gravimetrically) using deionised water every 2 days during seedling emergence and twice weekly thereafter.

Seedling emergence commenced in all pots 5 days after sowing. Plants were thinned to three average-sized seedlings per pot 10 days after sowing. Nitrogen (N) fertiliser was applied as urea-ammonium nitrate solution at the rate of 50 L ha^{-1} 2 and 4 weeks after sowing.

Sample collection and analysis

Soil solution was extracted from the subsoil horizon by ‘Rhizon MOM’ soil water samplers (Rhizosphere Research Products, Wageningen, The Netherlands) in pots with materials mixed through the subsoil at a high rate 2 days before harvest. Pots were watered to WHC 16 h before soil solution was collected. The collected soil solutions were analysed for pH and total aluminium concentration ([Al]). Ion speciation in subsoil solutions was estimated for selected treatments using the chemical speciation program Geochem-EZ.

The experiments were terminated 5 weeks after sowing. The soil was dissected into topsoil and subsoil portions, before washing roots free of soil over a 2 mm sieve. Roots from the subsoil horizon were analysed for root length using the WinRHIZO root analysis system (Régent Instruments Inc., Québec, CAN).

The experiments were conducted in triplicate and arranged in randomised block design. All data were subjected to 2-way ANOVA with application method and amendment material as the treatment factors. Where the interaction between the amendment and the application method was significant, 1-way ANOVA was conducted for each application method with amendment material as the treatment factor. Comparison of mean values was assessed by the Tukey’s t-test at the 5 % confidence interval (Genstat 14th Edition; VSN International, Hertfordshire, UK).

Results

Root length

Root length in the subsoil horizon (Figures 1 & 2) was significantly influenced by the soil amendments only where materials were mixed through the subsoil at a high rate, and not via other methods of application (application x material $p \leq 0.01$). For the limesand, dolomitic lime and biochar materials, the length of fine roots in the subsoil, total root length in the subsoil, total root length per pot and the proportion of roots allocated to the subsoil horizon were all significantly increased where the amendments were mixed through the subsoil at a high rate, for both soils. The biochar, limesand, and dolomite treatments were clearly segregated from all other treatments for the above variables. Limesand and dolomitic lime increased the total root length in the subsoil 3-fold in the Merredin soil and 50-fold in the South Carrabin soil (Figures 1 & 2). Generally speaking, root length in the subsoil was slightly (but not statistically) greater than the unamended control where the prilled limes, liquid limes, and diatomaceous earths were mixed through the subsoil at a high rate. It is possible that these materials may have a capacity to ameliorate Al toxicity in subsoil that may only be realised if they are applied at higher rates than those assessed in the current study.

Limesand or dolomite, mixed through the topsoil at a high rate, elicited a small and statistically significant increase in the length of fine roots, and consequently total root length, in the South Carrabin, but not in the less acidic Merredin subsoil (Figure 2). Slow and partial migration of alkalinity from topsoil into the subsoil following lime application has been widely documented, and Al toxicity in the upper part of the subsoil layer may have been influenced by lime amendments in the topsoil. The Epsom salt treatment produced similar length of subsoil roots as the unamended control, suggesting that that any potential nutritional benefit of Epsom salt did not influence the capacity of roots to grow in the Al-toxic South Carrabin subsoil.

None of the amendments had a significant effect on root length when banded in subsoil at a low rate, demonstrating the importance of the amount, as well as distribution of amendments. However, some of the materials tested are promoted as improving crop tolerance to acidic subsoil, when drilled below seed with fertiliser, at a low rate. We think this proposed mechanism was adequately assessed in the present study; however, proliferation (ie. tolerance) of plant roots in the acidic subsoil did not increase in response to any of the materials, when drilled below seed at a low rate.

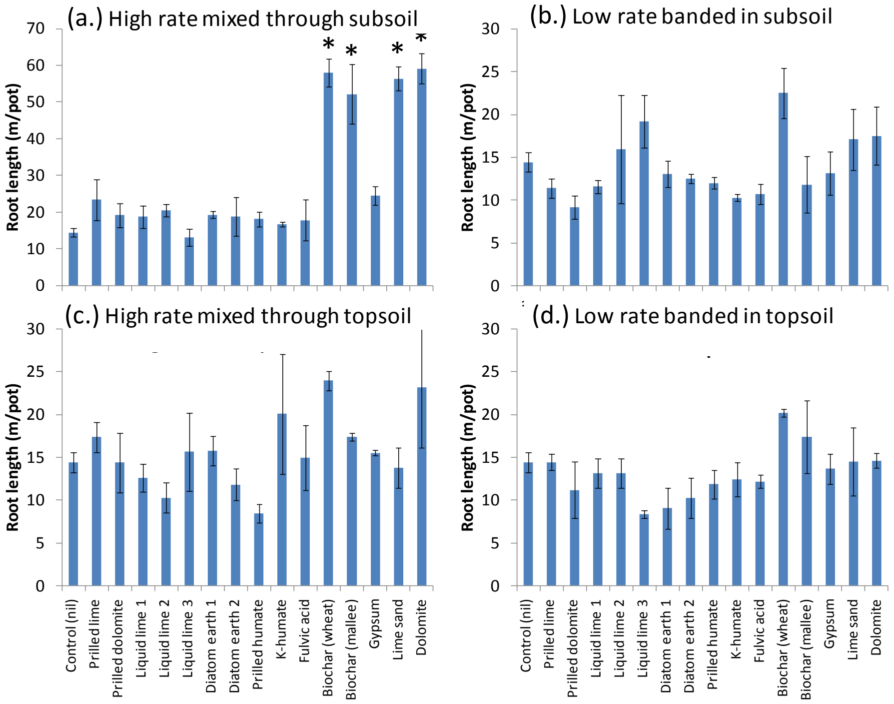

Figure 1: Root length in the subsoil horizon of Merredin soil after application of various materials. Note the difference in the Y-axis scale.

*Vertical error bars are ± standard errors; * denotes mean values that are significantly different from the unamended control at p=0.05*

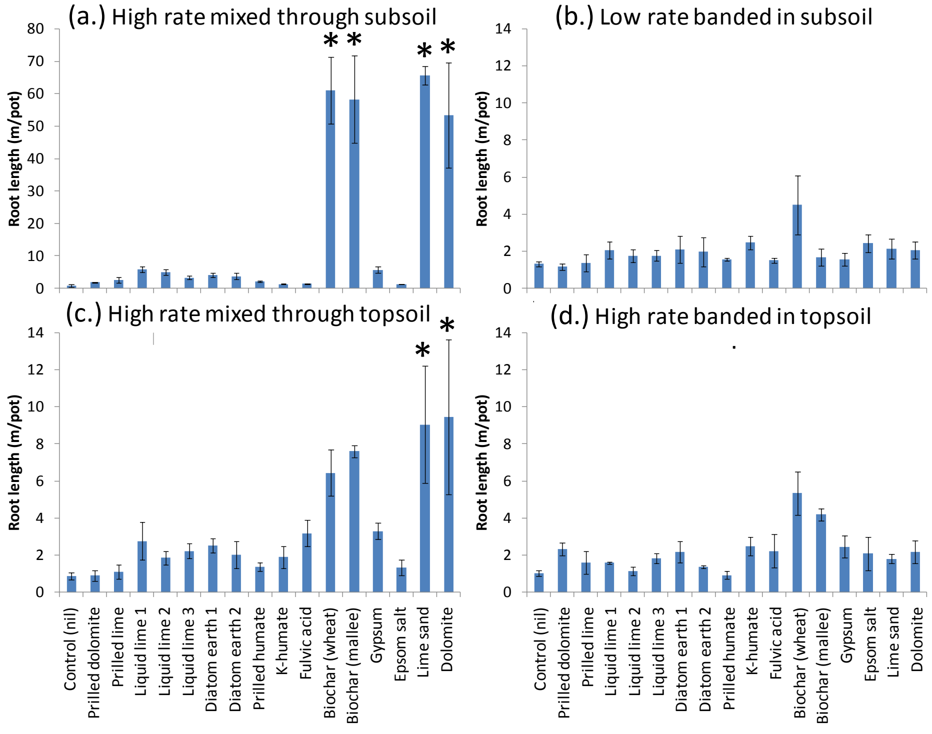

Figure 2: Root length in the subsoil horizon of South Carrabin soil after application of various materials. Note the difference in the Y-axis scale.
*Vertical error bars are ± standard errors of means; * denotes mean values that are significantly different from the unamended control at p=0.05*

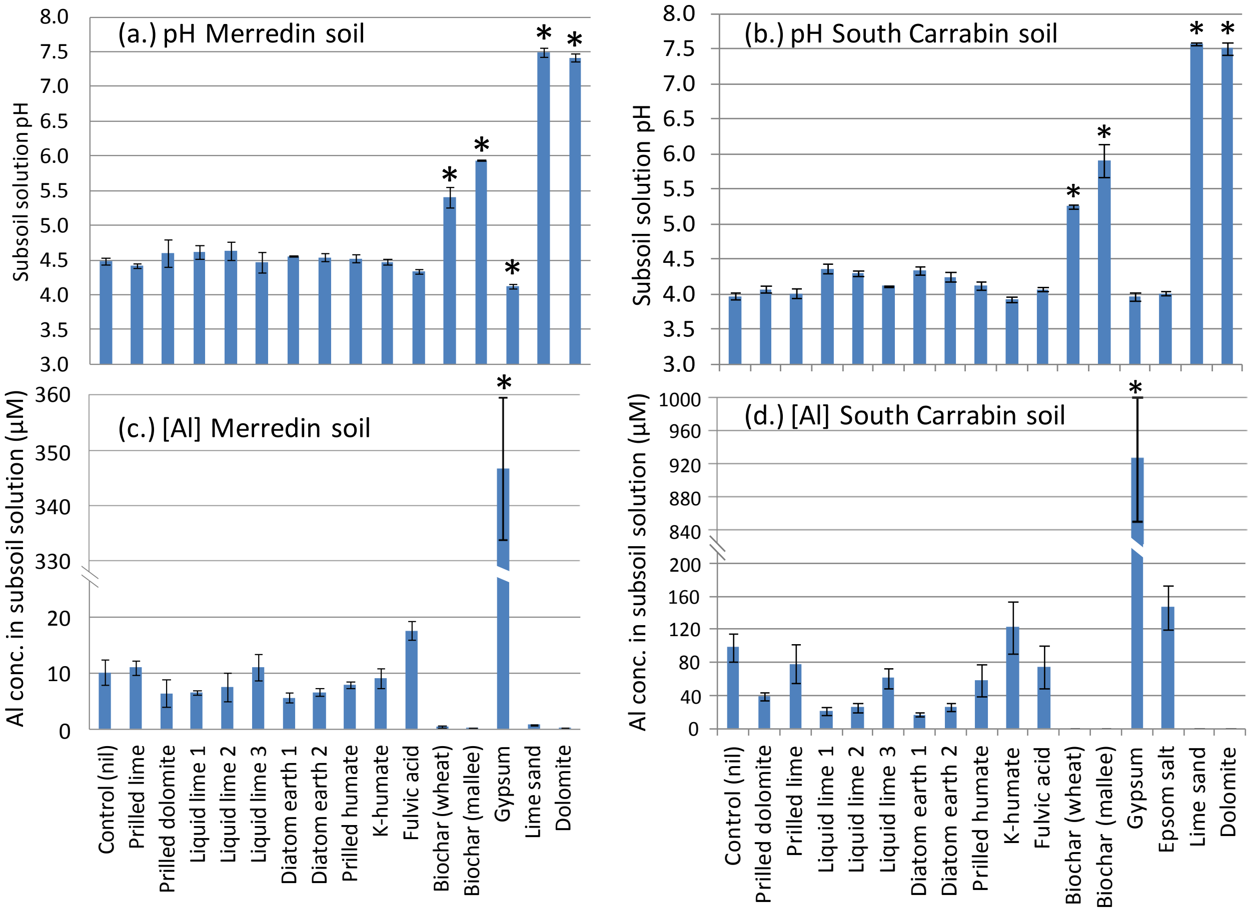

Figure 3: The pH of soil solution extracted from the subsoil horizon in the layered (a.) Merredin, (b.) South Carrabin soil and total aluminium concentration ([Al]) in the same soil solution from (c.) Merredin and (d.) South Carrabin soil. *Vertical error bars are ± standard errors, * denotes mean values that are significantly different from the unamended control at p=0.05*

Soil solution chemistry

The effects of soil amendments on the pH and Al concentration of the subsoil solution (Figure 3) were consistent with the responses of root length in the subsoil, where materials were mixed through the subsoil at a high rate.

The pH of subsoil solution was significantly increased in both soils by limesand, dolomitic lime, and biochars mixed through the acidic subsoil at a high rate (Figure 3), demonstrating the acid-neutralising potential of these materials. The 2 biochars assessed were from different feedstocks and therefore had different chemical and physical characteristics (reported extensively in many UWA publications), yet their effect on soil solution chemistry and root growth was similar. Compared to the unamended control, gypsum lowered the pH of the soil solution significantly (by 0.4 units) in the Merredin, but not the South Carrabin soil, demonstrating a soil type-specific response. The chemical reactions of gypsum in soil are complex, but neither soil demonstrated a self-liming effect in response to gypsum application.

Except limesand, dolomitic lime and biochars, all other materials demonstrated poor capacity for acid-neutralisation in soil under the experimental conditions. However, a trend of small (non-significant) increases in the pH of the subsoil solution (~0.1 units) was associated with the liquid limes, prilled limes, or diatomaceous earths compared to the unamended control.

The increased pH of subsoil solution in the treatments where limesand, dolomite, or biochar was mixed at a high rate resulted in the Al concentration in the subsoil solution decreased to undetectable levels (Figure 3) (these differences were statistically significant only when the gypsum treatment was omitted from the analysis). Gypsum application increased the Al concentration in the subsoil solution 34-fold (from 10 µM to more than 340 µM) in the Merredin soil, and from 100 µM to almost 1000 µM in the South Carrabin soil, despite not having a significant effect on soil solution pH in the South Carrabin soil (Figure 3). Despite huge increases in total Al concentration in the subsoil solution of the gypsum treatment, no increase in Al phytotoxicity was detected (see Figs. 1 and 2) because geochemical modelling indicated that 89 % of the Al in soil solution was complexed in the non-phytotoxic $Al_x(SO_4)_y$ form in both soils (data not shown). The reactions of gypsum in soil are complex, and the net effect on the toxicity of the soil solution to roots is not well understood. Characterisation of the underlying mechanisms will require additional investigation.

Conclusion

Fine limes in liquid or prilled formulations did not ameliorate acid soil toxicity under the test conditions, even when mixed through subsoil. Biochar, when incorporated into subsoil at a high rate, was highly effective in neutralising soil acidity, eliminating Al toxicity, and promoting extensive root proliferation in the subsoil horizon. As expected, agricultural limesand and dolomite were highly effective in neutralising soil acidity when mixed through the subsoil. However, when their placement was localised in a band on top of the subsoil horizon, the effects on soil chemistry were also localised, with no net effect on root growth for any of the materials assessed.

A limited number of soils, and rates and modes of application were tested in the present study in pots during the early stages of wheat growth. Further work is therefore warranted before any definitive conclusions about potential usefulness of the tested materials can be reached.

Key words

Acid soil toxicity, agricultural lime, liquid lime, pelletised lime, gypsum, aluminium.

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