Lime slotting effects on wheat growth in an acidic soil profile

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Key messages

- Wheat plants responded to lime-slotting treatments in an acidic soil profile with crop rows positioned above, but not away from, lime-amended slots.
- Root proliferation within the lime-amended slots allowed wheat plants to utilise water from the deep subsoil, beneath the acidic layer, earlier and in greater quantities than in an unamended profile.
- The response of wheat plants to lime-slotting treatments was similar under mild and severe drought scenarios.

Aims

Slotting lime-amended soil to depth has potential to increase crop yields on soils with an acidic subsoil constraint. However, there is limited knowledge of the relative importance of operational factors such as the width, spacing, depth, continuity, and position of limed slots on crop yield responses. By investigating the effect of the width, spacing and position of slots of lime-amended soil in an acidic soil profile on wheat growth, we aimed to better understand the dominant processes driving crop responses to lime slotting.

Method

Experimental setup

A glasshouse experiment was conducted in large plastic tubs to evaluate the response of wheat plants to the width, spacing and position of lime-amended soil slotted in an acidic soil profile. The 50-cm-long, 30-cm-wide and 80-cm-deep constructed soil profiles (Figure 1) contained (from the top down): a 7 cm layer of acidic (pH_{Ca}=4.2) sand topsoil; a 33 cm deep, highly acidic (pH_{Ca}=3.8), Al-toxic, loamy sand subsoil layer; and a 40 cm deep, mildly acidic (pH_{Ca}=5.5) non-toxic, sand subsoil (Table 1). The acidic topsoil (0-7 cm depth) and highly acidic subsoil (7-40 cm depth) were collected from a wheat cropping paddock near Kalannie, Western Australia (WA) and the mildly acidic subsoil (40-80 cm depth) was collected from a quarry near Gingin, WA.

Lime-slotting treatments were applied as 4-cm- or 8-cm-wide sections of limed Kalannie subsoil extending from 7 cm to 40 cm depth. The slotting treatments were as follows: (1) 4-cm-wide slot between crop rows (interrow), (2) 4-cm-wide slot under one row, (3) 4-cm-wide slots under each row, (4) 8-cm-wide slot in the interrow, (5) 8-cm-wide slot under one crop row, and (6) unamended soil profile (control). The treatments represented a 50 cm spacing for limed slots (treatments 1, 2, 4, 5), or a 25 cm spacing (treatment 3). Limed Kalannie subsoil was amended with a high grade limesand at a rate of 0.64 g kg^{-1} soil, thoroughly mixed, to attain a target pH_{Ca} of 5.5. The target pH_{Ca} of 5.5 is recommended as a lower threshold for topsoils in the main cropping regions of WA (Gazey *et al*., 2014). The limesand had a $CaCO_3$ purity of 95 % with 72 % of particles smaller than 250 µm and 100 % of particles smaller than 500 µm.

The experiment was subjected to two watering regimes (termed mild and severe drought) to represent two seasonal rainfall scenarios. For the mild drought treatment, de-ionised water was applied on a weekly basis at a rate of 1.5 L pot^{-1} (equivalent to 10 mm of precipitation) for the first six weeks, and withheld thereafter. For the severe drought treatment, water was applied at 0.75 L pot^{-1} $week^{-1}$ (equivalent to 5 mm precipitation) for the first four weeks and withheld thereafter.

Plant Culture

The soil profiles were sown with two rows of Mace wheat at 25 cm row spacing, each row being 30 cm long. Mono-ammonium phosphate granules (at a rate equivalent to 100 kg ha^{-1}) and sodium molybdate solution (at a rate equivalent to 126 g Mo ha^{-1}) were banded 2 cm below seed. Wheat seedlings were thinned one week after sowing to achieve 12 plants per row; equivalent to 150 plants m^{-2}. Nitrogen fertiliser was re-applied as urea-ammonium nitrate solution at a rate equivalent to 50 L ha^{-1} two weeks after sowing, when plants were at the three-leaf growth stage.

Sample collection and analysis

The experiment was terminated eight weeks after sowing when plants were at the anthesis stage. Shoots were cut at ground level, dried at 65 °C, and analysed for weight and nutrient content. The soil profiles were then de-constructed by dissecting and removing soil and roots, layer by layer, according to the following horizontal/vertical sampling grid. Horizontally: 0-8 cm (edge), 8-16 cm (4 cm each side of plant row #1), 16-21 cm, 21-29 cm (interrow slot position), 29–34 cm, 34-42 cm (4 cm each side of plant row #2), and 42-50 cm (edge). Vertically, the pots were dissected at 0-7 cm depth (topsoil), 7-17 cm, 17-27 cm, and 27-40 cm. The lower part of the soil profile (40-80 cm depth) was then dissected into two parts, which were associated with crop row #1 and row #2, respectively. Roots from each sampling segment were washed free of soil with running water over a 2 mm sieve and analysed for length using the WinRHIZO system (Regent Instruments, Quebec, Canada).

The experiments were conducted in triplicate and arranged in randomised block design. All data were subjected to ANOVA for treatment effects. Comparison of mean values was assessed by the Tukey's t-test at the 5 % confidence interval (Genstat 14th Edition; VSN International, Hertfordshire, UK).

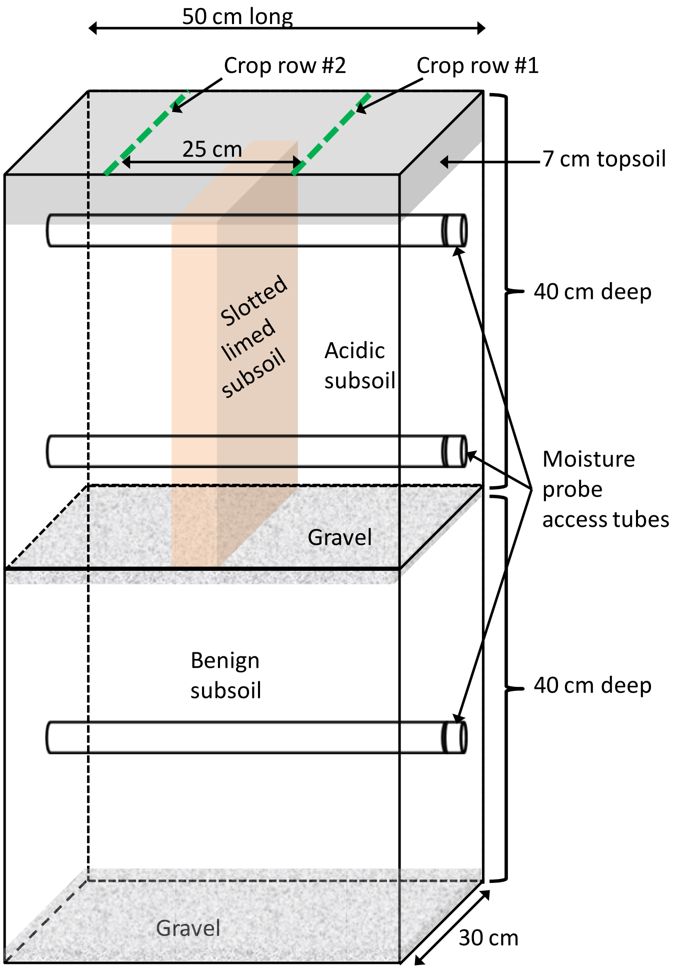

Figure 1: Scale representation of the experimental system to mimic the chemical attributes of deep slotting limed soil in a sandy soil profile with acidic topsoil (0-7 cm) and acidic subsoil (7-40 cm) layers overlying benign subsoil (40 80 cm). There is capacity for routine soil water content analysis using a Diviner 2000 capacitance probe via the horizontally-inserted access tubes.

Table 1: Some chemical properties of the constructed soil profile.

	pH	Al	Ca	K	Mg	Na	CEC	S	NO_3^-	NH_4^+	P	Org C
	($CaCl_2$)	mg/kg					cmol(+)/kg	mg/kg				%
Acidic Topsoil	4.2	14	186	60	30	18	1.70	11.4	16	1.7	19	0.95
Acidic subsoil	3.8	59	27	17	5	5	1.31	33.4	2.1	0.27	2.3	0.26
Benign Subsoil	5.5	23	75	10	10	<2	0.74	5.9	4.1	0.95	3.5	0.18

Results

Wheat growth responded to the position, but not the width, of the lime-amended slots (Figure 2). Growth of wheat plants was greater for rows positioned directly above lime-amended slots, and unaffected in rows positioned off the lime-amended slots, regardless of slot width.

Wheat rows positioned above lime-amended slots had significantly greater shoot biomass (Figure 2), number of heads per row, and number of spikelets per head (data not shown) compared to the unamended control. For plant rows that were not situated directly over a limed slot, growth (Figure 2) and nutrient uptake (data not shown) were similar to the unamended control.

The above-ground response of plant rows to the lime amended slots was related to increased root proliferation below-ground. Localised proliferation of roots within the lime-amended slots resulted in a 5- to 10-fold increase in root length for soil sections associated with the limed slots (Figure 3).

Smaller increases (2- to 3-fold, e.g. in the 7-17 cm layer, from 7 to 21 m/L soil, Figure 3a and b)) in root density where the slot of limed soil was in the interrow (only 9-10 cm from the plant row) did not result in significantly increased biomass in this experiment.

The uptake of water from the acidic subsoil horizon at 15 cm and 30 cm depth was largely similar among the lime-slotting treatments (data not shown). However, greater growth of plant rows located above slots of limed soil was associated with greater use of subsoil (40-80 cm) water (measured at 60 cm depth, Figure 4). Plant roots accessed the subsoil water resource earlier, and in greater quantities (Figure 4) in treatments where lime-amended soil was slotted beneath one or both plant rows, compared to treatments where the acidic subsoil was either unamended, or amended in the interrow.

Although watering regime significantly influenced plant growth (Figure 2) and water use (Figure 4), the response to lime-slotting treatments was typically similar under both severe and mild drought conditions.

Lime amendment of the slotted, acidic Kalannie subsoil increased the pH (in 0.01M $CaCl_2$) from 3.8 (± 0.01) to 5.1 (± 0.24) and reduced aluminium concentration (in 0.01M $CaCl_2$) from 33 (± 1) mg kg^{-1} to <1 mg kg^{-1} at the termination of the experiment.

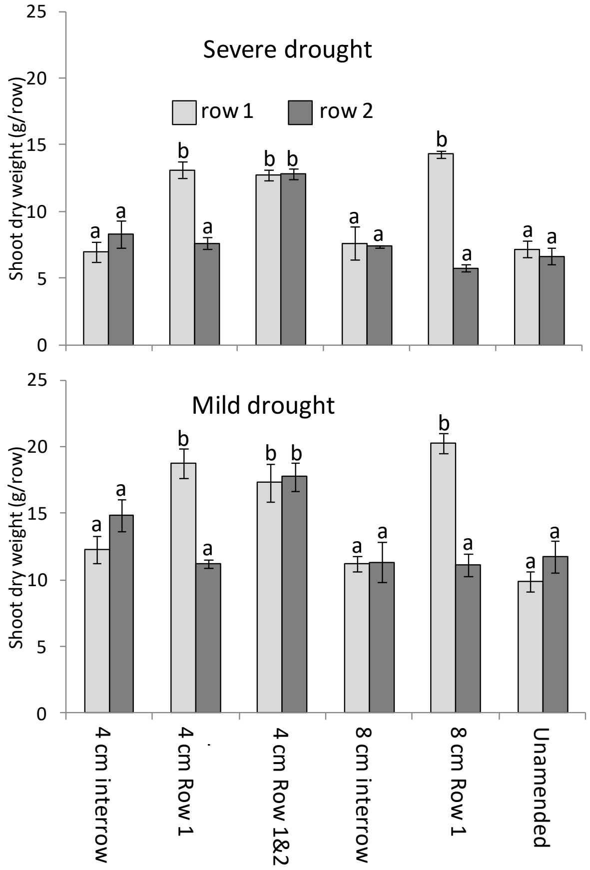

Figure 2: The dry shoot biomass of eight-week-old wheat plants at anthesis. Plants were grown in a glasshouse in a constructed acidic soil profile amended with slots of limed subsoil. Lime slotting treatments (x-axis) were 4 cm wide in the interrow, 4 cm wide under row #1, 4 cm wide under row #1 **and** row #2, 8 cm wide in the interrow, 8 cm wide under row #1, or an unamended control.

Values are means of three replicates; Vertical error bars are ±standard errors of means. Letters above columns indicate significant difference among means at the 95% confidence level.

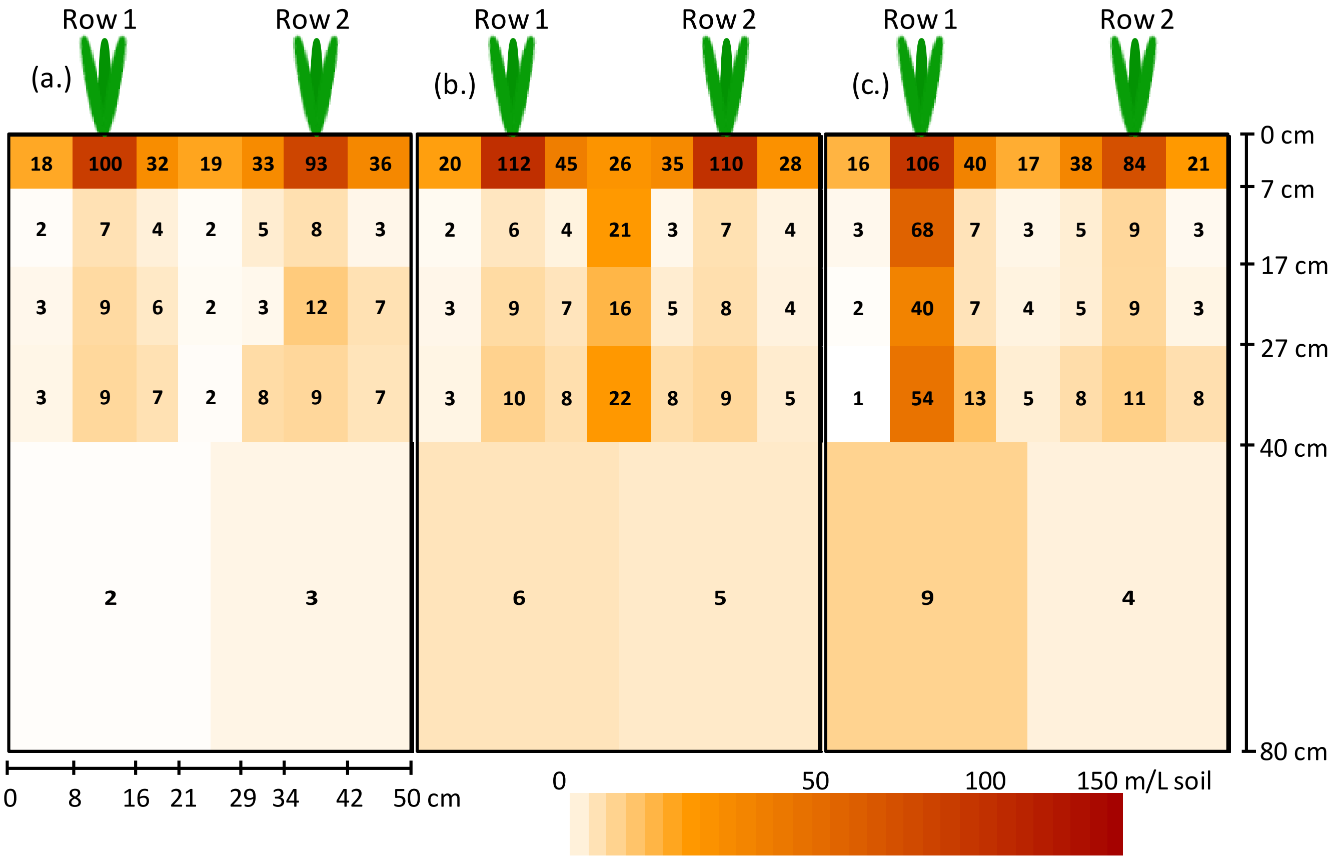

Figure 3: Cross-sectional map of the root length density of wheat plants growing in a constructed acidic soil profile with lime amended slots under a mild drought. (a.) unamended control, (b.) 4 cm slot interrow, and (c.) 4 cm slot under row #1. The numbers within sections are mean root length density in soil portions (m/L), and the colour scale corresponds with increased root length density in soil. The 50-cm-long, 30-cm-wide and 80-cm-deep pots were dissected horizontally into 7 sections, and vertically into 5 sections. The 0-7 cm deep layer was acidic (pH_{Ca} 4.2) topsoil, 7-40 cm layer was acidic (pH_{Ca} 3.8), Al-toxic subsoil, and 40-80 cm layer was mildly acidic (pH_{Ca} 5.5), non Al-toxic subsoil. The 40-80 cm deep subsoil horizon was dissected into 2 sections, associated with plant rows #1 and #2.

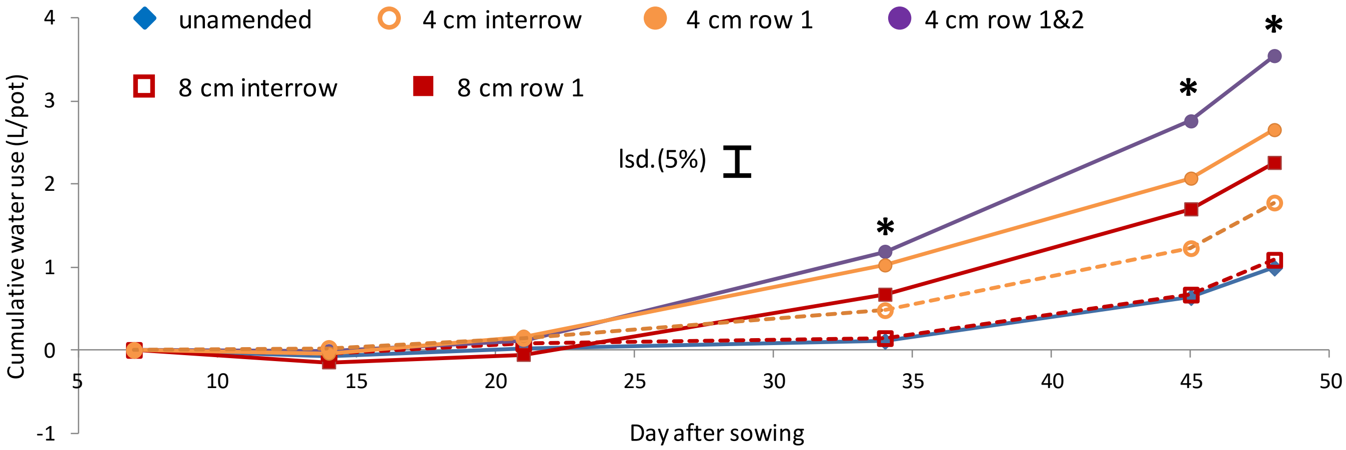

Figure 4: The cumulative water use (L pot-1) from the deep subsoil horizon (40-80 cm) by wheat plants grown in a constructed, acidic soil profile in the glasshouse.
***** *denotes means significantly different from the unamended control (Tukey's 5%). The error bar denotes lsd (5%).*

Conclusion

Wheat growth responded to the distance from a crop row, but not the width, of lime-slotting treatments in an acidic soil profile. Crop rows positioned above lime-amended slots had greater shoot and root growth and yield parameters, whereas the growth of those positioned away from the lime-amended slots was similar to an unamended profile. Where limed slots were positioned beneath one or both crop rows, plants accessed subsoil water (40-80 cm), beneath the acidic layer, earlier and in greater quantities than where the acidic subsoil was unamended or amended in the interrow. Root proliferation was 5 to 10-fold greater within the lime-amended slots compared to corresponding sections of the unamended profile, but root proliferation beyond the lime-amended slots was similar to the unamended profile. If the soil below slotting depth has good pH, slotting limed topsoil could be considered as an option to facilitate root growth into the soil and access moisture and nutrients.

Although soil water and nitrogen acquisition have previously been identified as major drivers of crop responses to lime slotting (B. Bowden, pers. comm.), nitrogen uptake by the crop rows (data not shown) was not related to growth responses under the conditions of this study. While the constructed soil profile isolated crop responses to spatial amelioration of Al-toxicity, the nutrient re-distribution within the soil profile by slotting lime-amended topsoil, rather than subsoil, is likely to influence nutrient availability to the crop. Furthermore, specific nutrient responses are likely to be soil-type specific.

The results provide an insight into some of the mechanisms driving yield responses to slotting lime into acidic soil profiles (*eg.* Blackwell *et al.*, 2016). Yield responses to lime slotting amendments in the field could be dominated by the yield response of the crop rows above, or near to, the lime-amended slots. Differences in the width of the lime amended slots that can be achieved by different approaches (Davies *et al.,* 2015) may not be a priority for maximising yield responses in the field.

Further Reading

Blackwell P, Isbister B, Riethmuller G, Barrett-Lennard E, Hall D, Lemon J, Hagan J, Ward P, (2016) Deeper ripping and topsoil slotting to overcome subsoil compaction and other constraints more economically: way to go!, Proceedings GRDC Grains Research Updates 2016, http://www.giwa.org.au/2016researchupdates

Davies S, Gazey C, Parker W, Blackwell P, Riethmuller G, Wilkins A, Negus P, Hollins T, Gartner D and Lefroy W (2015) Lime incorporation into acidic subsoils – assessing cost, efficacy, value and novel approaches Agribusiness Crop Updates 2015 Perth. http://www.giwa.org.au/2015-crop-updates

Gazey, C., Davies S.L., Masters R. (2014) Soil Acidity: A Guide for WA Farmers and Consultants, Second Edition. Bulletin 4858 (Western Australia. Department of Agriculture and Food). https://researchlibrary.agric.wa.gov.au/bulletins/223/

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