Ameliorating Soil Acidity Led to Reduced Weed Growth

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Key messages

Prior application of lime in field trials at Merredin and Wongan Hills led to reduced density and biomass of annual ryegrass in wheat crops in the 2018 season.

Soil incorporation reduced the biomass of wheat seedlings and the emergence and biomass of annual ryegrass seedlings in a pot trial compared to un-incorporated soil, indicating that crop and weed establishment may be poor in the year following soil renovation.

Aims

Soil acidity reduces crop growth due to direct toxicities (predominantly aluminium in Western Australia) or nutrient deficiencies of molybdenum, nitrogen, sulphur, phosphorus, calcium and magnesium (Moore, 2001). Liming is used to alter soil pH to improve crop health in acidic soils, and competition from a healthy crop remains one of the most cost effective methods of weed control (Moore, 2001; Widderick et al, 2018). Prior research indicated that trial plots with increased soil pH (limed in 1991 and 2000) had increased barley yield and reduced annual ryegrass (*Lolium rigidum* Gaudin) biomass in 2009 (Gazey & Andrew, 2010). However, there are no detailed studies on the long term impact of varying lime rates on crop competitive ability with annual ryegrass, or the impact of incorporation of lime. We tested the hypothesis that application of lime and incorporation of lime would lead to reduced growth and seed set of annual ryegrass within a crop.

Method

Screen house trial

Yellow orthic acidic Tenosol soil was collected from the DPIRD Merredin Research Station on 31 August 2018, by collecting the A1 horizon (0-10cm, pH_{H2O} of 6.2, Al concentration of 0.8mg/kg), removing the A2 horizon and collecting the B1 horizon (20-40cm, pH_{H2O} of 4.3, Al concentration of 19.5mg/kg). This soil is acidic to a depth of over 1m, potentially as a result of agricultural practices but also because this soil type is naturally acidic. On 3 September 2018, soil was sieved to 4mm to exclude plant debris but include soil micro-aggregates for in-pot culture (Augé et al, 2001). Sieved soils were placed in 2.5kg pots. Treatments included lime (neutralising value of 94.9%, 99.2% particles <0.5mm) at 0, 0.5, 1, 1.5 and 2t/ha, on the soil surface or fully incorporated (in a randomised block design with three replications). Lime rates were selected because prior trials indicate a larger impact of lime in pots than in field conditions (Azam et al, 2018). Each pot was lined with a paper towel, and held 2kg of B1 horizon soil and 0.5kg A1 soil. For the non-incorporated treatment, B1 soil and then A1 soil was placed in the pot to artificially create the separate horizons. Lime was sprinkled evenly over the surface. For the incorporated treatments, bulk soil from the two horizons and lime at the appropriate rates were mixed in a rotary mixer and 2.5kg of the resulting soil was added to each pot. Pots were placed in trays containing 4cm of water for 3 hours, to allow the soil to absorb water through capillary action. Holes of 3mm were punched in the soil to place five seeds of Mace⁽ᴰ⁾ wheat at 2cm depth (i.e. 60kg/ha of wheat), five seeds of annual ryegrass at 0.5cm depth (i.e. 200 plants/m^2) and fertiliser (80kg/ha K-Start10 Trace, 12.0 N:13.1 P:10.0 K:3.0 S:0.1 Cu:0.2 Zn w/w%, bulk density 1.1, Landmark) at 4cm depth (seeding system and fertiliser rate attempted to mimic grower practice in the Merredin area). Pots were placed in a screen house and watered 6mm every three days to supplement natural rainfall.

On 4 October 2018 plant density was assessed. For each pot with full incorporation, a single soil sample was taken. For each pot with no incorporation, a soil sample was taken from both the A1 and B1 horizon. Samples were used to determine pH_{CaCl2} and aluminium (Bromfield, 1987; Rayment & Lyons, 2011). The remaining soil was washed away to extract the wheat and annual ryegrass seedlings. Bulk fresh root and shoot biomass for wheat and annual ryegrass was assessed for each pot, plant material was dried at 60^{o}C for three days and dry biomass was assessed.

A regression analysis was used to compare pH and aluminium concentration of each pot. An ANOVA was used to compare means, with lime and incorporation as the factors and root and shoot biomass as the variates. A linear contrast was used to investigate increasing rates of lime. Least significant difference was used to compare means that were not subject to a contrast.

Merredin trial

A field trial was established at the Merredin Research Station in 2016 on a Yellow orthic acidic Tenosol soil (i.e. the same site used to collect soil for the screen house trial). Topsoil (0-10cm depth) had a pH_{CaCl} of 4.5 and Al concentration of 3.2mg/kg. Subsoil (10-60cm depth) had a pH_{CaCl} of 3.8 and Al concentration of 16.1mg/kg. Treatments included a continuous wheat (2016-2018) or wheat-chemical fallow rotation (i.e. wheat in 2016, chemical fallow in 2017 and wheat in 2018), lime (neutralising value of 90.0%, 99.0% particles <0.6mm) at 0, 2, 4 or 6t/ha and initial cultivation to incorporate the lime (with offset discs to a depth of 15cm). The trial was laid out in a split-split plot design with four replications, and a plot size of 20m by 1.54m. Annual ryegrass density was assessed on 12 July 2018 and annual ryegrass biomass was harvested on 10 October 2018, from two 50cm by 50cm quadrats per plot. Biomass samples were dried at $60^{o}C$ for three days and weighed to determine dry biomass.

An ANOVA was used to analyse the data, with crop rotation, incorporation and lime as the factors and annual ryegrass density and biomass as the variates. A linear contrast used to assess the impact of increasing lime rates and LSD was used to compare means that were not subject to a contrast. A square root transformation was used for the annual ryegrass density and biomass variates to stabilise variance, with data presented as back-transformed means.

Wongan Hills trial

The Wongan Hills trial was established in 1994 on a Yellow orthic acidic Tenosol soil. The soil had pH_{CaCl} 5.0 at 0-10cm and 4.2 at 10-30cm, and an Al concentration of <1.0mg/kg at 0-10cm and 7mg/kg at 10-30cm. This soil is acidic to a depth of 40cm (as a result of agricultural practices) but the B2 horizon beyond 40cm is not acidic (with full details of soil properties in Azam et al, 2019). Treatments in 1994 included lime (neutralising value of 94.9%, 99.2% particles <0.5mm) at 0, 0.5, 1, 2 and 4t/ha, in a completely randomised block design with four replications (paired plots of 1.8m by 30m). In 1998 an additional 1.5t/ha of lime was added to one of each pair of plots, changing the design to a split plot design with four replications (single plots of 1.8m by 30m). In 2014, an additional 3t/ha of lime was added to each plot, changing the design to a split-split plot design with 4 replications (plots of 1.8m by 15m). In 2018 the plots were split into three to apply a cultivation treatment, with a rotary hoe used to incorporate soil to 0, 15 or 25cm (split-split-split plot design, 4 replications, plots of 1.8m by 5m). Note that initial lime treatments were determined by taking the industry standard lime rate (1t/ha) and comparing it to a halved, doubled and quadrupled rate. Future treatments were applied to investigate the long term impact of reapplication of lime, at higher than industry standard rates (as the industry standard of the time was relatively low).

Measurements were not taken from every plot in 2018. The treatments of interest were 0, 2 or 4t/ha of lime in 1994, an additional 0 or 1.5t/ha of lime in 1998, and an additional 0 or 3t/ha of lime in 2014 (i.e. total lime rates from 1994 to 2018 of 0, 1.5, 2, 3.5, 4, 4.5, 5.5, 6.5, 8.5t/ha), across each of the three tillage depths. The trial was sown to wheat in 2018, with full trial details available in Azam et al (2019). Initial annual ryegrass density was low (0 to 5 plants/m^2) due to a dry autumn, but cohorts emerged later in the season. On 19 October 2018, annual ryegrass density was recorded in two 50cm by 50cm quadrats per plot, before harvesting annual ryegrass biomass. Samples were processed as for the Merredin site. An initial ANOVA showed no impact of incorporation, so to simplify results, data are presented as mean annual ryegrass density or biomass at each lime rate, with standard errors to differentiate between means.

Results

Screen house trial

The pH of the soil in pots with full incorporation ranged from 4.2 to 6.6, as lime rate increased from 0 to 2t/ha (Table 1). In the pots with no incorporation, pH of the surface soil ranged from 5 to 7 as lime rates increased, but pH of the subsoil remained at 3.9. Aluminium concentration was closely correlated to pH (Table 1, Figure 1). Aluminium increased rapidly below pH of 4.3, and so was relatively low in the incorporated pots, low in the A1 horizon of the non-incorporated pots and consistently high in the B1 horizon.

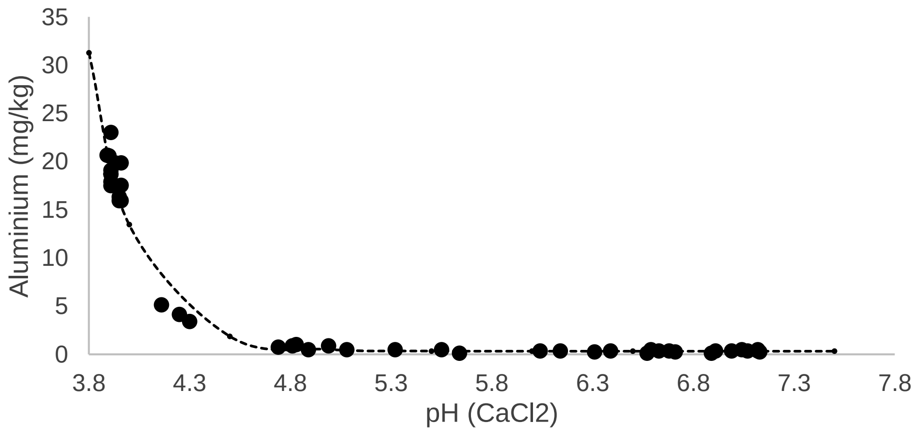

Figure 1. The pH and corresponding aluminium concentration in each pot. The dotted line indicates the exponential regression $y = 0.323 + 370509794 * 0.014^X$ ($P < 0.001$, $R^2 = 98.4$).

Lime did not influence plant density, but increasing rates of lime did increase the dry biomass of wheat and annual ryegrass (Table 1). Incorporation did not affect crop density, with an average of 4.9 wheat seedlings per pot. However, annual ryegrass density was reduced from 4.07 seedlings/pot in the non-incorporated treatments to 2.73 seedlings in the incorporated treatments (P: 0.009, LSD: 0.95). Incorporation (compared to non-incorporation) reduced the dry weight of crop roots (average weight of 0.724 and 0.487g, P<0.001, LSD: 0.121), crop shoots (0.584 and 0.442g, P: 0.012, LSD: 0.106), annual ryegrass roots (0.0231 and 0.0069g, P<0.001, LSD: 0.0051) and ryegrass shoots (0.0245 and 0.0053g, P<0.001, LSD: 0.0056). The interaction of lime and incorporation was not significant for plant density or biomass.

Table 1. The pH and aluminium of the A1 and B1 horizon in the non-incorporated pots and in the single horizon in the incorporated pots, as well as dry biomass of the wheat and ryegrass shoots and roots averaged over the incorporated and non-incorporated treatments, at lime rates of 0 to 2t/ha (where P values indicate the significance of the linear contrasts from each analysis of biomass).

Measurement	Incorporation	Lime (t/ha)					P
		0	0.5	1	1.5	2	
$pH_{(CaCl2)}$ A1 horizon	No	5.0	6.5	6.8	7.1	7.0	
$pH_{(CaCl2)}$ B1 horizon		3.9	3.9	3.9	3.9	3.9	
$pH_{(CaCl2)}$	Yes	4.2	4.8	5.9	5.8	6.6	
Aluminium (mg/kg) A1 horizon	No	0.8	0.4	0.2	0.3	0.5	
Aluminium (mg/kg) B1 horizon		19.5	18.4	16.1	18.4	19.8	
Aluminium (mg/kg)	Yes	4.2	0.7	0.3	0.4	0.2	
Wheat shoot weight (g)		0.405	0.393	0.473	0.672	0.623	<.001
Wheat root weight (g)		0.444	0.479	0.633	0.739	0.733	<.001
Annual ryegrass shoot weight (g)		0.012	0.008	0.018	0.019	0.017	0.039
Annual ryegrass root weight (g)		0.010	0.009	0.018	0.019	0.019	0.004

Merredin trial

Annual ryegrass density and biomass were reduced by increasing rates of lime (Table 2).

Table 2. The annual ryegrass density and biomass at lime rates of 0 to 6t/ha; where P values indicate the significance of the linear contrast of lime rate.

Annual ryegrass	Lime (t/ha)				P
	0	2	4	6	
Density (plants/m^2)	14.2	11.3	4.1	1.8	<0.001
Biomass (g/m^2)	26.8	30.9	10.8	11.4	0.008

The wheat-chemical fallow rotation had lower annual ryegrass density than the continuous wheat rotation (1.0 and 17.9 plants/m^2, P: 0.019, LSD: 4.9) and lower annual ryegrass biomass (3.6 and 46.2g/m^2, P: 0.006, LSD: 4.8).

Incorporation of lime did not have a significant impact on ryegrass density or biomass. However, there was a significant interaction between crop rotation and incorporation on annual ryegrass density. In the continuous wheat rotation, annual ryegrass density was greater in the non-incorporated treatments (25.1 plants/m^2) compared to in the incorporated treatments (12.1 plants/m^2), whereas there was little difference in the wheat-fallow rotation due to very low weed density (1.5 and 0.6 plants/m^2 in the incorporated or non-incorporated treatments in the fallow treatments, P: 0.006, LSD: 4.5 or 0.7 for comparing means with the same level of crop). Annual ryegrass biomass was not affected by cultivation and there was no significant interaction between crop rotation and cultivation.

Wongan Hills trial

Annual ryegrass density and biomass was reduced with increasing total rates of lime, although there was no difference between 0 and 1.5t/ha of lime (Figure 2). Incorporation did not affect annual ryegrass density or biomass.

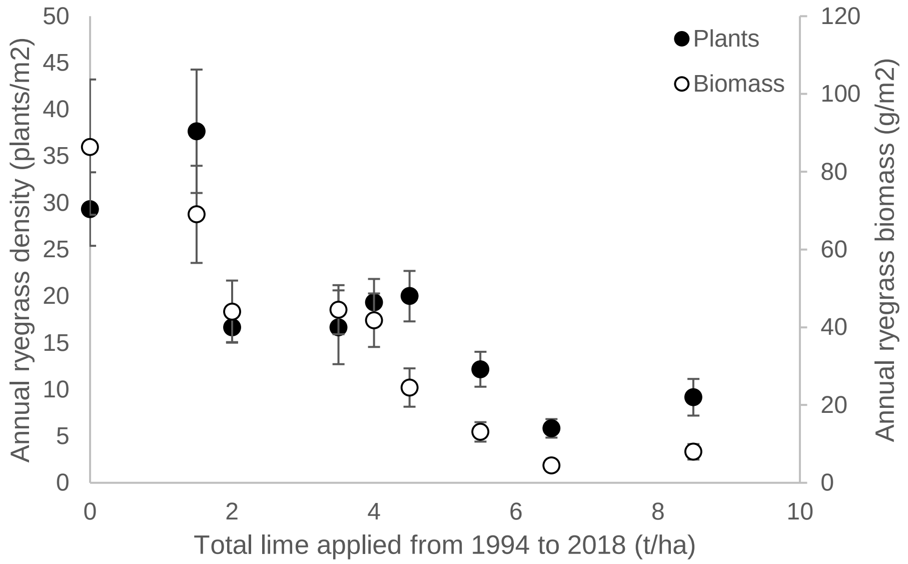

Figure 2. Average annual ryegrass density and biomass at each rate of lime applied from 1994 to 2014 (0 to 8.5t/ha), with vertical bars indicating the standard error of 24 values.

Conclusion

It is clear from the field trials that addition of lime is correlated to a reduction in the density and biomass of annual ryegrass, which is similar to the findings of Hashem and Borger (2018). The pot trial indicates that lime improves the initial growth of both wheat and annual ryegrass. Increased growth of wheat seedlings was expected, but the soil pH required for optimal growth of annual ryegrass has not been investigated (Moore, 2001). Bolland *et al.* (2001) noted increased dry biomass of Italian ryegrass (*L. multiflorum* cv. Aristocrat) in pot trials as soil pH increased from 4.2 to 5. Conversely, Hochman *et al*. (1990) noted that application of lime to pastures containing mixed swards of subterranean clover (*Trifolium subterranean* L.) and annual ryegrass had no impact on ryegrass growth. Our results suggest that annual ryegrass growth is improved by lime application, but further research is required to determine optimal soil conditions for common weeds in Western Australia. Given that annual ryegrass growth was reduced in the field trials, it is likely that application of lime and the subsequent increase in soil pH improved the growth and competitive ability of wheat. Altered soil chemistry from lime application may also have influenced herbicide performance, but Hashem and Borger (2018) found no interaction between liming and efficacy of various herbicides. Improved crop competition has previously been shown to reduce annual ryegrass growth and seed production (Widderick et al, 2018). On a national scale, annual yield loss due to competition from surviving in-crop weeds is estimated to cost growers $278 million (Llewellyn et al, 2016). It is likely that this cost of weed competition could be reduced in areas with acidic soils by increasing soil pH to improve the competitive ability of the crop.

Incorporation is a highly effective method to integrate lime; increasing the impact of lime on crop growth and reducing lime loss through erosion (Whitten et al, 2000; Moore, 2001). However, the pot trial indicated that incorporation could reduce early growth of wheat and annual ryegrass. Azam *et al*. (2019) found that incorporation to 15cm did not affect crop yield in the Wongan Hills trial and incorporation to 25cm increased grain yield. This indicates that if early crop growth is reduced in the field, plants can recover during the season. The Merredin trial indicated lower weed density in the continuous wheat plots where lime was incorporated. This may result from improved competitive ability of the crop due to improved capacity of incorporated lime to reduce soil acidity. It may also result from reduced initial annual ryegrass seed number, as the incorporation event buries some weed seed below a depth appropriate for emergence (Agriculture and Food Western Australia, 2016). By comparison, incorporation did not affect weed density or biomass at Wongan Hills, possibly because crops at Wongan Hills are more competitive and higher yielding than Merredin crops regardless of soil pH. It is clear that further research is required on initial weed and crop growth following soil renovation. Reduced early growth of wheat will reduce its competitive ability against annual ryegrass. This effect is alleviated if the annual ryegrass also has reduced or delayed emergence, but delayed emergence will make it more difficult to control the annual ryegrass with non-selective and pre-seeding herbicides.

A chemical fallow in the Merredin trial significantly reduced the annual ryegrass density and biomass, and is an excellent weed control technique. However, it is not an economically beneficial form of integrated weed management except in cases of exceptionally high weed density (Monjardino et al, 2004). Therefore, fallow should only be used in those low rainfall areas where stored soil moisture and increased nitrogen mineralisation will make it a profitable option in the rotation (Oliver & Sands, 2013).

Key words

Lime, soil acidity, annual ryegrass, *Lolium rigidum*

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