Lime improves control of wild radish and annual ryegrass in acid soils of Western Australia

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Summary Most sandy soils of Western Australia (WA) are acidic, which may influence the competitive ability of crops against weeds like wild radish (*Raphanus raphanistrum* L.) and annual ryegrass (*Lolium rigidum* Gaudin). We examined the effect of lime applied to acidic soils on weed control and crop yield over four seasons at three locations (Eradu, Wongan Hills and Merredin) of the WA wheatbelt. All experiments were conducted in a split-plot design with lime in the main plots replicated four times and herbicides in the sub-plots. Limesand was applied in the first year (2010) on the soil surface and incorporated by sowing. Lime treatments increased soil pH by approximately one unit in the top soil (0 to10 cm) but the sub-soil pH (20–30 cm) remained at or below 4.8. Lime treatments had no effect on the density of weeds in the first three years after application, but in the fourth year lime at 2.5 and 5.0 t ha^{-1} reduced the in-crop density of wild radish by 45% at Eradu and annual ryegrass by up to 60% at Merredin. Herbicides applied in the sub-plots increased barley grain yield by 54–58% in the fourth year (2013) after lime application at Merredin and Eradu. Lime applied to the soil surface can reduce weed density but it may take three to four years after application to show the effect.

Keywords Soil acidity, lime, wild radish, annual ryegrass, weed control.

INTRODUCTION

The most important causes of soil acidification on agricultural land are the application of ammonium-based fertilisers and urea, elemental sulphur fertiliser and the growth of legumes (Goulding 2016). Crop growth is reduced in acidic soils, which is likely to make the crop less competitive against weeds (Scott *et al.* 1997). This may compound the effects of weed competition resulting in further reductions in grain yields. Wheat yield can be reduced by 50% due to annual ryegrass competition (Hashem *et al.* 1998). The presence of 10–75 wild radish plants m^{-2} can reduce wheat yields by 7–56% and lupin yields by 28–92% (Hashem *et al.* 2006). A potential option of increasing the competitive ability of crops against annual ryegrass in low pH soil is to apply lime (Goulding 2016). Gazey and Andrew (2010) demonstrated that the application of lime increased the biomass of a barley crop and decreased the biomass of annual ryegrass with markedly different soil pH profiles in a long-term lime trial at Kellerberrin, Western Australia (WA).

Application of lime may also influence herbicide efficiency. There is little data available on the influence of lime on the performance of herbicides to control annual ryegrass or wild radish. The aim of this study was to examine the impact of lime and herbicides on the control of annual ryegrass or wild radish in low pH soils. The study hypothesised that application of lime would improve weed suppression and increase grain yield in a wheat-wheat-lupin-barley rotation.

MATERIALS AND METHODS

Four sites were established in WA, to investigate annual ryegrass (Merredin and Wongan Hills) and wild radish (Eradu and Wongan Hills). The crop rotation at all four sites was wheat-wheat-lupin-barley, grown from 2010–2013. Trials at each site were set up in a split plot design. Four rates of limesand (0, 1.25, 2.5 and 5 t ha^{-1}) were allocated in the main plots and five rates of selective herbicide (Table 1) in the sub-plots. The unit plot size was 20 m by 2 m, replicated four times. Measurements included pH ($CaCl_2$) of soils collected just before sowing crop and application of herbicide each year, weed and crop density (from two 50 cm by 50 cm quadrats per plot) and crop yield.

RESULTS

Lime effect on soil pH In 2010–2012, lime increased soil pH by about one unit at 0–10 cm depth, but the pH in the sub-soils remained below 4.8 (the desirable pH for optimum crop plant growth) at all sites. In 2013 (the fourth year), lime at 2.5 and 5 t ha^{-1} increased soil pH ($CaCl_2$) by 0.67−1.23 units at 0–10 cm depth, 0.22–0.87 units at 10–20 cm and 0.08–0.35 units at 20–30 cm.

Lime effect on weed density and crop Lime did not have a significant impact on weeds in first, second and third year after lime application (from 2010–2012). In the fourth year (2013), initial annual ryegrass density was reduced with the increases in lime rate (compared to no lime); from 28 plant m^{-2} at 0 t ha^{-1} to 16 plant m^{-2} at 5.0 t ha^{-1} (41% reduction) at Wongan Hills and from 139 plant m^{-2} on no-lime to 56 plants m^{-2} at 5.0 t ha^{-1} (59% reduction) at Merredin site (Table 2). Likewise, lime reduced the initial density of wild radish in 2013 by 1% (at 1.5 t ha^{-1}) to 48% (at 5.0 t ha^{-1}) at Eradu where wild radish density was 120 plants m^{-2} in the no-lime control (Table 2). Wild radish density at Wongan Hills was too low to show a significant impact of lime, with an average of 2 plants m^{-2} in the no-lime control (Table 2).

Likewise, lime had no significant impact on crop yield from 2010–2012. However, in the fourth year (2013), lime significantly increased barley grain yield by 6% (at 5.0 t ha^{-1}) at the Wongan Hills wild radish site and 7% (at 2.5 t ha^{-1}) at the Wongan Hills annual ryegrass site (Table 3). At Eradu and Merredin, ryegrass site, there was no significant increase in grain yield resulting from lime (Table 3).

Herbicide effect on weed control and crop growth

In the wheat crops grown in 2010–2011, annual ryegrass control at Wongan Hills improved with increasing

Table 1. Herbicides applied across lime treatments to control annual ryegrass (Merredin and Wongan Hills) and wild radish (Eradu and Wongan Hills) in different crops from 2010–2013.

Site and weed species	Herbicide treatments
Annual ryegrass at Merredin and Wongan Hills	Wheat crop in 2010 and 2011: Sakura® (pyroxasulfone 850 g kg^{-1}) at 0, 60, 90, 120, 150 g ha^{-1} at pre-plant.
	Lupin crop in 2012: Simazine (simazine 500 g L^{-1}) 2000 mL ha^{-1} at post-plant across all plots except in the no herbicide control.
	Barley crop in 2013: Boxer Gold® (prosulfocarb 800 g L^{-1} + s-metolachlor 120 g L^{-1}) at 0, 1000, 1500, 2000, and 2500 mL ha^{-1}at pre-plant.
Wild radish at Eradu and Wongan Hills	Wheat crop in 2010 and 2011: Velocity® (bromoxynil 210 g L^{-1} + pyrasulfotole 375 g L^{-1}) at 0, 250, 350, 500 and 670 mL ha^{-1} at post-emergent.
	Lupin crop in 2012: Simazine® (simazine 500 g L^{-1}) 2000 mL ha^{-1} at post-plant across all plots except in the no-herbicide control.
	Barley crop in 2013: Velocity® (bromoxynil 210 g L^{-1} + pyrasulfotole 375 g L^{-1}) at 0, 250, 350, 500 and 670 mL ha^{-1} at post-emergent.

Table 2. Cumulative effect of lime applied in 2010 and herbicides applied each year from 2010–2013 on the initial density of weeds recorded after crop emergence and before application of post-emergent herbicides in 2013 season at each site. For herbicide rates, refer to Table 1.

		Wild radish (plant m^{-2})		Annual ryegrass (plant m^{-2})	
Lime/ Herbicide	**Rate**	Eradu	Wongan Hills	Wongan Hills	Merredin
Lime (t ha^{-1})	0	120	2	28	139
	1.25	105	2	26	114
	2.5	63	1	19	82
	5	66	1	16	56
	LSD ($P<0.05$)	39.4	NS[1]	11.1	35.3
Herbicides	Rate 1	163	5.1	86	235
	Rate 2	63	1.4	9	114
	Rate 3	65	0.5	7	87
	Rate 4	72	0.5	5	34
	Rate 5	78	0.1	3	19
	LSD ($P<0.05$)	39.5	1.27	14.6	82.6

[1] NS= Non-significant.

rates of Sakura®, leading to increased grain yield. At Merredin, increasing rates of Sakura® improved control of annual ryegrass and improved wheat grain yield by 4−8% in 2011 (data not presented). No clear interaction of lime and herbicide was found on weed control or yield at either site of ryegrass. At the wild radish sites, increasing rates of Velocity® improved weed control at Eradu and Wongan Hills. Velocity® at lower rates was more effective on wild radish at Eradu than at Wongan Hills, and increased wheat grain yield by 17–18% in 2011 (data not presented). Again, there was no interaction of lime and herbicide at either site of wild radish.

In the 2012 lupin crops, simazine, together with the cumulative effect of herbicides applied in 2010 and 2011 seasons, significantly increased control of wild radish and annual ryegrass compared to the no herbicide control plots.

In the 2013 barley crop, Velocity® was effective on wild radish at both sites. Further, the broadleaf herbicides sprayed on wild radish in 2010, 2011 and 2012 had a cumulative effect on the reduction of wild radish in 2013. Prior to spraying Velocity® in 2013, the density of wild radish counted at the tillering stage of the barley crop was reduced from 163 to 63 plants m^{-2} (64% reduction) at Eradu and 5.1 to 0.1 plants m^{-2} (98% reduction) at Wongan Hills (Table 2).

Herbicide effect on grain yield In 2012, herbicide treatments increased lupin grain yield by 62–227%, with the exception of the Merredin annual ryegrass site where lupin growth was very poor due to low rainfall in 2012 season (data not presented).

Increases in rates of Boxer Gold® controlled annual ryegrass by 51–91% and increased the yield of barley by 6−16% at Wongan Hills (Table 3). Likewise, herbicides increased ryegrass control by 51–92% and barley grain yield by 79–116% at Merredin (Table 3). Velocity® increased barley grain yield by 132−138% at Erdau, 7–9% at Wongan Hills (Table 3).

DISCUSSION

Application of lime increased soil pH in the top 10 cm. However, it took four years for the lime to leach down, to alter pH at a depth of 10–30 cm. Further, sub-soil pH was still lower than is optimal for crop growth (pH ≥4.8). At all sites except Eradu, the pH in the sub-surface layers (20–30 cm) with or without lime remained at or below 4.5. This low pH in the sub-soil suggests that soil acidity at the sub-soil layers was restricting barley crop root growth even three years after lime application.

Prior to 2013 there were only small increases in soil pH and consequently no observed effect on the density of annual ryegrass and wild radish populations. Surface-applied limesand took a long time to impact on sub-soil pH; therefore growers need to consider incorporation of limesand via deep ripping or other methods of soil renovations. A change in the pH at 2.5 and 5.0 t ha^{-1} in the upper soil layers in 2013, increased the barley crop competitiveness against weeds, as indicated by reduced weed density and increased grain

Table 3. Effect of increasing rates of lime and herbicides on the grain yield of barley at Eradu and Merredin, 2013. For herbicide rates used, refer to Table 1.

Lime/herbicide	Rate	Barley grain yield (t ha^{-1})			
		Wild radish		Annual ryegrass	
		Eradu	Wongan Hills	Wongan Hills	Merredin
Lime (t ha^{-1})	0	3.28	3.96	3.36	1.11
	1.25	3.30	4.09	3.36	1.11
	2.50	3.35	4.18	3.59	1.13
	5.00	3.33	4.21	3.56	1.16
	LSD (P<0.05)	NS	0.123	0.194	NS
Herbicides	Rate 1	1.60	3.84	3.13	0.62
	Rate 2	3.71	4.09	3.43	1.11
	Rate 3	3.81	4.18	3.62	1.20
	Rate 4	3.72	4.14	3.56	1.33
	Rate 5	3.72	0.138	3.60	1.34
	LSD (P<0.05)	0.197	0.138	0.217	0.184

yield. A competitive crop is a highly effective form of weed control. There was no interaction of herbicide and lime in this short term study. However, annual ryegrass prefers soil at the same pH as crops. Therefore, liming should make ryegrass less stressed, and less stressed weeds are more responsive to herbicide. Some evidence indicates that wild radish prefers acidic soils (Willis 2006) and so liming may be detrimental to the growth and development of wild radish. More research is required on the long term effect of lime on wild radish and ryegrass.

These results reinforce the fact that surface applied lime takes a long time to alleviate the sub-surface acidity problem and suggests the necessity of continuing to monitor the limed plots for a longer period of time.

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