Liming changes more than the pH – A field study on wheat and pasture species

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Abstract
This experiment was conducted to investigate the enduring effects of prior liming of an acidic duplex soil. In 2018, the response of cereal crops (wheat and cereal rye) and pasture legumes (serradella, subterranean clover and lucerne) spanning a range of susceptibility to acid soil was assessed. Despite the site having uniform nutrient additions and crop management over a number of years, nutrient availability (particularly nitrogen, phosphorus and potassium) was still significantly lower in the unlimed strips compared with the limed strips. Of the root diseases assessed, most were more prevalent under cereals and had a greater disease risk rating in limed plots. There was no effect of lime on shoot and root DM of acid soil tolerant varieties (i.e yellow serradella and cereal rye). Acid soil tolerant varieties are a good option in these soil types but the potential use of higher yielding, acid soil sensitive varieties combined with the longevity of the liming effects in low rainfall environments should be taken into account when considering the economics of soil amelioration by liming.

Key Words
Acid soil, cereal rye, pasture legumes, soil nutrition, wheat, yield

Introduction
Liming has become a necessary practice in areas of the Western Australian wheatbelt where acidic soil types are common (Gazey et al. 2013). The use of acid-tolerant plant species has been a useful means of maintaining productivity (Foy 1988) while farmers grapple with the economics of lime freight costs. Although the time required to change subsoil pH significantly in arid environments (without incorporation to depth) can be lengthy, the resulting impacts can often continue for some time (Bromfield et al. 1987; Edmeades et al. 1984). Low soil pH is often associated with elevated levels of exchangeable aluminium (Al) and there are significant cultivar differences with regards to Al tolerance among wheat (Amjad 2013) and pasture varieties (Helyar 1994). Increasing soil pH with lime is a means of reducing aluminium availability in the soil, expanding the number of cultivar options available for the farmer, enabling the choice of varieties with greater yield potential and creating flexible crop rotation options to mitigate disease, weed or herbicide issues. This experiment investigated the long-term effects of prior liming on soil nutrition and how prior liming affected plant disease risk, crop growth and yield of a number of cereal and pasture legume varieties differing in acid soil tolerance.

Methods
Site description
This field experiment was sown on May 11 2018) at the Department of Primary Industries and Regional Development (DPIRD) research station in Merredin Western Australia (31.29° S, 118.13° E). Total growing season rainfall was 228 mm but September was very dry with only 2.7 mm recorded. The soil is described as a Wodjil, typified by very low pH and high levels of exchangeable Al, increasing with depth. Soil samples for analysis were collected in February 2018 (Table 1). The site consisted of six 20 m wide strips, with three having had no history of lime application, and three having had a surface application of 3.5 t/ha lime sand in 2008 and a further 3 t/ha in 2012. The entire site was ripped to 30 cm and worked with a grizzly plough in 2015. Three successive years of oat crops then preceded this experiment, which was sown on the – lime and + lime strips in 2018.

The treatments included a legume comparison comprising three acid soil tolerant French serradella (cv. Cadiz, Margurita, Erica), three yellow serradella (cv. Santorini, Yellotas and 87GEH72.1a), subterranean clover varieties (cv. Dalkeith), and an acid soil sensitive lucerne (cv. SARDI 10). The cereal comparison comprised four wheat lines, two that were susceptible to Al toxicity (cv. Scepter, ES8-), aluminium tolerant (cv. Westonia, ET8+) and an acid-soil tolerant cereal rye. The isogenic wheat varieties ES8 (Al susceptible) and ET8 (Al tolerant) differ only in the absence/presence of a genetic marker for Al induced malate export (Delhaize et al. 1993). Plots were 2.1 m wide and 20 m long and sown at 25 cm row spacing. Legumes were sown at 10 kg/ha, Scepter wheat and cereal rye (50 kg/ha) and ET8-/ES8+ wheat (30 kg/ha) Cereals were sown at 30 mm and the legumes at 10 mm depth with the appropriate rhizobia as ALOSCA granules (i.e., Group C subterranean clover; Group S serradella and; Group AL lucerne). The cereals and legumes were sown as two separate randomised blocks for ease of management. On each of the unlimed (3) or limed (3) strips, the cereals received 20 kg/ha urea at 3 weeks and a further 40 kg/ha 12 weeks after emergence, while the legumes received 100 kg/ha pasture CZM multi-nutrient fertilizer (percentage content – P 18.7, S 5.1, Ca 13.6, Cu 0.6, Zn 0.3, Mo 0.04) four weeks after emergence.

Table 1. Soil analyses of the Merredin site topsoil (0-10 cm) and subsoil (10–20 cm) within unlimed (-) and limed (+) treatments prior to fertiliser application.

Element and analysis	unit	Topsoil (0-10 cm)		Subsoil (10-20 cm)	
		- Lime	+ Lime	- Lime	+ Lime
pH ($CaCl_2$)		4.6	6.5	4.2	4.6
Calcium (AmmAc)	mg/kg	260.2	827.4	143.2	348.6
Aluminium ($CaCl_2$)	mg/kg	2.6	0.1	10.7	1.1
Aluminium (Exch)	%	17.0	0.4	36.6	6.6
Nitrate - N (2M KCl)	mg/kg	3.2	18.8	3.1	25.2
Ammonium - N (2M KCl)	mg/kg	1.0	2.3	≤1	4.0
Colwell Phosphorus	mg/kg	13.0	44.6	12.4	47.0
Colwell Potassium	mg/kg	29.8	87.2	35.8	70.8
KCl Sulfur (S)	mg/kg	19.4	10.0	21.6	12.5
Magnesium (AmmAc)	mg/kg	22.8	56.8	15.8	35.0
Organic Carbon (W&B)	%	0.7	1.0	0.6	1.0
Sodium (AmmAc)	mg/kg	8.0	15.1	8.0	13.9
ECEC	cmol/kg	2.0	4.9	1.7	2.5
Ca:Mg	ratio	6.7	8.8	5.2	6.1

Agronomic assessments

Germination counts were completed in June, 3 weeks after emergence by examining 5 random samples per plot (30 x 30 cm quadrat) to estimate plants / m^2. Shoot and root dry matter (DM) samples (and nodulation assessments) were completed at 12 weeks growth by excavating and bulking plants from 5 x 0.5 m transects per plot, separating roots and shoots, drying at 70°C and weighing. Cereals were harvested with a conventional plot harvester. The seed/pod yield of legumes were estimated by bulking 5 random quadrat samples per plot once plants had senesced. Soil samples (10 core to 100mm depth per plot) were taken at the end of the growing season for Predicta B (PIRSA) analyses of soil micro-organisms and root pathogens. Pathogens assessed for which there were values; Rhizoctonia (*Rhizoctonia solani*); Yellow spot (*Pyrenophora tritici-repentis*); Leaf spot (*Bipolaris* sp.); Pythium (*Pythium* sp. Clade F); Ascochyta blight (*Didymella pinodes* and *Phoma pinodella*); Root rot (*Macrophomina phaseolina*).

Results

There were a number of nutritional differences between the treatments (Table 1). The historical application of 6.5 t/ha lime sand had increased 0-10 cm pH from 4.6 to 6.5 and tripled the levels of calcium. In the 10-20 cm layer, subsoil pH increased from pH 4.2 to 4.6 but that difference was sufficient to reduce subsoil aluminium availability from 10.7 to 1.1 mg/kg. The availability of nitrate nitrogen was up to 6x lower, potassium 3x lower and phosphorus 3x lower in unlimed plots compared to limed plots. Sulphur concentrations were greater in unlimed plots.

An analysis of broadacre plant pathogens using Predicta B (Table 2) revealed that a number of pathogens were present and that the crop variety had an effect on their disease risk ($P<0.05$). The only pathogens that fell into a high-risk category were those associated with ascochyta blight and they were prevalent only in the legume plots. Pathogens associated with root rot were predominantly found in soil from cereal plots. Soil from the unlimed plots of Scepter and ES8 wheat were high enough in the root rot pathogen to be considered a medium risk to wheat yield. On the other hand, *Rhizoctonia solani*, *Pythium* sp. and a number of pathogens known to cause diseases such as yellow spot, leaf spot and root rot were found at low risk levels in many of the cereal plots and were commonly at higher risk levels in limed plots ($P<0.05$). These pathogens were largely absent from legume plots.

Table 2. Disease risk assessment (low, medium or high on - lime and + lime plots) for a number of broadacre pathogens as determined by Predicta B DNA analysis (log transformed data) n=3. Below detection limit (BDL)

Variety	Rhizoctonia		Yellow spot		Leaf spot		Pythium		Ascochyta blight		Root rot	
	Control	Limed	Control	Limed	Control	Limed	Control	Limed	Control	Limed	Control	Limed
Cadiz	BDL	0.51	BDL	BDL	0.82	BDL	0.87	BDL	3.32	3.43	BDL	BDL
Margurita	BDL	0.63	BDL	BDL	BDL	0.62	0.00	BDL	2.72	2.70	BDL	BDL
Erica	BDL	0.84	BDL	0.37	BDL	1.85	BDL	BDL	2.85	2.12	BDL	BDL
GEH72.1a	BDL	BDL	BDL	BDL	BDL	0.66	BDL	BDL	2.58	2.29	BDL	0.55
Santorini	BDL	BDL	BDL	0.49	BDL	1.65	BDL	0.97	2.73	2.05	BDL	BDL
Yellotas	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2.61	3.06	BDL	BDL
SARDI 10	BDL	0.74	0.00	0.00	0.47	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dalkeith	BDL	BDL	0.00	0.00	BDL	0.62	BDL	BDL	2.68	1.22	BDL	BDL
ES8	1.43	1.30	0.49	1.11	1.06	1.36	0.66	0.66	BDL	BDL	1.30	0.59
ET8	BDL	2.20	0.36	1.38	BDL	2.01	BDL	0.90	BDL	BDL	0.76	0.67
Cereal rye	1.10	1.06	0.31	BDL	1.50	1.33	0.80	BDL	BDL	BDL	BDL	0.70
Scepter	1.24	1.48	0.51	1.11	1.42	1.99	0.77	0.74	BDL	BDL	1.38	1.19
Low	<1.50		<1.85		<1.20		<1.40		<2.00		<1.16	
Medium	<2.00		<2.88		<2.10		<2.00		<2.50		<2.00	
High	≥2.88		≥2.88		≥2.10		≥2.00		≥2.00		≥2.00	

A number of agronomic parameters differed between the control and limed treatments (Table 3). The number of germinating seedlings was greater in limed plots among all legume varieties but not for cereals. Shoot and root DM increased in all cereal varieties in limed treatments but there was no treatment effect among serradella varieties Shoot and root DM increased in lucerne within limed plots but decreased for subterranean clover. A manganese deficiency induced by liming appeared to reduce growth of subterranean clover in limed plots. Nodulation score generally decreased in all legumes in limed treatments (except subterranean clover) and nodule size was noticeably greater in unlimed plots (data not shown). This response may have been a result of greater nitrogen availability in limed plots rather than pH (Carroll et al. 1990). Grain yield increased in limed plots for Scepter (2.4-3.2 t/ha), ES8 (0.54-0.88 t/ha) and Westonia (2.7-3.1 t/ha) wheat but not in cereal rye or ET8 wheat. For legume varieties, pod yield was generally greater in unlimed plots (except for cv. Erica). The highest yields were recorded for the yellow serradellas cv. Santorini (2.8 t/ha) and 87GEH72.1a (2.4 t/ha), which both yielded more than double the yield of the French serradella varieties.

Table 3. Agronomic parameters assessed in limed and control (unlimed) plots (n=3). For legumes, seed yield estimates are given for subterranean clover (cv. Dalkeith) and pod yield estimates for the serradella varieties (top rows are French serradella, next three rows are yellow serradella). Nodulation rating adapted from Howieson et al. (2016). The bottom four rows are cereal varieties.

	Germination (plants/m^2)		Shoot DM (kg/ha)		Root DM (kg/ha)		Nodulation score (0-6)		Seed / pod yield (kg/ha)	
Variety	- Lime	+ Lime	- Lime	+ Lime	- Lime	+ Lime	- Lime	+ Lime	- Lime	+ Lime
Cadiz	414	626	1689	1808	192	181	4	3	1217	737
Margurita	308	351	1572	1460	164	149	4	3.7	1154	686
Erica	271	342	1418	1295	151	138	4	3.7	868	893
GEH72.1a	325	375	1594	1723	161	157	3.3	2.7	2486	2138
Santorini	271	362	1899	2160	182	180	1.7	3	2864	2569
Yellotas	445	528	1734	1701	254	234	3.3	3	717	582
SARDI 10	174	231	283	562	281	374	2	1.7	0	0
Dalkeith	66	82	1738	1056	105	59	1	2.7	252	202
ES8	104	123	473	685	106	161			542	880
ET8	119	85	540	656	112	134			1476	1044
Cereal rye	202	242	2080	2543	143	176			2662	2564
Scepter	144	142	1434	2066	143	228			2442	3244
Westonia			2167	2512	206	239			2793	3138
P-value (interaction)	<0.001		0.002		<0.001		ns		0.016	
LSD (*P*=0.05)	53.8		426		31.9				511	

Discussion

Soil amelioration by liming with some incorporation can have significant lasting effects on acidic soils, particularly in low rainfall environments (Edmeades et al. 1984). Despite historically uniform cropping programmes and regular superphosphate and nutrient applications at the site, there were still significant differences in nutrient availability between unlimed and limed treatments, particularly for nitrogen, phosphorus and potassium. Also, in spite of the comparatively small pH change in the 10-20 cm soil layer the nutrient availability was greatly improved suggesting that even shallow incorporation of lime can be beneficial.

Despite the high transport costs associated with liming there are a number of potential payoffs. These include access to a greater range of (potentially) higher yielding crop varieties and lower fertiliser inputs due to increased nutrient availability at higher pH. At this site, the potential yield of wheat cv. Scepter (one of the most popular and widely adapted commercial cultivars in W.A) was restricted by 25% where no soil amelioration (liming) had occurred. Disease risk ratings were generally higher in limed treatments. However, it is difficult to conclude whether this result was due to better growth of the host plant thereby promoting the growth of the pathogen, or if it was reflective of the pH preference of the pathogen themselves. The absence of most pathogens from the legume plots reinforces the benefit of a legume rotation as a disease break for cereals.

The use of acid-tolerant crop and legume varieties is a viable means of maintaining productivity in highly acidic soil types (Foy 1988). The tolerance of yellow serradella varieties and cereal rye to acid soils was confirmed on this acidic soil type. Serradellas have extensive root systems that increase their nutrient foraging capacity compared to other legumes (Haling et al. 2016), and this trait likely assisted their growth in unlimed control plots where nutrients were less available. French serradella also displayed acid soil tolerance, but seed yield was severely restricted in limed treatments. The lower yields could be a result of moisture stress at seed set as plant numbers were greater than in control plots. The consistently high seed yields of yellow serradella cv. Santorini and GEH72.1a indicates they are better fit for this environment.

Conclusion

This experiment describes the long-term soil effects of liming and the impact this has on the contemporary response of a range of cereals and pasture legumes ranging in acid soil tolerance. Liming was shown to have a lasting positive effect on soil pH and nutrient availability, an effect that resulted in greater biomass and up to 25% greater seed yields of acid soil sensitive species. The use of acid-tolerant species was shown to be a worthy investment in the absence of liming but this approach will limit the crop options available.

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