Soil acidification and liming in the low rainfall wheatbelt of south-western NSW.

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ABSTRACT

Soil acidity is well documented in the high rainfall (> 600 mm/yr) eastern wheat belt of NSW and has been thought to be largely confined to that area. Our study investigated soil acidity in the low rainfall south-western wheat belt near Barellan NSW (< 450 mm/yr). Twenty sites paired for agricultural and non-agricultural history were studied and showed that agriculture has caused a significant decline in soil pH_{Ca} at 0-10 cm depth. In a single field experiment, grain yield of wheat and canola were not increased by lime application. We attributed this to low aluminium saturation percentage of the effective cation exchange capacity. A glasshouse experiment on soil from the site showed a significant response to lime at an early growth stage in canola and wheat. We concluded that surface soil is acidifying in the south-western wheat belt but plant growth may not be reduced, as exchangeable aluminium was not yet at toxic concentrations.

KEY WORDS

Aluminium, canola, lime, manganese, pH, wheat.

INTRODUCTION

Soil acidification is a known problem in high rainfall eastern NSW (1, 2, 3) but little is documented in the low rainfall wheat belt. In a study of an east-west transect across south-western NSW from Cootamundra to Grong Grong, Chartres *et al.* (4) found that surface soil acidity was prevalent in the eastern wheat belt of NSW but less common in the western section of their transect.

It was anticipated that the rate of acidification due to product removal would be slower due to the low rainfall (< 450 mm/yr) and the resulting lower productivity in this area of the wheat belt compared with further east. Limited soil testing during the course of earlier research indicated low pH at some sites. It was important that any acidity problem in this low rainfall area be defined quickly to prevent large yield losses and the occurrence of subsurface acidity that has become evident in eastern NSW (5, 3, 6).

Increased exchangeable aluminium (Al) and/or manganese (Mn) in acidic soil reduces yield of crop and pasture species. The critical levels associated with damage in sensitive species are 5% Al saturation of the effective cation exchange capacity (ECEC, 7) and 0.3 cmol(+)/kg of exchangeable Mn.

The aim of our study was twofold: (i) to define the impact of agriculture on soil acidity in the < 450 mm/yr rainfall zone of south-western NSW and (ii) to measure the impact of soil acidity on plant production in that region by assessing the response of crops to lime application.

METHODS AND MATERIALS

Survey of paired sites

Twenty paired sites were soil sampled during 1997 and 1998, to identify any soil pH change due to agriculture. The sites were located within 50 km of Barellan. Soil was sampled in 10 cm intervals to 20 cm depth. Ten soil cores were taken from each area (agricultural and non-agricultural) and bulked to give four samples at each site. Soil pH_{Ca} was determined in 1:5 soil:0.01 M $CaCl_2$ and exchangeable cations (Ca, Mg, K, Na, Mn and Al) were measured by the method of Gillman and Sumpter (8). Percentage Al saturation (Al%) was the exchangeable Al expressed as a percentage of ECEC.

Field experiment

A field experiment was established in 1997 at a site near Colinroobie (S 34?? 27.4’ E 146?? 31.9’). The site was a red earth (Gn2.12; (9); Red Kandosol; (10)). This site was amongst the most acidic agricultural sites of the survey (site 17). The soil pH_{Ca} profile at the site was as follows 0 to 10 cm, 4.32; 10 to 20 cm, 4.16; 20 to 30 cm, 4.35; 30 to 40 cm, 5.29 and 40 to 50 cm, 5.80.

The experiment was limed on the 5/5/1997 using a field plot lime spreader (11). The experiment consisted of eight lime rates (nil, 0.5, 1, 1.5, 2, 3, 4 and 5 t/ha) in 4 replicates. The limestone was fine (99.5% < 250 mμm) and chemically pure (98% $CaCO_3$). Each plot was 4m x 20m. The cooperator subsequently incorporated the lime and sowed wheat (cv Janz) across the experiment in 1997 and canola in 1998. Harvest in 1997 was with a small plot header and in 1998 quadrats (4 per plot, each 0.5m x 0.5m) were hand cut and threshed to estimate grain yield. The effect of lime application on soil pH_{Ca} was determined on soil samples collected to 10 cm depth on all plots in April, 1999.

Glasshouse experiment

In 1998, unlimed soil from the experimental site was collected from the 0 to 10 cm and 10 to 20 cm layers for a glasshouse study on the response of selected acid sensitive crops (lucerne, canola, barley and wheat) to lime. The two soils were dried at 40??C, sieved (?≤ 10 mm) and 750 g (oven dry soil basis) was placed into cylindrical pots (8 cm diameter, 15 cm high) lined with plastic bags. There were 2 soils, 3 lime rates and 4 replicates in the experiment. Lime (superfine lime) was applied at rates equivalent to of nil, 1 and 2 t lime/ha and the soil and lime were thoroughly mixed. The pots were watered to 80% field capacity on 3-4 occasions over several weeks to permit the lime to react. A basal nutrient solution containing N, P, K, S, Mg, Cu, Zn, Mo and B was added to the soil. Pots were sown on 4/12/1998. Plants were thinned to either 6 (cereals) or 7 (canola and lucerne) per pot within 10 days and shoots were harvested 32 days after sowing. At the end of the experiment soil pH_{Ca} and exchangeable cations were measured in soil cored from the centre of each pot.

Statistical Analysis

The field and glasshouse experimental data were analysed by analysis of variance using the GENSTAT program (12). The paired site data was analysed using a paired t-test.

RESULTS

Survey of Paired Sites

Averaged over all sites, 0-10 cm soil was more acidic (P ?≤ 0.05) under agriculture (pH_{Ca} 4.88) than under non-agriculture (pH_{Ca} 5.23; Table 1), although only 13 of 20 sites had lower pH under agriculture. The 10-20 cm soil showed a similar but non significant trend (pH_{Ca} 4.97 cf 5.10 respective).

Table 1. The soil pH ($CaCl_2$) at two depths at paired sites (agricultural and undisturbed, non agricultural) in the low rainfall wheat belt of south-western NSW

site	Site coordinates	pH_{Ca} 0-10 agric	pH_{Ca} 0-10 non agric	pH_{Ca} 10-20 agric	pH_{Ca} 10-20 non agric	site	Site coordinates	pH_{Ca} 0-10 agric	pH_{Ca} 0-10 non agric	pH_{Ca} 10-20 agric	pH_{Ca} 10-20 non agric
1	S 34?13.0’ E 146?33.2'	4.51	5.20	4.22	5.88	11	S 34?10.5’ E 146?41.9'	5.11	6.42	5.63	7.22

2	S 34?11.2' E 146?32.4'	4.35	4.37	4.42	4.37	12	S 34?02.9' E 146?45.9'	5.30	4.92	4.93	4.66
3	S 34?04.6' E 146?35.6'	6.11	6.11	6.40	6.77	13	S 33?57.5' E 146?46.4'	4.80	4.55	4.54	3.82
4	S 33?57.2' E 146?31.2'	5.22	6.52	4.90	5.70	14	S 33?57.5' E 146?46.4'	5.28	5.00	5.66	5.27
5	S 34?22.2' E 146?15.6'	5.05	5.91	4.64	5.85	15	S 34?01.7' E 146?51.3'	4.95	5.17	4.96	4.87
6	S 34?12.8' E 146?20.2'	4.34	4.69	4.30	4.50	16	S 34?04.7' E 146?49.8'	4.30	6.02	6.27	4.22
7	S 34?10.3' E 146?20.7'	4.90	4.72	5.00	4.84	17	S 34?27.4' E 146?31.9'	4.45	4.71	4.32	4.93
8	S 34?06.4' E 146?22.1'	4.66	4.53	4.94	4.60	18	S 34?21' E 146?35'	4.71	5.08	5.04	5.20
9	S 34?14.9' E 146?34.7'	5.00	4.57	4.97	3.86	19	S 34?29' E 146?35'	4.74	5.37	4.98	5.64
10	S 34?11.6' E 146?37.9'	4.84	5.38	4.37	4.33	20	S 34?23' E 146?30'	4.92	5.41	4.91	5.55

Field Experiment

The unlimed soil was acidic (pH_{Ca} 4.49) with 5% Al saturation (Table 2). Mn was present on the exchange sites but at concentrations which would not be expected to be toxic. Lime application 23 months prior, raised pH_{Ca} and lowered exchangeable Al and Mn (Table 2). Soil pH_{Ca} was related to lime rate applied and increased by about 0.3 pH_{Ca} units per t/ha of lime (soil pH_{Ca} = 4.43 + 0.29.lime (t/ha); r^2 = 0.98). Exchangeable Al was near zero at soil pH_{Ca} > 5. Exchangeable Ca increased from 53% to 75% of ECEC with lime application.

There was no significant yield response to lime in either the wheat crop in 1997 or the canola crop in 1998. The grain yield was 2.13 t/ha (? 0.09) for wheat and 2.37 t/ha (? 0.38) for canola which were average crops for the district in the year grown.

Table 2. Surface soil (0-10 cm) pH_{Ca} and exchangeable cations for nil and 5t/ha treatments 23 months after lime application at a site near Colinroobie, NSW.

Lime Rate	Exchangeable Cations (cmol(+)/kg)

(t/ha)	pH_{Ca}	Ca	Mg	K	Na	Al	Mn	ECEC
Nil	4.49	3.48	0.91	1.38	0.18	0.32	0.26	6.53
5	5.65	7.00	0.79	1.30	0.15	0.02	0.14	9.40

Glasshouse Experiment

The surface soil (0-10 cm) had a pH_{Ca} of 4.44 (Table 3) and a buffering capacity of 0.4 pH units for each tonne lime/ha, whereas the subsurface soil (10-20 cm) was pH_{Ca} 4.57 and had a buffering capacity of 0.7 pH units for each tonne lime/ha.

Table 3. Characteristics of soil used in the glasshouse experiment collected near Colinroobie, NSW.

			Exchangeable cations (cmol(+)/kg)						
Depth	Soil	pH_{Ca}	Ca	Mg	K	Na	Al	Mn	ECEC
0-10 cm	1	4.44	3.79	0.92	1.58	0.19	0.44	0.21	7.13
10-20 cm	2	4.57	3.93	1.23	0.81	0.20	0.29	0.13	6.59

Table 4. Yield of dried shoots (g/pot) for four plant species in a glasshouse experiment on two acidic soils from Colinroobie, NSW, with lime application.

Lime Rate	0 t/ha	1 t/ha	2 t/ha	Lime Rate	0 t/ha	1 t/ha	2 t/ha
			Wheat (cv. Janz)				
Soil 1 (0-10 cm)	1.25	1.23	1.35	Soil 2 (10-20cm)	0.98	0.80	1.07
Analysis of variance: Lime (L), [A]*; Soil (S), ***; L X S, n.s.; SED = 0.10							
			Barley (cv. Schooner)				
Soil 1 (0-10 cm)	1.79	1.91	2.00	Soil 2 (10-20cm)	2.02	1.53	1.79
Analysis of variance: Lime (L), n.s.; Soil (S), n.s.; L X S, n.s.; SED = 0.18							
			Canola (cv. Oscar)				

Soil 1 (0-10 cm)	1.70	2.20	2.32	Soil 2 (10-20cm)	1.62	1.66	1.79

Analysis of variance: Lime (L), ***; Soil (S), ***; L X S, ***; SED = 0.07

Lucerne (cv. Aurora)

Soil 1 (0-10 cm)	0.49	0.32	0.38	Soil 2 (10-20cm)	0.37	0.30	0.37

Analysis of variance: Lime (L), n.s.; Soil (S), n.s.; L X S, n.s.; SED = 0.07

[A] *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$; n.s., not significant.

There was a significant lime response in shoot yield of wheat and canola but not for barley or lucerne. The interaction (Lime x Soil) was significant with canola but was not significant with lucerne, barley nor wheat (Table 4). In the canola the major effect was that lime increased growth in soil 1 (0-10cm).

The yield increase of canola in the 0-10 cm soil is interesting as canola exhibited Mn toxicity symptoms on the unlimed soil. In the surface layer canola showed a leaf crinkling and yellowing of the leaf margins consistent with Mn toxicity; lucerne also produced some yellowing of the leaf margin.

DISCUSSION

Survey of Paired Sites

The results of the survey showed that soils of the Barellan area were of similar pH_{Ca} to the transect of Chartres *et al.* (4) although Barellan is further to the north-west than the western end of that transect. The mean pH_{Ca} for 0-10 cm agricultural soil from the Chartres transect was 4.92 and for non-agricultural soil 5.03. The survey around Barellan gave corresponding results of 4.88 and 5.23 respectively. Our survey and Chartres transect contrast with the results of Young *et al*. (13) around Condobolin, which is north-north-east of Barellan. Young *et al.* found that the cropped sites had a higher mean surface (0-10 cm) pH_{Ca} than the uncropped sites; cropped soil was 5.31 and uncropped soil was 5.15.

Our data indicated a slightly more acidic soil in the Barellan area compared with the map of soil acidity estimates for NSW by Helyar *et al.* (3). Their map indicated a pH_{Ca} between 5.1 and 6.0 whereas our data indicated pH_{Ca} between 4.5 and 5.5. Helyar *et al.* (3) indicate that soils with a pH_{Ca} < 5.0 extended further inland in southern NSW compared with northern NSW but they seem to have underestimated the extent of soil acidity in southern NSW.

Field Experiment

The surface soil pH_{Ca} in field experiment was comparable to the most acidic soils of the paired site survey. The subsurface soil pH_{Ca} at the site was below 5.0 to a depth of 30 cm, with the 10-20 cm layer having a pH_{Ca} of 4.16, which was more acidic than any soil sampled in the survey. The results of the field experiment are therefore likely to be extreme compared with the district averages.

In the field experiment there was no yield response to lime. This was not consistent with similar experiments in eastern NSW (14, 15, 16). The lack of yield increase with lime was likely to be a reflection of the low Al saturation in this soil (Table 2). The highest Al saturation measured was 7%, near the 5% Al threshold for symptoms of Al toxicity in sensitive pasture and crop species. We suggest that the threshold value for Al toxicity may occur at a slightly lower soil pH_{Ca} than anticipated from research in the eastern wheat belt. These results agree with Conyers (17) who found Al (both exchangeable and saturation percentage) to be lower at a given pH_{Ca} in the inland cereal cropping area than in the eastern area.

Glasshouse Experiment

The lime response of canola in the 0-10 cm soil was not consistent with the field experiment. Mn toxicity may be different in the field compared with the glasshouse. Mn concentration varies considerably with seasonal conditions. The appearance of Mn toxicity in the glasshouse experiment indicated that Mn toxicity could be a field problem in some years for canola and possibly lucerne at that site.

CONCLUSION

Surface soil acidity was apparent in the south-western NSW wheat belt and agricultural soils had lower pH_{Ca} compared with non agricultural soils. In the field experiment grain yield did not increase with lime application as expected from experience in the eastern wheat belt. We suggest this was due to a lower Al% in these soils at a similar pH_{Ca} and yield declines due to Al toxicity may not be apparent until pH_{Ca} has declined further. Mn toxicity in canola and possibly lucerne may be a more immediate concern in this area. The soil acidity problem will need to be addressed before subsurface acidity develops.

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