Acidification of Western Australia's agricultural soils and their management

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Abstract

About one-third or 5.3M ha agricultural soils of Western Australia (WA) are prone to or have subsurface acidity. These soils have acidified since being cleared for agriculture. Susceptible soil types include the deep sands, sandy earths, gravels and duplex soils with low clay and organic carbon content and low pH buffering capacity. Acidic layers often form between 30-40 cm. As the pH (measured in 0.01 mol $CaCl_2$) declines to <4.5 aluminium (Al) solubility increases and becomes toxic to root growth. Surface liming can prevent and correct subsurface acidification but it can take >5 years to raise the soil below 10 cm. Prevention of subsurface acidification by surface liming can give wheat yield responses of 30% after 8 years in one trial at Bindi Bindi. Attempts to more rapidly ameliorate subsurface acidity with direct placement of lime behind deep ripping tines have had mixed success but in one trial at Bodallin subsurface liming increased wheat and barley yields by 30-40% within the first three years. Currently the most practical and efficient management option is to use surface liming to prevent and correct subsurface acidification. The use of crops and varieties tolerant to Al toxicity in soils where the subsoil acidity exists is essential.

Key Words

Subsurface acidity, liming, pH, deep ripping, aluminium toxicity

Introduction

Many of the agricultural soils of Western Australia (WA) are highly weathered and before clearing had neutral to slightly acidic pH (McArthur 1991). Since being cleared for agricultural use these soils have acidified and in many soils an acidic layer has formed at 10-40 cm in the soil profile (Dolling and Porter 1994). As the soil pH declines to <4.5, aluminium (Al) is dissolved and its concentration in soil solution can increase substantially as pH declines (Fig. 1a). All soil pH values are in 1:5 0.01 mol $CaCl_2$. Root growth and productivity of Al sensitive wheat is reduced when the $CaCl_2$-extractable soil Al concentration is >6 mg/kg (Tang *et al.* 2001).

Surface applications of lime and other neutralising amendments (eg. dolomite) are the most common way to correct acidity but it can take many years for surface liming to begin to correct acidity in the subsoil (Whitten *et al.* 2000). Placement of lime directly into the subsoil has been investigated as a way of more rapidly ameliorating subsurface acidity and getting an increase in grain yield sooner. In this paper we examine the extent of subsurface acidity in Western Australian soils and its correction using surface applied and deep placed lime.

Methods

Extent and distribution of subsurface acidity

Estimates of the extent of subsurface acidity were determined using the Western Australian Department of Agriculture and Food's map unit database (Schoknecht *et al.* 2004) accessed May 2006. The area represents soils that had a pH<4.5 at 20 cm and soils highly likely to acidify to <4.5 at 20 cm within 10 years (van Gool *et al.* 2005). This provides the best representation of the area currently affected by acidity as many of those soils that were highly susceptible to acidification when they were measured will have acidified and now have subsurface acidity.

Surface and subsurface liming management of subsurface acidity

The effect of surface applied limesand on subsurface acidity in a sandy gravel was examined over 8 years in a trial at Bindi Bindi (35 km east of Moora). Limesand was applied at 0, 1 and 2 t/ha in 1996. Wheat yield response to liming was measured in 1996, 1998 and 2004. Soil pH in 1997 and 2004 are reported here. Subsurface liming involved the placement of a seam lime into the subsoil behind the tines of a deep ripping machine. Two trials conducted on yellow loamy sand at Maya and Bodallin used modified farm machinery to apply lime. At Bodallin, limesand was fed from a belt-type spreader and distributed through a venturi to tubes with Morris gumbo boots with 3 outlets placed behind the ripping tines. There were 16 tines spaced 18 cm apart. With one pass limesand was applied at 1t/ha. Treatments were: a control (no ripping, no lime), ripping in one pass to 13 cm with (1 t lime/ha total) or without limesand and, ripping to 13 cm then to 18 cm in two passes with (2 t lime /ha total) or without limesand. At Maya a modified air-seeder was used to distribute and blow crushed limestone through two tubes placed behind the shanks and tines of a deep ripper with tines spaced 38 cm apart and ripping to a depth of 35 cm. Crushed limestone was applied at 1.2 t/ha in one pass to a depth of 25 cm. Treatments included an untreated control and ripped but not limed treatment. Grain yield, soil pH and extractable Al were measured at each site.

Results and Discussion

Extent and distribution of subsurface acidity

Subsurface acidity is widespread through the agricultural soils of WA with nearly one third, 5.3M ha, of agricultural land affected or at high risk (Fig. 1b). The deep sands comprise 37% of the affected soils, the deep sandy duplex 28%, the sandy earths 16% and gravels 9%. These predominantly coarse textured soils account for 90% of the total soils affected. These soils are prone to leaching, have low clay content ranging from <5% in the pale siliceous sands to 5-10% in the sandy earths and the organic carbon content of the subsoil is usually well below 1%. Consequently these soils have low pH buffering capacity and the rate of acidification can be high.

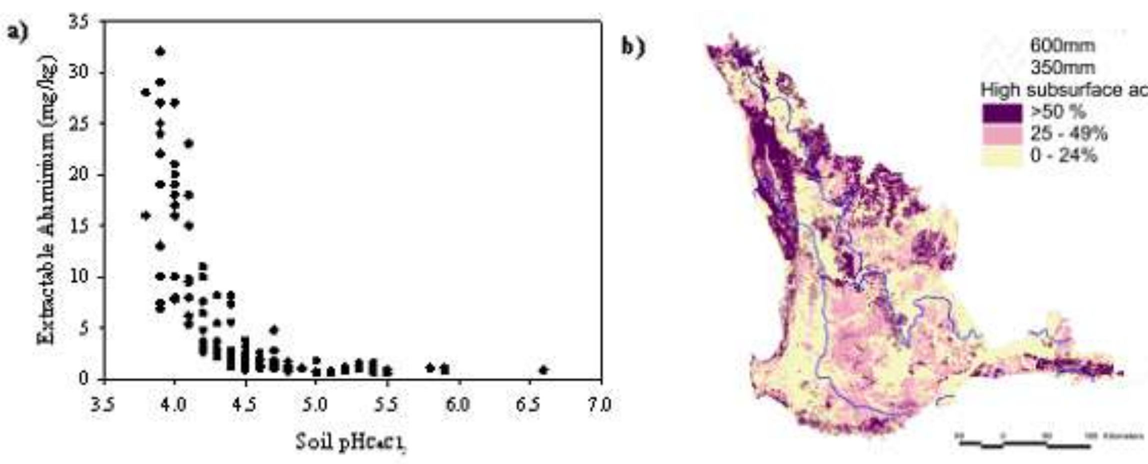

Figure 1. (a) The relationship between extractable aluminium and soil pH for 135 topsoil and subsoil samples collected throughout the south-west of Western Australia in 2005 and (b) the distribution of soils that are currently acid (pH<4.5 at 20 cm) or at high risk of subsurface acidity (within 10 years) determined using the WA Department of Agriculture and Food's map unit database accessed in May 2006.

Management of subsurface acidity

Surface application of limesand at 1 or 2 t/ha prevented ongoing acidification at 10-20 cm in the soil profile at Bindi Bindi (Table 1). In the control plots (no lime) the pH of the whole profile declined by half a pH unit from 1997 to 2004. In the limed plots soil pH was maintained at or above 1996 levels for the top 20 cm and reduced the decline in pH at 20-30 cm (Table 1). Extractable Al was reduced from 9 mg/kg at 10-20 cm in control plots to <4 mg/kg after liming (data not shown).

Table 1. Soil pH values in response to lime applied to the soil surface in 1996 at Bindi Bindi.

Soil depth (cm)	Control		1 t lime/ha in 1996	2 t lime/ha in 1996
	1997	2004	2004	2004
0-10	4.9	4.4	5.0	5.6
10-20	4.3	3.9	4.4	4.3
20-30	4.5	4.0	4.2	4.3

There were no wheat yield increases due to liming in the year of lime application or in 1998 (Table 2).. In 2004, 8 years after surface applications of lime, 700 kg/ha more wheat grain was produced where 2 t lime/ha had been applied (Table 2). Grain yield responses to surface liming usually do not occur in the year lime is applied and it can take a number of years for the maximum benefit to be realised, as was the case with the Bindi Bindi experiment. Large yield gains are seen when subsurface acidity is corrected but it can take >5 years for surface liming to raise subsurface pH (Whitten *et al.* 2000; Tang *et al.* 2003).

Table 2. Grain yield responses to lime applied to the surface in 1996 at Bindi Bindi. For each column, yields followed by the same letter are not significantly different at $P = 0.05$

Treatment	Wheat yield (t/ha)		
	1996	1998	2004
nil lime	2.2a	1.61a	2.5a
1t lime/ha	2.3a	1.74a	2.7a
2t lime/ha	2.2a	1.82a	3.2b

At Bodallin pH in the limed seam was increased to >5.5 (Fig. 2a) at 10-20 cm and extractable Al reduced to <1 mg/kg to a depth of 20 cm (Fig. 2b). At 30 cm the soil remained strongly acidic and extractable Al was still >8 mg/kg soil.

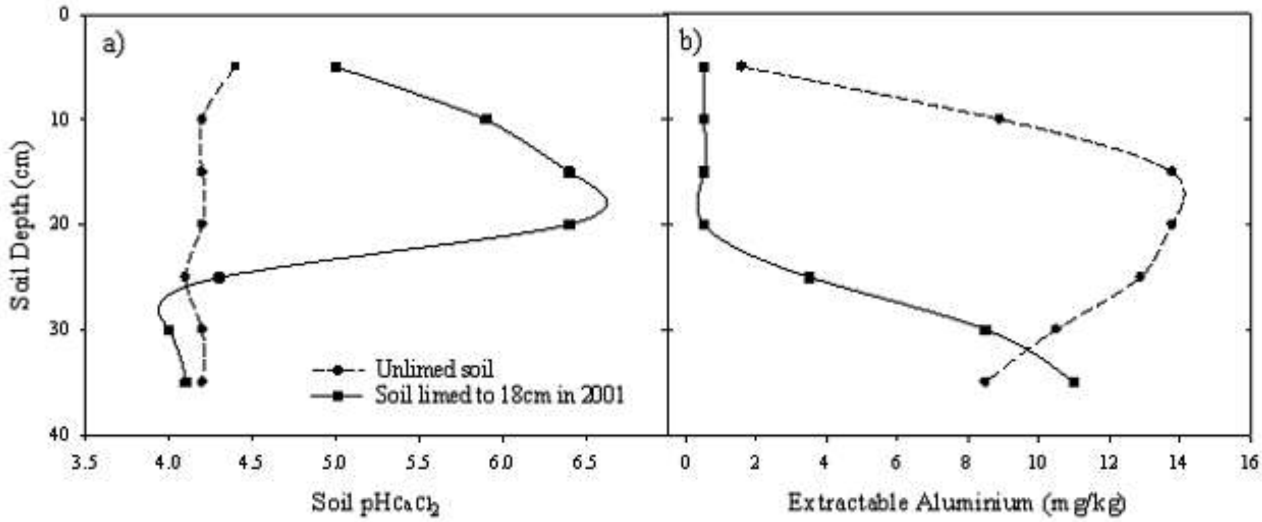

Figure 2. Soil pH (a) and extractable aluminium (b) in deep placed lime seams (■) and unlimed (●) yellow loamy sand soil at Bodallin measured May 2005.

At Bodallin there were large yield increases (Table 4) for the 2 t lime/ha treatment, with the lime mixed through the entire seam from the surface to a depth of 20 cm (Fig. 2a,b). This treatment increased cereal grain yields above the untreated control by 410, 480 and 370 kg in 2001, 2003 and 2004, respectively and by 180, 530 and 400 kg compared with the ripped to 18 cm without lime treatment (Table 4). Ripping without lime gave no yield response possibly due to high extractable Al preventing root growth.

Table 4. Grain yields of wheat and barley following deep ripping and lime treatments applied in February 2001. Data mean of 4 replicates. For each column, yields followed by the same letter are not significantly different at *P* = 0.05.

	Grain yield (t/ha)		
Treatment	2001 Wheat	2003 Wheat	2004 Barley
Control: not ripped, no lime	2.63a	1.74a	1.03a
Rip 13 cm, no lime	2.75a	1.70a	1.12a
Rip 13 cm then 18 cm, no lime	2.86a	1.69a	1.00a
Rip 13 cm while applying 1 t/ha lime	2.56a	1.81a	1.13a
Rip 13 cm while applying 1 t/ha lime, + rip 18 cm while applying 1 t/ha lime	3.04b	2.22b	1.40b

At Maya the deep placed lime was not evenly distributed down the ripped seam (Fig. 3a). It was intended that the lime would be mixed in the disturbed soil as the ripping tines moved through the soil at 35 cm and the lime was placed at 25 cm but most of the lime remained at 25 cm with much smaller increases in pH at 20 and 30 cm (Fig. 3a). Acidity was most severe, pH<4.0 at 15 cm (Fig. 3a) with high soil extractable Al >7 mg/kg (data not shown) and this strongly acid layer remained in the limed soil seam above the deposit of deep placed lime (Fig. 3a).

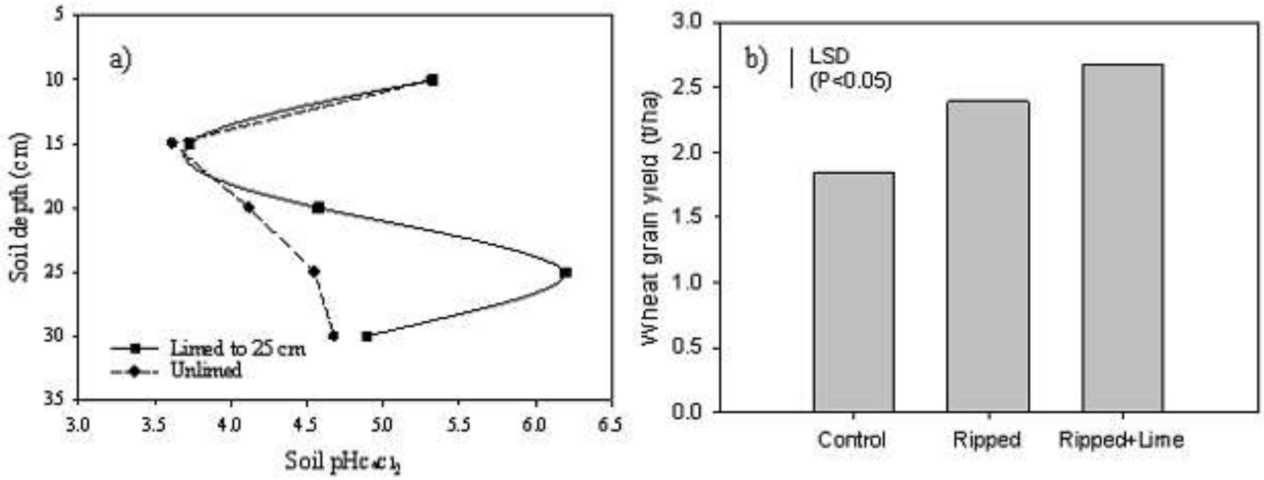

Figure 3. (a) Soil pH in deep placed lime seams (■) and unlimed (●) yellow loamy sand soil at Maya measured April 2004. (b) Wheat grain yield (t/ha) in 2004 for untreated (control), deep ripped to 35 cm without lime (Ripped) and deep ripped to 35 cm with 1.2 t/ha crushed limestone placed at 25 cm (Ripped+Lime).

In 2004, there was a significant grain yield response to ripping but no response to the deep placed lime (Fig. 3b). This may be because the acid layer was not fully ameliorated and a band of strongly acid and Al toxic soil remained at 15 cm (Fig. 3a) preventing a grain yield response. This is similar to other deep placed lime trials where the lime did not get fully mixed vertically throughout the ripping seam (data not shown). Large yield responses to deep ripping are common in these sandy earth soils (Schmidt *et al.* 1994), similar to the soil at Maya. However, at Maya, the levels of extractable Al apparently were not high enough to prevent a grain yield response to deep ripping unlike the Bodallin site.

Conclusion

Subsurface acidity is a widespread and increasing problem in the agricultural soils of Western Australia. Deep placement of lime to ameliorate subsurface acidity can increase grain yields by 30-40% where successful but this is technically difficult and expensive. Surface liming to increase and maintain surface pH >5.5 to prevent subsurface acidity before the subsoil pH declines to 4.5 is the best management strategy. In situations where the subsoil pH<4.5, the use of surface lime and growing crop varieties tolerant to high soil Al is recommended until lime moves into the subsoil.

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