Effectiveness of common brown manures and $Ca(NO_3)_2$ in ameliorating acid soils

Clayton Butterly, Peter Sale and Caixian Tang

Department of Animal, Plant and Soil Sciences, La Trobe University, Melbourne, VIC 3086, C.Butterly@latrobe.edu.au

Abstract

The incorporation of crop residues into acidic subsoils via deep ripping could be an effective approach to ameliorate the effects of acidity of crop growth. The utilisation of on-farm residues is thought to be more cost effective than other materials, such as litters and manures, which are expensive and difficult to transport. Brown manuring could providing a source of residue while also facilitating the control of herbicide-resistant weeds. Crop residues generate alkalinity during decomposition. In addition, using NO_3^- as the form of N can facilitate alkalinisation of the rhizosphere due to the excess uptake of anions over cations by plant roots. A pot experiment was conducted in a glasshouse to evaluate the effectiveness of 4 commonly used brown manures, field pea, oats, vetch and wheat in combination with two $Ca(NO_3)_2$ levels (64 and 191 mg N/kg) in improving wheat growth in two contrasting acid soils. Residues were added at 16 g/kg soil to a Sodosol (pH 3.9) with an extractable Al of 9 mg/kg soil and low pH buffer capacity (pHBC) of 23 mmol$_c$/kg soil/pH. An experimental soil (pH 3.9) consisting of a 60/40 mix of Ferrosol/Dermosol with high extractable Al (38 mg/kg) and pHBC (86 mmol$_c$/kg soil/pH). All treatments increased plant growth and soil pH, and decreased Al concentration, with legume residues (field pea and vetch) being more effective than cereal residues (oat and wheat). Higher rates of $Ca(NO_3)_2$ further increased pH except when combined with legume residues in the Sodosol. Improvements in ES8 wheat biomass were not always associated with greater reductions in Al in the Sodosol, since most treatments had reduced Al concentrations to below toxic levels.

Keywords

Subsoil acidity, soil pH, aluminium, crop residues.

Introduction

Acidic subsoils (pH < 5.5) severely limit agricultural productivity in southern Australia, primarily due to high Al^{3+} and Mn^{2+} concentrations which are toxic to plants. Lime ($CaCO_3$) applied on the soil surface moves very slowly through the soil profile and is not suitable to ameliorate deep acidic soil layers (10-30 cm) in the short term. Consequently, direct incorporation of lime and organic amendments into these layers has gained recent attention. Organic amendments generate alkalinity as they decompose, improving soil physiochemical properties while also providing essential crop nutrients (Butterly et al. 2003). Combined incorporation of lime and organic materials is likely to be an effective solution to subsoil acidity. In particular, litters and manures are effective amendments for acid soils but these may not always be practical and/or profitable due to the high costs associated with their purchase and transport. On-farm organic materials, such as crop and pasture residues, could be a suitable alternative. In particular, crops grown as brown manures would generate suitable biomass for subsoil amelioration while providing the opportunity to control weeds. Also, soil pH could be increased further by using $Ca(NO_3)_2$ as the N fertiliser form. A net excess uptake of anions over cations induced by plant NO_3^- uptake results in the release of OH^-/HCO_3^- into the rhizosphere (Tang et al. 2011; Weligama et al. 2008). This study aimed to evaluate the effectiveness of 4 commonly used brown manures in combination with $Ca(NO_3)_2$ in ameliorating acid soils.

Methods

Soil and residue collection

Soils from roadsides were collected in March 2016 from two different soil types, Ferrosol and Dermosol (Isbell 1996) in Kinglake West, Victoria (37°28’02.0” S 145°15’34.5” E). An experimental soil was derived by combining 60% Ferrosol and 40% Dermosol with a pH_{CaCl2} 3.9, high extractable Al of 38 mg/kg and pHBC 86 mmol$_c$/kg soil/pH unit. A Sodosol (Isbell 1996) with a pH_{CaCl2} 3.9, moderate extractable Al of 9 mg/kg soil and low pH buffer capacity (pHBC) of 23 mmol$_c$/kg soil/pH unit was collected from a cropped paddock at Dirnaseer near Cootamundra, NSW (34°38’30.5” S 147°49’44.3” E) in August 2016. All soils were air-dried, passed through a 2-mm sieve and thoroughly mixed.

Residues (shoots) of field pea (*Pisum sativum*), oats (*Avena sativa*), vetch (*Vicia sativa*) and wheat (*Triticum aestivum*) crops were collected from field sites in September 2016 from Normanville, Victoria (35°48'32.7" S, 143°45'34.9" E). All crops were in mid reproductive stages with the timing of biomass collection coinciding with the termination of vetch for weed control. The residues were transferred to a well-vented glasshouse where they were allowed to slowly desiccate over a 3-week period under natural light and ambient temperatures. Subsequently, residues were chopped (2-4 cm), dried at 70°C for 3 days, ground using a Retsch ZM200 centrifugal mill until all material passed through a 2-mm sieve.

Experimental details and design

A pot experiment evaluated the effectiveness of 4 commonly used brown manures, field pea, oats, vetch and wheat in combination with two $Ca(NO_3)_2$ levels (64 and 191 mg N/kg) in improving wheat growth in two contrasting acid soils. Residues were added at 16 g/kg soil to a Sodosol and a Dermosol after the addition of the following basal nutrients (mg/kg); K_2SO_4, 147; $CaCl_2.2H_2O$, 186; $MgSO_4.7H_2O$, 122; $ZnSO_4.7H_2O$, 8; $CuSO_4.5H_2O$, 6; $Na_2MoO_4.2H_2O$, 0.4 and KH_2PO_4, 112.5, except that 10 times more P was added to the Dermosol due to its high P-fixing capacity. Soils were then transferred to black HDPE pots (130 mm diameter × 122 mm high) (P130SLTLW, Garden City Plastics, Victoria) lined with plastic bags to prevent leaching. Pots were filled to the same height which resulted in 880 g Dermosol and 1180 g Sodosol due to their different bulk densities of 1.1 and 1.5 g/cm^3, respectively. Pots were wet to field capacity, 331 g/kg Dermosol and 148 g/kg Sodosol, with reverse osmosis (RO) water and transferred to a glasshouse at AgriBio, La Trobe University, with an average temperature of 20-25°C and an average light period of 15 hours. After 5 weeks incubation, 10 pre-germinated seeds of ES8, an Al-sensitive wheat genotype were planted within each pot at a depth of approximately 1.5 cm. The first $Ca(NO_3)_2$ treatment was applied immediately after sowing. After 1 week, wheat plants were thinned to 5 plants/pot. Pots were adjusted to field capacity at regular intervals with RO water and two additional applications of $Ca(NO_3)_2$ were applied at 19 and 33 days after planting. Every few days pots were rotated in the glasshouse to account for any differences in light and temperature.

Sampling and analyses

Plants and soil within the pots were destructively sampled after 6 weeks of growth. Plant shoots were removed, washed in 0.1 M HCl and rinsed three times with Milli-Q water. Roots were carefully removed from the soil, cleaned free of debris, washed thoroughly with RO water then soaked in 0.01 M $BaCl_2$ for 5-10 min before being rinsed three times with Milli-Q water. Shoot and root samples were then dried at 70°C for 3 days. Soil from each pot was thoroughly mixed, subsampled, and air-dried at 25°C. Soil pH was quantified using a pH electrode (HI1043, Hanna Instruments, USA) after shaking end-over-end for 1 h in a 0.01 M solution of $CaCl_2$ (1:5 soil:solution), followed by centrifugation at 839 × *g* for 5 min. The $CaCl_2$ extracts were passed through 0.22-µm filters and the Al concentrations were determined via inductively coupled plasma optical emission spectroscopy (ICP-OES) (Perkin Elmer Optima 8000, USA).

Statistical analyses

For each soil, a two-way analysis of variance (ANOVA) in a fully randomised design was used to test the effects of crop residue and $Ca(NO_3)_2$ level on shoot and root biomass and soil chemical parameters. Significant ($P = 0.05$) differences between means were established using the least significance difference (LSD) test.

Results

Plant growth

All crop residues significantly increased ES8 wheat shoot growth compared with non-amended control (shoot biomass response ratio), except for oats and wheat residue plus high $Ca(NO_3)_2$ treatment (Table 1). Vetch showed the greatest effect on ES8 shoot growth, with 3.7 to 4.2 and 3.24 to 5.12 times more shoot biomass in the Dermosol and Sodosol, respectively. Notably, field pea residue had a lesser effect on the shoot biomass in the Sodosol (~2.01) than the Dermosol (~3.26). Overall, the effect of $Ca(NO_3)_2$ was less significant in the Dermosol (P=0.014) than in the Sodosol (P<0.001), with the higher $Ca(NO_3)_2$ level having a negative impact on ES8 shoot growth in the Dermosol. In contrast, the significant (P=0.05) of amendment and $Ca(NO_3)_2$ resulted in increases in the ES8 shoots biomass ratio of 0.4, 1.0, 1.7 and 1.9 for field pea, wheat, oats and vetch, respectively.

Root biomass response ratios to the treatments were generally proportional to that of the shoots, albeit lower in magnitude (Table 1). The exception was wheat-amended Sodosol which showed greater root than shoot response. Root biomass response ratios to the treatments were generally proportional to that of the shoots, albeit lower in magnitude (Table 1). The exception was wheat-amended Sodosol which showed greater root than shoot response. ES8 wheat root growth was ~2.3 and 2.7 times greater in field pea- and vetch-amended Dermosol than the non-amended controls, with wheat and oats having the same effect (~1.16). The higher rate of $Ca(NO_3)_2$ significantly ($P<0.05$) reduced ES8 root growth in the Dermosol amended with the vetch residue but not with other amendments. Similar for shoots, a significant ($P<0.001$) interaction of amendment and $Ca(NO_3)_2$ was observed for roots, whereby greater increases in root biomass response were observed for oats (~2.22) and wheat (~1.46), cereal residues, than for field pea (~0.44) or vetch (~0.45), legumes residues.

Table 1. Shoot and root biomass response ratio (g dry weight amended/g dry weight non-amended) of ES8 wheat plants grown for 6 weeks in Dermosol and Sodosol amended with field pea, oats, vetch or wheat residues and $Ca(NO_3)_2$ at either 64 or 191 mg N/kg. Not significant (n.s.), *, ** and * indicate $P>0.05$, $P\leq0.05$, $P\leq0.01$ and $P\leq0.001$ for two-way analyses of variance (amendment × $Ca(NO_3)_2$).**

Amendment	$Ca(NO_3)_2$	Shoot biomass ratio		Root biomass ratio	
	(mg N/kg)	Dermosol	Sodosol	Dermosol	Sodosol
Field pea	64	3.24	1.83	2.26	0.86
	191	3.27	2.19	2.33	1.30
Oats	64	1.19	1.27	1.25	1.27
	191	0.96	2.93	0.99	3.50
Vetch	64	4.20	3.24	3.01	2.99
	191	3.70	5.12	2.43	3.45
Wheat	64	1.30	0.59	1.26	0.81
	191	1.06	1.63	1.13	2.27
	LSD ($P=0.05$)	0.25	0.40	0.27	0.36
	Significance level				
	Amendment	***	***	***	***
	$Ca(NO_3)_2$	*	***	*	***
	Amendment × $Ca(NO_3)_2$	n.s.	**	n.s.	***

Table 2. Changes in soil pH (Δ pH_{CaCl2}) of Dermosol and Sodosol amended with field pea, oats, vetch or wheat residues and $Ca(NO_3)_2$ at either 64 or 191 mg N/kg, planted with ES8 wheat relative to non-planted controls. Not significant (n.s.), ** and * indicate $P>0.05$, $P\leq0.01$ and $P\leq0.001$ for two-way analyses of variance (amendment × $Ca(NO_3)_2$).**

Amendment	$Ca(NO_3)_2$	Δ pH_{CaCl2}	
	(mg N/kg)	Dermosol	Sodosol
Field pea	64	0.182	0.295
	191	0.242	0.319
Oats	64	0.020	0.303
	191	0.089	0.425
Vetch	64	0.117	0.466
	191	0.204	0.482
Wheat	64	0.020	0.194
	191	0.066	0.304
Nil	64	-0.014	0.086
	191	0.059	0.054
	LSD ($P=0.05$)	0.025	0.041
	Significance level		
	Amendment	***	***
	$Ca(NO_3)_2$	***	***
	Amendment × $Ca(NO_3)_2$	n.s.	**

Changes in pH of ES8 planted treatments relative to the non-planted controls (Δ pH_{CaCl2}) were greater in the Sodosol than Dermosol as expected, reflecting the difference in pHBC (Table 2). However, the relative effectiveness of the organic amendments was different between the two soils. In the Dermosol, changes in pH ($P<0.001$) were in the order field pea > vetch > oats ~ wheat ~ nil. For all treatments, adding higher amounts of $Ca(NO_3)_2$ to the Dermosol further increased soil pH by up to 0.087 pH units. In the Sodosol, there was a significant ($P=0.003$) amendment × $Ca(NO_3)_2$ interaction whereby all amendments increased pH compared to nil controls with the order of magnitude was vetch > oats ~ field pea > wheat and the higher $Ca(NO_3)_2$ rate only further increased pH (up to 0.122 pH units) for wheat and oat-amended soil. Reductions in Al concentrations varied between the soils (Table 3). In the Dermosol, the significant (P=0.019) interaction between amendment and $Ca(NO_3)_2$ was such that the greatest reductions on Al were for vetch and field pea residues and $Ca(NO_3)_2$ only further reduced Al for these residues and not cereal residues. Further, field pea and vetch were 6 times more effective than oat of wheat residues in the Dermosol but the relative differences between treatments were much less in the Sodosol. In the Sodosol, a significant (P<0.001) interaction between amendment and $Ca(NO_3)_2$ occurred whereby all amendments reduced Al by more than 80%, except for wheat residue + $Ca(NO_3)_2$ 64 mg N/kg treatment. Also, the higher rate of $Ca(NO_3)_2$ only reduced Al further in oat and wheat-amended Sodosol. Interestingly, $Ca(NO_3)_2$ achieved a 33.3-45.3% reduction in Al concentration in the Sodosol in the non-amended (nil) treatment.

Table 3. Reduction in Al concentration (%) of Dermosol and Sodosol amended with field pea, oats, vetch or wheat residues and $Ca(NO_3)_2$ at either 64 or 191 mg N/kg, planted with ES8 wheat relative to non-planted controls. * and * indicate $P \leq 0.05$ and $P \leq 0.001$ for two-way analyses of variance (amendment × $Ca(NO_3)_2$).**

Amendment	$Ca(NO_3)_2$ (mg N/kg)	Reduction in Al (%)	
		Dermosol	Sodosol
Field pea	64	61.3	81.0
	191	66.2	83.1
Oats	64	11.6	81.5
	191	11.9	94.0
Vetch	64	64.4	93.4
	191	71.1	95.4
Wheat	64	7.5	71.7
	191	8.3	85.3
Nil	64	0.6	45.3
	191	1.6	33.3
	LSD (P=0.05)	2.1	1.9
	Significance level		
	Amendment	***	***
	$Ca(NO_3)_2$	***	***
	Amendment × $Ca(NO_3)_2$	*	***

Conclusion

This study showed that crop residues, particularly vetch, effectively increased pH, reduced Al and hence improved ES8 wheat growth. While the decomposition of crop residues grown *in situ* does not result in any net change in alkalinity within that soil profile, the redistribution of crops residues (and hence alkalinity) into hostile acidic soil layers is hoped to vastly improve the productivity of the system. The use of $Ca(NO_3)_2$ to increase pH and reduce Al concentration is not likely to be effective in highly acidic and highly buffered soils as some root function is needed to take up the nitrate and the capacity to change pH is reduced. Also, the ability to manipulate rhizosphere pH by adding $Ca(NO_3)_2$ was considerably reduced in soils amended with legume residues due to the higher soil N pool, compared with cereal-amended soils. This research aims to generate new knowledge to assist growers and land managers to better manage their farming systems and *do more with less* by not solely relying on costly off-farm products to combat acid soils.

Acknowledgements

This work is part of a GRDC project (DAN00206) investigating innovative approaches to managing subsoil acidic in the southern grain region of Australia.

References

Butterly CR, Baldock JA and Tang C (2013). The contribution of crop residues to changes in soil pH under field conditions. Plant and Soil 366, 185-198.

Isbell R (1996). The Australian Soil Classification, CSIRO Publishing, Melbourne.

Tang C, Conyers MK, Nuruzzaman M, Poile GJ and Liu DL (2011). Biological amelioration of subsoil acidity through managing nitrate uptake by wheat crops. Plant and Soil 338, 383-397.

Weligama C, Tang C, Sale PWG, Conyers MK and Liu DL (2008). Localised nitrate application together with phosphorus enhances root proliferation of wheat and maximises rhizosphere alkalisation in acid subsoil. Plant and Soil 312, 101–115.