The impact of lime and gypsum on pasture composition in a grass/legume mixture grown on a shallow acidic loam

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Abstract
Lime (nil, 2.5, 5, and 7 t/ha) and/or gypsum (nil, 2.5, 5, and 7 t/ha) were applied in 2008 to the surface of a shallow, acidic, shale-derived soil near Goulburn, NSW. The experimental area was sown to a mixture of pasture species which included phalaris (*Phalaris aquatica*), cocksfoot (*Dactylis glomerata*), tall fescue (*Lolium arundinaceum*), subterranean clover (*Trifolium subterraneum*) and white clover (*T. repens*) 8 weeks after treatments were imposed. The site was rotationally grazed under standard farmer practice. Changes in soil chemistry and botanical composition were monitored for three years. Results showed that soil pH had increased by up to 1.5 units from pH_{CaCl2} 4.4 at the 0-5 cm depth interval 24 months after lime was applied, with little difference observed below that depth. Lime increased the white clover component in the sward by up to 27%, but decreased the subterranean clover component from 20% to <5% of total sward biomass, despite previous studies showing there to be little difference in the acid soil tolerance of these two species. Overall, total legume content in the sward increased over 3 years due to lime. Cocksfoot was the dominant perennial grass species comprising 26-58% of pasture biomass across the various treatments after 3 years. Phalaris and tall fescue had declined to negligible levels in all treatments after only 3 years despite the 3 grass species establishing at equivalent initial plant densities. Gypsum had little effect on pasture composition in this soil compared to the nil treatment.

Key Words
Cocksfoot, white clover, subterranean clover, phalaris, tall fescue, sodic soil

Introduction
The constraints to pasture production posed by soil acidity and related nutrient imbalances in Tablelands environments was reviewed by Scott *et al*. (2000). In general, soil acidity in permanent pasture environments is more difficult to combat than in mixed farming environments due to practical constraints associated with incorporating lime into the top soil. In addition, many shallow acidic soils are constrained by multiple abiotic factors. Soil sodicity is known to inhibit pasture production but can be ameliorated by gypsum (Dear *et al*. 2010). In soils that are both acidic and sodic, management strategies are less well understood, particularly in a permanent pasture context. The current study aimed to assess the impact of surface applied lime and gypsum to soil chemical characteristics and pasture composition of a newly sown pasture on the Southern Tablelands of NSW.

Methods
The experiment was established on a shallow, acidic, shale-derived loam near Goulburn, NSW. Lime and gypsum were applied at 5 t/ha and 7 t/ha alone, or in combination (mixture) in a 1:1 ratio at 2.5, 5 and 7 t/ha and compared to a nil control. Where mixtures were applied, the lime component was applied first followed by the gypsum component. The experiment was a randomised design replicated 4 times. Plot size was 10 x 4 m and lime and gypsum were applied by hand on 27 April 2008. The pasture was direct-drilled on 26 June 2008, 8 weeks after treatments were imposed, using a John Shearer SSD linkage tyne seed-drill with T-boots by the farmer. The sowing mixture included 4 kg/ha phalaris (cvv Australian 2 kg/ha, Holdfast 1 kg/ha, Sirosa 1 kg/ha), 3 kg/ha cocksfoot (cvv. Currie and Porto 1.5 kg/ha each), 4 kg/ha tall fescue (cv. Demeter), 4 kg/ha subterranean clover (subclover, cvv. Leura and Goulburn 2 kg/ha each) and 1 kg/ha white clover (cv. Haifa). Granuloc 15 fertiliser (14.3% N, 12% P, 10.5% S) was applied at sowing at 140 kg/ha. The site was managed according to the farmer's rotational grazing regime along with the remainder of the 17 ha paddock.

Establishment density of all sown species was determined on 23 October 2008 by counting plant numbers in

4 x 1 m sections per plot of drill rows selected at random. Soil samples were collected 26 months following lime/gypsum application by taking 10 soil cores per plot at 0-5 cm and 5-10 cm depths.
Soil pH was measured on a 1:5 soil:0.01*M* $CaCl_2$ solution. Electrical conductivity was measured on a 1:5 soil:distilled water solution. Soil P was determined by the method of Colwell (1963) which involved the end-over-end shaking of a 1:100 soil:0.5*M* sodium bicarbonate solution for 16 hours at 20ºC, followed by immediate filtering through Whatman no 40 papers with P in solution determined colorimetrically following development of the phospho-molybdenum-blue colour reaction. Soil exchangeable cations were determined by extraction using a 1:10 soil:0.1*M* $BaCl_2$/0.1*M* NH_4Cl solution. Solutions were centrifuged and the supernatant analysed by atomic absorption spectroscopy for cations (Al, Mn, Ca, K, Na, Mg) (Gillman and Sumpter 1986). Cations were summed to give effective cation exchange capacity (ECEC).

Pasture composition was assessed on 8 November 2010, approximately 29 months following lime and gypsum application, using the dry weight rank (botanal) technique replicated 10 times per plot. Herbage production was not assessed as the experiment was grazed in rotation along with the remainder of the paddock. Data were subjected to analysis of variance using Genstat 13.2 (VSN International, Hemel Hempstead, United Kingdom) and least significant differences calculated at the 5% level.

Results

Either lime, gypsum or their combinations had no effect (P=0.05) on the establishment density of phalaris (35.4 plants/m^2), subclover (3.1 plants/m^2) or white clover (4.7 plants/m^2). For both cocksfoot and tall fescue, establishment density tended to be lower where gypsum was applied in the absence of lime, and higher where lime was applied at the highest rate either on its own or in a mixture with gypsum (Table 1).

Table 1. Effect of lime and/or gypsum on establishment density (plants/m^2) of cocksfoot and tall fescue.

Treatment	Cocksfoot	Tall fescue
Nil	26.5	30.5
Lime 5t/ha	22.4	29.3
Lime 7t/ha	27.1	32.2
Gypsum 5t/ha	20.8	28.0
Gypsum 7t/ha	20.0	33.9
Mixture 2.5t/ha	22.7	35.8
Mixture 5t/ha	25.3	38.0
Mixture 7t/ha	24.7	40.7
l.s.d.$_{0.05}$	*4.88*	*8.25*

Table 2. Effect of different rates of gypsum and/or lime (t/ha) on pH and electrical conductivity (EC; dS/m) of soil at the 0-5 and 5-10 cm depths, and exchangeable aluminium (Al) and sodium (Na) concentrations (expressed as a percentage of the ECEC) of samples from the 0-5 cm depth taken in June 2010.

Treatment	pH_{Ca}	EC	Al (%)	Na (%)	pH_{Ca}	EC
	0-5 cm				*5-10 cm*	
Nil	4.41	0.12	21.2	5.1	4.37	0.12
Lime 5t/ha	5.55	0.15	0.4	2.8	4.37	0.14
Lime 7t/ha	6.13	0.25	0.7	2.1	4.58	0.11
Gypsum 5t/ha	4.38	0.21	20.4	2.7	4.23	0.22
Gypsum 7t/ha	4.43	0.36	15.3	3.8	4.25	0.29
Mixture 2.5t/ha	5.12	0.16	1.5	3.0	4.30	0.18
Mixture 5t/ha	5.91	0.37	0.3	1.8	4.47	0.29
Mixture 7t/ha	5.72	0.42	0.5	2.9	4.60	0.32
l.s.d.$_{0.05}$	*0.365*	*0.188*	*4.78*	*ns*	*ns*	*ns*

Twenty-six months after application, soil pH increased from 4.41 up to 6.13 at the 0-5 cm depth with the highest rate of lime and Al was reduced to <2% of the effective cation exchange capacity with all rates of lime, but gypsum had no effect on either soil pH or exchangeable Al concentration (Table 2). There was no effect of lime or gypsum on soil pH below 5cm. Gypsum increased the electrical conductivity of the soil from 0.12 to 0.42 dS/m but had no effect on the concentrations of exchangeable Na at the soil surface. There was no effect of lime or gypsum on Colwell P at either the 0-5 cm (20 mg P/kg) or 5-10 cm (6 mg P/kg) depths. The Colwell P for the more commonly reported sampling depth of 0-10 cm was 13 mg P/kg.

Cocksfoot and volunteer species were most prevalent in the nil treatment (Fig. 1). White clover only comprised 10% of the nil treatment sward compared to 26-38% of swards in which lime was applied. Cocksfoot was also more prevalent than white clover in the gypsum-only treatments, which was in contrast to treatments in which lime was applied. Gypsum or lime treatment had no effect (P=0.05) on the proportions of phalaris (1.2%), tall fescue (0.9%), subclover (31.1%), or naturalised annual legumes (13.7%) in the swards. The combined legume content (white clover, subclover and naturalised annual species) of the sward increased from 47% of the nil swards to ~80% of swards to which lime was applied.

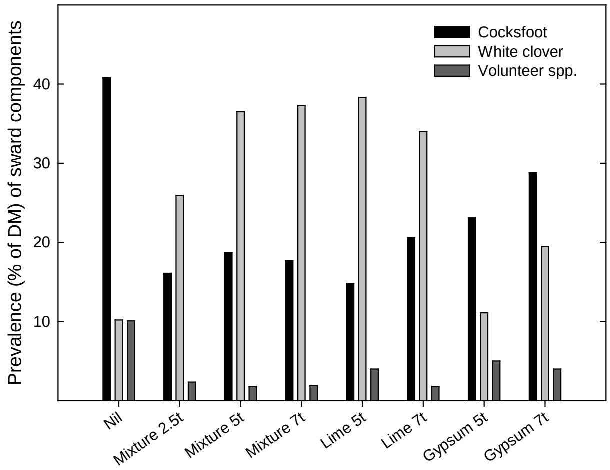

Fig.1. Effect of different rates of gypsum and/or lime (t/ha) on the prevalence of cocksfoot, white clover and volunteer species in the pasture swards in 26 months after treatment imposed.

Discussion

There were two major findings of this study. First, the application of lime increased the proportion of white clover in the sward from 10% to 26-38%. White clover has been previously shown to be relatively tolerant of soil acidity and Al toxicity (McVittie *et al.* 2012), so the strong response to lime was not anticipated. Indeed, subclover is also relatively tolerant of soil acidity and its prevalence in the pasture sward remained at ~30% regardless of soil amendment.

White clover is known to be sensitive to drought stress (Lane *et al.* 2000) and aluminium toxicity is known to inhibit root growth and reduce the capacity of the plant to explore the soil volume for water. Where lime was applied in our experiment, Al concentrations were reduced from ~20% to <1.5% in the 0-5 cm depth. The implication here is that lime increased the capacity for white clover to explore the surface 5 cm of soil volume, increasing its ability to compete for soil moisture and persist. Alternatively, the increased root growth in the surface 5 cm enhanced the capacity of white clover to explore the soil volume and penetrate the >5 cm depths by accessing less acidic pores in the subsoil. Either way, white clover persistence was increased. A similar effect was noted in seedling phalaris establishing under moisture stress (Culvenor *et al.* 2011), suggesting that one way to improve the persistence of white clover in acid soil environments of the Tablelands is to select for improved tolerance to Al toxicity, similar to the approach taken in phalaris.

The second major finding of this study was the superior persistence of cocksfoot in these mixed swards compared with phalaris and tall fescue. Phalaris (35 plants/m^2), tall fescue (34) and cocksfoot (24) all established at similar densities, albeit some effects of soil treatment were observed on the establishment of the latter 2 species (Table 1). However, after 26 months both phalaris and tall fescue had declined to negligible components (<1.5%) of the pasture sward. This is in contrast to previous studies (Virgona and Hildebrand 2007; Hayes *et al.* 2010) which have found phalaris in particular to be much more dominant in pasture mixtures than cocksfoot. There are two possible explanations for the result we observed. Firstly, cocksfoot is reported to have increased acid soil tolerance, which could explain its superior performance in this environment. However, if soil acidity was the major constraint to phalaris and tall fescue performance, one might expect them to have responded positively to the high rates of lime applied. As their prevalence in the pasture sward was unaffected by lime, we believe a more likely explanation of the dominance of cocksfoot in this mixture is due to its superior tolerance to low soil nutrition. The paddock in which this experiment was sown had no history of superphosphate application or other pasture improvement. After 29 months of improvement of pasture, which included one application of fertiliser at sowing and 2 top-dressings in subsequent years, Colwell P was only 13 mg P/kg in the 0-10 cm zone, whereas optimal pasture productivity would be expected at 25-35 mg P/kg (Gourley *et al.* 2007). Nitrogen was also likely to be highly deficient which is perhaps the reason total legume content of the swards ranged from 47-80% despite the acidic and low-P nature of this soil. There are currently no data that quantify the relative nutritional requirements of phalaris, cocksfoot and tall fescue, so these differences require further investigation.

The high rates of gypsum applied in this experiment provided no benefit to pasture productivity, in fact there was evidence that it may have inhibited the establishment of cocksfoot and tall fescue at least. This inhibiting effect was likely associated with an increased salt concentration at the soil surface, which was still evident in the soil 29 months after application. The soil was mildly sodic with levels of exchangeable sodium up to 5.1% in the surface 5 cm. However, based on our results there is little justification for applying gypsum to a soil such as this other than as a source of sulphur. In that instance, a far lower rate would likely be required which would most likely reduce the negative effects on seedling establishment which we observed.

Conclusion

This study has shown significant benefit of lime application in a permanent pasture setting in the absence of complete soil disturbance. The experiment continues to be monitored so that longevity of lime effect on pasture productivity can be quantified. This study has also identified two aspects of research that require further investigation. First is the possibility of increasing white clover persistence in similar Tablelands environments by selecting for increased tolerance to Al toxicity, thereby increasing root growth in the soil surface. Second is the differential tolerance of the temperate perennial grasses to nutrient deficiencies, which may enable us to refine our understanding of the landscapes in which these species should be sown.

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