Phalaris and lime – improving productivity on an acidic soil in a drought-prone 'high-rainfall' environment

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Abstract

The experiment was conducted on a highly acidic Sodosol soil with hydrophobic properties on the Southern Tablelands, New South Wales. Prior to sowing, lime ($CaCO_3$) was incorporated at 3.5 t/ha, increasing soil pH_{Ca} from 4.1 to 5.5 in the surface 0.10 m. Seven perennial pasture species, phalaris, cocksfoot, chicory, tall fescue, birdsfoot trefoil, grazing brome and Yorkshire fog were sown in monocultures. Available soil water (ASW) was monitored for 18 months following sowing, as were plant establishment, persistence and herbage mass. Lime increased ASW by up to 15% in the surface 0.30 m which was most likely due to increased infiltration. Total pasture herbage mass increased by an average of 33% due to lime in the establishment year whereas yield of sown perennial species increased by 60% on the limed treatments compared with the unlimed treatments. Lime had no effect on the establishment of any perennial species. Phalaris was the only species to persist beyond the first summer in the absence of lime with a basal frequency > 20% and most other species died in the second year, including cocksfoot which is commonly reported to be more acid tolerant. Lime increased phalaris yield by 69% in the second year. The two key findings from this study were that i) phalaris was the most viable perennial option for this highly acidic soil, despite previous reports of its relative sensitivity to acid soils, and ii) the increases in pasture yield due to lime were likely, in part, due to the observed increase in ASW.

Key Words

Phalaris aquatica, Dactylis glomerata, Cichorium intybus, Festuca arundinacea, Lolium arundinaceum

Lotus corniculatus, Bromus stamineus, Holcus lanatus

Introduction

Soil acidity is a major impediment to agricultural production in New South Wales, Australia, particularly in the 'high' rainfall Slopes and Tablelands where severely acidic soils ($pH_{CaCl2} < 4.5$) are common (Scott et al. 2000). Although classified as high rainfall (> 600 mm average annual rainfall) this region has experienced long dry periods receiving rainfall well below the long-term average for many years which offered the opportunity to test the drought tolerance of many temperate species. Exacerbating the severity of drought is the shallow nature of many soils typical of this region which provides a limited capacity to store water in the profile that can be utilised by plants during subsequent dry periods. As a consequence, many productive temperate perennial species such as perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) are unsuitable for large areas of this region due to insufficient drought tolerance (Reed 1996; Lane et al. 2000).

Lime has a well-documented capacity to amend acidic topsoils, particularly in situations in which it is incorporated with the soil. The amendment of acidic subsoils takes decades to achieve (Li et al. 2010), which is why it is recommended to use lime in combination with acid tolerant species to maximise productivity from these soils (Scott et al. 2000). Over the past 50 years, average annual rainfall across

much of this region has declined by 15-30 mm/10 years (BOM 2010), with much speculation about a continued drying trend into the future. This presents a clear challenge to farmers in this region to manage their acid soils in the face of a drying climate. The current study tested the impact of lime on soil water and evaluated the productivity and persistence of 7 perennial pasture species on a severely acid soil.

Methods

A field experiment was established in 2005 near Goulburn (34?34'S, 149?44'E) in the Southern Tablelands of New South Wales. It was replicated 4 times in a randomised split-plot design where the mainplot was pasture species and the subplot was either nil or 3.5 t/ha lime. The soil was a Yellow Sodosol (Isbell 1996) with a pH_{CaCl2} 4.1 on the unlimed plots and 5.5 on the limed plots at 0-0.10 m. Aluminium comprised 26-42% of the effective cation exchange capacity in the surface 0.4 m. More than 6% of the exchangeable cations below 0.40 m were sodium, sodicity in the profile peaking at 14% at 1-1.4 m. There were seven species, namely cocksfoot (*Dactylis glomerata*) cv. Currie (6 kg/ha), chicory (*Cichorium intybus*) cv. Grasslands Puna (7 kg/ha), phalaris (*Phalaris aquatica*) cv. Landmaster (6 kg/ha), grazing brome (*Bromus stamineus*) cv. Gala (30 kg/ha), tall fescue (*Lolium arundinaceum*) cv. Demeter (17 kg/ha), birdsfoot trefoil (*Lotus corniculatus*) cv. Goldie (8 kg/ha) and Yorkshire fog (*Holcus lanatus*) cv. Forester (7 kg/ha), sown in monocultures using a cone seeder on 6 May 2005. Plot size was 4 ? 4 m. An aluminium access tube was inserted in the centre of each plot and available soil water (ASW) was monitored at 9 depths to 1.65 m using a neutron moisture meter.

Initial seedling density of perennial species was assessed 21 weeks after sowing using two 1 m^2 quadrats per plot. Quadrat locations were marked and a subsequent estimate of basal frequency was taken on 3 February 2006 and again on 11 July 2008. Available biomass was assessed on two occasions (12 December 05 and 24 August 06) using a visual technique dividing each plot into 4 cells and giving each cell a score out of ten. The visual scores were averaged for each plot and then converted to DM using an appropriate calibration equation derived from 10 quadrat cuts ($0.1m^2$) on each occasion. An assessment of botanical composition was also made at 10 random locations per plot using the dry-weight-rank method (t' Mannetje & Haydock 1963). Immediately following both herbage yield assessments the site was grazed with ~ 200 sheep for 1-2 days which left only a small amount of residual herbage on plots.

Results

All species established at plant densities exceeding 135 plants/m^2. However, by February 2006 (9 months after sowing), basal frequency of perennial species had declined to negligible levels in many treatments (Table 1). An assessment of basal frequency two years later showed that only two species, phalaris and grazing brome, had persisted adequately. In both cases basal frequency was shown to be significantly higher ($P < 0.05$) where lime was applied, increasing from 5.2% to 38.4% for grazing brome and from 44.2% to 60.0% for phalaris.

Table 1. Seedling density and basal frequency of seven perennial pasture species grown with and without lime on an acid soil near Goulburn, NSW.

Treatment	Density (plants/m^2)	Basal frequency (%)	
	October 2005	February 2006	July 2008
Grazing brome	144	0.1	21.8
Chicory	136	15.9	0.2

Cocksfoot	187	5.0	5.1
Tall fescue	441	7.6	4.1
Yorkshire fog	655	0.0	3.1
Birdsfoot trefoil	139	0.0	0.0
Phalaris	226	48.0	52.1
l.s.d. (species; *P* < 0.05*)*	*77.4*	*19.08*	*15.22*
Nil lime	288	7.5	7.7
+ Lime	263	14.4	17.0
P value	*ns*	*P = 0.018*	*P = 0.025*

Lime increased total sward herbage yield by approximately 30% in 2005 and 2006 (Table 2). The responses of sown perennial species were even greater. In year 1, yield of sown species increased by 60% with lime and in year 2, phalaris yield increased by 69% from 1.5 to 2.53 t/ha with lime.

Volumetric water content was significantly higher on the limed treatments than unlimed treatments in the surface 0.30 m of the profile, but no difference was found below this depth. The largest difference in volumetric water content was observed in February 2006 (Fig. 1) where ASW was 15% higher on the limed treatment compared with unlimed treatments in the surface 0.3 m. The site received 102.6 mm rain in two large rainfall events in January, 30 days prior to this sampling. The experimental site received 93, 15.6 and 29.8 mm in the 30 days prior to the December, May and August samplings, respectively.

Table 2. Herbage yield (t DM/ha) of 7 perennial pasture species and total sward (perennial species + weeds) yields when grown with and without lime on an acid soil near Goulburn, NSW.

Treatment	**Yield Dec 2005 (t DM/ha)**		**Yield Aug 2006 (t DM/ha)**	
	Sown perennial	Total sward	Sown perennial	Total sward
Grazing brome	1.56	3.37	0.35	0.88
Chicory	1.33	3.11	0.05	0.46
Cocksfoot	2.15	4.61	0.29	1.45

Tall fescue	1.95	3.16	0.19	0.60
Yorkshire fog	5.99	6.24	0.03	0.24
Birdsfoot trefoil	0.53	3.26	0.00	0.93
Phalaris	5.82	7.30	2.02	2.33
l.s.d. (P < 0.05; *species)*	*2.608*	*2.546*	*0.186*	*0.173*
Nil lime	2.13	3.80	0.29	0.87
+ Lime	3.40	5.07	0.54	1.11
P value	*P < 0.001*	*P = 0.003*	*P = 0.020*	*P < 0.001*

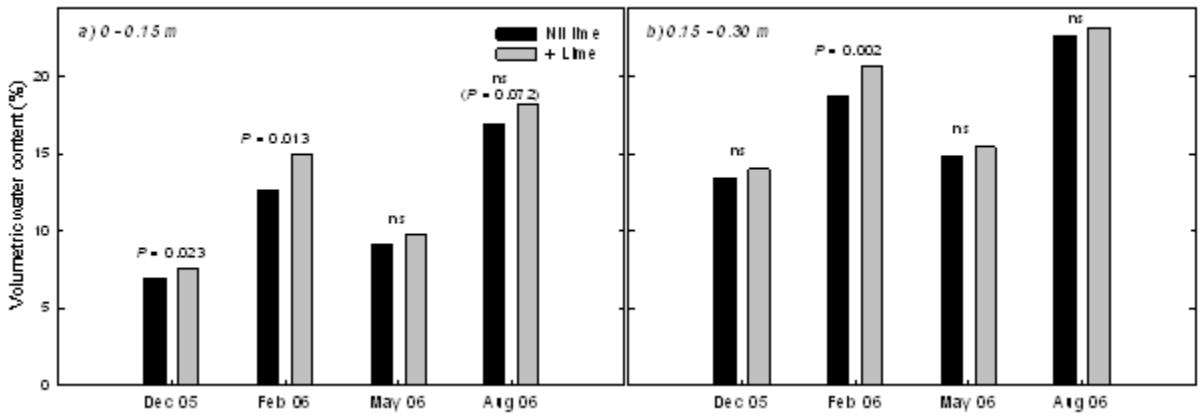

Figure 1. Volumetric water content of soil at a) 0 – 0.15 m and b) 0.15 – 0.30 m measured on 4 occasions across limed (n = 28) and unlimed (n = 28) pasture treatments.

Bars marked ns indicate no significant difference (*P* = 0.05) between liming treatments at that depth.

Discussion

There were two key findings of this experiment. First, that phalaris was the only species to persist adequately on this highly acid soil in the absence of lime. Phalaris has been previously reported to be sensitive to soil acidity and aluminium toxicity (Helyar & Anderson 1971), more so than species such as cocksfoot and tall fescue (Culvenor et al. 1986; Scott et al. 2000). There are two possible explanations for the superior performance of phalaris in the current study; i) soil acidity is only one of multiple stresses impacting on pasture performance. The drought tolerance of phalaris through increased development of deep roots (Culvenor 2009), for example, may have compensated for its relative sensitivity to aluminium

toxicity, and ii) subsequent to the earlier studies reporting its sensitivity to acidity, phalaris has been actively selected for tolerance to acid soils resulting in the release of cultivars such as Landmaster (Oram 1996). Modern cultivars may therefore be more tolerant of soil acidity than the literature suggests. The failure of all other species to persist in the absence of lime is a graphic reminder of the importance of adequate drought tolerance, even in supposedly higher rainfall environments.

The second key finding was the benefit of lime in increasing ASW. It is postulated that the observed increase in ASW on the limed treatments was due to increased infiltration rate as lime would likely reduce the water repelling nature of this soil (after Roper 2005). Although the benefits of lime for reducing water repellancy have been previously reported, it is often overlooked as a major benefit of liming as mineral toxicities and deficiencies associated with acid soils generally consume much of the focus (Scott et al. 2000). However, the current study suggests there is a need to revisit this issue particularly in the tablelands environments of south-eastern Australia, as lime may provide a feasible option for managing agricultural production as rainfall continues to decline (BOM 2010). Increasing water availability is an important strategy for managing acid soils, particularly soils such as in the current study where Al comprised up to 42% of the effective cation exchange capacity. Toxic concentrations of Al in the soil are known to stunt root development in sensitive species, limiting their capacity to explore the soil volume for water and nutrients. Increasing ASW would compensate to some extent against stunted root development, providing some buffer against moisture stress for affected plants by enabling them increased access to water between rain events. Increased infiltration is also especially important in this environment due to the shallow nature of many soils which limits the opportunity to store moisture in the profile for subsequent use by plants. It is therefore important to maximise the infiltration of water when rainfall does occur. More research is required to establish the extent of water repellancy in Tablelands soils in south-eastern Australia to further refine management of acid soils in this zone.

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