Long-term liming ameliorates subsoil acidity in high rainfall zone in south-eastern Australia

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Abstract
Management of Acid Soils Through Efficient Rotations (MASTER), is a long-term agronomic experiment commenced in 1992. The primary objective was to develop and demonstrate a sustainable farming system that is agriculturally productive, economically viable and environmentally effective to manage the highly acid soils in the high rainfall region (550–800 mm) of south-eastern Australia. The experiment was a fully phased design with 3 major treatment contrasts, *a)* annual systems versus perennial systems; *b*) limed versus unlimed treatments; and *c*) permanent pastures versus pasture-crop rotations. Results showed that the soil acidification rate was 0.1 pH units per year under the production system studied, and acidity amelioration rate was 0.044 pH units per year under the liming regime used. It is estimated that the system requires 270-300 kg lime/ha/year, or 1.6-1.8 t lime/ha every 6 years, to keep the system sustainable. It was concluded that the subsoil acidity can be alleviated by surface liming over the long term.

Key Words
Aluminium, manganese, perennial pasture, annual pasture, farming system.

Introduction
Liming is one of the most cost effective ways to alleviate the soil acidity. However, surface-applied lime is often slow to move down into the root zone where it is most needed (Helyar 1991), and incorporation by tillage is not always feasible due to the risk of erosion on steep slopes and the non-arable nature of many pastoral soils (Chan *et al.* 2004). In southern Australia decreases in soil pH of about 1 unit in 50 years have been recorded under annual subterranean clover/volunteer grass pastures that are fertilised with superphosphate, and under similar pasture in rotation with cereal crops (Bromfield *et al.* 1983; Helyar 1991; Williams 1980). Management of Acid Soils Through Efficient Rotations (MASTER), is a long-term agronomic experiment commenced in 1992. The primary objective was to develop and demonstrate a sustainable farming system that is agriculturally productive, economically viable and environmentally effective to manage highly acid soils in the high rainfall region (550–800 mm) of south-eastern Australia. The paper reports the long-term trends of soil acidification rate and amelioration rate under a long-term liming program.

Materials and methods
The experiment was conducted on the property ‘Brooklyn’, operated by the Hurstmead Pastoral Company Pty Ltd, at Book Book (147°30′E, 35°23′S), 40 km south-east of Wagga Wagga, New South Wales, Australia. The long-term average annual rainfall was 614 mm. The soil at the site is a subnatric yellow sodosol (Isbell 1996), a Typic Fragiochrept in USDA taxonomy (Soil Survey Staff 2006). It has a strong texture contrast or duplex profile, with a loamy sand to sandy loam A horizon overlaying a clay B horizon commencing at 20-60 cm depth. The average pH in 0.01 M $CaCl_2$ (pH_{Ca}) at 0-10 cm soil depth was 4.0 and the subsurface pH_{Ca} was below 4.5 to at least 20 cm, which is typical of the more acidified soil in the region.

The experiment was a fully phased design with 6-year (phase) as a cycle. There were 8 treatments, 80 plots in total, with 3 major treatment contrasts, a) annual systems versus perennial systems; b) limed versus unlimed treatments; and c) permanent pastures versus pasture-crop rotations. Plot size was 30 × 45 m. Lime at 3.7 t/ha was initially incorporated into top 10 cm of soil in 1992. The target was to maintain pH_{Ca} in the surface 10 cm at 5.5 over the 6-year liming cycle. The maintenance lime was top-dressed every 6 years at 2.6 t/ha in the second cycle and 1.6 t/ha in the third cycle (**Figure 5**). Further details of experimental design, treatment description and grazing management were reported by Li *et al.* (2001, 2006a, 2006b).

Soil samples, comprising 20 cores (3.5 mm in diameter) per plot, were taken at the break of season in autumn annually at 0-10, 10-15 and 15-20 cm on all plots, and analysed for pH, aluminium (Al) and manganese (Mn) in 0.01 M $CaCl_2$ (Conyers *et al.* 1991), and exchangeable Al, Mn, calcium, magnesium, potassium and sodium (Gillman and Sumpter 1986).

Results

Soil acidification rate

The initial liming lifted soil pH_{Ca} from 4.1 to 5.7 at 0-10 cm in the 2nd year after liming. Soil pH_{Ca} remained largely unchanged in the 3rd year, but decreased sharply to about 5.0 after 6 years of liming (**Figure 5**). In the 2nd and 3rd cycles, similar patterns of pH changes were found in response to maintenance liming, but with slightly slow rate of pH decrease. Averaged across cycles, it was estimated that the acidification rate was 0.1 pH unit per year (**Figure 6**). In contrast, soil pH on the unlimed treatments fluctuated around 4.0–4.3 at 0-10cm (**Figure 5**), but the system was acidifying the subsoils.

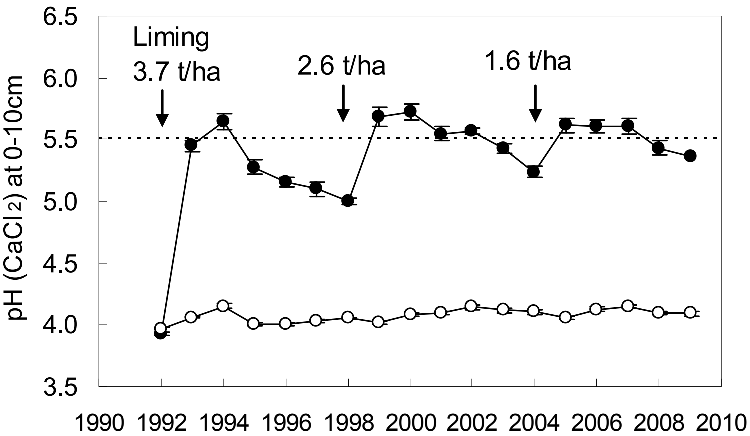

Figure 5. Soil pH_{Ca} trend at 0–10 cm in 1992-2009. ● Limed treatments, mean of plots which were at phase 1 in 1992. ○ Unlimed treatments, mean of all unlimed treatments. Vertical bars represent standard errors

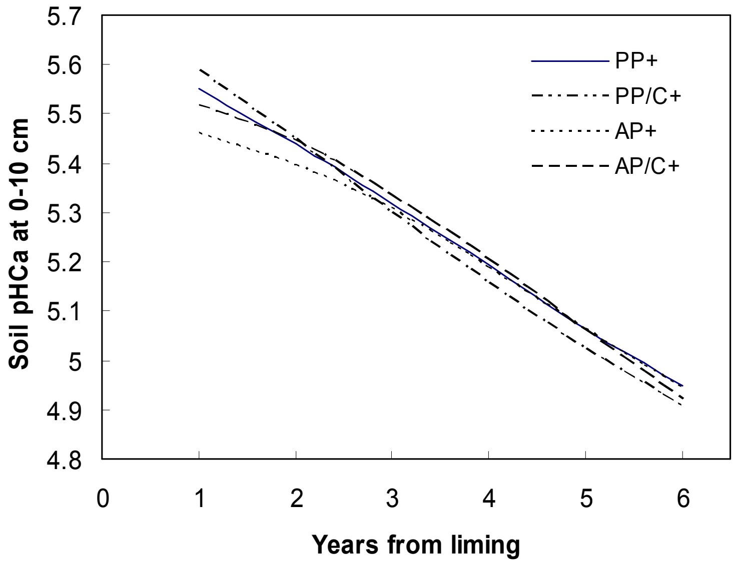

Figure 6. Soil pH_{Ca} changes at 0-10 cm from years 1 to 6 after liming. PP+, perennial pastures; PP/C+, perennial pasture-crop rotations; AP+, annual pastures; AP/C+, annual pasture-crop rotations

Soil acidity amelioration rate

Soil pH_{Ca} at 15–20 cm increased gradually at a rate of 0.044 pH_{Ca} units per year since 1992 by maintaining an average pH_{Ca} of 5.5 at 0-10 cm. The percentage of exchangeable Al at 15-20 cm decreased from 42% in 1992 to below 10% in 2005, 13 years after initial liming (**Figure 7**). It was observed that a significant number of lucerne plants survived in the limed swards at the start of the 3rd cycle of the experiment, most likely due to the incremental amelioration of subsoil acidity.

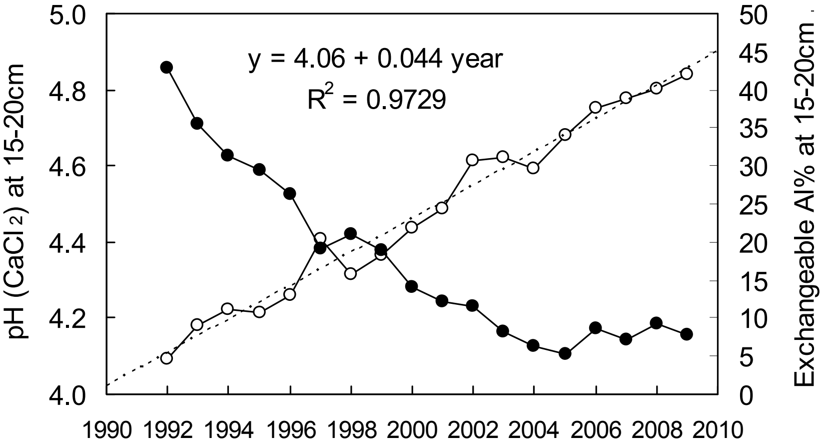

Figure 7. Long-term trends of subsurface soil pH_{Ca} (○) and percentage of exchangeable aluminium (●) at 15-20 cm on the limed treatments in 1992-2009.

Discussion

The most important finding from this long-term experiment is that the subsoil acidity can be alleviated by surface liming over the long term. Under the current lime regime at the MASTER site, the rate of amelioration was 0.044 pH units per year, which means that the subsoil pH would increase by one pH unit over 23 years. The implication of this result is that we could reverse the soil degradation associated with acidity in less than half of the time that caused by the introduction of subterranean clover with superphosphate fertilisers half century ago (Williams and Donald 1957; Williams 1980). The significant decreases in subsoil pH and levels of exchangeable Al and Mn would allow greater exploration of subsoil by acid sensitive species currently restricted by Al and Mn toxicity (Helyar 1991; Slattery and Coventry 1993). A financial analysis based on data from the MASTER site showed that liming pastures on soils that have a sub-surface acidity problem is profitable over the long term for productive livestock enterprises (Li *et al.* 2010). This gives farmers confidence to invest in a long-term liming program to manage highly acid soils in the traditional permanent pasture region of the high rainfall zone (550–800 mm) of south-eastern Australia.

Results showed that the acidification rate was 0.1 pH units per year under the current production system, which was equivalent to 281 kg/ha of lime per year based on the pH field buffering capacity on the site. It is estimated that 2/3 of 'lime equivalent' (180-200 kg/ha/year) has been used to neutralise acids added by the production system, and 1/3 of 'lime equivalent' (90-100 kg/ha/year) has been leached or physically moved into the 10-20 cm soil depth which has accounted for the increase in pH in the subsurface soil. On the unlimed treatments, although pH remained around 4.0, the system has been acidifying the subsoil and progressing toward a pH 4.0 profile to the bottom of the root zone which is much hard and costly to ameliorate.

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