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Soil chemistry change on MASTER long term soil liming experiment

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Abstract

MASTER experiment is a long-term agronomic experiment that commenced in 1992. It was designed to develop and demonstrate a sustainable agricultural system that is economically viable and environmentally effective to manage the highly acid soils in the high rainfall region (500–800 mm) of south-eastern Australia. Over the past 18 years, long-term favourable trends in soil chemistry have begun to appear. Results showed that subsoil acidity is manageable. Soil fertility has been improved as evidenced by increased soil carbon and soil phosphorus (P). Efficient nutrient recycling from subsoils to the surface soil will improve soil chemical and physical properties and also benefit to animal health. The site offers a unique opportunity to characterise the soil inorganic and organic P pools and to understand the processes leading to accumulation of organic P in soil and the bioavailability of those organic P pools. The site is also ideal for quantifying soil carbon sequestration potential under pastures. Assessing the full potential of carbon sequestration under pasture can place farmers in a better position for carbon trading/credit schemes.

Executive summary

MASTER experiment is a long-term agronomic experiment that commenced in 1992. It was designed to develop and demonstrate a sustainable agricultural system that is economically viable and environmentally effective to manage the highly acid soils in the high rainfall region (500–800 mm) of south-eastern Australia. It was designed to run for 6-year cycles (Li et al. 2001). By 2010, we have successfully completed 3 cycles.

Over the past 18 years, subsurface soil acidity has been slowly ameliorated. Results showed that soil pH at 15-20 cm depth increased more than half of a pH unit over 18 years at 0.045 pH units/year whereas the exchangeable Al decreased from 42% in 1992 to below 10% in 2006 at 15-20 cm soil depth by maintaining pH of 5.5 at 0-10 cm. It is estimated that about 180–200 kg/ha/year of lime has been used to neutralise acids added by the system. About 90–100 kg/ha/year has been leached to the subsoil, which has accounted for the increase in pH below 10 cm.

A large amount of soil phosphorus (P) has accumulated on all treatments with 15 kg P/ha applied each year. Results showed that soil Colwell-P at 0-10 cm has been gradually built up, especially on the unlimed treatments. It appeared that limed treatments used more P with better P use efficiency. The site offers a unique opportunity to characterise the soil inorganic and organic P pools and to understand the processes leading to accumulation of organic P in soil and the bioavailability of those organic P pools.

At the MASTER site, soil organic carbon content increased under both perennial and annual pastures. Results from the Roth-C simulation model showed that perennial pastures sequestered slightly more carbon in soil than annual pastures, but the difference is small. It is estimated that perennial pastures sequestered an additional 7.9 t C/ha and annual pastures 6.5 t C/ha over 15 years on the MASTER site, yielding an average 0.57 and 0.46 t C/ha/year for perennial and annual pastures, respectively.

The current changes in redistribution of Mg and K resources from the subsoil to the topsoil is a reversal of the historic weathering of the soil that was associated with soil acidification. The exciting prospect is that we can use the subsurface soil resources of nutrients (K, Ca and Mg) and of alkalinity to partially ameliorate the acidic surface soil. At the same time removal of Mg from the subsurface soil in exchange for acid may have long term benefits for improving subsoil structure and reducing dispersion. In addition, an increase of Mg in soil would increase the Mg content in pastures, hence reducing the risk of a “grass tetany” problem.

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1. Background

Soil acidification is one of the most important land degradation issues in the 500-800 mm rainfall zone of south-eastern Australia. It was estimated that there were about 24 million ha of highly acidic soils ($\text{pH}_{\text{Ca}} < 4.8$) and another 16 million ha of soils at moderate acidity ($\text{pH}_{\text{Ca}} 4.9-5.5$) in this region (Dolling *et al.* 2001). Lime application has proved to be one of the most effective ways to alleviate the acidity problem in mixed farming systems where cropping enterprises can be used to pay for high initial rates of lime over a short period (Li *et al.* 2010). However, on the permanent pasture zone, it is always more difficult to demonstrate economically viable responses to lime in pasture and animal production than in cropping systems (Scott *et al.* 2000). To date, results from a long-term liming site (MASTER) has successfully proved that liming pasture is profitable over the long term. Li *et al.* (2006) found perennial pastures under the limed treatments carried 29% more stock (up to 4 DSE/ha), producing 27% more liveweight gain (62 kg/ha/year) and 28% more greasy wool (13 kg/ha/year) compared to the unlimed treatments at the MASTER site.

The MASTER experiment is a long-term agronomic experiment that 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 (500–800 mm) of south-eastern Australia. It was designed to run for 6-year cycles (Li *et al.* 2001). By 2010, we have successfully completed 3 cycles. This report will emphasize the long-term trends on soil chemistry and their effects on soil fertility.

2. Project objectives

The objective of the project was to complete the third cycle of the MASTER experiment and keep the integrity of liming cycle as originally designed for its new cycle pending on future funding. More specifically:

- To collect soil samples (both surface and deep soil coring down to 120cm) for all annual and perennial pastures with and without lime;
- To conduct full soil chemical analysis of soil samples in 2010;
- To analyse soil carbon data to 100 cm soil depth using archived samples in 1992/93 in comparison with data in 2010;
- To apply lime as per protocol to keep integrity of experimental design;
- To negotiate the renewal of lease with the Manager of the property.

3. Methodology

The experimental site is located on a farm property 'Brooklyn', at Book Book, 40 km south-east of Wagga Wagga. The average annual rainfall was 614 mm. Soil type is yellow podzolic. Soil pH at the site was around 4.1 at 0–10 cm depth, and subsoil below 20 cm was also highly acidic.

The experiment is a fully phased design with 8 treatments and 80 plots (45 × 30 m). The major treatment contrasts are i) annual pastures versus perennial pastures; ii) annual pasture-crop rotations versus perennial pasture-crop rotations; and iii) limed versus unlimed treatments as outlined in Figure 1.

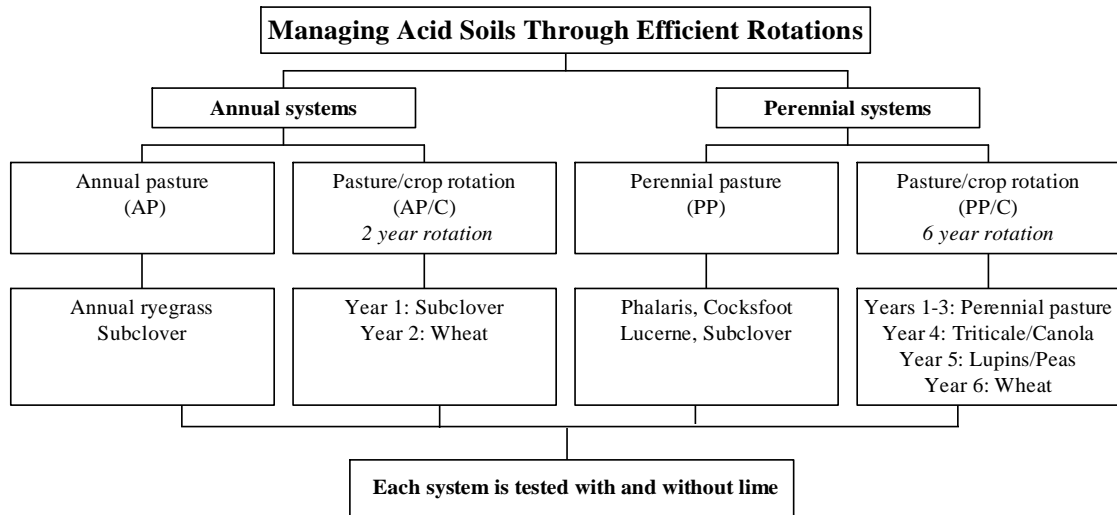


Figure 1 Treatments for the long-term liming experiment.

4. Results and discussion

4.1. Soil acidification and amelioration

The initial lime application (3.7 t/ha) was incorporated into 0-10 cm soil depth and the maintenance lime was top-dressed at the start of phase 1 at 6-year intervals. The maintenance lime rate was 0.7 t/ha in 1993-1996, 2.6 t/ha in 1997-2002, and 1.5 t/ha from 2003 onwards (Figure 2). The target is to maintain an average pH (in CaCl₂) of 5.5 in the 0-10 cm soil layer over the 6-year liming cycle.

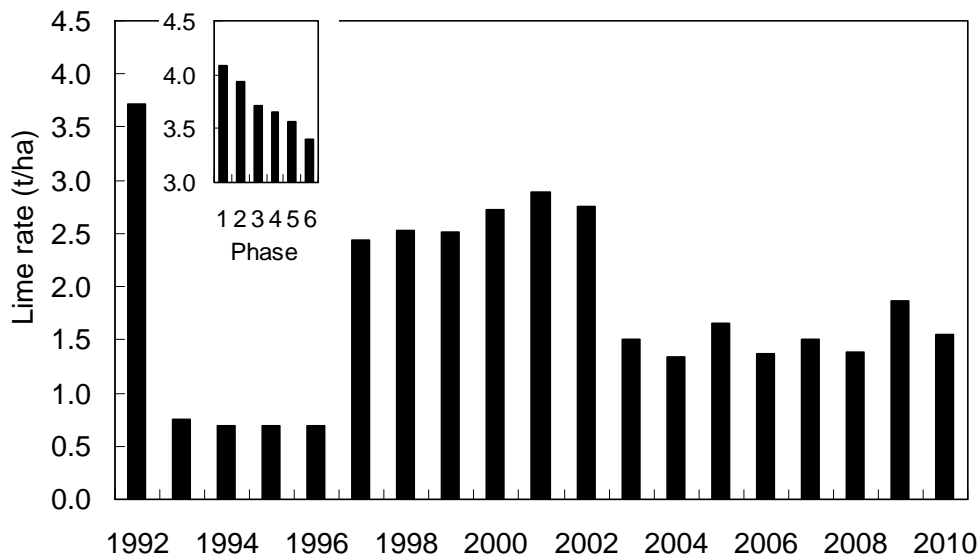


Figure 2 Lime rate (t/ha) at the MASTER site. The initial lime was incorporated into 0-10 cm in 1992 and maintenance lime was top-dressed. The numbers on the x-axis in the inside graph refer to liming phases.

At the 0-10 cm soil depth, there is a clear pattern of pH increase after liming and re-acidification over time for the surface soil pH (Figure 3). It is calculated that the re-acidification rate was 0.1 units of pH in 0-10 cm soil depth. During the first cycle, we did not achieve our target pH of 5.5 due to underestimation of soil acidification. From

1997, the maintenance lime increased to 2.6 t/ha for 6 years. However, the average pH over 6 years was still slightly below 5.5. From 2003 onward, the maintenance lime stabilised at 1.5 t/ha and we had similar trends as the previous cycle. It is worth noting that Figure 3 is only for those plots at phase 1 in 1992. There were another 5 sets of data for plots at phases 2-6 (data not shown).

In contrast, soil pH for the unlimed treatments fluctuated around 4.0. It is assumed that the acid produced at the surface soil has been dumped into subsurface soil which is hard to ameliorate.

At the 15-20 cm soil depth, soil pH increased 0.045 pH units/year and the exchangeable Al at the same depth decreased from 42% to below 10% over the last 18 years (Figure 4) by maintaining a pH of 5.5 in the top 10 cm depth.

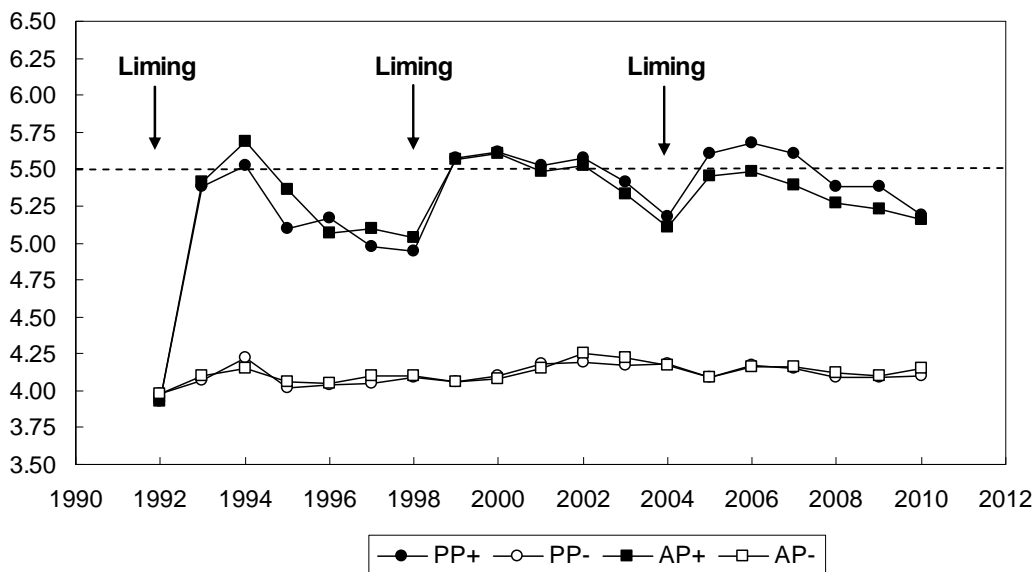


Figure 3 Soil pH for plots at phase 1 in 1992 at 0-10 cm over 18 years from 1992 to 2010 under limed perennial (PP) and annual pasture (AP) with (+) and without lime (-).

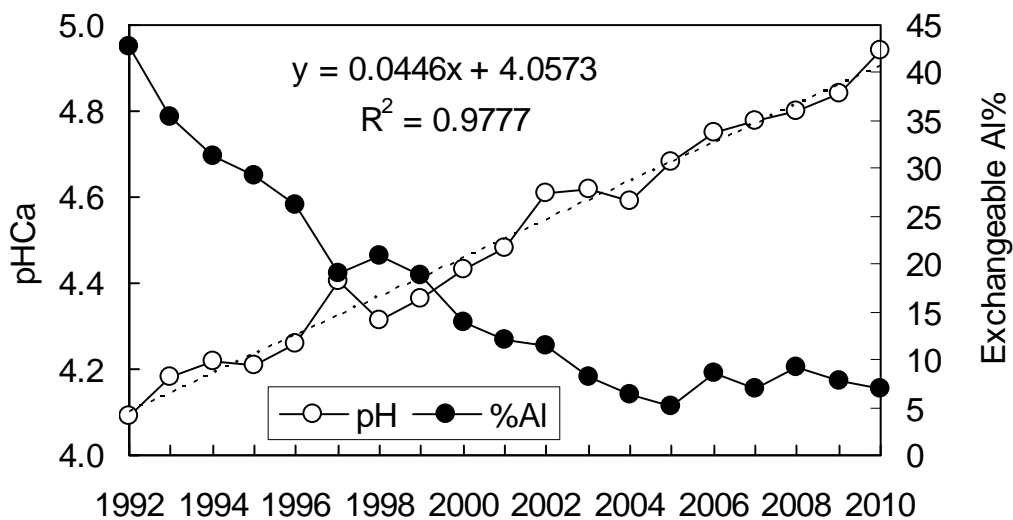


Figure 4 Subsurface soil pH and exchangeable Al% trends at 15-20 cm over time

Results from deep soil coring confirmed that the lime effect has been extended to subsurface soils with increased pH (Figure 5) and decreased exchangeable Al (Figure 6) down the soil profile. It was observed that more acid sensitive pasture species, such as lucerne, have survived at the start of cycle 3 in 2004 (Plate 1).

Over the past 18 years, it is estimated that about 180–200 kg/ha/year of lime has been used to neutralise acids added by the system. About 90–100 kg/ha/year has been leached to subsurface soil, which has accounted for the increase in pH below 10 cm.

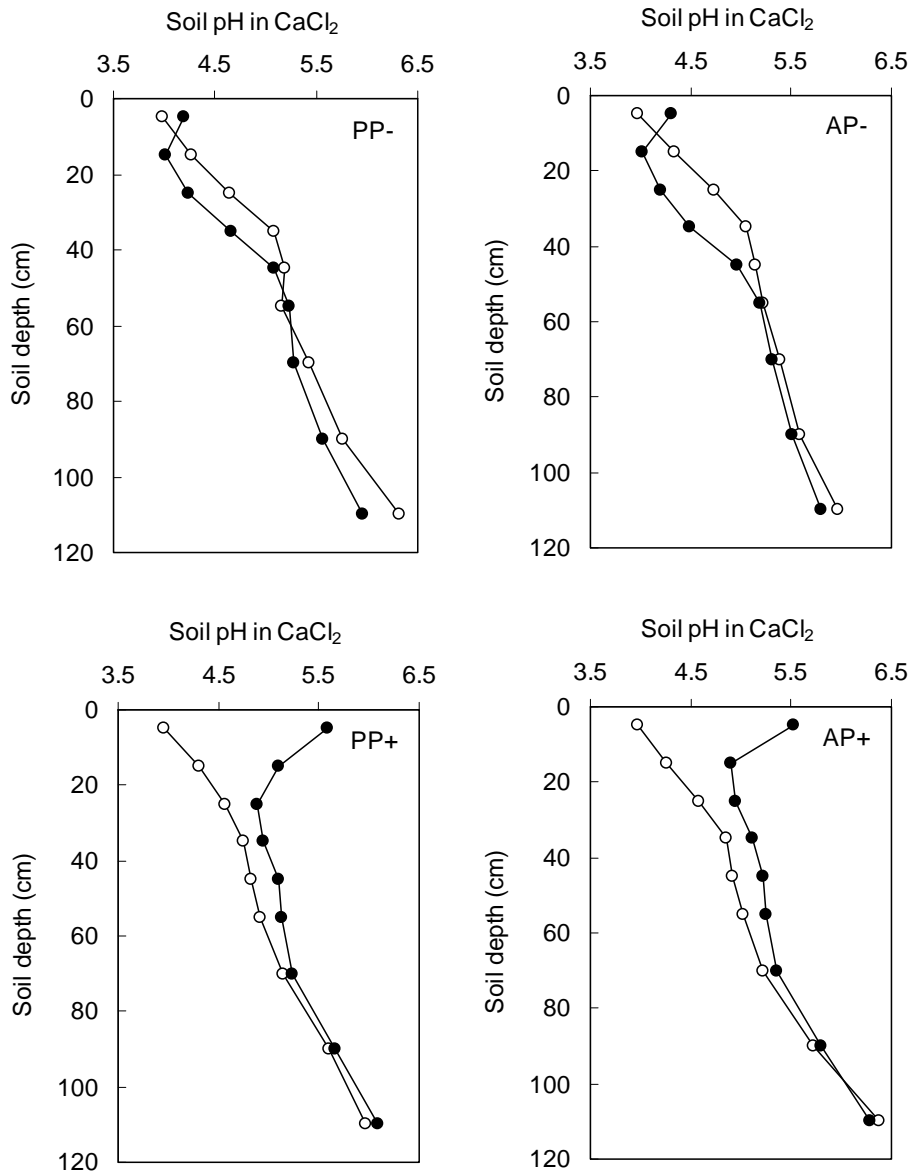


Figure 5 Soil pH to 120 cm depth in 1992 (○) and 2010 (●) under perennial (PP) and annual pasture (AP) with (+) and without lime (-)

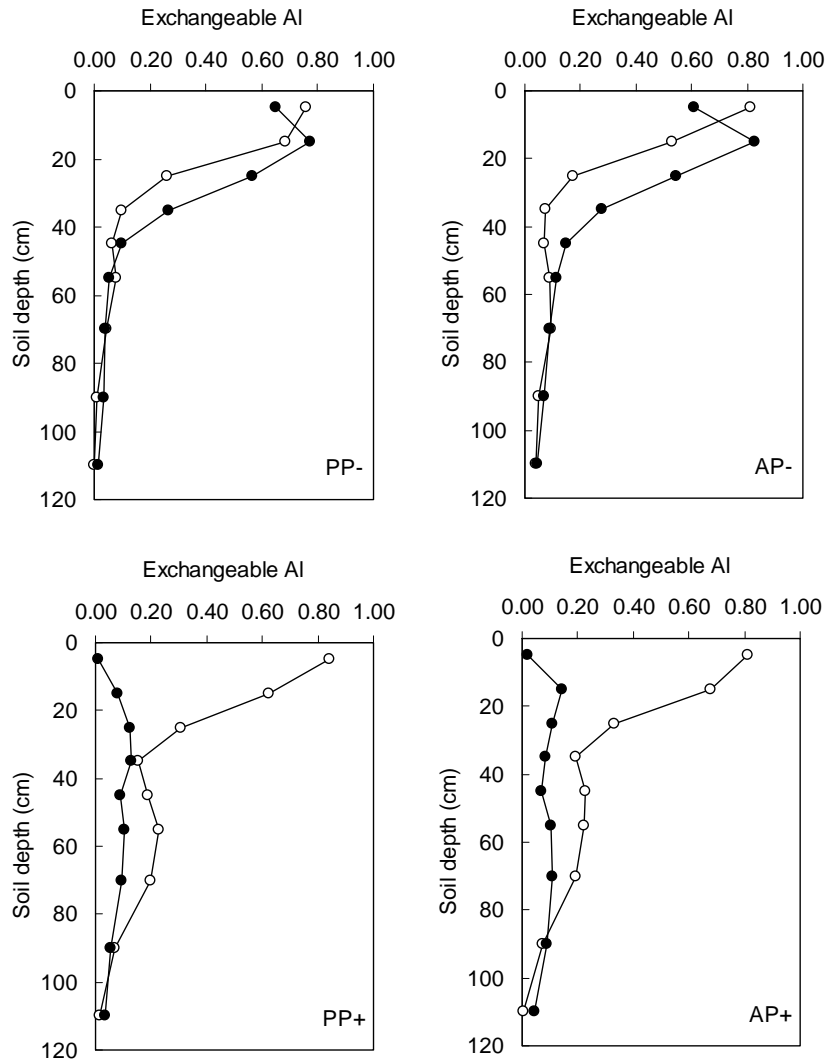


Figure 6 Soil exchangeable Al (cmol+/kg) to 120 cm depth in 1992 (○) and 2010 (●) under perennial (PP) and annual pasture (AP) with (+) and without lime (-)



Plate 1: Lucerne on the limed treatment in cycle 3 (Feb 2005)

4.2. Soil phosphorus and soil carbon

Phosphorus (P) was applied at 15 kg P/ha as single superphosphate on all treatments each year. Over 18 years, a large amount of soil P has accumulated on all treatments. Results showed that soil Colwell-P at 0-10 cm has been gradually built up, especially on the unlimed treatments (Figure 7). It appeared that limed treatments used more P with better P use efficiency as expected as the limed pastures were more productive.

The site offers unique opportunity to characterise the soil inorganic and organic P pools and to understand the processes leading to accumulation of organic P in soil and the bioavailability of those organic P pools. A new proposal has been submitted to MLA to use new and alternative pasture species to improve P use efficiency at the MASTER site. The novel plants could increase access to less available soil P by altered root morphology or modified root functions. For example, plants with larger rhizosphere volume would have higher P use efficiency, and plants with high phosphatase activity and which release of organic anions would increase P availability to current and possibly subsequent plants.

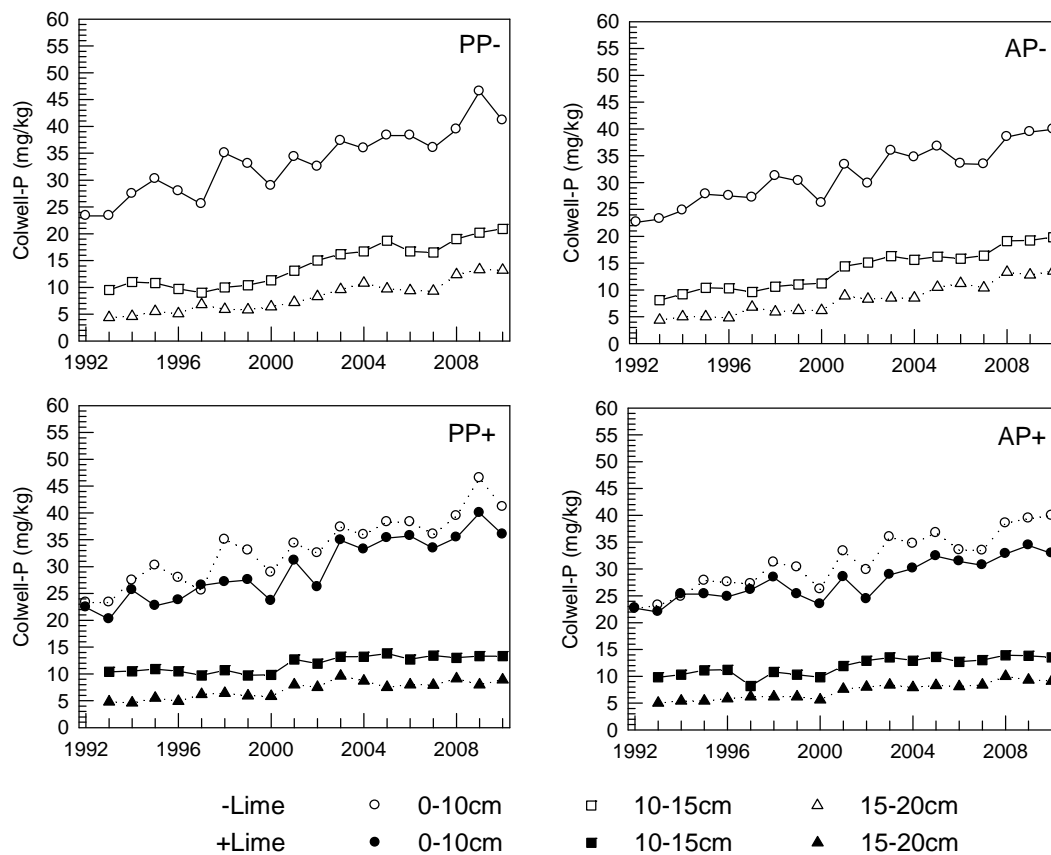


Figure 7 Soil Colwell phosphorus changes over 18 years from 1992 to 2010 at 0-10, 10-15, 15-20 and 20-25 cm under perennial (PP) and annual pasture (AP) with (+) and without lime (-).

Recent evidence has shown that increased P fertility in pastures also drives C sequestration (Chan *et al.* 2010). Results from MASTER showed that soil organic carbon content increased under both perennial and annual pastures (Figure 8). However, no lime effect was detected on soil carbon content. Roth-C simulation model predicted that perennial pastures sequestered slightly more carbon in soil than annual pastures, but the difference is small

(Figure 9). It is estimated that perennial pastures sequestered an additional 7.9 t C/ha and annual pastures 6.5 t C/ha over 15 years on the MASTER site, yielding an average 0.57 and 0.46 t C/ha/year for perennial and annual pastures, respectively (Liu *et al.* unpublished data).

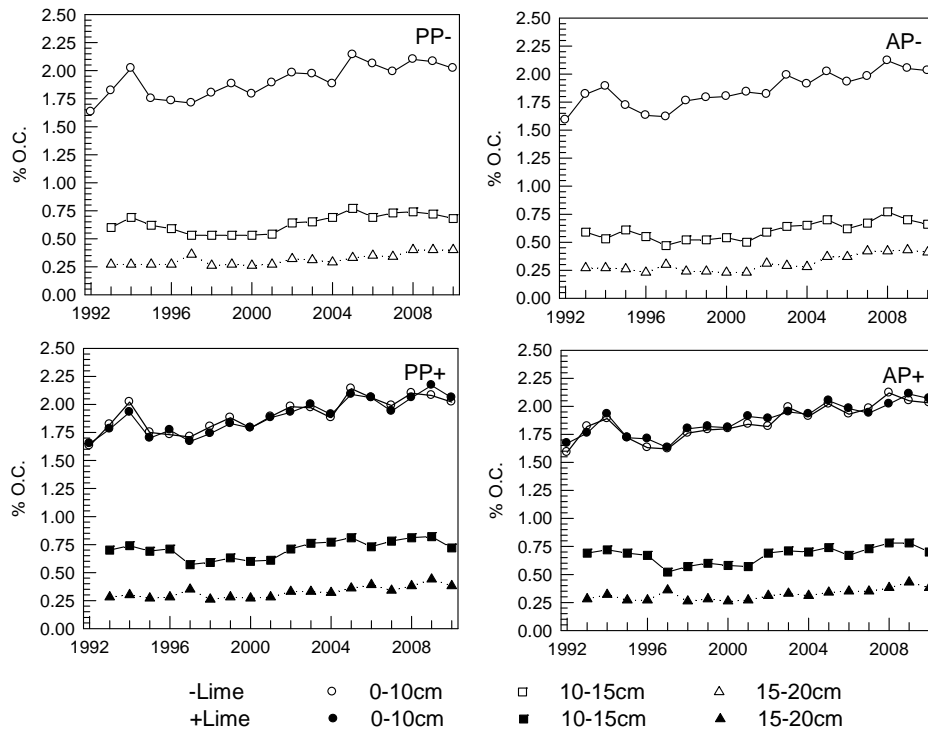


Figure 8 Soil organic carbon (%) changes over 18 years from 1992 to 2010 at 0-10, 10-15, 15-20 and 20-25 cm under perennial (PP) and annual pasture (AP) with (+) and without lime (-).

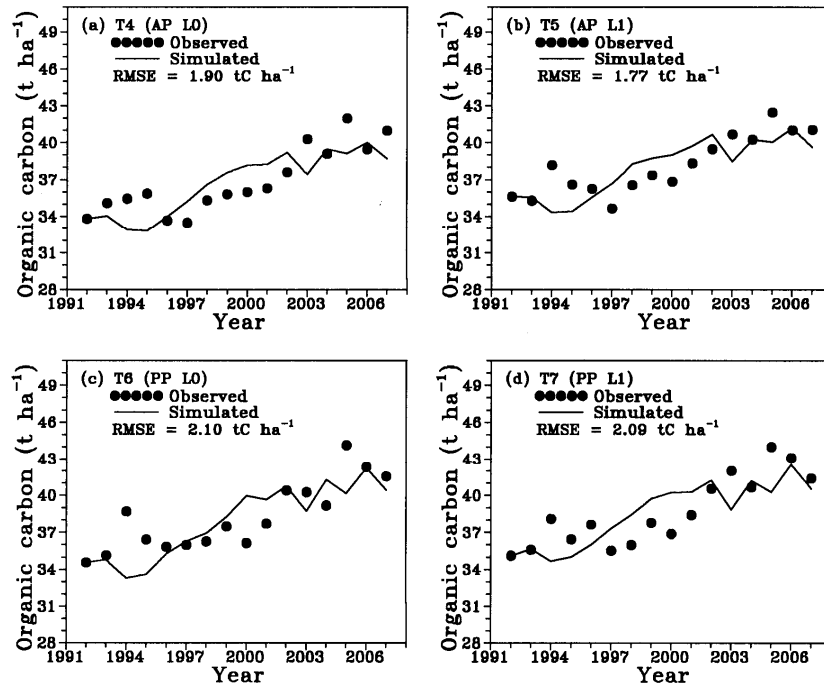


Figure 9 Comparison between the simulated and observed organic carbon content of soils in 0-30cm at the MASTER site under annual (AP) and perennial pasture with (L1) and without lime (L0) (Liu *et al.* unpublished data).

4.3. Soil nutrient recycling

One of the important findings from the MASTER site is that the limed treatments bring more alkaline components, such as Mg^{2+} , K^+ , from subsoil soil to the surface soil (Figure 10 and Figure 11). The efficient recycling of cations and alkalinity from subsoil to the surface soil is an important process that counters nutrient leaching, and the reverse processing of soil weathering. In addition, an increase of Mg in soil would increase the Mg content in pastures, hence reducing the risk of “grass tetany” problem. A similar trend was found for exchangeable potassium.

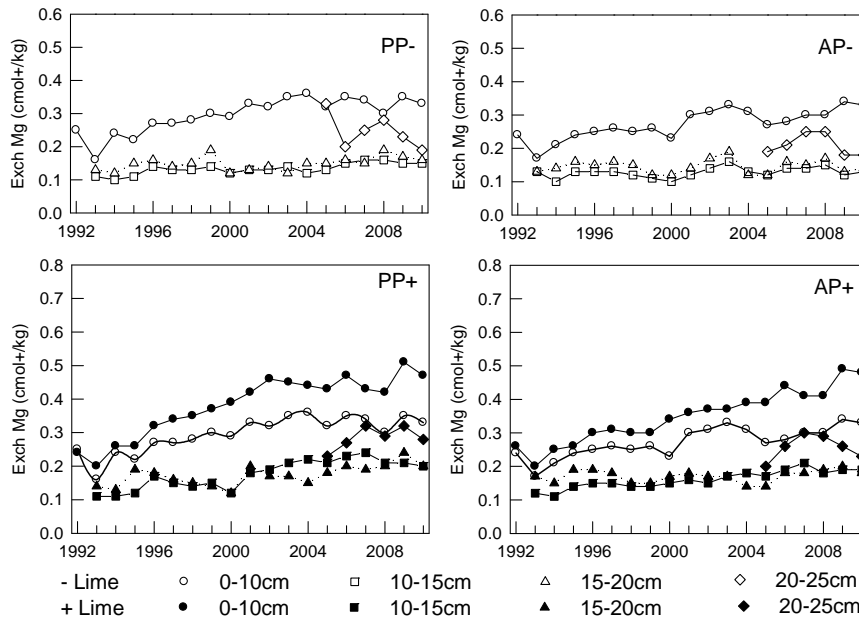


Figure 10 Soil exchangeable Mg (cmol+/kg) changes over 18 years from 1992 to 2010 at 0-10, 10-15, 15-20 and 20-25 cm under perennial (PP) and annual pasture (AP) with (+) and without lime (-).

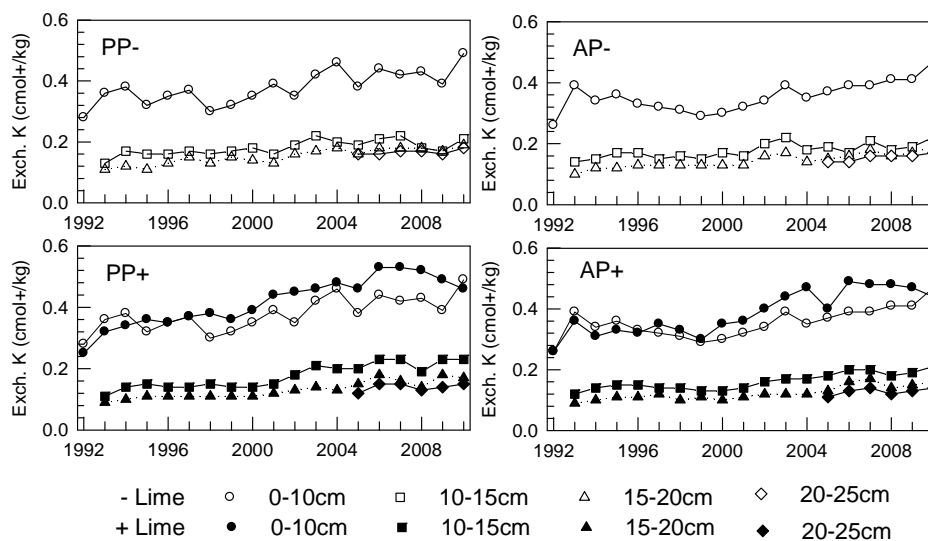


Figure 11 Soil exchangeable K (cmol+/kg) changes over 18 years from 1992 to 2010 at 0-10, 10-15, 15-20 and 20-25 cm under perennial (PP) and annual pasture (AP) with (+) and without lime (-).

5. Conclusion

- Subsurface soil acidity is manageable. One of the significant achievements was that the pH at 15-20 cm depth increased more than half of a pH unit over 18 years at 0.045 pH units/year whereas the exchangeable Al decreased from 42% in 1992 to below 10% in 2006 at 15-20 cm soil depth by maintaining pH_{Ca} of 5.5 at 0-10 cm.
- The re-acidification rate was 0.1 pH units per year. It is estimated that about 180–200 kg/ha/year of lime has been used to neutralise acids added by the system. About 90–100 kg/ha/year has been leached to the subsoil, which has accounted for the increase in pH below 10 cm.
- Soil P has been built up over the past 18 years, which offers unique opportunity to characterise the soil inorganic and organic P pools and to understand the processes leading to accumulation of organic P in soil and the bioavailability of those organic P pools.
- Soil organic carbon also increased under both perennial and annual pastures. Assessing the full potential of carbon sequestration under pasture will place farmers in a better position for carbon trading/credit schemes.
- Efficient recycling of cations and alkalinity from subsoils to the surface soil will improve soil chemical and physical properties and also benefit to animal health.

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