100 Years of superphosphate addition to pasture in an acid soil

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Abstract
Pasture-based animal production systems, which occupy a significant proportion of the landscape in Victoria, have historically been nutrient-limited, with phosphorus (P) often the most limiting nutrient. The 'Permanent Top-Dressed' (PTD) pasture experiment was established in 1914 at the Rutherglen Research Station (Victoria, Australia) to investigate the management of this deficiency. The objective of the PTD experiment was to demonstrate the value of adding P fertiliser to increase pasture productivity for lamb and wool production in an era of poor pasture production and limited understanding of the value of nutrient inputs. Of the original treatments which were established, only three have been maintained since 1914; unimproved pasture, as well as improved pasture with 125 or 250 kg single superphosphate/ha applied every second year.

One hundred years of continuous management has allowed us to investigate the long-term effects of applying P to soil, in terms of P, carbon (C), nitrogen (N) and soil acidification. These changes are a response to changes in pasture composition and production over time due to P fertiliser inputs. The analysis of soil samples from 1965 and 2013 have shown the impact of P fertiliser on soil pH, total carbon and nitrogen values, and Olsen P levels. These results show that 100 years of superphosphate has decreased the soil pH while increasing the Olsen P contents of the soil. The very low pH values indicate that future management of the site will require the inclusion of a liming material to counteract the soil acidification, which may also develop new avenues of enquiry focussed on the soil and pasture response to increasing pH.

Key words
Long term trials, phosphorus, nitrogen, carbon, pH

Introduction
Pasture-based animal production systems occupy a significant proportion of the landscape in Victoria, Australia. Productivity in these systems has historically been nutrient-limited, with phosphorus (P) often the most-limiting nutrient affecting pasture growth (White et al., 2000). This P deficiency was identified as early as 1912, leading to the establishment of the 'Permanent Top-Dressed' (PTD) pasture experiment in 1914 at the Rutherglen Research Station (now Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Rutherglen Centre), Victoria. The PTD pasture experiment is the longest running P fertiliser trial under permanent pasture in temperate Australia (Grace, 1993). The objective of the PTD experiment was to demonstrate the value of adding P fertiliser at two rates to increase pasture productivity for lamb and wool production, in an era of poor pasture production and limited understanding of the value of nutrient inputs. The PTD experiment also included a fertiliser plus lime treatment which was terminated in the late 1980s.

Now, 100 years on, it is well recognised that the soils of north-east Victoria still face significant challenges around the availability of P and the influence of low soil pH on P chemistry. One hundred years of continuous management has allowed us to investigate the long-term effects of P fertiliser on the forms and distribution of P and other relevant soil parameters. In 2014, the centenary of the site, extensive soil analysis was conducted to investigate the current status of the PTD soils (Schefe et al., in press). Unfortunately there was limited chemical analysis of the soils over time, with the exception of soil pH which has been recorded in 1948, 1965, 1986 and 2013. A recent search of the soil archives identified samples for the PTD site from 1965. This paper will investigate the changes in soil phosphorus, carbon (C)and nitrogen (N) over the last 50 years, utilising archived soil samples from 1965 and results from 2013 soil sampling.

Methods

The PTD long-term experiment was established in 1914 at the Rutherglen Research Station (36°06’38”S, 146°30’33”E). Of the original treatments which were established, only three have been maintained since 1914. These are: i) unimproved pasture (0kg); ii) 125 kg single superphosphate/ha applied every second year (125kg); and iii) 250 kg single superphosphate/ha applied every second year (250kg). The site consists of three adjacent paddocks of varying sizes: The control is 1.5 ha, the 125kg treatment is 3.1 ha, and the 250kg treatment is 4.6 ha (Figure 1). The average annual rainfall at the site is 590 mm with a winter dominated rainfall pattern. The soil is a bleached eutrophic yellow Dermosol (Isbell, 1996), which is the dominant soil type within the strongly acidic agricultural zone in Victoria (Isbell et al., 1997).

Archived soil samples from 1965 were identified within DEDJTR’s soil archives. No details are known regarding the sampling strategy for these samples other than the paddock sampled. They are assumed to be 0-10cm soil depth based on records of sampling in the 1970’s. These samples had initially been analysed for reaction(pH), available potassium and organic P (acetic and alkaline) in 1965. For comparison with more recent soil analyses these soils were re-analysed in 2015 using current standard analytical techniques.

The 2013 samples were collected in November with 20 sampling positions per treatment selected to ensure that in field variability would not confound treatment effects. At each soil sampling position, cores were sectioned into depth increments including 0-5, 5-10 and 10-20cm and bulked for each depth. The samples were oven-dried at 40°C for 48 hours were passed through a 2 mm sieve. More details of the sampling strategy and analysis can be found in Schefe et al.(in press).

Soil samples from 1965 and 2013 were analysed for pH (in water and $CaCl^{2}$), and Olsen P as described in methods 4B4 and 9C2a of Rayment and Lyons (2011). Total C and N were determined using a LECO total C and N analyser (LECO TruMac, LECO Co. St Joseph, USA) after being fine ground in a partially stabilised zirconia (PSZ) ring and puck mill.

Results and Discussion

Soil pH

The PTD experiment is situated within the strongly acidic agricultural zone in Victoria. However, historic pH data from the control and 125kg treatments (Figure 2) has shown that these soils were near neutral in 1948 (pH_{water} of 7.2 for the control treatment).

Figure 1. Aerial photograph of the PTD site showing the 125kg treatment at the top, control in the middle and the 250kg treatment at the bottom (Google™earth, Image © 2014 DigitalGlobe).

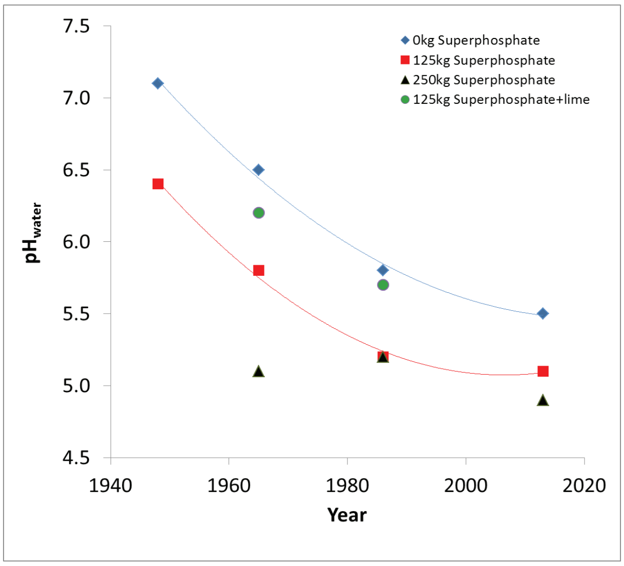

Figure 2. Soil pH_{water} over time showing the 1965, 2013 results and historical data (1948 and 1986) from Ridley et al. (1990).

Prior to finding these archived soil samples from 1965, we were restricted in the investigation of trends over time to data from the control and 125kg treatments. Now with the addition of these samples, the 2013 and archived soils, we can look at the pH of the 250kg treatment and the 125kg treatment (part of which was limed until the late 1980's). Both the control and 125kg treatments have experienced a decline in pHwater of approximately 1.5 units over 65 years (Figure 2). The results from the 125kg-limed treatment appear to track closely with the unfertilised results. In contrast the 250kg treatment was more acidic than the other treatments in 1965, with minimal change over time. By the mid 1980's the 125kg treatment had a similar pH to the 250kg treatment.

Acidification of these soils is believed to be a natural process associated with soil weathering, accelerated acidification in pasture systems through product export (hay, meat and wool), accumulation of organic matter and the leaching of nitrate. By 1939 records show that the fertilised treatments were sub-clover dominated pastures with double the stocking rate of the control, these differences would result in greater rates of product removal and higher nitrogen concentrations and leaching (Figure 3). These processes are distinct from the temporary acidification in the vicinity of superphosphate granules which does not directly contribute to soil acidification (Lindsay, 1979).

From the data presented here and Schefe et al. (in press) , we know that the site has continued to acidify (surface 0-10 cm) over time with soil acidity and associated Aluminum concentrations in the fertilised treatments approaching a level which should impact on production and where broadcasting of lime would be recommended.

Soil Carbon and Nitrogen

Both total C and total N concentrations of the surface (0-10cm) increased in response to fertiliser addition (Figure 3), with both the C and N concentrated in the surface soils (Schefe et al., in press). Interestingly, while there was a difference between the fertilised treatments and the control in terms of total C and N, the difference between the two fertiliser rates is small and this was consistent in both the 1965 and 2013 samples. While Total N has been reasonably consistent over the two sampling times, Total C appears to have increased over time in the fertilised treatments.

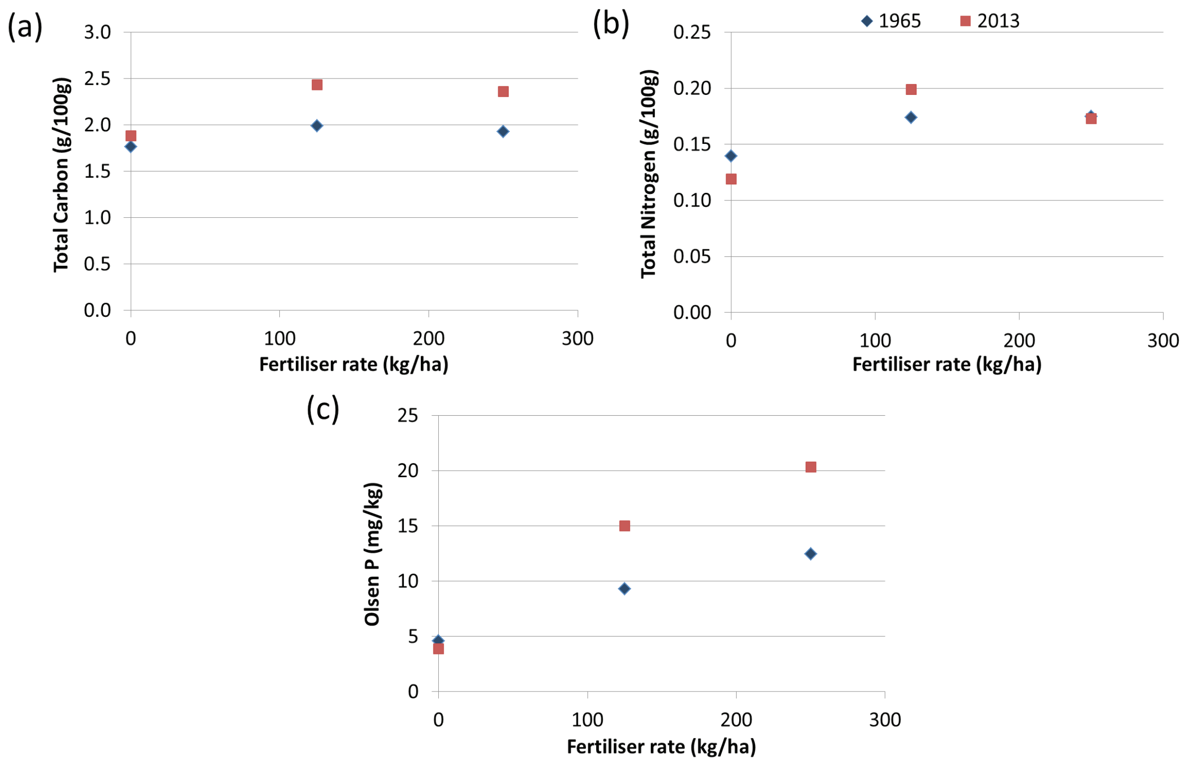

Figure 3. Concentrations of (a) Total C, (b) Total N, and (c) Olsen P measured in surface soils (0-10cm) collected in ♦ 1965 and ■ 2013.

Soil phosphorus

Over the 100 years of the PTD trial there have been 50 fertiliser applications resulting in a total application of 550 kg P/ha and 1100 kg P/ha being applied to the 125kg and 250kg treatments, respectively (assuming a

P content of 8.8% in single superphosphate). This has resulted in an increase in P in the fertilised treatments (Figure 3). Phosphorus fertiliser additions over the 100 years of operation has resulted in a clear distinction in Olsen P concentrations between the control and fertilised treatments.

The critical Olsen P levels for grazed pastures are in the range of 14-15 mg P/kg (Cayley et al., 2002; Gourley et al., 2007). This suggests that the control pasture, in both 1965 and 2013 is likely to be P limited with an Olsen P of 4-5 mg P/kg. In contrast, in the fertilised treatments P would not be limiting production in 2013, with an Olsen P of the surface soil (0-10 cm) of 15 and 20 mg P/kg for the 125kg and 250kg treatments. However, in 1965 the Olsen P would probably still be limiting at 9.3 and 12 mg P/kg for the 125kg and 250kg treatments. In the unfertilised pasture the low constant rate of P suggests an equilibrium between solid and solution P within the soils. Despite the 50 and 100 years of fertiliser application the Olsen P levels are still quite low due to the continual removal of P (hay and sheep) and the high absorption capacity of the soil.

Conclusions

Grazing systems in north-east Victoria have traditionally operated on a rule of thumb rate of application of a bag to the acre of single superphosphate each year, equivalent to 125kg single superphosphate per hectare (Sue Briggs, DEDJTR pers. comm. 2014). The fertiliser rates used on the PTD site over the 100 years are half (125kg) or equivalent (250kg) to this as they were applied every second year.

One hundred years of continuous, non-disturbed pasture has allowed us to investigate the long-term effects of applying P to soil, in terms of P, C, N and soil acidification despite limited soil analysis over time and no replication. After 100 years these rates of fertiliser application have resulted in a notable increase in available P with fertilizer, although we can't determine statistical significance.

For this site to be maintained, and to continue to add value to our understanding of soil processes in acid agricultural soils, future management of this experiment needs to include the application of a liming material to address the declining pH. The future value of this site may lie in the opportunity to better understand how increasing soil pH changes the form and availability of P and N and the ability to maintain soil C.

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