Phytoextraction of phosphorus from Australian dairy pasture soils to reduce environmental loss

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Abstract
The loss of phosphorus (P) from land used for primary production to the environment is of considerable interest for the research and policy fields. Phytoextraction of pasture soil P through management practices such as reducing or omitting P fertiliser application may reduce concentrations and ultimately losses to the environment in surface runoff. The rate of soil P decline when phytoextracted by intensive pasture systems is not known, but preliminary results suggest that the initial soil extractable P concentration, soil buffering properties, P removal rate, P fertiliser rate and time may affect the rate of decline. We investigated the effect of these factors on the rate of P decline on six soils in north-west Tasmania. Olsen, Colwell and $CaCl_2$ P extractions are being used as agronomic (Olsen and Colwell P) and environmental ($CaCl_2$) measures of soil P. It is hypothesized that soil characteristics are the main driver behind the rate of P decline and the effects of various properties are being examined.

Key Words
Mining, withdrawal, decline

Introduction
Phosphorus (P) contained in runoff from intensively managed pastures can contribute to eutrophication of surface waters. Surface runoff concentrations are strongly related to soil P concentrations (Sharpley and Rekolainen 1997). Recent surveys in Tasmania and NSW have found that 60-70% of paddocks used for dairying have 2-3 times more P than the agronomic optimum. Soil P concentrations above agronomic optimum represents an unnecessary environmental risk. Strategies need to be developed to reduce soil P concentrations and hence runoff P. Few options for reducing environmental P loss that land owners will readily adopt have been proposed. Omitting P fertiliser application to high P concentrated soils may be one method of reducing the risk of P loss that could be readily adopted.
Research has been undertaken concerning phytoextraction of P concentrations under cropping systems. The emphasis has been on monitoring crop yield during the withdrawal stage (Paris *et al.* 2004), and is usually restricted to a limited range of soil types and initial P concentrations. Research was undertaken in the Netherlands concerning enriched grassland soils through omitting P application (VanderSalm *et al.* 2009), however the variety of soils used were small. The most broad source of P decline data comes from descriptions of P decline of control treatments i.e. (Roberts *et al.* 1994; Burkitt *et al.* 2002a), however high P concentrated soils are not usually included in these treatments. Little emphasis has been placed on the rate of P decline (mg/kg) across a range of initial soil P concentrations, soil types and characteristics, which may be the drivers under pasture systems.

Methods

Site management and soil characterisation
Six field sites were established on rain-fed commercial grazing properties across the major grazing areas of north and north-west Tasmania. All sites were used for permanent pasture, comprising predominantly perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), received a mean annual rainfall of 800–1000 mm (BOM 2005) and were grazed rotationally with varying stocking rates by dairy or beef cattle.
Treatments
At each site four soil P categories (defined by Olsen P) were established to represent typical paddock concentrations as follows; low ≤ 15 mg/kg, medium 16–30 mg/kg, high 31–40 mg/kg, and very high ≥ 41 mg/kg. In a fully factorial design, four P fertiliser rates were applied every six months, all treatments being replicated three times. The P fertiliser treatments were 0, 0.5, 1 and 2 times estimated P maintenance rates, according to site P buffering properties and soil P concentration, and maximum rates varied between 20 and 50 kg P/ha/yr between sites.

Soil sampling and analyses
Fifteen soil cores were sampled from each plot to a 100 mm depth for all treatments immediately before fertiliser application. To date, samples have been taken every 6 months from May 2005 until November 2009. The samples were analysed for Colwell (Colwell 1963), Olsen (Olsen *et al.* 1954) and $CaCl_2$ extractable P (Murphy and Riley 1962).
The data were analysed using a mixed model beginning with the full model containing all terms and interactions and subsequent elimination of non-significant terms.

Results

The Olsen P data for the initial two years are shown in Figure 1. There was an overall decreasing trend with time. There was an interaction between initial P concentration and time, with higher initial P concentrations declining more rapidly than lower ones.

For Olsen P, the very high concentrated soils declined by 2.5075 mg/kg per six months; high by 1.4281 (=-2.5075+1.0794) mg/kg per six months, but was not significantly different from the very high rate (P=0.0943); medium declined by 0.3602 (=-2.5075+2.1473) mg/kg per six months; and low declined by 0.0757 (=-2.5075+2.4318) mg/kg per six months, which was not significantly (P<0.05) different from zero. Thus Olsen P declined only for high and very high P concentrated pasture soils.

The inclusion of low PBI soils in this investigation highlights the environmental risk of fertilising these soils. Interestingly, Olsen and Colwell P concentrations at Site 3 could not be built beyond the initial concentrations of 23 and 30 mg/kg respectively, even after application of 250 kg/P/ha. We hypothesize that this is because P applied to these soils leached beyond the top 100 mm due to the low P buffering. The other sites had Olsen and Colwell P concentrations ranging from 51-111 and 256-433 mg/kg, respectively for the same treatments.

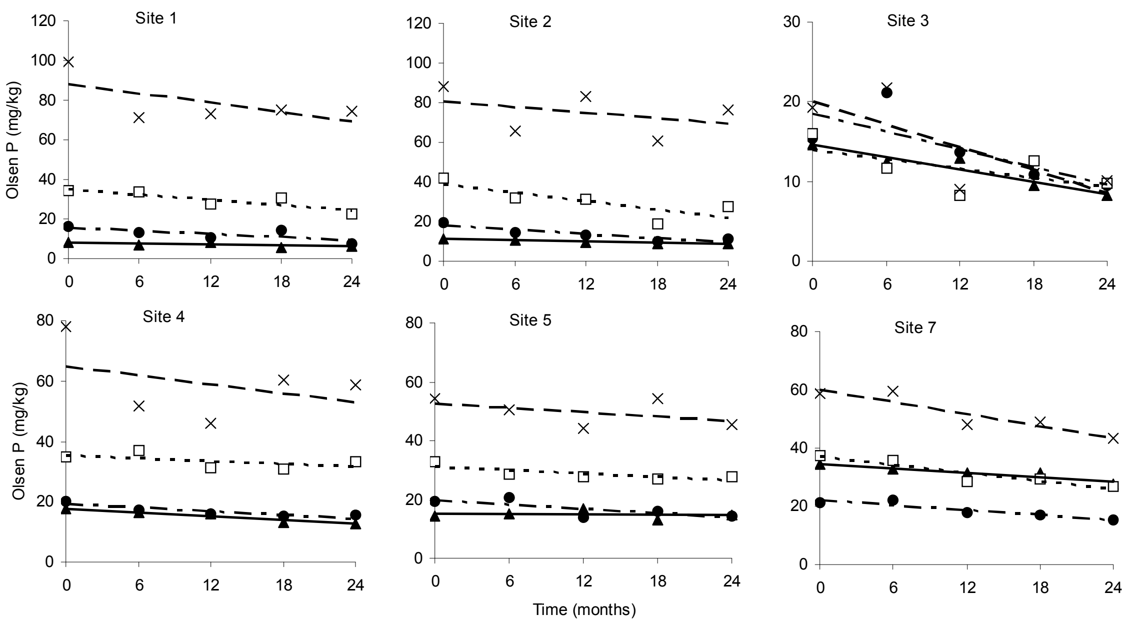

Figure 1. Two year decline in Olsen P concentration for the low (—▲—), medium (--•--), high (···□···) and very high (--x--) categories when fertiliser P is omitted at each site. Note that the scale of the y-axis varies.

Table 1. Selected chemical properties measured from the surface of pasture soils (0–100 mm) sampled from six field sites located in north and north-west Tasmania, prior to P fertiliser treatment.

	Site					
Characteristic	1	2	3	4	5	7
pH ($CaCl_2$)	5.4	4.8	3.9	4.9	4.8	4.6
Olsen P (mg/kg)	11.9	11.9	16.3	18.4	18.3	37.2
Colwell P (mg/kg)	40	39	30	43	69	72
Total P (mg/kg)	1287	418	314	406	1680	326
Organic P (mg/kg)	971	363	265	222	1019	248
Organic C (g/kg)	95	28	114	26	60	87
CEC ($cmol_c$/kg)	21	9	19	5	24	13
Ox-Al (mg/kg)	5849	2589	286	676	5186	797
Ox-Fe (mg/kg)	4680	4030	774	2340	12320	693
PBI_{+ColP}[A]	519	232	6	70	430	71
PBI_{+ColP} category[B]	High	Moderate	Extremely Low	Very Low	High	Very Low

[A] Phosphorus buffering index$_{+ColP}$ (Burkitt *et al.* 2002b).
[B] Phosphorus buffering index category (Moody 2007).

Conclusion

Preliminary results suggest the higher the initial P concentration, the greater the initial rate of decline. In addition there is a significant P fertiliser rate effect on rate of P decline. In addition to further monitoring, in the future we will be investigating the environmental implications of various fertiliser P rates, in particular withholding fertiliser P on high P concentrated soils.

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