Agriculture, Ecosystems and Environment 185 (2014) 65–76

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Manipulation of fertiliser regimes in phosphorus enriched soils can reduce phosphorus loss to leachate through an increase in pasture and microbial biomass production

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ARTICLE INFO

Article history:
Received 18 August 2013
Received in revised form 5 December 2013
Accepted 11 December 2013
Available online 1 January 2014

Keywords:
Phosphorus
Leaching
Lysimeter
Phytoextraction
Soil microbial biomass

ABSTRACT

Phytoextraction of phosphorus (P) has been proposed as a strategy to reduce the potential for P loss from P enriched soils. Compared to pastures that receive adequate P fertilisers to maintain soil P concentrations, applying half maintenance rates, or no P, slowly decreases soil P concentration and P losses to water. We hypothesise that the quantity of P lost in leachate can be further decreased by the addition of nitrogen (N) fertiliser to stimulate plant-P uptake. A 451 day lysimeter trial investigated subsurface P losses from three New Zealand soil types (USDA soil taxonomy: Udand, Dystrudept and Vitrand) under three N fertiliser rates, zero, 150 and 300 kg N ha^{-1} yr^{-1} and two rates of P fertiliser, zero and half maintenance application with regular cutting and removal of pasture. For two of the soil types (Dystrudept and Vitrand), N application increased pasture production and decreased the load of dissolved reactive P (DRP) leached by 53–76% and the load of total dissolved P (TDP) by 39–53% compared to when no N was applied. Furthermore, for these soils, compared to the no P and no N treatment, applying P at half the rate designed to maintain soil P concentration, decreased the load of DRP and TDP in leachate by a 62–68% and 54–59% due to immobilisation of P within the microbial biomass. A high sorption capacity, leading to slow but sustained release of P to the soil solution, was seen as the probable reason for the lack of treatment effect in the third soil (Udand). This study highlights the potential for manipulating fertiliser regimes and implementing a cut and carry system on critical source areas of P loss within a farm as a strategy to reduce P loss from P enriched pastoral soils without impacting on productivity.

1. Introduction

Agricultural soils enriched with phosphorus (P), due to a history of P fertilisation in excess of crop requirements, have potential to impair surface water quality (Sharpley et al., 1994). Decreasing soil P concentrations following a halt to fertiliser inputs has been shown to be slow (McCollum, 1991; Ma et al., 2009). Furthermore, following recent investigation of P-enriched pastoral soils, Dodd et al. (2012) suggested that decreasing soil P concentration through halting P fertilisers may lead to a decline in pasture production and various long-term fertiliser trials on grazed New Zealand pastures found decreases in both pasture and animal production in as little as two years following a halt to P fertiliser application (Gillingham et al., 1990; McBride et al., 1990; O'Connor et al., 1990; Dodd and Ledgard, 1999). One potential strategy to decrease P loss from P enriched soils without compromising farm productivity (viz. pasture production) is the cessation of P fertilisers while maintaining pasture production with nitrogen (N) inputs.

In mixed grass/clover pastures, plant growth is generally N-limited, and is especially so for soils with high P concentrations. Increased N fertiliser application will increase pasture growth leading to an increase in plant uptake of P, which we suggest will also strip P from the soil solution and decrease P losses in leachate. Perring et al. (2009) modelled the response of soil P concentrations to increased additions of N and demonstrated that short term application of N fertiliser coupled with regular cutting and removal of the biomass could decrease residual fertiliser P stored within the soil. Experimentally, Koopmans et al. (2004) found that the environmental soil P metrics of calcium chloride extractable P ($CaCl_2$-P; 1:10 soil-to-solution ratio) and water extractable P (WEP; 1:2 soil-to-solution ratio) decreased on average by 93% in greenhouse pot experiments where grass was grown on a P enriched soil with N fertilizer additions and regular harvests over 978 days. Similarly, van der Salm et al. (2009) found that halting P fertilizer application for 5 years reduced orthophosphate concentration by 30–90% in the

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0167-8809/$ – see front matter
http://dx.doi.org/10.1016/j.agee.2013.12.018

Table 1
Location of field sites from which the lysimeters were taken, soil type and initial soil properties at the 0–75 mm depth. Values in parenthesis show one standard error of the mean.

Sampling location	Soil type (New Zealand soil classification/USDA soil taxonomy)[a]	pH	Particle size (% sand, clay, silt)	Olsen P (mg kg^{-1})	WEP (mg L^{-1})	P retention (%)	Soil C (g kg^{-1})	Soil N (g kg^{-1})
Ruakura Research Centre, Waikato, NZ	Horotiu Silt Loam (Typic Orthic Allophanic soil/Udand)	4.9 (0.04)	60, 20, 20	34 (2)	0. 074 (0.006)	72 (4)	45.9 (1.8)	5.07 (0.25)
Woodlands Research Station, Southland, NZ	Waikiwi silt loam (Typic Firm Brown soil/Dystrudept)	5.0 (0.02)	20, 30, 50	37 (1)	0.076 (0.002)	53 (1)	57.2 (1.4)	5.54 (0.12)
Rerewhakaaitu Farm, Bay of Plenty, NZ	Taupo sandy loam (immature Orthic Pumice soil/Vitrand)	4.4 (0.02)	80, 10, 10	33 (2)	0.070 (0.003)	51 (2)	59.9 (2.1)	5.26 (0.28)

[a] New Zealand soil classifications converted to US soil taxonomy according to Hewitt (2010).

soil solution extracted from the top 0–5 cm of samples taken from field plots receiving 300 kg N ha^{-1} yr^{-1}. However, to our knowledge, there has been no direct measurement of P loss to water following the implementation of this strategy. Considering that P enriched soils have the potential to lose environmentally significant amounts of P via subsurface leaching, cessation of P fertiliser, increased application of N and applying a cut and carry system should reduce P loss to subsurface leaching within a short timeframe.

In addition to affecting pasture production, application of N and P fertilisers may have implications on below ground productivity and cycling of nutrients. Soil micro-organisms play an important role in the immobilisation or release of nutrients for plant uptake and loss to leachate (Blackwell et al., 2009). While, various studies have found a decline in microbial carbon (C), N and P concentration following the application of N fertiliser (e.g. He et al., 1997; Li et al., 2013), P fertilisation has been shown to increase microbial P and C content (He et al., 1997; Griffiths et al., 2012). Furthermore, Olander and Vitousek (2000) suggested that microbial supply of P is coupled to demand, in part through the release of phosphatase enzymes, maintaining soil solution P at levels which meet plant requirements but never greatly exceed it. Similarly, phosphatase activity has also been shown to be affected by fertiliser regime with N application increasing activity and P application suppressing activity (Marklein and Houlton, 2012). Hence, applying N fertiliser to increase pasture production together with small application rates of P fertiliser, may decrease soil solution P and leachate P losses, compared to no fertiliser. Furthermore, due to the concerns over the effect of halting P fertiliser application on productivity there may be resistance within the farming community to a complete cessation of P fertiliser application and a decrease in P fertiliser application rate may be a more acceptable, and therefore more widely adopted, strategy. Consequently, in addition to N application to strip soil P and boost pasture production, we also aimed to test what the effect was on P losses in subsurface flow from the application of half of the fertiliser P required to maintain the existing Olsen P concentrations (termed half maintenance).

The overall aim of this study was to assess the proposed strategy of applying N fertiliser with and without a half maintenance rate of P fertiliser, and cutting and removal of pasture, to increase the plant off-take of P and decrease P loss in leachate and to test the following two hypothesis; based on a cut and carry system.

1. Increased application of N fertiliser will increase P off-take in pasture and thereby reduce P loss to subsurface flow compared to simply withholding P fertiliser and;
2. Application of a half maintenance rate of P fertiliser can stimulate microbial growth, immobilise P within the microbial biomass and suppress exudation of phosphatase enzyme, decreasing soil solution P and leachate loss.

This was achieved using lysimeters of a range of soil types and applying N and P fertilisers in a factorial design with three rates of N fertiliser zero, 150 and 300 N ha^{-1} yr^{-1} and two rates of P fertiliser, zero and half maintenance application. In addition to dissolved reactive P (DRP), dissolved organic P (DOP) was determined since DOP can contribute to algal growth when converted into orthophosphate by phosphatase enzymes (Whitton et al., 1991). Dissolved inorganic N species (nitrate- and ammonical-N) were also measured to ensure the application of N fertiliser did not lead to unacceptable N leaching losses. Soil microbial biomass C, N and P was determined at the end of the trial along with soil phosphatase activities to assess the effect of fertiliser regime on biological nutrient cycling.

2. Methods

2.1. Soil description

Grazed pasture sites were selected on contrasting soil types with similar known topsoil Olsen P concentration, namely a Horotiu silt loam, a Waikiwi silt loam and a Taupo sandy loam (Table 1). These soil types cover three contrasting soil orders commonly under pasture in New Zealand, Allophanic, Brown and Pumice (Hewitt, 2010). The pasture was a mixture of ryegrass (*Lolium perenne* L.) and clover (*Trifolium repens* L.). Initial soil chemical data for the top 0–75 mm of soil, at the time of sample collection are presented in Table 1. Olsen P ranged from 33 mg P kg^{-1} on the Taupo sandy loam to 37 mg P kg^{-1} on the Waikiwi silt loam while WEP concentration ranged from 0.070 mg P L^{-1} on the Taupo sandy loam to 0.076 mg P L^{-1} on the Waikiwi silt loam. The Taupo sandy loam had the highest sand content at 80% compared to 60% for the Horotiu silt loam and 20% for the Waikiwi silt loam. The Horotiu silt loam had a high P retention of 72% compared to 53% and 51% for the Waikiwi and Taupo soils respectively.

2.2. Lysimeter setup

Twenty-four lysimeter cores (220 mm deep by 160 mm diameter) were taken of each soil by carefully excavating around the soil core and gently lowering a PVC pipe. Once the pipe was completely lowered, the soil beneath was cut with a knife to ensure a clean break. The soil cores were transported to the Invermay Agricultural