Agriculture, Ecosystems and Environment 202 (2015) 139–147

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Carbon and nitrogen leaching under high and low phosphate fertility pasture with increasing nitrogen inputs

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ARTICLE INFO

Article history:
Received 19 June 2014
Received in revised form 27 December 2014
Accepted 30 December 2014
Available online 16 January 2015

Keywords:
Urea
Phosphorus
Herbage
Stocks
Lysimeter
N saturation
Urine

ABSTRACT

Intensive pastoral land use is associated with increased use of phosphate (P) and nitrogen (N) to enhance food and fibre production, but the interaction of N and P, particularly on carbon (C) storage, is not well understood. Our objectives were to determine the quantity and forms of C and N leached and also the changes in soil stocks in association with progressively increasing urea additions in two similar soils with high and low phosphate (P) fertility. A pasture cut-and-carry lysimeter experiment was established in the Waikato region of New Zealand, using soils from sheep grazed farmlets with a P management history of either no P or high P additions. Treatments imposed were a continuation of no P and high P (31.5 kg ha^{-1} y^{-1}) inputs in combination with 0, 100, 200, 400 kg urea–N ha^{-1} y^{-1} in 50 kg split dressings or a single spring application of 400 kg N ha^{-1} y^{-1} of bovine urine. The high P soil had greater dissolved organic carbon (DOC) leaching, and DOC leaching in both soils increased with increasing urea inputs. Soil C decreased in the high P soil with N inputs, although there was no correlation between the rate of N addition and C loss. Urea addition led to increased N leaching in both soils, but was reduced in the high P soil compared with the no P soil. Greater herbage production may have utilised more dissolved N in the high P than in the no P soils, which led to less N available for leaching in the high P soil. Urine additions also led to greater C and N leaching in both the no P and high P soils.

1. Introduction

Nitrogen (N) and phosphorus (P) are essential for the production of food and fibre; however, excessive N and P can have negative effects on ground and surface water quality (Vitousek et al., 1997; Di and Cameron, 2002a; UNEP and WHRC (2007)). Eutrophication of waterways causes a reduction of the oxygen content of the water and can lead to a loss of biodiversity and cause the production of toxic algal blooms (Carpenter et al., 1998). Pastoral farming, including dairy and sheep and beef production, is the main contributor of excess N and P in the environment in NZ (Carpenter et al., 1998; Elliott et al., 2005; Drewry et al., 2006; Parfitt et al., 2012, 2013).

There has been considerable research into the effects of N fertiliser application on N leaching and greenhouse gas production (e.g. Oenema et al., 1997; Ledgard et al., 1999), but there is limited knowledge on the effect of combined N and P inputs on N, P and carbon (C) leaching. Parfitt et al. (2009) established a field trial on two similar soils with different P management histories, and assessed the effect of urea additions of 300 kg N ha^{-1} y^{-1} on leaching. They found greater leaching of P and N in soil applied with 34 kg P ha^{-1} y^{-1} (high P soil) compared with soil with no P inputs (no P soil) under the same land use. Further, they measured greater dissolved organic carbon (DOC) leaching from the no P soil than from the high P soil with N application. Phoenix et al. (2003) reported less N leaching following the application of both N and P fertilizer compared with application of N fertilizer alone. They suggested greater soil P availability increased plant production, microbial activity, and microbial immobilization of the N inputs, therefore reducing N leaching with P inputs.

It is widely accepted that urine deposition increases N leaching due to the addition of more N than can be taken up by plants (Di and Cameron, 2002b; Wachendorf and Wachendorf, 2005). Lambie et al. (2012a,b); Lambie et al. (2012a,b) have also shown increased soil C loss in urine-treated soil, which would also contribute to increased organic N losses. Therefore, fertilizer and urine inputs could increase both N and C leaching in grazed pasture; however,

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http://dx.doi.org/10.1016/j.agee.2014.12.021
0167-8809/

there is limited information on the effect of P and N fertiliser inputs on C leaching from urine patches.

N and P inputs not only influence leaching, but also the storage of N and C in soils. Parfitt et al. (2009) reported that initial N inputs were retained by the no P soil, but N leaching did occur in the second year of the field trial. He et al. (2013a) found that N additions led to increased C storage, as did P additions, which was thought to be due to increased C inputs from enhanced litter and root production. However, He et al. (2013a) did not assess the combined effect of P and N inputs on C storage. Bradford et al. (2008) found that N inputs increased C sequestration but P inputs decreased C decomposition and the combination of N and P inputs decreased C decomposition with increasing N input. Fornara et al. (2013) reported that in a grassland nutrient addition experiment, combined nutrient additions of N, P, potassium, and magnesium had no effect on C sequestration compared with a no input control, while an N only treatment increased C sequestration.

To build further on the work of Parfitt et al. (2009), we established a lysimeter experiment to assess the quantity and forms of C and N leaching losses and changes in soil C and N stocks with increasing N inputs (added as either urine or urea) to two similar soils with differing P fertility.

2. Materials and methods

2.1. Soil collection and lysimeter installation

Undisturbed soil cores were collected from the Ballantrae Hill Country Research Farm (AgResearch Ltd., New Zealand) located on the eastern slopes of the Ruahine Ranges in the southern Hawke's Bay Region (40°18′S, 175°50′E) in November 2005.

The soil cores came from a long-term fertiliser and sheep-grazing study with no P fertiliser (no P) and 34 kg P ha^{-1} y^{-1} (high P) farmlets (Lambert et al., 2000; Parfitt et al., 2009). The soils from both farmlets are classified as acidic orthic brown soils (Hewitt, 1998) or typic dystrudepts (Soil Survey Staff, 2010) and were formed on mudstones and loess. For specific site climate data, soil properties, fertiliser application history and plant species present at both collection sites refer to Parfitt et al. (2009). Neither the no P or high P soils had received nitrogen from fertiliser since 1980 (Parfitt et al., 2009), but would have had urine-N inputs. The stocking rates for the no P and high P sites were 6 and 16 ewe equivalents per hectare, respectively (Parfitt et al., 2009). Due to the differing intensities in stocking rates, the high P site would also have received greater dung inputs than the no P site.

Fifty undisturbed soil cores (30 cm diameter × 36 cm deep) were collected by carving a soil core that enabled a PVC sleeve (40 cm diameter × 50 cm depth) to encase the monolith progressively as the soil was carved away (Cameron et al., 1992; Di and Cameron, 2002b). To prevent bypass flow down the edge of the cores, heated petroleum jelly was used to fill the gap between the soil and the sleeve.

The cores were subsequently transported to a lysimeter facility that enabled them to be installed with pasture at ground level (Ruakura Research Farm, Hamilton, New Zealand; 37°47′S, 175°19′E). Core installation at the lysimeter facility was completed in April 2007. Leachate was collected in 20-L plastic containers in a trench below the base of the lysimeters. Rainfall and climate data were collected from the Ruakura Weather station (37°78′S, 175°32′E). Evapotranspiration was estimated using the Penman–Monteith equation.

2.2. Nitrogen treatments

The high P soil received 350 kg single superphosphate ha^{-1} y^{-1}, or the equivalent of 31.5 kg P, in March of each year to maintain its high P fertility status. Both the no P and high P soils received 4 levels of N fertiliser – 0, 100, 200, or 400 kg N ha^{-1} y^{-1} urea – applied in 50-kg split dressings beginning in August (Table 1). A further treatment of a single cow urine addition of 400 kg N ha^{-1} y^{-1}, applied annually in October, was also included. There were five replicates of each treatment for each soil.

The urea was dissolved in 373 mL (equivalent to 10 mm of irrigation) and the equivalent volume of water added to the other cores. Urine was collected from Friesian cows during milking, following grazing of ryegrass clover sward (Ruakura Research Farm, Hamilton, New Zealand). The urine was bulked as collected, a subsample analysed for N concentration, and the remainder frozen. On the day of urine application, the urine was thawed and applied to the cores at a rate of 400 kg N ha^{-1}.

The cores were irrigated during summer, with annual additions of irrigation (including when urea was added) of 42, 180, 32, and 26 mm in 2007, 2008, 2009, and 2010, respectively. Despite irrigation during drought periods, the 2009/2010 summer grass on the lysimeters had to be resown with ryegrass on 12 May 2010. The timing of N fertilizer applications varied slightly between the 3 years of the trial (Table 1).

2.3. Leachate nitrogen, carbon and phosphorus

Leachates from the lysimeters were generally collected weekly, a subsample was filtered through a 0.45-μm cellulose acetate membrane and both the filtered and unfiltered samples were frozen. Leachate collected over each 2-month period was defrosted, proportionately bulked, and analysed. Clough et al. (2001) found that freezing leachates containing nitrite and an acidic pH, caused an increase in NO_3, and a decrease in NH_4 and nitrite concentrations. The pH of the leachates from our lysimeter trial had a pH around neutral; however, we recognise that some increase in NO_3 and reduction in NH_4 may have occurred in our samples.

Total carbon (TC) and inorganic C were also quantified on unfiltered samples by high temperature combustion of dissolved C into carbon dioxide and subsequent infrared quantification (Elementar Analysensystems GMbH, Hanau, Germany; American Public Health Association, 2005). Dissolved organic C (DOC) was measured as the difference between the total carbon and inorganic C concentration of the filtered (0.45 μm) leachate (Elementar Analysensystems GMbH, Hanau, Germany; American Public Health Association, 2005). Total dissolved N (TDN) was quantified in filtered (0.45 μm) samples using persulphate digestion (Hosomi and Sudo, 1986). Dissolved reactive phosphorus (DRP), nitrate

Table 1
Urea and urine application rates and frequency over 3 years of the lysimeter trial.

Treatment	N added kg N ha^{-1} y^{-1}	Year 1 Time of application	Years 2 and 3 Time of application
$Urea_0$	0	n/a	n/a
$Urea_{100}$	100	Aug, May	Aug, April
$Urea_{200}$	200	Aug, Nov, Feb, May	Aug, Nov, March, June
$Urea_{400}$	400	Aug, Oct, Nov, Dec, Feb, April, May, June	Aug, Sep, Nov, Dec, March, April, June, July
$Urine_{400}$	400	Nov	Sep