Phosphorus leaching from pastures can be an environmental risk and even a significant fertiliser expense

MATT R. REDDING[1], A. GHANI[1], M. KEAR[1], M. O'CONNOR[1] and W. CATTO[2]
[1]*Land and Environment Management, AgResearch, East Street, Ruakura*
[2]*Ballance Agri-nutrients Ltd, Private Bag 12503, Tauranga*
matt.redding@agresearch.co.nz

Abstract
While it is true that leaching is usually not a strong pathway for phosphorus (P) loss under many systems, is it true for all? Two studies reported in this paper sought to establish if significant phosphorus leaching can occur under normal pastoral production systems. Undisturbed-core lysimeters collected from a Wharekohe silt loam from Northland were treated with fertiliser P (reactive phosphate rock and superphosphate) then leached from August to November, 2005. In a second study, soil profiles under pasture for sheep/beef and dairy production in the catchments of the Rotorua lakes were sampled to depths of 1.5 m (28 sites), and soil Olsen P and P retention capacity index were determined down these profiles. Phosphorus losses from the Wharekohe soil to 25 cm depth were up to 33% of the P applied (superphosphate applications of 50 and 100 kg P/ha). Some Rotorua soils displayed enriched P concentrations at depth (to 1.5 m), often coupled with moderate or low P sorption capacities. If connectivity exists between leaching pathways and surface water bodies these observations indicate that alternative management strategies need to be developed and adopted for soils that leach significant quantities of P. The Wharekohe silt loam is one such soil.
Keywords: phosphorus, leaching

Introduction
Leaching is a pathway for phosphorus loss that is often dismissed as not of either economic or environmental significance. However, there is no shortage of literature establishing the occurrence of P leaching in a variety of different soils and productions systems (Chardon *et al.* 1997; Redding 2001; Toor *et al.* 2005). A build-up of excess P in the soil can eventually lead to P leaching despite increased sorption at depth. However, the soil's P sorption characteristics assessed by sorption curves or "anion storage capacity" measurements cannot stand alone as an indicator of P leaching potential, since soil structure, artificial drainage, phosphorus forms, desorption characteristics, and climate all influence whether the soil's potential to sorb phosphorus is realised (McDowell *et al.* 2004).

The purpose of this paper is to present the results of some recent research regarding the leaching of phosphorus from a variety of New Zealand soils. The studies sought to determine whether leaching is of environmental or even economic significance.

Methods
Study one: Wharekohe soil monolith lysimeter leaching trial
Undisturbed soil cores (234 mm diameter) were collected from 0 to 250 mm depth in June 2005 (soil initial assays, Table 1), and encased in PVC.

Table 1 Initial soil characteristics. Phosphorus retention capacity index (ASC) determined according to Saunders (1964).

Analysis	Result
pH	5.1
Ca (Quick Test)	9
Olsen P (mg kg^{-1})	9
K (Quick Test)	3
S (SO_4; mg kg^{-1})	3
Organic S (mg kg^{-1})	5
Mg (Quick Test)	16
Na (Quick Test)	6
P Sorption Index (0-75 mm)	4 %
P Sorption Index (0-150 mm)	8 %
P Sorption Index (150-225 mm)	4 %

The encased columns were fixed to a base constructed from a funnel filled with gravel. Each of the completed lysimeters was installed in-field at the Ruakura Research Centre at Hamilton, and leachate captured in collection vessels. The installation was configured as a randomised two-row array, with 20 lysimeters in total (at about 1 m spacing). Each column received 3.05 g of gypsum and 64.6 g of lime, and basal fertiliser sufficient to adjust the low fertility of the site to the recommended agronomic status (Table 1).

The treatments applied to the columns included Gafsa phosphate rock (12.91% P), and superphosphate (10.1% P) each applied at 50 and 100 kg of P/ha; treatments are henceforth abbreviated as Gafsa 50, Gafsa 100, super 50, super 100. Four replicates of each treatment and a control were prepared.

Leachate was collected from August to November. Ruakura rainfall was supplemented with purified water to the 10 year average measured for Kaikohe (an

Table 2 Some details of the pastoral sites that were sampled from catchments around lakes in the Rotorua area.

Land use	Soil type	Sites	Lakes
Dairy	Rotomahana shallow sandy loam	1, 2	Rotorua
Dairy	Te Ngae loamy sand	3	Rotorua
Bull beef	Te Ngae loamy sand	4, 5	Rotorua
Sheep/beef	Ngakuru Sandy loam	6, 7, 13	Rotorua
Dairy runoff/Dry stock	Oropi Hill soil	8	Rotorua
Dairy	Oropi Sand	9, 11	Rotorua
Sheep/beef	Oropi Sand	10	Rotorua
Dairy runoff/Dry stock	Waiowhiro sand	14	Rotorua
Dairy runoff/Dry stock	Ngakuru Sandy loam	15	Rotorua
Sheep/beef	Rotoiti loamy sand	16	Rotorua
Maize	Te Ngae loamy sand	17	Rotorua
Maize	Waiowhiro sand	18	Rotorua
Dairy runoff/Dry stock	Waiowhiro sand/Utahina peaty loam	24	Rotorua
Bull beef	Rotoiti loamy sand	19, 23	Rotoiti
Dairy runoff/Dry stock	Waiowhiro sand/Utahina peaty loam	12	Rotoiti
Deer	Rotomahana sandy loam	20, 21	Tarawera
Sheep/beef	Rotomahana hill soil	22	Tarawera
Dairy	Te Rere shallow sand	25, 26	Rerewkakaaitu
Dairy	Matahina gravel	27, 28	Rerewkakaaitu

additional 210 mm, applied as a monthly supplement to natural rainfall at Ruakura). Filtered (< 0.45 mm pore size membrane) and unfiltered leachate samples were analysed for total and molybdate reactive P (Murphy & Riley 1962).

Pasture was cut when it reached a height of about 100 mm. Dry matter production was determined from the cut vegetation, along with P and K uptake.

A field plot trial is in progress at the site from which the lysimeters were collected, though only preliminary results are available. This trial includes eight control plots, and four replicates each of 25, 50, and 100 kg P/ha of Gafsa PR and superphosphate.

Standard analysis of variance techniques (with uniformity dry-matter cuts or pre-treatment leachings as co-variates) were appropriate for most data analysis. However, it was necessary to log transform some data sets due to heteroscadistic residuals for the untransformed data.

Study two: assessment of phosphorus leaching risk around Rotorua Lakes

Twenty eight sites were selected for sampling based on soil type and P retention information. Seventeen farms from the Lake Rotorua catchment were sampled: four each from Lake Tarawera and Rerewhakaaitu catchments, and two samples from catchments of Lake Rotoiti (Table 2).

From an area of 25 m^2, three deep cores (0 - 150 cm) were collected at each site. Olsen P (Olsen *et al*. 1954) and P retention capacity index (ASC; Saunders 1964) measurements were made on air dried samples. Linear regression techniques were used to investigate relationships between analyte concentrations at the different depth intervals. Total organic carbon (C; by combustion method using a LECO C/N analyser), total N and total P were measured on the 0 – 10 and 10 – 20 cm depth intervals.

Results and Discussion

Study one

Leaching losses of P were lowest in the Gafsa 50 and Gafsa 100 treatments (0.3 and 0.4% of the total applied, adjusted for control losses; soil ASC 5%; Fig. 1). In contrast leaching losses were > 30% of superphosphate applied.

Pasture growth was only sufficient to allow two pasture cuts during the experiment, and these showed no significant differences between treatments. Clear, statistically significant differences ($P<0.05$) between product types for cumulative P uptake were observed with uptake greater from the superphosphate treatment than from either the Gafsa treatment or the control (Fig. 2).

The losses of superphosphate P were large enough to be both an immediate economic concern and an environmental risk (33 to 34% of that applied). The magnitude of these losses is probably attributable to the free draining nature of the soil columns, and the low phosphorus sorption capacity (indicated by low ASC) of the soil.

Edwards (1997) suggested a range of measures to minimise phosphorus losses from this soil, including the use of frequent small applications of fertiliser P rather than larger less frequent applications, and application of less soluble fertilisers. However, recent research has indicated that more frequent application of small quantities of fertiliser may result in increased

Figure 1 Cumulative phosphorus leachate losses from the columns. Note that these values are transformed means used for statistical analysis. Actual percentage losses are recorded above each bar.

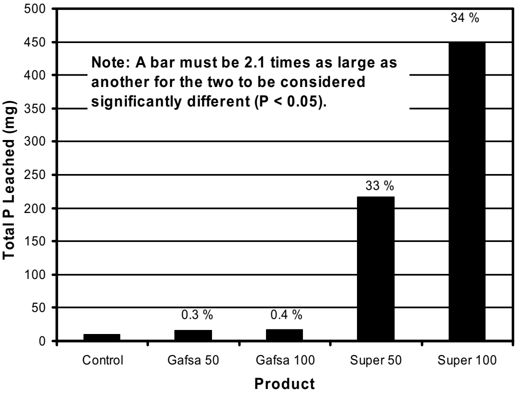
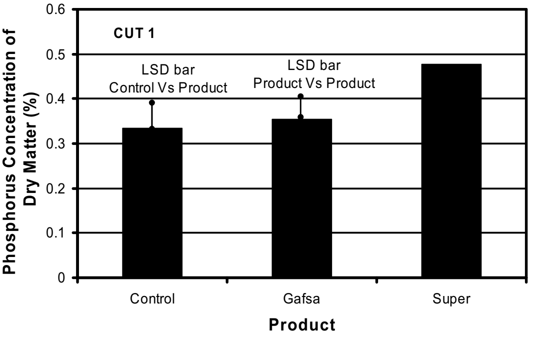
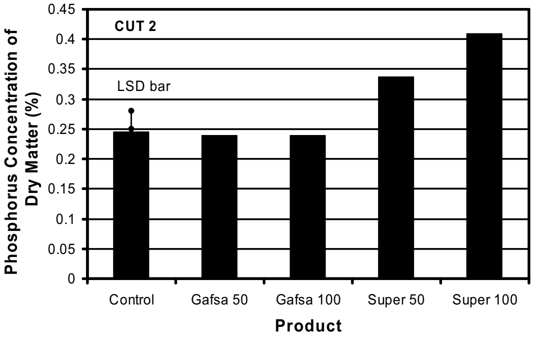


Figure 2 Dry matter P concentrations from two cuts of the lysimeter trial. Note that significant product differences were observed for cut 1, while both significant product and rate differences were observed for cut 2 (P < 0.05).





losses, due to the vulnerability of fertiliser P to transport immediately after application (McDowell & Catto 2005). Use of a less soluble fertiliser remains a viable alternative practice. An ideal fertiliser for the location would combine the resistance to leaching of the phosphate rock with the uptake characteristics of the superphosphate.

Early field trial results support the conclusions from the lysimeter trial. No significant difference has so far been observed between either dry matter production or phosphorus uptake from the Gafsa PR and the superphosphate applications ($P<0.05$). The advantages of each fertiliser form appear to be counteracted by its disadvantages. Other fertiliser forms should be investigated for use in this and similar soils.

It is important to note that the lysimeters used in the study did not include the silica pan that exists at greater depth in the Wharekohe soil. It is possible that this pan may negate or exacerbate transfer of leachate to surface waterbodies.

Study two

More than 66% of the dairy sites sampled had Olsen P concentrations greater than the optimum range (35-45 µg P/ml; a possible exception to this recommendation are coarse soils such as the Tarawera/Matahira gravels where optimum levels differ, however, the optimal range for these coarse soils was exceeded at sites 27 and 28). Phosphorus retention measured by ASC varied from 1 to 95% (Table 3). The sheep/beef farms that were sampled had appropriate Olsen P concentrations for optimal pasture production.

Table 3 Distribution of P retention capacity index (ASC) in soils at various depths.

Soil depth (mm)	% ASC Mean	Range
0-100	40	13 - 82
100-200	39	7 - 84
200-400	42	4 - 95
400-700	50	3 - 86
700-1000	51	2 - 85
1000-1500	47	1 - 91

Some enriched Olsen P concentrations were observed at depths below 200 mm at sites with low to moderate ASC values (Table 3; Olsen P values 200-400 mm ranged from 1 to 35 mg P/ml). Though the sampled locations allowed no comparison with untreated sites, there is a suggestion that high Olsen P concentrations at depth (1000-1500 mm) were weakly related to high Olsen P concentrations in the 0 – 100 mm interval ($y = 0.0827\ x + 1.75$: $R^2 = 0.23$, $P < 0.05$). It seems unlikely that the high concentrations of Olsen P at depths below 200 mm can be attributed to root development or worm activity. Data for New Zealand pastures suggest that most earthworm activity occurs in the surface 300 mm of the soil, with one species displaying some activity to a depth of 1 m (Reg Keogh pers. comm.). Similarly, New Zealand data suggests that the great majority of pasture root mass in grazed pastures occurs at depths less than 200 mm (e.g. > 95%; Nie *et al.* 1997). The equation of McDowell and Condron (2004) can be used to estimate P movement in subsoil from Olsen P and ASC values. For example, an Olsen P concentration of 20 and ASC of 20% would result in a likely P concentration of 0.05 mg/L and may cause significant enrichment of deeper layers should leaching occur.

Conclusions

The data collected here provide some examples where P leaching may occur under conventional pastoral agriculture. Losses are generally not of immediate economic importance to the farmer, though they can be, as evidenced by the leaching data collected from the Wharekohe lysimeters. Where phosphorus is added in excess of pasture requirements, P loss can occur and these losses could enter surface water bodies. These observations reinforce that Olsen P concentrations in excess of those required for near-maximum pasture production may be a liability rather than "money in the bank".

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