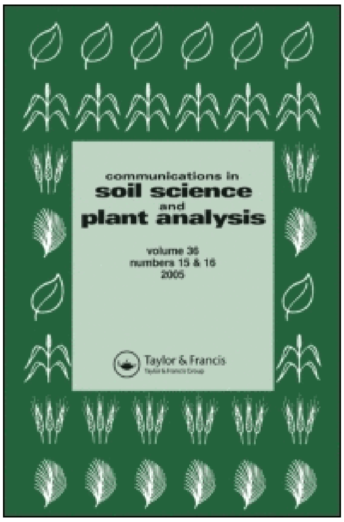

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R. W. McDowell[a]; R. W. Muirhead[a]; R. M. Monaghan[a]
[a] AgResearch Ltd., Invermay Agricultural Centre, Mosgiel, New Zealand

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Nutrient, Sediment, and Bacterial Losses in Overland Flow from Pasture and Cropping Soils Following Cattle Dung Deposition

R. W. McDowell, R. W. Muirhead, and R. M. Monaghan
AgResearch Ltd., Invermay Agricultural Centre, Mosgiel, New Zealand

Abstract: The loss of phosphorus (P), suspended sediment (SS), ammonia (NH_4^+-N), nitrate (NO_3^--N), and *Escherichia coli* in overland flow (OF) from dairy cattle dung can impair surface water quality. However, the risk of P and N loss from grazed pastures varies with time. Current practice in southern New Zealand is to select a field, cultivate, sow in *Brassica spp*., and graze in winter to save remaining pasture from damage. This deposits dung when soil is wet and OF likely. Hence, we determined P, NH_4^+-N, NO_3^--N, and *E. coli* loss from dung in OF via simulated rainfall from intact grazed pasture and cropland treatments of a soil. Analysis of OF, 0, 1, 4, 11, 24, and 43 days after dung deposition at the upslope end of soil boxes indicated that total P (TP), NH_4^+-N, and SS concentrations decreased sharply from day zero and leveled out after 11 days. More particulate P and SS were lost from the cultivated than pasture treatment, whereas the reverse occurred for dissolved organic P because of greater sorption of phytase active materials. *Escherichia coli* losses were high (1×10^5 100 mL^{-1}) in both treatments throughout. Using the equations of fit in an example field site indicated that management of dung deposition could affect up to 25–33% of TP lost in OF.

Keywords: Nitrogen, phosphorus, sediment, *E. coli*

INTRODUCTION

Loss from dairy cattle dung of phosphorus (P) and nitrogen (N) sediment and harmful bacteria represent a significant cause of impaired water quality

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Address correspondence to R. W. McDowell, AgResearch Ltd., Invermay Agricultural Centre, Private Bag 50034, Mosgiel, New Zealand. E-mail: richard.mcdowell@agresearch.co.nz

(Wilcock et al. 1999). In New Zealand, dairy cattle graze on pastures for most of the year. However, in cooler areas such as southern New Zealand, poor pasture growth in winter requires an alternative strategy. Here, animals are typically placed in a field where pasture has been cultivated and a forage crop grown for winter feed (e.g., *Brassica rutabaga* L.). This is done to protect remaining pastures on the farm, but results in dung deposition and soil disturbance when the soil is typically wet (McDowell et al. 2003b).

Grazing and dung deposition enhances the loss of nutrients, sediment, and fecal bacteria in overland flow (OF) and, consequently, stream flow. Doran et al. (1981) showed a 1.1–1.8-fold increase in nutrient (e.g., NH_4-N, NO_3-N, soluble and total P) loss in OF from grazed pasture than when pasture was not grazed. Furthermore, soil compaction and disturbance from animal hooves can increase sediment loss, especially in wet conditions (Nguyen et al. 1998). However, some results in the literature contradict these findings. For example, Milne (1976) sampled flow from five stations along a stream in Montana, adjacent to a cattle wintering operation but found that wintering cattle had no appreciable effect on chemical water quality. Similarly, Edwards et al. (2000) concluded that application of manure (in simulated dung pats) to 15 m^2 pasture plots at rates up to 5.6 kg per plot had negligible effect on the nutrient content of OF.

Studies looking at the transfer of micro organisms and specifically bacteria harmful to human health have largely concluded that spreading manure or dung deposition from grazing animals causes a significant increase in the concentration and load of bacteria in OF. For instance, Fenlon et al. (2000) found that approximately 7–10% of *E. coli* and *E. coli* O157 applied to 600 m^2 plots were lost in flow (overland and subsurface) and that most loss was associated with heavy rainfall events. Milne (1976) noted total coliforms increased by more than three orders of magnitude downstream of grazing cattle. However, the loss of bacteria from arable land appears to be different. For instance, Giddens and Barnett (1980) noted that no bacteria were lost in OF from manure applied to bare soil compared with grassland. King et al. (1994) also noted that more bacteria may be lost in OF from manure applied to no-till plots than plots that had been plowed 24 h prior to application.

The mechanisms of nutrient, sediment, and fecal bacteria loss in OF between land uses are unclear. This is important for rotational grazing systems where pastures are grazed for 1–2 days, livestock removed, and the pasture grazed again 14–30 days later, but up to 90 days in winter. If modeling losses due to inputs from grazing animals are to be successful, then data on the contribution of dung to losses are needed. At present, less is known about nutrient, sediment, and *E. coli* loss from grazed pastures than manure broadcast on pasture or arable (cultivated) land, and very little is known of losses from grazed cropland (e.g., Mueller et al. 1984; Gangbazo et al. 1997; Gupta et al. 1997; Preedy et al. 2001; Withers et al. 2001). To correct this, our work aims to determine nutrient (P and N), sediment, and

E. coli losses in saturation excess OF derived from cattle dung pats deposited on grazed pasture and forage cropland of the same soil type in boxes. Second, we determined short-term (up to 43 days) changes in nutrient, sediment, and *E. coli* concentration in OF with time since dung deposition.

MATERIALS AND METHODS

Soil and Preparation

The soil (Waitahuna silt loam: USDA Taxonomy-Typic Hapludalf, NZ Classification-Mottled Fragic Pallic) was taken from two adjacent treatments on a dairy farm in the Dull Burn catchment (NZ Map Grid East 2257950, North 5450100) Balclutha, South Otago, New Zealand. Each treatment site was 0.5 ha in size. One was under grass, whereas the other had been cultivated into winter crops [*Brassica rutabaga* L. (swede) and *Brassica oleracea* L (kale)]. Three years prior to sampling, six plots, each $36\,m^2$ in size, were randomly located at each site; one site was plowed and sown in swede and kale 18 months prior to sampling in spring, whereas the other remained in pasture. Equal quantities of fertilizers ($34\,kg\,P\,ha^{-1}$, $42\,kg\,S\,ha^{-1}$, and $76\,kg\,N\,ha^{-1}$) were applied annually to both sites in spring, but after sampling. Soil sampling of each plot (0–7.5 cm) was conducted in late summer 2003 for chemical and physical analyses, and the mean data are given in Table 1. Prior to plot installation, both sites had been in pasture grazed by sheep and beef cattle and had the same Olsen P concentration ($25 \pm 2\,mg\,kg^{-1}$).

Intact soil blocks were taken of each land use by using a 2-m-long by 20-cm-wide metal cutting blade to 10-cm depth. The pasture had a 95% ground cover, whereas the cultivated site had been grazed 4 months prior to sampling leaving less than 5% of the ground covered with a crop. Soil blocks were placed in boxes, 2-m-long by 20-cm-wide by 10-cm-deep, with six 1-mm holes drilled to allow some drainage (up to $1\,mm\,h^{-1}$). On the 1st day of the experiment, approximately 40 kg of feces (total P concentration $7850\,mg\,kg^{-1}$) was collected from the concrete holding pen of a nearby dairy farm and thoroughly mixed. Eighteen boxes of each land use then received a 1 kg dung pat (moisture content *c*. 88%) placed within a 20-cm-diameter metal ring at the upslope end of each box. This is equivalent to typical dung deposition over $0.4\,m^2$ for a 24- to 36-h grazing period. The metal rings were removed and soils were moved outside and inclined at 5% slope (similar to that found at the sampling site). Vegetation in the pasture soil boxes was trimmed to 5 cm during the experiment, but because of cool conditions, little growth was noted. The 18 samples of each land use were split into six sets of three replicates. One set of each land use treatment plus a set of controls each were then moved into an indoor artificial rainfall facility, rained upon, OF collected, and the soil blocks discarded after use.

Table 1. Mean concentrations for nutrients, sediment, and *E. coli* in overland flow for all events and least significant difference (LSD) at the $p < 5$ level of significance of the control (before dung application) pasture and cultivated Waitahuna silt loam soils

Parameter	Pasture	Cultivated	LSD_{05}
Olsen P ($mg\,kg^{-1}$)	69	44	27
DRP ($mg\,L^{-1}$)	0.15	0.05	0.06
DOP ($mg\,L^{-1}$)	0.18	0.05	0.11
PP ($mg\,L^{-1}$)	0.08	0.16	0.10
TP ($mg\,L^{-1}$)	0.54	0.25	0.15
NO_3-N ($mg\,L^{-1}$)	5.4	3.8	1.5
NH_4-N ($mg\,L^{-1}$)	0.1	0.1	0.1
SS (g $100\,mL^{-1}$)	0.07	0.15	
E. coli (Log_{10} $100\,mL^{-1}$)	0.78	1.34	1.34
Langmuir P sorption maximum ($mg\,kg^{-1}$)	469	1655	421
Langmuir P sorption affinity ($L\,mg^{-1}$ P)	0.021	0.031	0.005
Sand ($g\,kg^{-1}$)	7.5	6.0	2.0
Silt ($g\,kg^{-1}$)	64.5	66.0	3.5
Clay ($g\,kg^{-1}$)	28.0	28.0	2.5
Surface roughness coefficient (%)	6.2	24.8	1.7
K_{sat} ($mm\,hr^{-1}$)[a]	169	786	221

[a]Saturated hydraulic conductivity.

Simulated rainfall occurred either immediately, 1, 4, 11, 24, and 43 days after dung deposition. Meteorological data were taken at hourly intervals from a site 150 m away and summed to get daily rainfall and averaged for daily moisture under pasture in the top 5-cm depth.

Overland Flow

Overland flow was generated by applying artificial rainfall (tap water, P less than detection limit of $0.005\,mg\,P\,L^{-1}$, NH_4^+-N $< 0.01\,mg\,N\,L^{-1}$, NO_3^--N $< 0.1\,mg\,N\,L^{-1}$) at $16\,mm\,h^{-1}$ to each boxed soil inclined at 5% slope. The rainfall simulator uses one TeeJet 1/4HH-SS30WSQ nozzle (Spraying Systems Co., Wheaton, IL) approximately 250 cm above the soil surface to gain terminal velocity. The nozzle, plumbing, in-line filter, and pressure gauge were fitted onto a 305-cm-high by 305-cm-wide by 305-cm-deep aluminum frame with tarpaulins on each side to provide a wind screen. Simulated rainfall had drop-size, velocity, and impact energies approximating natural rainfall (Shelton et al. 1985). The $16\,mm\,h^{-1}$ rainfall intensity has a return frequency of approximately three times a year for a

15-min event. Overland flow was collected for 20 min and a subsample was taken for analysis.

Water, Soil, and Dung Analyses

Air-dried samples of soils were analyzed in triplicate for bicarbonate extractable P (Olsen P) by using the method of Olsen et al. (1954). For P sorption, soils (g) were mixed with 20 mL of solutions containing graduated (0, 1, 2, 4, 10, 20, and 50 mg P mL^{-1}) solutions of P (as KH_2PO_4) and shaken for 16 h. Samples were then filtered and P was determined colorimetrically. The Langmuir equation was used to obtain estimates of the P sorption maximum (P_{max}; mg kg^{-1}) and the P affinity parameter (binding strength, *k*; mg P L^{-1}).

Saturated hydraulic conductivity (K_{sat}) was determined as described by Drewry et al. (2000). Briefly, two soil cores were collected from each plot by using stainless steel rings (10-cm-diameter and 6.5-cm-high). The inside of each ring was coated with petrolatum to avoid edge flow. Once inserted into soil, cores were excavated and transported to the laboratory. Here, the base of each core was trimmed, whereas the top surface was coated with $CaSO_4$ slurry, left to dry, and later "peeled" away to give an unsmeared surface. Earthworms were removed with formaldehyde, and K_{sat} was measured via a Mariotte vessel to pond water on the soil surface. Surface roughness was determined by using a 100-cm chain (Saleh 1993), whereas soil textural analyses were conducted by using the hydrometer method of Sheldrick and Wang (1993).

Overland flow samples were immediately filtered ($<0.45\ \mu m$) and analyzed for DRP within 24 h, and total dissolved P (TDP) after Kjeldahl digestion within 48 h. An unfiltered sample was also digested and TP measured within 7 days. Fractions defined as dissolved unreactive (largely organic) P (DOP) and particulate P (PP) were determined as TDP less DRP and TP less TDP, respectively. Suspended sediment (SS) was determined by weighing the residue left after filtration through a GF/A glass fiber filter paper. Flow samples were analyzed for ammonium-N and nitrate-N concentrations using standard autoanalyzer procedures (FIA analysis Tecator application note 50-02/82, and 62-02/83, respectively).

For the determination of organic P fractions, enzyme assays using alkaline phosphatase (EC 3.1.3.2.), phosphodiesterase (EC 3.1.4.1.), and phytase (EC 3.1.3.8) were run by using the method outlined in Turner et al. (2002). Briefly, 0.1 *M* sodium azide and the appropriate buffered enzyme mixture were added to a sample of OF in the ratio of 1 : 1 : 9, respectively, and incubated overnight at 37°C in inert plastic centrifuge tubes. The next morning, DRP was determined. Blank samples of deionized water were also included to account for P release from the enzyme and any interference from the proteins themselves. For the determination of phosphodiesters, alkaline phosphomonoesterase was also added to fully convert esters to orthophosphate detectable by colorimetry. The concentration of diesters was then calculated as P released from the combined alkaline phosphomonoesterase and diesterase mix minus P released from alkaline phosphomonoesterase alone.

Escherichia coli was measured in this study because it is the preferred fecal indicator bacteria for freshwater in New Zealand (MfE 2002). Before each rainfall simulation event, a small sample (20 g) of each dung pat was collected and subsampled for *E. coli* and total solids (TS). For *E. coli* analysis in dung, samples collected immediately, 1 and 4 days after dung application were diluted 1 : 100 w/w (otherwise 1 : 10 w/w) with sterile distilled water and blended in a domestic blender for 60 s. Overland flow samples were prepared for analysis by blending a 300-mL subsample for 30 s prior to analysis. Samples (flow and dung) were enumerated by using the Colilert® media and the Quanti-Tray® enumeration system (IDEXX Laboratories, Maine, USA). Total solids in dung pats were measured by drying a subsample at 104°C.

Statistical Analyses

The fit of P isotherm data to the Langmuir equation and all summary data (means, analysis of variance, and 95% confidence intervals) for soil analyses and P fractions, N species, sediment, and *E. coli* in OF from each treatment after an event were assessed by using SPSS v10.0 (SPSS, Inc. 1999). A negative power function ($y = \alpha t^{-\beta}$) was fitted to the change in concentration with time. The parameters α and β are fitted coefficients relating to the initial value of y (P, N, SS, or *E. coli* concentration) and the decrease in y as a function of time, t, respectively. Curve fits were generated by least-squares regression, with data weighted according to standard errors. Only curve fits with a coefficient of determination greater than 0.9 and p less than 5% level or better are shown.

RESULTS AND DISCUSSION

Nutrient and Sediment Loss

Data for nutrient, sediment, and *E. coli* losses in OF from the control soils (no dung) are given in Table 1 and varied little (SE $<$ 10% of mean) between events. Soil Olsen P concentrations in the pasture soil are greater (but not significantly) than in the cultivated soil. This finding reflects the redistribution of soil P through the plow layer away from the surface where enrichment is caused by P inputs and soil sorption (Sharpley 2003). With regular soil testing to adjust fertilizer applications, cultivation and the distribution of soil P in the plow layer will become even. However, this will take several years in a recently converted dairy farm in southern New Zealand, because no one field is sown for winter grazing for more than 2 years. As such, studying soils with exactly the same Olsen P is not representative of the situation in this region. However, data for nutrient, sediment, and *E. coli* loss in OF from control soils are subtracted before presenting data in Figures 1 and 2. These data, therefore, represents the loss attributed to dung and OF through each land use treatment.

For both treatments, the maximum concentration of P lost in OF occurred in the first flow event, the same day as dung application (Figure 1) and decreased to a near constant concentration by the fourth event 10 days later. This decrease was described by a power function (Figure 1) and is similar to the trend of P loss in OF with time for slurry applications to grassland in the UK (Withers et al. 2003). This decrease with time could be due to factors such as movement of dung-P into soil via rainfall and immobilization, increased sorption of P by dung as it dried, or the formation of a surface crust on dung decreasing erosion and interaction with moist dung beneath (Smith et al. 2001a, b).

More DRP was lost from the pasture treatment than the cultivated treatment for the first three events (Figure 1). A difference between treatments was also noted for DOP losses during events on days 0, 1, and 12 days after dung deposition. During the first event on the day of dung deposition, more PP was lost from the cultivated treatment than the pasture treatment and can be attributed to the filtration effect of the pasture sward retaining PP. This was also reflected by SS loss. Although SS losses during the two subsequent events were greater in the pasture treatment than the cultivated treatment, this was not significant. The low SS concentration in OF from both treatments reflect the dominance of fine particle sizes lost in OF from dung that weigh little. The greater loss of DRP from pasture can be attributed to flow through soil with a greater P concentration and less P sorption affinity and roughness (if used as a surrogate for surface area) than the cultivated soil (Table 1). Although Olsen P was not significantly different between treatments, both P_{max} and k were (Table 1). Other studies have shown less P lost from cultivated soil than the same soil in pasture, despite having similar soil P concentration (e.g., McDowell and Monaghan 2002). Studies have also shown that certain DOP species are more strongly sorbed to soil than others. For instance, Leytem et al. (2002) showed inositol phosphate (phytic acid) was more strongly bound to soil than inorganic orthophosphate. Dung, like most types of manure, contains some P in organic forms. Turner (2004) found that a major component of organic P in dairy manure was orthophosphate monoesters, largely inositol phosphate. If soil surface area and sorption affinity play a role in DOP uptake, then this will influence DOP mobility in OF.

Analysis of DOP species in OF using phosphatase enzymes showed that much DOP was cleaved to orthophosphate by phytase (Table 2). Turner et al. (2002) classified this as largely inositol hexakisphosphate, whereas the other enzymes used in our study were said by Turner et al. (2002) to cleave

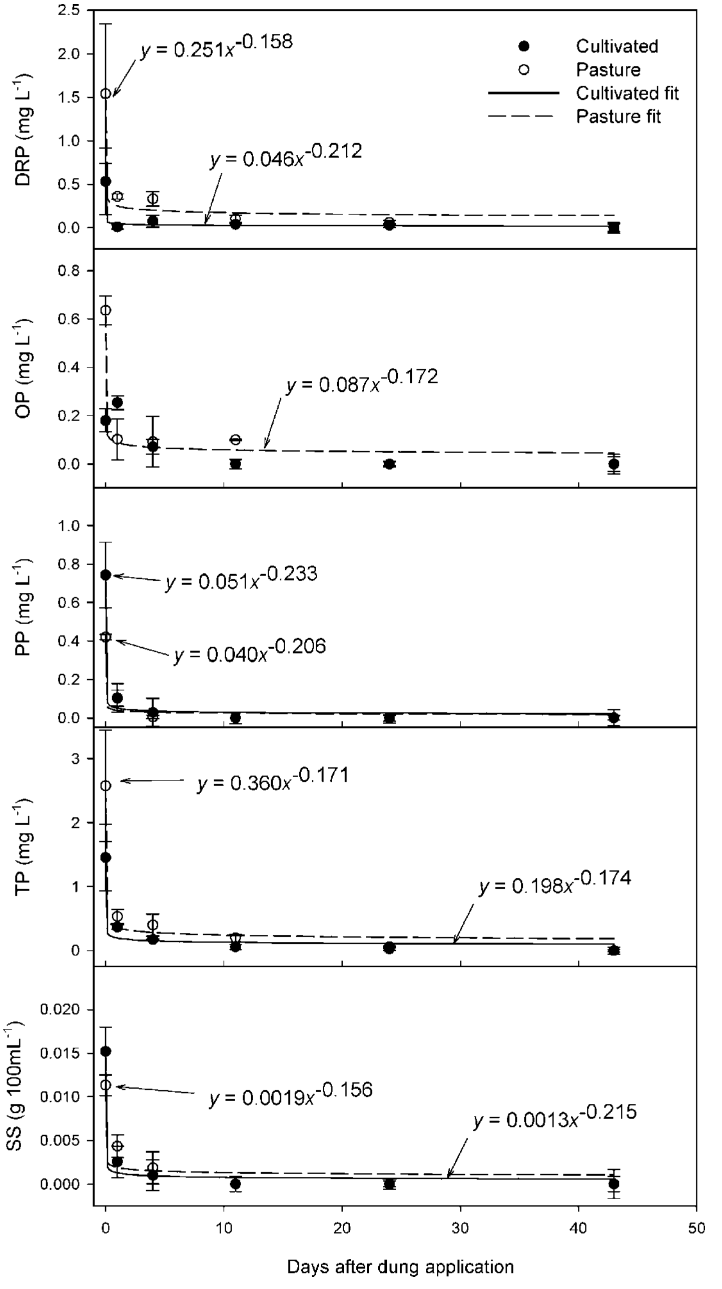

Figure 1. The mean concentration of P fractions [dissolved reactive P (DRP); dissolved organic P (DOP); particulate P (PP); total P (TP)] and suspended sediment (SS) in overland flow from dung deposited on pasture and cultivated treatments after each event. Error bars are ±95% confidence intervals for three replicates of each treatment.

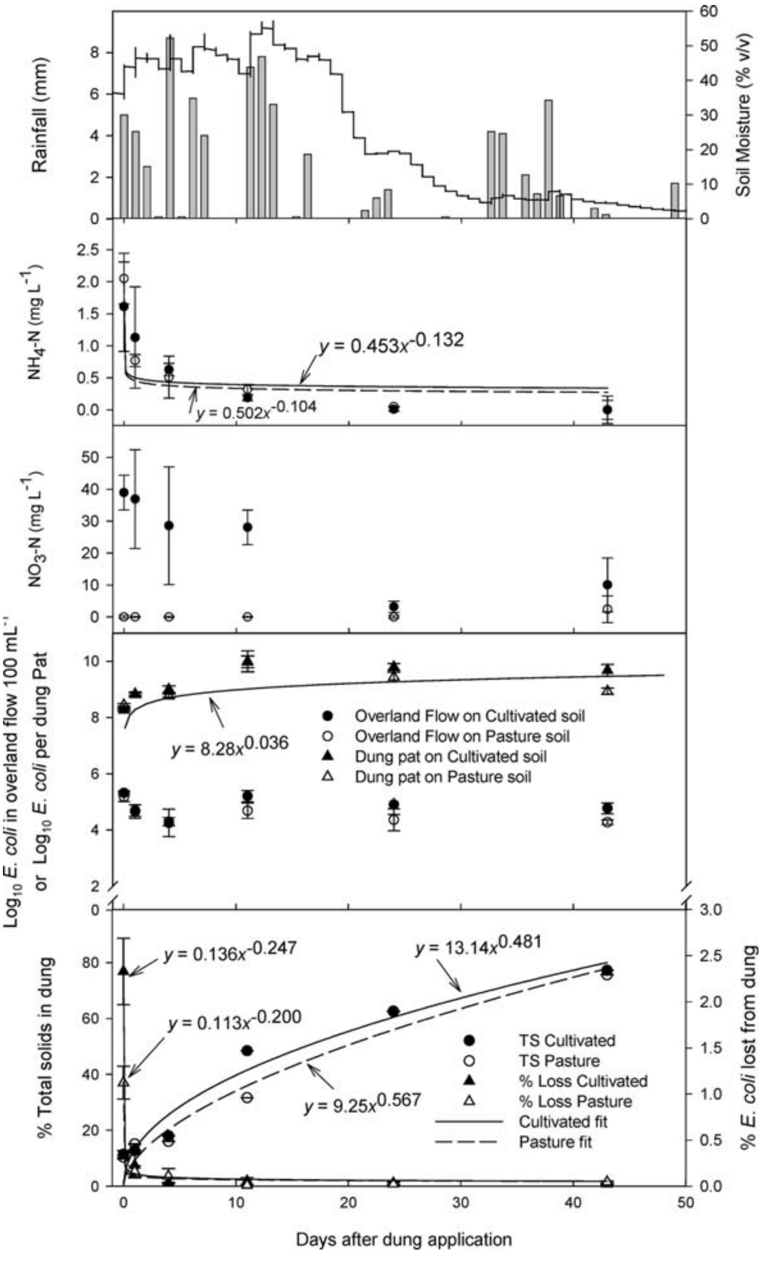

Figure 2. Continuous mean daily rainfall (bars) and soil moisture data along with the mean concentrations of NH_4^+-N and NO_3^--N species and *E. coli* in overland flow, *E. coli* and total solids (TS) in dung, and the percentage of *E. coli* lost from dung during each event. Error bars are $\pm$95% confidence intervals for three replicates of each treatment.

Table 2. Mean concentration ($\pm$95% confidence intervals) of dissolved organic P fractions cleaved by phosphatase enzymes

Days since dung deposition	Alkaline phosphatase (mg L^{-1})	Phosphodiesterase (mg L^{-1})	Phytase (mg L^{-1})
Pasture			
0	0.131 (0.051)	0.162 (0.090)	0.157 (0.136)
1	0.047 (0.030)	0.012 (0.005)	0.060 (0.014)
4	0.053 (0.044)	0.027 (0.024)	0.042 (0.040)
11	0.004 (0.012)	0.001 (0.002)	0.004 (0.001)
27	—[a]	—	—
46	—	—	—
Cultivated			
0	0.038 (0.020)	0.059 (0.044)	0.029 (0.012)
1	0.029 (0.024)	0.016 (0.022)	0.026 (0.023)
4	0.031 (0.023)	0.011 (0.007)	0.001 (0.006)
11	—	—	—
27	—	—	—
46	—	—	

[a]No DOP detected after subtraction of DOP from control soils (i.e., no dung applied).

orthophosphate diesters (phosphodiesterase) and labile orthophosphate monoesters (phosphomonoesterase). All three classes of DOP compounds are thought to have some degree of bioavailability to blue-green algae in surface waters and, thus, represent an eutrophication risk (Whitton et al. 1991; Turner et al. 2002). However, inositol hexakisphosphate is strongly sorbed to the soil, whereas diesters are only weakly sorbed and monoesters somewhere in between (Stewart and Tiessen 1987). Hence, DOP in OF from dung should be dominated by mobile DOP species with strongly sorbed species retained in the soil. Indeed, data in Table 2 showed that a greater concentration of phytase active materials was in OF from pasture than in cultivated soil in events up to 11 days after dung deposition ($p < 0.05$).

Extracts of fresh manure in water (1 g in 30 mL, shaking for 30 min and filtering the suspension) are well correlated with P concentrations in OF from recently manured soils (Kleinman et al. 2002). It was assumed that this was also true for extracts of fresh dung. A series of enzyme assays on an extract of fresh dung showed that the major DOP species were classified as inositol hexakisphosphate (31%), orthophosphate monoesters (25%), and orthophosphate diesters (16%), with the remaining 28% undetermined. In contrast to dung, the major group of DOP species in the first flow event was diesters. Thus, we infer that more sorptive species were retained either before or during flow. However, it is possible that changes to DOP species and mobility occur with time as dung dries.

Concentrations of NH_4^+ -N in OF (Figure 2) followed a similar temporal pattern to P fractions. In both pasture and cultivated treatments, the maximum concentrations of NH_4^+ -N occurred in the first few flow events following dung deposition. With time, these concentrations decreased to a near constant concentration by the fourth event, 11 days after dung was deposited. With the exception of the event on day 44 (pasture treatment only), NO_3^--N concentrations in OF from the pasture treatment were generally unaffected by dung deposition, indicating that NO_3^--N was being retained and perhaps used by limited pasture growth during the experiment, whereas NO_3^--N concentrations were much greater from cultivated treatment because there was no plant uptake ($p < 0.05$, Figure 2).

Losses of *E. coli*

Initial total solids (TS) content of dung pats averaged 10.9% (Figure 2) and increased with time (about 75% by day 43) as dung dried. The initial concentration of *E. coli* per dung pat was not significantly different ($p > 0.05$) between treatments as was the trend of *E. coli* concentrations in OF with time (F-test indicated no significant difference between β parameters). However, the survival pattern of *E. coli* in dung (Figure 2) did not follow first-order decay models commonly used to describe the survival of enteric bacteria in the environment (Kress and Gifford 1984; Crane and Moore 1986). Instead, *E. coli* concentrations remained high in OF and dung long after deposition. Other studies have shown an initial rise in *E. coli* concentrations in dung followed by a logarithmic decrease in *E. coli* concentration in OF with time (e.g., Thelin and Gifford 1983; Wang et al. 1996). Concentrations in OF, although similar to those reported by Edwards et al. (1997) were also two orders of magnitude less than those presented by Kress and Gifford (1984) and Thelin and Gifford (1983). The difference may be due to the analysis of composite samples in this study, whereas Kress and Gifford (1984) and Thelin and Gifford (1983) present peak concentrations from samples collected over 30 s. However, it is more likely due to the measurement of OF from $0.2\,m^2$ impervious wooden boards by Kress and Gifford (1984) and Thelin and Gifford (1983), whereas we used $0.4\,m^2$ boxes and intact soils.

The transport mechanism studied here, saturation-excess OF, indicated that *E. coli* concentrations of greater than $1 \times 10^4\ 100\,mL^{-1}$ can be sustained from cattle dung pats more than 40 days old, considerably greater than the recommended limit for freshwaters in New Zealand of 127 per $100\,mL^{-1}$ (McBride et al. 1997). Vinten et al. (2004) showed that losses of *E. coli* from sheep grazed pastures can be sustained at concentrations one order of magnitude greater than ungrazed plots (mean value of grazed plots was 4.4 $\log_{10}$ 100 mL^{-1}) for more than 9 weeks under cool-moist conditions. These findings, and ours, suggest that *E. coli* losses are a function of hydrological conditions, and if grazing occurs in winter in temperate maritime climates when soils are wet, then much *E. coli* loss can be expected if OF occurs. After grazing a cropped soil, for the remainder of the winter until spring, the soil remains much wetter than if in pasture. Recent work has shown that *E. coli* losses were still high (about 1.5 $\log_{10}$ 100 mL^{-1}) in late winter from a grazed cropland plot, despite not being grazed for more than 50 days (McDowell unpublished data). Consequently, a key management approach to mitigate fecal contamination of surface waters by grazing animals, especially in winter, is to keep animals off high-risk areas when OF is likely and restrict winter grazing of cropland to areas where OF is unlikely.

Application

These equations for loss in OF could estimate the contribution of dairy cattle dung to nutrient loss in the field provided the concentration in dung is similar. As an example, data were gathered for a 2-year trial examining P loss from a similar soil (Pukemutu silt loam; USDA Taxonomy, Typic Hapludalf) by Monaghan et al. (2002 and unpublished data). The trial was located in Southland, New Zealand, and grazed with dairy cattle. The mean load of P lost in OF from eight, 16 × 30 m hydrologically isolated plots was about 0.3 kg P ha^{-1} in 12 events in 2002 and 0.8 kg P ha^{-1} in 20 events in 2003. All events occurred between May and November. The mean soil Olsen P concentration was about 30 mg kg^{-1} and ranged between 22 and 50 mg kg^{-1}.

The equation of McDowell and Condron (2004) was used to determine the contribution of soil derived P in OF during each event (Table 3, Figure 3). The soil-P component included an additional 25% extra P to

Table 3. Modeled individual P loads (percentage of sum in parenthesis) for soil, dung, and fertilizer, the sum and the actual load (all g ha^{-1}) of total P in overland flow from a dairy grazed trial in Southland, New Zealand, for 2002 and 2003

	Modeled P load				
Year	Soil-P	Dung-P	Fertilizer-P	Sum	Actual load[a]
2002	0.27 (64)	0.11 (25)	0.05 (11)	0.40	0.29
2003	0.41 (51)	0.29 (36)	0.10 (13)	0.80	0.81

[a]Actual load data taken from Monaghan et al. (2002) and unpublished data.

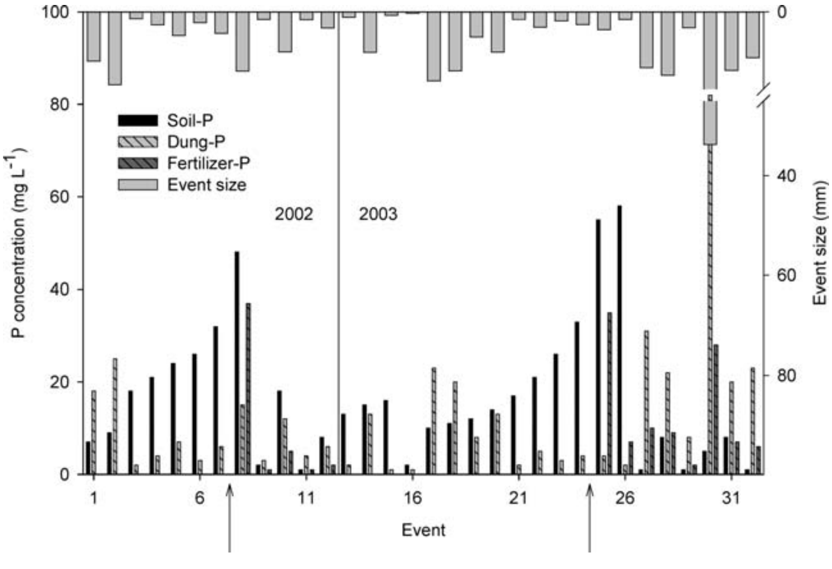

Figure 3. Modeled concentration of P from soil, dung, and fertilizer in each overland flow event for years 2002 and 2003 from a dairy cattle grazed trial in Southland, New Zealand. Note arrows indicate when superphosphate fertilizer was applied in September.

account for PP not estimated by the equation of McDowell and Condron (2004) but found to be less than 20% in subsequent fractionation of OF (McDowell, unpublished data). About 300 kg of superphosphate was applied to all plots in September each year. The application rate was the same as that used by McDowell (2004) and similar (34 kg P ha^{-1}) to that used by McDowell et al. (2003a) in studies examining P loss from fertilizer with time since application. The equations generated by these studies were used to determine the loss of fertilizer-derived P (Table 3, Figure 3). Lastly, the equations generated here for dung P loss with time since deposition were used to determine the load of dung-derived P from each OF event (Table 3, Figure 3). The application rate of dung used in this trial is similar to that evident for a 24- to 36-h grazing period, and it was assumed that the P concentration in dung was similar to that in the field trial. The sum of estimated total P lost was 138% of actual total P lost in 2002 but almost equal to TP lost in 2003 (99%). Of the estimated P losses, fertilizer comprised 11–13%, whereas dung P losses were 25–36% of the estimated TP lost. Unfortunately, similar equations for soil and fertilizer loss from cultivated soils in NZ do not exist. However, this example shows not only the application of data to indicate the potential for P losses but may also provide data for the role of incidental P losses and, consequently, how to better manage them.

CONCLUSIONS

The pattern of P and SS loss in saturation excess OF from pasture and cultivated treatments following a cattle dung deposition were similar—concentrations of these constituents were initially high and decreased exponentially with time. Concentrations of DOP in flow from the pasture treatment were much greater than from the cultivated treatment and attributed to greater retention of phytase-available compounds (commonly inositol phosphates) via sorption and retention in the cultivated treatment. Losses of NH_4-N in flow showed a similar pattern to P. In contrast, losses of *E. coli* remained high throughout the 46-day experiment, indicating good survival conditions and that *E. coli* losses reflect hydrological conditions. This new information concerning *E. coli* and the decrease in concentration of P fractions and NH_4^+-N with time since dung deposition highlights the need to carefully manage the grazing of areas prone to OF. An example shows that good management of animals and dung deposition away from areas connected to streams could decrease up to a third of total P lost during a year.

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REFERENCES

Crane, S.R. and Moore, J.A. (1986) Modeling enteric bacterial die-off: a review. *Water, Air, and Soil Pollut.*, 27: 411–439.

Doran, J.W., Schepers, J.S., and Swanson, N.P. (1981) Chemical and bacteriological quality of pasture runoff. *Journal of Soil and Water Conservation*, 36: 166–171.

Drewry, J.J., Littlejohn, R.P., and Paton, R.J. (2000) A survey of soil physical properties on sheep and dairy farms in southern New Zealand. *New Zealand Journal of Agricultural Research*, 43: 251–258.

Edwards, D.R., Larson, B.T., and Lim, T.T. (1997) Nutrient and bacteria content of runoff from simulated grazed pasture. In *1997 ASAE Annual International Meeting*, Paper No. 972055. St. Joseph, Michigan: ASAE.

Edwards, D.R., Larson, B.T., and Lim, T.T. (2000) Runoff nutrient and fecal coliform content from cattle manure application to Fescue plots. *Journal of American Wat. Resource Association*, 36: 711–721.

Fenlon, D.R., Ogden, I.D., Vinten, A., and Svoboda, I. (2000) The fate of *Escherichia coli* and *E. coli* O157 in cattle slurry after application to land. *Journal of App. Micro. Sym. Suppl.*, 88: 149S–156S.

Gangbazo, G., Peasant, A.R., Côté, D., Barnett, G.M., and Cluis, D. (1997) Spring runoff and drainage N and P losses from Hog-manured corn. *Journal of American Water Resource Association*, 33: 405–411.

Giddens, J.D. and Barnett, A.P. (1980) Soil loss and microbiological quality of runoff from land treated with poultry litter. *Journal of Environmental Quality*, 9: 518–520.

Gupta, R.K., Rudra, R.P., Dickinson, W.T., and Wall, G.J. (1997) Surface water quality impacts of tillage practices under liquid swine manure application. *Journal of American Wat. Resour. Assoc.*, 33: 681–687.

King, D.J., Watson, G.C., Wall, G.J., and Grant, B.A. (1994) *The Effects of Livestock Manure Application and Management on Surface Water Quality*; Summary Technical Report GLWQPAAFC Pest. Agriculture and Agrifood Canada, Management Research Centre: London, Ontario, Canada.

Kleinman, P.J.A., Sharpley, A.N., Wolf, A.N., Beegle, D.B., and Moore, P.A., Jr. (2002) Measuring water-extractable phosphorus in manure as an indicator of phosphorus in runoff. *Soil Science Society of America Journal*, 66: 2009–2015.

Kress, M. and Gifford, G.F. (1984) Fecal coliform release from cattle fecal deposits. *Water Resources Bulletin*, 20: 61–65.

Leytem, A.B., Mikkelsen, R.L., and Gilliam, J.W. (2002) Sorption of organic phosphorus compounds in Atlantic coastal plain soils. *Soil Science*, 167: 652–658.

McBride, G.B., Cooper, A.B., and Till, D.G. (1997) *Microbial Water Quality Guidelines for Recreation and Shellfish Gathering Waters in New Zealand*; New Zealand Department of Health: Wellington, New Zealand.

McDowell, R.W. (2004) *Incidental Losses of Phosphorus from Four Fertilizers*; AgResearch Client Report for Ballance Agri-Nutrients, AgResearch, Invermay Agricultural Centre: Mosgiel, New Zealand, 12.

McDowell, R.W. and Condron, L.M. (2004) Estimating phosphorus loss from New Zealand grassland soils. *New Zealand Journal of Agricultural Research*, 47: 137–145.

McDowell, R.W. and Monaghan, R.M. (2002) The potential for phosphorus loss in relation to nitrogen fertiliser application and cultivation. *New Zealand Journal of Agricultural Research*, 45: 245–253.

McDowell, R.W., Monaghan, R.M., and Carey, P.L. (2003a) Phosphorus losses in overland flow from pastoral soils receiving long-term applications of either superphosphate or reactive phosphate rock. *New Zealand Journal of Agricultural Research*, 46: 329–337.

McDowell, R.W., Drewry, J.J., Muirhead, R.W., and Paton, R.J. (2003b) Cattle treading and phosphorus and sediment loss in overland flow from grazed cropland. *Australian Journal of Soil Research*, 41: 1521–1531.

MfE (Ministry for the Environment) (2002) *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*; Ministry for the Environment, New Zealand Government: Wellington, New Zealand.

Milne, C.M. (1976) Effect of a livestock wintering operation on a western mountain stream. *Trans. ASAE*, 19: 749–752.

Monaghan, R.M., Horne, D., Hedley, M., and Nguyen, L. (2002) *Subsurface Drainage Review: Water and Contaminant Loads from Artificial Subsurface Drainage Systems in New Zealand*; AgResearch Client Report for Fonterra Research Centre, AgResearch, Invermay Agricultural Centre: Mosgiel, New Zealand, 73.

Mueller, D.H., Wendt, R.C., and Daniel, T.C. (1984) Phosphorus losses as affected by tillage and manure application. *Soil Science Society of America Journal*, 48: 901–905.

Nguyen, M.L., Sheath, G.W., Smith, C.M., and Cooper, A.B. (1998) Impact of cattle treading on hill land 2. Soil physical properties and contaminant runoff. *New Zealand Journal of Agricultural Research*, 41: 279–290.

Olsen, S.R., Cole, C.V., Watanabe, F.S., and Dean, L.A. (1954) *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*, United States

Department of Agriculture Circular No. 939. United States Government Printing Office: Washington, D.C.

Preedy, N., McTiernan, K., Matthews, R., Heathwaite, L., and Haygarth, P. (2001) Rapid incidental phosphorus transfers from grassland. *Journal of Environmental Quality*, 30: 2105–2112.

Saleh, A. (1993) Soil roughness measurement: Chain method. *Journal of Soil Wat. Conserv.*, 48: 527–529.

Sharpley, A.N. (2003) Soil mixing to decrease surface stratification of phosphorus in manured soils. *Journal of Environmental Quality*, 32: 1375–1384.

Sheldrick, B.H. and Wang, C. (1993) Particle size distribution. In *Soil Sampling and Methods of Analysis*; Carter, M.R., ed.; Lewis Publ.: Boca Raton, Florida, 499–511.

Shelton, C.H., von Bernuth, R.D., and Rajbhandari, S.P. (1985) A continuous-application rainfall simulator. *Trans. ASAE*, 28: 1115–1119.

Smith, K.A., Jackson, D.R., and Pepper, T.J. (2001a) Nutrient losses by surface run-off following the application of organic manures to arable land. 1. Nitrogen. *Environmental Pollution*, 112: 41–51.

Smith, K.A., Jackson, D.R., and Withers, P.J.A. (2001b) Nutrient losses by surface run-off following the application of organic manures to arable land. 2. Phosphorus. *Environmental Pollution*, 112: 53–60.

SPSS, Inc. (1999) *SPSS*, Version 10.0; Chicago, Illinois: SPSS, Inc.

Stewart, J.W.B. and Tiessen, H. (1987) Dynamics of soil organic phosphorus. *Biogeochemistry*, 4: 41–60.

Thelin, R. and Gifford, G.F. (1983) Fecal coliform release patterns from fecal material of cattle. *Journal of Environmental Quality*, 12: 57–61.

Turner, B.L. (2004) Optimizing phosphorus characterization in animal manures by solution phosphorus-31 nuclear magnetic resonance spectroscopy. *Journal of Environmental Quality*, 33: 757–766.

Turner, B.L., McKelvie, I.D., and Haygarth, P.M. (2002) Characterisation of water-extractable soil organic phosphorus by phosphatase hydrolysis. *Soil Biology and Biochemistry*, 34: 27–35.

Vinten, A.J.A., Douglas, J.T., Lewis, D.R., Aitken, M.N., and Fenlon, D.R. (2004) Relative risk of surface water pollution by *E. coli* derived from faeces of grazing animals compared to slurry application. *Soil Use Management*, 20: 13–22.

Wang, G., Zhao, T., and Doyle, M.P. (1996) Fate of enterohemorrhagic *Escherichia coli* O157 : H7 in bovine feces. *Applied and Environmental Microbiology*, 62: 2567–2570.

Whitton, B.A., Grainger, S.L.J., Hawley, G.R.W., and Simon, J.W. (1991) Cell-bound and extracellular phosphatase activities of cyanobacterial isolates. *Microbial Ecology*, 21: 85–98.

Wilcock, R.J., Nagels, J.W., Rodda, H.J.E., O'Connor, M.B., Thorrold, B.S., and Barnett, J.W. (1999) Water quality of a lowland stream in a New Zealand dairy farming catchment. *New Zealand Journal of Mar. Freshwat. Res.*, 33: 683–696.

Withers, P.J.A., Clay, S.D., and Breeze, V.G. (2001) Phosphorus transfer in runoff following application of fertilizer, manure, and sewage sludge. *Journal of Environmental Quality*, 30: 180–188.

Withers, P.J.A., Ulen, B., Stamm, C., and Bechmann, M. (2003) Incidental phosphorus losses—are they significant and can they be predicted? *Journal of Plant Nutrition and Soil Science*, 166: 459–468.