DRAINAGE DITCHES AS SINKS FOR ATTENUATING N AND P POLLUTANTS FROM DAIRY FARMS

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ABSTRACT

Drainage ditches are normally components of drainage networks in farming systems to remove surplus water from the major plant rooting zones within pastures. However, drains may act as a major conduit of agricultural pollutants and potentially become a significant source of nitrogen (N) (e.g., nitrate-N and ammoniacal-N) and phosphorus (P) to streams. The extent of N and P transport in drainage waters, and hence potential water-quality impacts in streams is partly governed by the ability of drainage ditches to utilize and immobilize these nutrient pollutants. This paper reports results obtained from field studies investigating the transport and in-situ attenuation of these pollutants in tracer solutions added to vegetated drainage ditches. The trial site was a 160-m open ditch (wetted area 0.98m wide x 101mm deep) on a high productivity New Zealand dairy farm. We applied a solution containing either ammonium (NH_4-N) and phosphate (PO_4-P), or nitrate (NO_3-N) and PO_4-P at the rate of 300 ml/minute for 5.5 hours. Lithium bromide (LiBr) was included in the solution to trace the movement of water along the ditch. Water samples were collected at 26, 68, 110 and 150 m downstream and analysed for NH_4-N, NO_3-N, organic nitrogen, PO_4-P and Br. For the ammonium based tracer, in-situ concentrations of NH_4-N and PO_4-P peaked at 29 and 27 g m^{-3} respectively at the nearest sampling position (26m downstream of the input). After 22 hours (average retention time) and 150 m downstream NH_4-N and PO_4-P removals were 44% and 56%, respectively. In the nitrate based tracer experiment, NO_3-N and PO_4-P had peak concentrations of 22.7 and 16.4 g m^{-3} with removal (after 6–8 hrs and 150-m) of 35% and 11.4% respectively. Lower net removal rates in the second tracer experiment may have been influenced by higher flow rates in the drain, resulting in lower contact time of the tracer solution with drainage sediment and vegetation. Retention of NH_4-N, NO_3-N, and PO_4-P by drainage sediments was probably the major attenuation mechanism, with subsequent plant and microbial uptake and transformation of the nutrients as secondary removal mechanisms. Nitrification-denitrification may have played a role in N transformation and subsequent N-removal particularly for the nitrate tracer experiment.

Keywords: Best management practices, drainage ditches, nutrient removal,

INTRODUCTION

Farmers use drainage networks to improve the productivity of agricultural land by lowering the natural water table, particularly during wet periods, such as in winter. This practice is most common in relatively flat, lowland areas of high fertility. Farm nutrients that enter drainage networks potentially contribute nutrient pollutants and subsequent eutrophication to receiving water bodies unless drainage discharges are treated by natural wetlands or constructed wetlands located at the end of drains (Raisin and Mitchell 1995; Tanner et al. 2002; Tanner et al. 2003). However, surface drains that are frequently parts of drainage networks in lowland soils may act as temporary or permanent sinks of such drainage pollutants since organic sediments that have been accumulated in them may provide sorption sites for pollutant removal, and emergent and submerged vegetation found in many shallow drains may take up nutrients from drainage waters. In this study we measure the capacity of naturally vegetated surface drains to attenuate shock loads (short duration, high concentration) of phosphate and either ammonium or nitrate added as a continuous 5.5 h input.

METHODS

The studied drainage site was a shallow, fully-fenced 160-m vegetated drainage ditch (open drain) on a gently-rolling dairy farm of Toenepi dairy catchment in the Waikato Region of New Zealand's North Island. The Toenepi catchment is intensively grazed (2.9 cow ha^{-1}), and comprises 70% dairy farming, with the remainder as dry stock farms. Soils were a mixture of Kiwitahi and Kereone yellow-brown silt loams (USDA soil taxonomy, Typic Haplundand) (Wilcock et al. 1999). The experimental site was an unbranched drain, which had no artificial influent sub-surface tile and mole drainage.

Ammonium-Phosphate Tracer Experiment

A stock solution of 100 L of di-potassium hydrogen phosphate (1560 g P m^{-3}) and ammonium chloride (1750 g N m^{-3}) was prepared in a 200-L drum. Lithium bromide (LiBr) was added to the solution as a conservative tracer (6440 g Br m^{-3} final concentration). Input of tracer solution began at 11 am (16 November, 2001, Southern Hemisphere mid-spring) at a rate of 300 ml min^{-1}, continuing for 5.5 h. Immediately prior to the start of the tracer input, 50 ml of Rhodamine dye was added as a visual tracer. Previous weather was overcast with rain the previous night and some light squalls on the morning of the tracer. Four automatic samplers were placed at distances of 26m, 68m, 110m, and 150m downstream of the tracer input position (hereafter referred to as sites 1, 2, 3 and 4, respectively), which was 5 m from the head of the drain. In addition we placed two Datasonde loggers (Hydrolab Corp., Austin, TX, USA) at 50m and 130m downstream of the input to record pH, dissolved oxygen (DO) and conductivity. The upstream sonde also measured NH_4-N.

Each automatic sampler was programmed in such a way as to sample most intensively at the time when the tracer peak was passing, with fewer samples at other times. Samples were kept cool with ice, until returned to the laboratory within 24 h for analysis. Samples were analysed for NH_4-N, NO_3-N, PO_4-P, and Br.

Nitrate-Phosphate Tracer

The same drain and sampling protocol was used for the nitrate tracer experiment, started on 6 November, three weeks after the earlier tracer study. In this instance, the tracer solution was the same, except that potassium nitrate (1800 g N m^{-3}) was used in the place of ammonium chloride. Conditions during the experiment were overcast, but without significant rain, until 11a.m. on the final day, when the experiment was terminated. After the tracer sampling was completed, the drain was sampled for above ground plant biomass (30x30 cm quadrat) and species composition.

RESULTS

Ammonium-Phosphate Tracer

The background concentration of NH_4-N in the drain was <0.05 g N m^{-3}, PO_4-P was 0.2 g P m^{-3}, while NO_3-N was around 3.0 g N m^{-3}. Bromide data from each sampling location was used to calculate flow at each sampling site. These ranged from 0.14 l s^{-1} at site 1, 0.20 l s^{-1} at site 2, 0.25 l s^{-1} at site 3 and 0.28 l s^{-1} at site 4. Recovery of Br in a previous tracer experiment in a gauged drain on this farm exceeded 98%. Measured NH_4-N and PO_4-P concentrations were compared with bromide values to calculated relative attenuation (Figure 1). By integration under the area curve, net removal of NH_4-N and PO_4-P was calculated at each sampling location down the drain (see figure 2). Both PO_4-P and NH_4-N had considerably reduced during passage down the drain, as can be seen by comparing the actual concentrations with the "equivalent" values calculated using Br concentrations of the LiBr conservative tracer. By the time the peak of the tracer had reached the final sampling site, 14 h later at 150 m down the drain, the tracer had dispersed over a considerable length of drain, and took more than a full day to travel past the sampling location. Of the added nutrients, 43.8% of the NH_4-N and 56.2% of the PO_4-P had been attenuated. Removal was relatively uniform down the length of the drain (Figure 2). Concentrations of NO_3-N, which were around 1.7 g m^{-3} at site 4, increased only slightly above background after the tracer peak had passed to a maximum of 2.6 g m^{-3} (Figure 1).

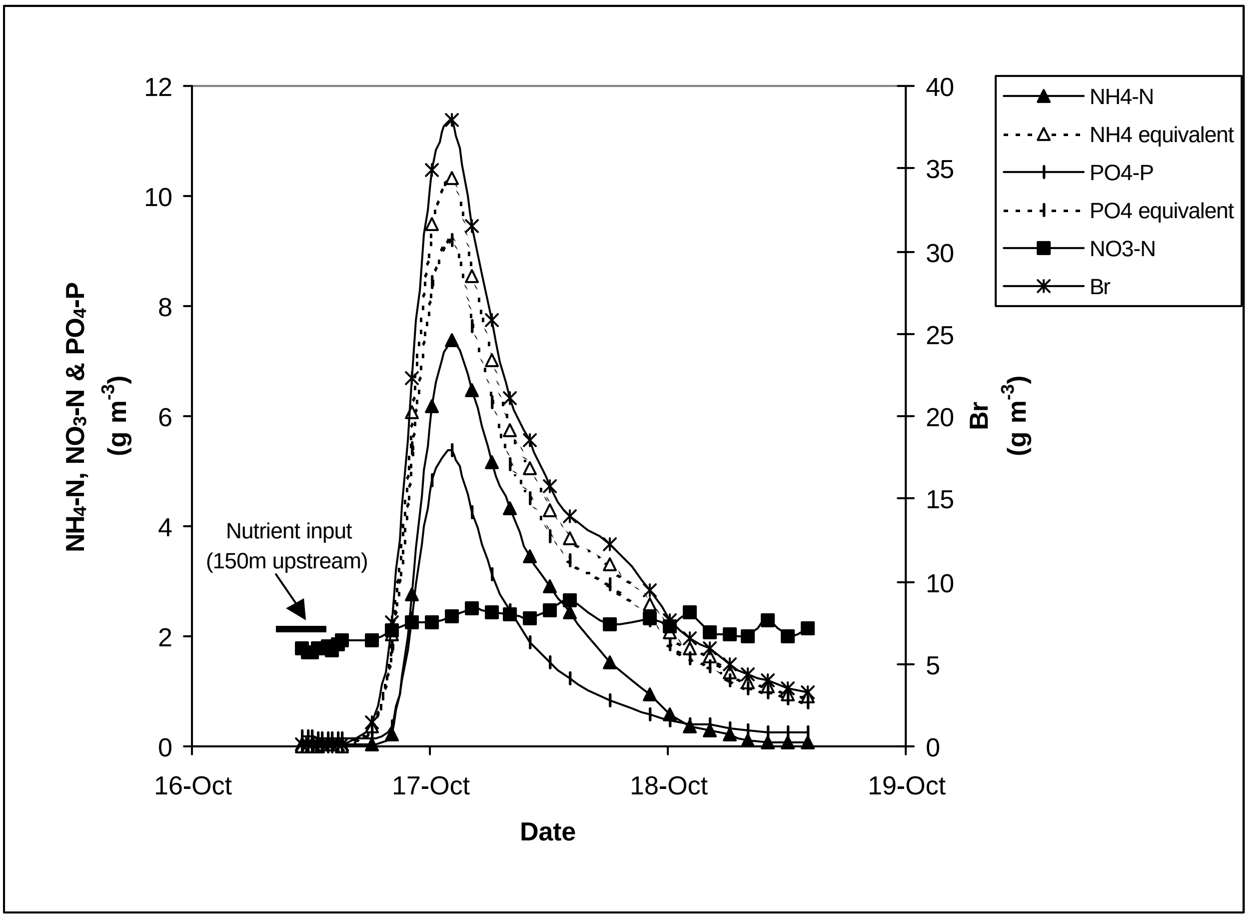

Figure 1. *Concentrations of NH_4-N, NO_3-N, PO_4-N and Br at site 4 (150 m downstream of input). NH_4-N and PO_4-P equivalent concentrations have been computed relative to measured Br concentrations.*

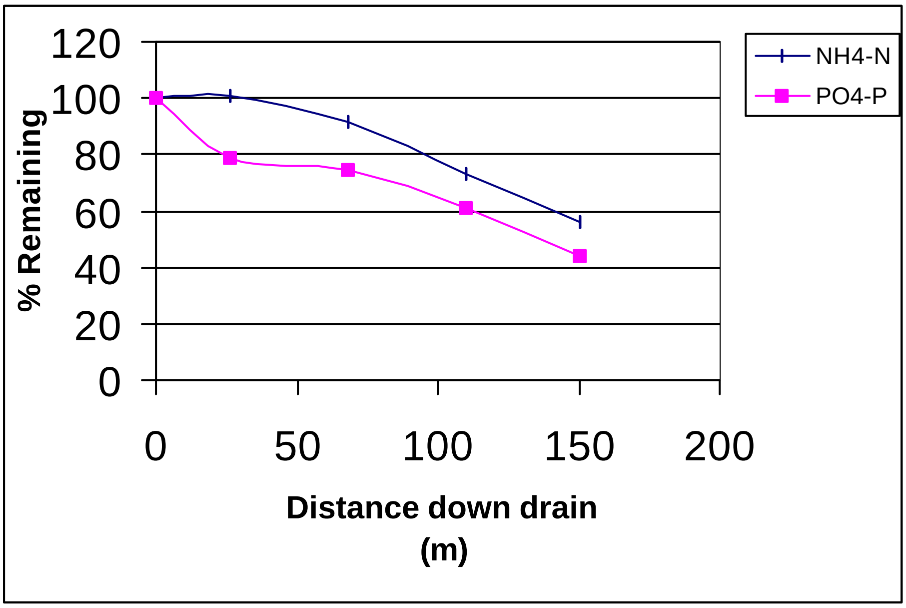

Figure 2. Percent removal of added NH_4-N and PO_4-P with distance down drain.

Nitrate-Phosphate Tracer

Background NO_3-N concentrations were higher than those measured 3 weeks previously for the ammonium/phosphate tracer study, at around 3.4 g m^{-3}, but PO_4-P was reduced at 0.02 g P m^{-3}. In addition, flow in the drain had also increased, reducing the residence time of the tracer in the drain to about 5 hrs (Figure 3). It was also apparent, that some of the tracer had not passed by the final sampling site when heavy rain and (anticipated) increased flows in the drain forced the termination of the experiment.

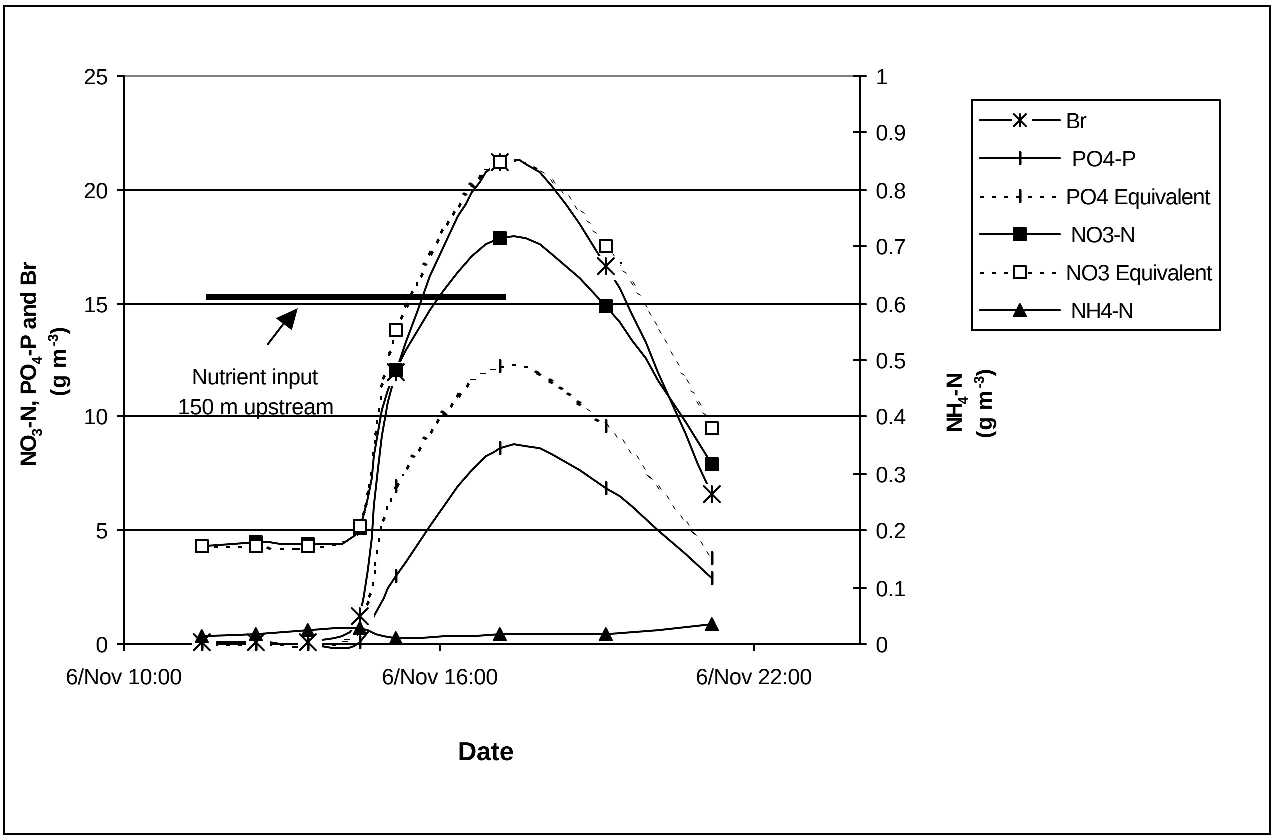

Figure 3. *Concentrations of NO_3-N, PO_4-P, NH_4-N and Br at site 4 (150 m downstream of input). NH_4-N and PO_4-P equivalent concentrations have been computed relative to measured Br concentrations.*

Figure 4 showed NO_3-N and PO_4-P removal at different sites along the drain. Attenuation of N as NO_3-N was much lower than measured previously for N as NH_4-N, at only 11.4% by the time the tracer had traveled the full length of the drain (Fig. 4). PO_4-P attenuation was much higher than N attenuation, at 35.4%, but still lower than in the previous experiment (56.2% PO_4-P removal). Background NH_4-N concentrations were negligible, at between 0.01–0.03 g N m^{-3}.

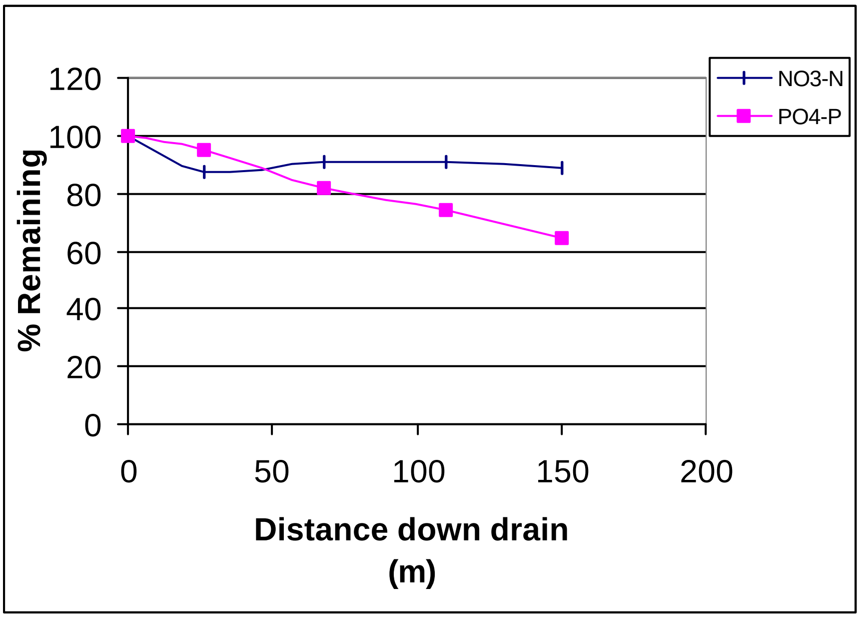

Figure 4. Removal of NO_3-N and PO_4-P with distance down the drain.

Plant biomass in the drain was substantial and averaged 904 g m^{-2} Dry Wt (97.4 kg total dry wt biomass), mainly comprising pasture grasses tolerant of wet conditions with Yorkshire fog as a dominant species (Table 1). Only 1.7 % of the drain cover was open water. These conditions were similar to that reported in a previous study (Nguyen et al. 2002).

Table 1. Plant species composition in the experimental drain.

Species	Common name	% cover
HOLCUS LANATUS	Yorkshire fog	92
Agrostis stolonifera		3.3
Lotus pedunculatus	lotus	2.4
Anthoxanthum oderatum	sweet vernal	2.2
Cirsium arvense	Canada thistle	0.90%
Juncus effusus	soft rush	0.2% (very occasional clump)

DISCUSSION

During the Ammonium/Phosphate tracer experiment it took around 5 hours for the solution to reach (peak) site 1, shortly before the tracer input was terminated. The peak of LiBr reached site 2 after 10 hours, site 3 after 12 hours, and site 4 after 14 hours. There appeared to be considerable dispersion of NH_4-N, PO_4-P, and Br due to the substantial amount of vegetation in the drain, and as a steady-state condition was never reached, the NH_4-N, PO_4-P, and Br concentrations at each site was notably peaked in shape (Figure 1). Removal of NH_4-N and PO_4-P from the added tracer solution was therefore calculated relative to concentrations of Br. Over the 150 m of drain (wetted area 147 m^2) 86.8g of P and 75.9 g of N were attenuated (0.59 and 0.51 g m^{-2} respectively). Removal in this experiment was relatively linear with distance. This differs with that reported in both wetlands (Kadlec 1978) and streams (Cooper and Cooke 1984), where depletion is proportional to the nutrient concentration, and thus removal follows first order kinetics.

The measured removal of PO_4-P within the drain can only be considered temporary attenuation, and was either sorption into the soil matrix (Syers et al. 1973), or incorporation in plant and microbial biomass. It is expected that the phosphate will continue to spiral in and out of these pools while continually moving down the drain, in a similar manner to that seen in streams (Webster and Patten 1979) and wetlands (Howard-Williams 1985). Retention within these pools depends upon PO_4-P concentrations in overlying water, and upon the biological cycle that maintains levels of live and dead plant and microbial material. If plant uptake is a major removal mechanism, then the level of attenuation recorded here is likely to be lower during colder autumn or winter months when plant growth is reduced. The initial attenuation of NH_4-N (510 mg m^{-2}) seen in this experiment similarly may have been adsorbed to the soil matrix, incorporated into plant biomass, or removed by microbial processes. As a cation, ammonium (NH_4^+) is readily adsorbed onto charged clay surfaces. However, it is also a preferred source of N for many plants. Regardless of the initial uptake mechanism, the adsorbed NH_4-N could then have spiralled in and out of the various nutrient pools, with sequential nitrification/denitrification providing the major permanent removal mechanism. Accumulated organic matter in the base of the drain would have provided both anaerobic sites as well as an available carbon source required for denitrification. Immediately after the added NH_4-N plume had passed by each of the sampling sites, NO_3-N concentrations were not significantly increased, and thus net nitrification-denitrification processes were unlikely to be a major factor in the initial attenuation recorded.

Three weeks later, when we undertook the Nitrate/Phosphate tracer experiment, flow in the drain was somewhat higher, considerably reducing the residence time of the tracer solution in the drain to around 5 hrs (from start of input until the peak reached the final sampling site). Attenuation of nitrogen as NO_3-N was substantially reduced, to just over 11% of added N (20 g N), or 0.14 g N m^{-2}. PO_4-P attenuation was also reduced to 0.38 g P m^{-2}. This lower level of removal could be attributed to reduced retention time in the drain, which was less than 1/4th of that in the earlier study. Lower sorptions of NO_3^- anions as opposed to NH_4^+ cations or simply that sorption sites were mostly occupied by the large input of nutrients from the earlier tracer study, are also potential explanations for the lower attenuation. On the basis of time that the nutrient plume was in the drain however, the removal rate of N was similar in both tracer experiments.

What is clear is that vegetated open drains can act to significantly reduce and disperse pulse loads of nutrients that may enter them from occasional high fluxes from agricultural land such as occur after prolonged dry periods, immediately after fertilizer applications or from intermittent point source inputs. Further studies are required to determine short and long-term (sustainability) nutrient removal rates in vegetated drainage systems during different seasons. The use of N^{15-}labelled-ammnium or nitrate tracers is also required to determine the rate of nitrate and ammonium transformations in soil and plant N pools and their spiralling processes within drains.

Several questions regarding drain management remain unanswered. How significant is the vegetation in the drain as a nutrient sink? At what point does increasing vegetation biomass reduce flows to the extent that the effectiveness of the drainage system is compromised? If nutrient attenuation is considered an important environmental function of drains, particularly in areas where natural wetlands and seepage zones have been removed, can these two aims be fulfilled, giving optimal nutrient removal without compromising the operation of the drainage network?

CONCLUSIONS

Vegetated drainage ditches in agricultural land can act as important sinks for attenuating N and P entering them via leaching and runoff of nutrients from soil and animal excreta after prolonged dry periods, immediately after fertilizer applications or from intermittent point source inputs. Attenuation of up to 0.59 g P m^{-2} and 0.51 g N m^{-2} were recorded in a system draining a high productivity lowland dairy farm in New Zealand. Future studies are required to assess the long-term sustainability of drainage ditches in removing these nutrients.

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