The impact of intensive dairy farming on the leaching losses of nitrogen and phosphorus from a mole and pipe drained soil

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Abstract

While it is widely believed that intensive dairy farming is a major contributor to the increased nutrient loads in surface waters, there is little current research quantifying the magnitude of nutrient loss from dairy farms to waterways, particularly from artificial drainage. An experimental site has been established on a Pallic soil (Tokomaru silt loam) to measure the impacts of intensive dairying on the quality and quantity of drainage water exiting from an artificial drainage system. A key component of this study is the development and evaluation of a land-based treatment system for farm dairy effluent (deferred irrigation). The research site has eight replicated plots, each with an isolated mole and pipe drain network. All the plots are subjected to the farm's standard grazing management. Four of the plots receive fertiliser according to the farm's fertiliser programme, while the other four plots receive applications of farm dairy effluent.

Measurements of drainage flows during year one of this study showed that the average concentrations of total nitrogen (12.9 mg N/L) and total phosphorus (0.15 mg P/L) in drainage water for the winter of 2002 under standard dairy farming practices were all well above the levels necessary to prevent aquatic weed growth in fresh water bodies.

Adherence to the scheduling criteria prescribed by the 'deferred irrigation' system prevented the direct loss of nutrients during irrigation of farm dairy effluent in the summer of 2001/2002. Summer applications of farm dairy effluent did not increase N loss in subsequent winter drainage. Effluent irrigation increased P loss during the subsequent winter drainage period by 0.52 kg total-P/ha (0.38 kg P/ha as DIP). However, this increase in total loss corresponds to less than 4% of the P (16 kg/ha) applied as effluent. Deferred irrigation proved to be a very successful tool for minimising nutrient losses from effluent irrigated areas in direct drainage of effluent at the time of irrigation and subsequent winter drainage. Dairy cattle grazing events also increased nutrient concentrations in drainage waters following grazing by approximately 5 mg total-N/L (nearly all in the nitrate form) and 0.1 mg total-P/L (nearly all in the DIP form). The effect of an application of urea in spring on nitrate-N concentrations in drainage water was minimal.

Keywords: dairying, effluent irrigation, mole and pipe drainage, nitrogen, nutrient leaching phosphorus, water quality

Introduction

It is widely believed that intensive dairy farming is a major contributor to the increased nutrient and suspended solid loads in waterways (Sharpley & Syers 1979; Monaghan *et al.* 2002). Accordingly, the dairy farming industry has come under substantial criticism recently for its potential role in the deterioration of the quality of fresh water bodies and streams. In this context, farm dairy effluent is often cited as a serious problem. Poorly managed effluent treatment systems can have a range of adverse environmental impacts: nutrient-rich surface runoff and drainage waters have the potential to pollute surface and ground water and high effluent loads decrease soil quality (Cameron *et al.* 1999; Heatley 1996; Silva *et al.* 1999). In particular, land treatment of dairy shed effluent on imperfectly drained soils is proving a major challenge for many farmers.

To help overcome the problems associated with the disposal of farm dairy effluent, a land based treatment system called 'deferred irrigation' has been developed. Deferred irrigation involves storing effluent in a two-pond treatment system and then applying it strategically from the aerobic pond when there is a suitable soil water deficit. Soil water balances (e.g. the model developed by Scotter *et al.* (1979)) may be used to determine when this soil water deficit is reached. Scheduling effluent irrigation in this manner reduces the risk of direct surface runoff or drainage, therefore allowing time for the removal of effluent applied nutrients via plant uptake and soil immobilization. In addition, a forage crop is harvested from the irrigated area to minimize the accumulation of nutrients, particularly potassium (K), in the soil-pasture system. Normal farm grazing applies for the rest of the season.

It has been 25 years since Sharpley & Syers

(1979) and Turner *et al.* (1979) investigated the impacts of fertilisation and animal grazing events on the quality of water exiting mole and pipe drainage systems on the No.4 Dairy Unit at Massey University, Palmerston North. There has been little work since then despite; the expansion of dairy farming on artificially drained soils, the more intensive nature of modern dairy production system, and the heightened awareness of the risks that polluted drainage water poses for both the environment and on-going market access for dairy produce. The aim of the current research is to measure the impacts of modern, intensive dairying on the quality and quantity of drainage water exiting from artificial drainage systems. In particular, the impacts of deferred irrigation of farm dairy effluent, grazing events and fertiliser additions are assessed.

Materials and methods

A research site to investigate the impacts of intensive dairy farming on drainage water quality has been established on a naturally poorly drained Pallic Soil, the Tokomaru silt loam, at Massey University's No. 4 Dairy Farm, Palmerston North. As part of this study, a sustainable land-based treatment system for farm dairy effluent, called 'deferred irrigation', is being developed and evaluated. The site has 8 replicated plots (40 m x 40 m). Each plot has an isolated mole-pipe drain network. Four of the plots (hereafter called the 'non-effluent' plots) are fertilised and grazed according to the farm's normal management programme (plots 1-4), whilst the other four plots (hereafter called the 'effluent' plots) receive aerobic pond effluent in accordance with the deferred irrigation scheduling criteria (plots 5-8). These plots are also grazed, and have a crop of forage removed annually. At the corner of each plot, a pit has been excavated and a v-notch weir placed at the exit of the pipeline to monitor drainage flow rates, and help facilitate the sampling of drainage events for subsequent measurements of water quality. All pits have been instrumented with data loggers to provide continuous measurements of flow rate. Comparisons are made of drainage water quality from the two different areas.

Following two seasons of farm dairy effluent application under the deferred irrigation system (2000/01 and 2001/02), monitoring of winter drainage water commenced in late April 2002. Water samples were collected manually. This sampling was scheduled strategically so as to get representative samples from all phases of the flow events. A suite of analyses was carried out including: suspended solids, total phosphorus (P) and total dissolved P (TDP), dissolved inorganic P (DIP), total nitrogen (N), nitrate-N, and ammonium-N. Analyses were carried out on a Technicon Auto Analyser using the following methods, Kamphake *et al*. (1967) for nitrate-N, Searle (1975) for ammonium-N, McKenzie & Wallace (1954) for Kjeldahl N and dissolved Kjeldahl N, O'Conner & Syers (1975) for total P and TDP and Murphy & Riley (1962) for analyses of DIP. Total N and TDN were calculated by adding Kjeldahl N and dissolved Kjeldahl N to nitrate-N.

On three occasions (mid-June, late-July, and late-September) grazing took place on all the plots approximately 7 to 10 days prior to a drainage event. On a fourth occasion in early-October, only the effluent plots were grazed. The stock density was 80 cows/ha and the grazing period was 12 hours. On 6 September 2002, the effluent plots received 80 kg/ha of urea (37 kg N/ha). Additions of P fertiliser were made to both the effluent and non-effluent plots outside of the winter drainage season, with the effluent plots receiving 22 kg P/ha and the non effluent plots 49 kg P/ha. MAF quick test values for K and Olsen P were 8 and 41, respectively, from the non effluent plots, and 13 and 48 for the effluent plots.

In the summer of 2001/02, 63 mm of farm dairy effluent was irrigated over the effluent plots. At an average N concentration of 150 mg N/l and an average P concentration of 25 mg P/L, effluent irrigation resulted in nutrient applications of 95 kg N/ha and 16 kg P/ha.

Deferred irrigation is being implemented and evaluated at the farm system level: use of the plots described above to gather detailed information is an integral part of this larger initiative. The requirement to gather data relevant to the farm scale necessitated the use of a standard travelling irrigator. Therefore, it was impracticable to randomise the 'effluent' and 'non-effluent' treatments across the plots. In other words, the effluent plots are adjacent to one another. Given this, the variability in measured data is quantified using the standard error of means (SEM).

Results and discussion

Effluent irrigation

The poor uniformity of distribution from a standard rotating travelling irrigator means that the maximum effluent application depth can be no more than half of the soil water deficit. The summer of 2002 was particularly wet and, therefore, soil water deficits were relatively small (between 20 and 80 mm). Consequently, effluent irrigation was spread out over seven events, at an average of 9 mm depth per application. This strategy of irrigation resulted in zero drainage of applied effluent from the mole-pipe system.

Drainage quantity

The winter of 2002 was very wet, particularly the months of June and July (Figure 1). Throughout the season there were 16 drainage events from the mole-pipe drainage system with a mean total of 220 mm of cumulative drainage. Large drainage events were measured through the wet June and July period, followed by smaller drainage events through spring (Figure 2). This was due to the fact that increased evapotranspiration in spring created small soil water deficits that had to be replenished before drainage commenced.

Flow rates and hence cumulative seasonal drainage from six of the eight plots (plots 1-4 and 7, 8) were relatively uniform. In comparison, much smaller quantities of drainage were recorded for plots 5 and 6 (Figure 3). Analyses of flow patterns indicate that drainage water is being lost from the moles on plots 5 and 6, at all but the greatest of flow rates, before it reaches the pipe drain. One possible cause of this loss is the interception of drainage water in the current mole drains by an old tile drain. Plots 5 and 6 have been omitted from the calculation of cumulative drainage, and so mean annual loss of nutrients (and SEM) for the effluent treatment is calculated using data from plots 7 and 8. Concentration data was not effected by the low cumulative drainage from plots 5 and 6 and as such were included in the calculation of mean concentrations both within drainage events and throughout the season.

Figure 1 Fifty year mean monthly rainfall during the winter/early spring period for the Manawatu compared with winter/early spring rainfall during 2002.

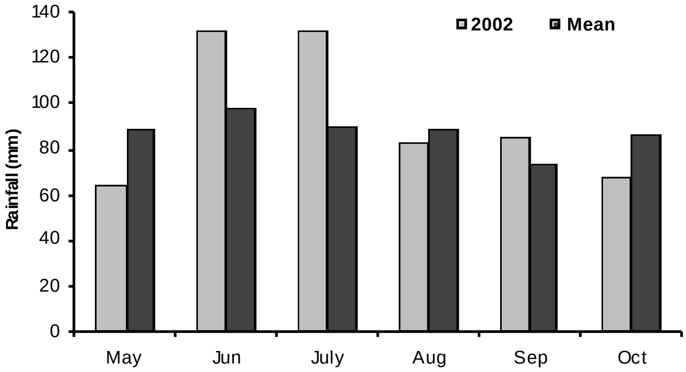


Figure 2 Typical hydrograph for one of the plots during the winter/spring period of 2002.

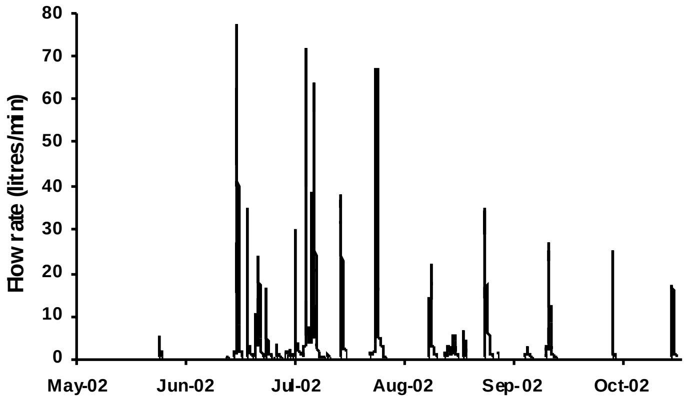
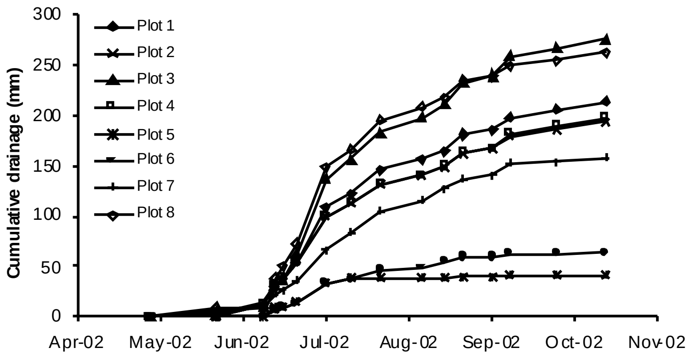


Figure 3 Cumulative drainage from the plots in the winter/spring period of 2002.



Drainage losses of N

The concentrations of total N in drainage water from all plots were ecologically significant as they were two orders of magnitude greater than the level (0.1 mg N/L) likely to promote aquatic weed growth (Ministry for the Environment, 1992). As much as 99% of the total-N measured in drainage water was in the dissolved form, most (88%) of which was nitrate-N (Table 1). Concentrations and losses of N in the winter drainage of 2002 were slightly greater from the effluent plots than from the non-effluent plots. The increase in total N lost in winter drainage from soils receiving summer applications of farm dairy effluent (3.3 kg N/ha) was 3.5% of the N applied in effluent.

Nitrate-N concentrations in drainage water displayed a marked trend (Figure 4). The first few drainage events of the winter had nitrate-N concentrations greater than 20 mg N/L. With increasing cumulative drainage, nitrate-N levels steadily declined to concentrations of less than 5 mg/L. A similar pattern of nitrate-N concentrations in artificial drainage waters was observed by Magesan *et al.* (1994), Heng *et al.* (1991) and Monaghan *et al.* (2002).

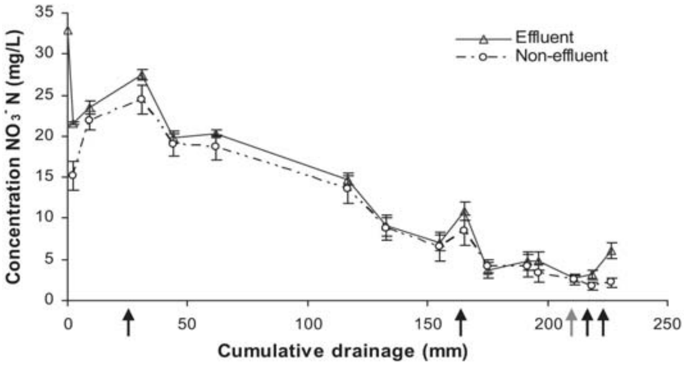
The average nitrate-N concentration of all the drainage water from all plots was greater than the recommend drinking water level of 11.3 mg/L (Ministry of Health 1995). Approximately 60% of the cumulative drainage water was in excess of the recommended drinking water level.

The summer application of farm dairy effluent, as part of the deferred irrigation system, did not increase the amount or concentration of nitrate – N in winter drainage water (Figure 4 and Table 1). The consistent manner in which the mean values for the effluent plots lie above the mean values for non-effluent plots in Figure 4 is interesting, and may warrant more detailed investigation in the future.

Table 1 The amounts and forms of N lost in winter drainage. SEM of annual loss and concentration data are presented in brackets.

N form	Treatment	Annual loss (kg/ha)	Concentration (mg/L)
Nitrate- N	Effluent	26.4 (9.4)	13.7 (1.1)
	Non-effluent	24.5 (2.2)	11.4 (1.4)
Tot Dissolved N	Effluent	30.0 (10.2)	15.8 (1.4)
	Non-effluent	27.2 (2.3)	12.6 (1.5)
Total N	Effluent	31.1 (10.1)	15.9 (1.1)
	Non-effluent	27.8 (2.3)	12.9 (1.5)

Figure 4 The trends in drainage nitrate-N concentration with total amount of accumulated drainage, showing the impact of cattle grazing events in both the non-effluent and effluent plots (bold arrows) and an application of urea at a rate of 37 kg N/ha to the effluent plots (grey arrow). Error bars represent one standard error.



Grazing resulted in an increase in nitrate–N concentration of drainage water of approximately 5 mg/L (Figure 4). Sharpley & Syers (1979) found that nitrate-N levels in drainage water were elevated by approximately 10 mg/L following grazing by dairy cattle at a stocking rate of 300 cows/ha. The difference between the results reported here and Sharpley & Syers (1979) suggest that decreasing cattle grazing density may be one way of reducing the concentration of nitrate-N leaching in drainage waters following grazing. The two spring grazing events did not increase the nitrate –N concentrations of drainage water to the same extent as the two mid-winter grazing events. This difference is most likely due to greater plant uptake of nitrate in spring compared with winter.

There was no increase in the nitrate-N concentrations of drainage water in the drainage event that occurred five days after the application of urea (Figure 4). However, as only five days had elapsed between urea application and drainage, most of the N supplied in the urea is likely to have been in the ammonium form and, therefore, less available for leaching. Also, at this time of the year, plant uptake of N would have been increasing as temperatures increased in early spring. It is possible that, along with the early October grazing, the urea application contributed to the increase in nitrate-N concentration in the final drainage event. The five-week period from urea application to the final drainage event would have given sufficient time for some of the ammonium to be converted to nitrate.

Ammonium-N results are not reported as in most cases ammonium-N was not found at detectable levels.

Drainage losses of P

The concentrations of total P in drainage water from all plots were ecologically significant, as they were all above the minimum concentration (0.1 mg P/L) considered to stimulate aquatic weed growth (Ministry for the Environment 1992). Furthermore, considerably more P was leached from the plots that received summer applications of farm dairy effluent (Table 2). The increase in total P loss in winter drainage from effluent plots (0.52 kg P/ha) equated to approximately 3% of the P applied in summer applications of effluent.

Dissolved P made up more than 80 % of total P losses (Table 2), consequently, less than 20 % was in the particulate form, which is the form more commonly found in drainage waters from mole-pipe networks (Sharpley & Syers, 1979; Monaghan *et al.* 2002). This result was supported by the low levels of suspended solids observed in the drainage water (data not presented).

DIP concentrations in drainage water did not exhibit a seasonal trend like that observed for nitrate-N. Monaghan *et al.* (2002) made a similar observation. The average concentration of DIP in drainage waters from the non-effluent plots (0.06 mg/L) is the same as that reported by Sharpley & Syers (1979), and a little higher than concentrations reported by Monaghan *et al.* (2002). Land application of farm dairy effluent consistently increased the concentration of DIP in drainage waters (Figure 5). This result is unexpected as the non-effluent plots received 49 kg of P/ha as fertiliser, while the effluent plots received 38 kg P/ha (22 kg P/ha as fertiliser and 16 kg P/ha as effluent). The difference in Olsen P levels (7 µg P/ml) between the effluent and non-effluent plots was not sufficient to account for the difference in DIP concentrations between the two treatments. This suggests that the increase in leaching of DIP from the effluent plots is related, in some way, to the application of farm dairy effluent. Perhaps it is due to the mineralisation of P from residual effluent in the soil-mole drainage network. Further monitoring over time is required.

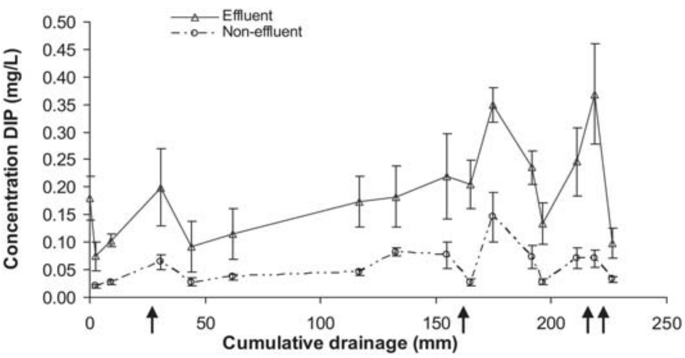
The impact of cattle grazing on P losses was evident throughout the drainage season. In most cases, the concentration of DIP in drainage water increased by approximately 0.1 mg/L following a grazing event (Figure 5). However, compared to the nitrate-N data, increases in DIP concentrations in drainage water following grazing were not as consistent in either magnitude or timing. The effects of the June and September grazing events on DIP concentrations were evident in the following drainage event, whilst the effect of the July grazing event was not evident until the second drainage event following grazing. The October grazing did not increase DIP concentrations. However, the low flow rate measured during this event would have provided an increased opportunity for P absorption.

Sharpley & Syers (1979) found that DIP concentrations in drainage waters increased approximately 15 fold following intensive grazing (300 cows/ha/12 hours) of pastures by dairy cattle. Sharpley & Syers (1979) measured peak concentrations of 0.25 mg P/L as DIP, which were considerably higher than the peak concentration of 0.15 mg DIP/L measured in the grazed (80 cows/ha/12 hours) non-effluent plots in the current study. As for nitrate-N, these results suggest that decreasing cattle grazing density during winter may be an effective way of decreasing the impact of grazing events on DIP concentrations in drainage water.

Table 2 The amounts and forms of P lost in winter drainage. SEM of annual loss and concentration data are presented in brackets.

P form	Treatment	Annual loss (kg/ha)	Concentration (mg/L)
DIP	Effluent	0.51 (0.001)	0.18 (0.05)
	Non-effluent	0.13 (0.026)	0.06 (0.01)
Total Dissolved P	Effluent	0.66 (0.003)	0.27 (0.05)
	Non-effluent	0.24 (0.022)	0.11 (0.01)
Total P	Effluent	0.86 (0.04)	0.35 (0.06)
	Non-effluent	0.34 (0.04)	0.15 (0.01)

Figure 5 The impacts of cattle grazing events and effluent irrigation on DIP concentrations. (Bold arrows positioned on the x-axis represent the timing of grazing events relative to cumulative drainage). Error bars represent one standard error.



Summary and conclusions

The average concentrations of N and P in winter mole-pipe drainage water from grazed dairy pastures were all well above the levels required to prevent aquatic weed growth in fresh water bodies. A number of common dairy farm practices increased the losses of N and P in the artificial drainage water. Recent grazing events increased nitrate-N and DIP concentrations in drainage by approximately 5 mg/L and 0.1 mg/L, respectively. The impact of an early spring application of urea on drainage water quality was minimal, suggesting that careful timing of urea applications at this time of year may result in little nitrogen leaching.

Effluent irrigation in the previous summer caused no real increase in total N concentration or loss in winter drainage water. Effluent irrigation resulted in a substantial increase in total P losses in winter drainage (0.52 kg P/ha). However, this increase represents less than 4% of the P applied in the effluent. By adhering to stringent scheduling criteria, such as those developed in the deferred irrigation system, it is possible to prevent the direct loss of nutrients following irrigation of farm dairy effluent and thus minimise nutrient leaching losses during winter.

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