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The Effects of Irrigation Scheduling on Nitrogen and Phosphorus Leaching Under Pasture

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ABSTRACT. *Leaching of nutrients such as nitrogen (N) and phosphorus (P) can impact negatively on the wider environment. Although there is some speculation on increased leaching under irrigated pasture, there has been little research conducted to quantify this effect. The amount of N leaching is influenced by the quantity of excess N in the soil profile and the volume of water draining through the soil. The objective of this study was to monitor soil water N and P concentrations at the bottom of the root zone of ryegrass and clover swards throughout the summer irrigation period and the subsequent early winter drainage season (23 Nov. 2000 to 31 July 2001) in New Zealand. Three irrigation frequencies - replenish the profile to field capacity at 20 mm soil moisture deficit (I-20), at 40 mm soil moisture deficit (I-40) and at 60 mm soil moisture deficit (I-60) - and two P fertility regimes - no applied P fertilizer (P-0) and P fertilizer applied at 40 kg P ha^{-1} (P-40) – were studied at Palmerston North, New Zealand. The concentrations of nitrate-N, ammonium-N and soluble inorganic P in soil water were measured. The amount of nutrient leached was calculated as the product of the mean nutrient concentration of soil water samples and the estimated drainage volume.*

Total nitrate-N losses until 31 July, 2001 indicated that irrigation frequency of ryegrass during the preceding summer did not have a major effect on the overall nitrate-N leaching losses during the late autumn/early winter period. However, nitrate-N losses under clover tended to be lower under less frequent irrigation. P and ammonium-N leaching losses were negligible.

INTRODUCTION

Leaching of nutrients such as nitrate-N and P can makes an impact negatively on the wider environment. It is often argued that irrigation will result in an increased downward soil water flux and, as a consequence, greater nutrient loss to ground water (Nguyen *et al*., 1996; Schneekloth *et al*., 1996). However, it is also possible that, as a result of improved water and N uptake by crops, efficient irrigation will reduce nutrient leaching (Hack-ten Broeke, 2001; Burgess *et al*., 2002). While there has been some speculation on the likelihood of increased leaching under irrigated pasture, there has been little research to quantify this risk. The amount of N leaching is influenced by the quantity of excess N in the soil profile and the volume of water draining through the soil. While there is a substantial body of New Zealand research describing the dynamics of N cycling in soils (Ledgard *et al*.,1996), there are very few studies on N leaching under irrigated pasture. Heckrath *et al*. (1995) reported that dissolved reactive P is the largest phosphorus fraction in drainage water in permeable soils. Therefore, DRP of the soil

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water samples can be considered as an indicator of loss of P, if any beyond root-zone through leaching.

The objective of this study was to determine the effects of irrigation scheduling or frequency on soil water N and P concentrations at a depth of 300 mm under non-grazed swards of ryegrass and clover throughout the summer irrigation period and the subsequent early winter drainage season.

MATERIALS AND METHODS

Field sampling

Soil water samples were collected from plots at a field experimental site located at Thealmerston North campus, Massey University, New Zealand. The taxonomic name of the soil at the site is Manawatu fine sandy loam which is classified as a Weathered Fluvial Recent soil (Hewitt, 1998). The experimental site was fallowed for previous two years at the time of seeding on 14 January, 2000. All the plots were mowed at 5 cm height on 23 November, 2000 prior to the commencement of the summer (2000/2001) irrigation cycle. Thereafter, all the herbage mass of the whole plot was mowed to 5 cm height with a power operated hand shear at three weeks interval. There was no grazing at the experimental site and therefore the role of dung and urine deposits in leaching is excluded here.

The experiment comprised combinations of three irrigation frequencies and two P fertility treatments, applied to swards of perennial ryegrass (*Lolium perenne* L.) or white clover (*Trifolium repens* L.). Each treatment was replicated four times. The plots were 1.5 m^2 and irrigated with micro-sprinklers. The irrigation frequency treatments were determined using the following scheduling criteria.

I-20: Irrigate at 20 mm soil water deficit (Replenish soil moisture to field capacity at 33% loss of the readily available water holding capacity (W_R)).

I-40: Irrigate at 40 mm soil water deficit (Replenish soil moisture to field capacity at 66% loss of W_R).

I-60: Irrigate at 60 mm soil water deficit (Replenish soil moisture to field capacity at 100% loss of W_R).

For the purpose of scheduling irrigation, water loss from the soil profile (i.e. the cumulative soil water deficit) was estimated using climate data and the water balance model proposed by Scotter *et al*. (1979).

The two P fertilizer treatments were:P-0: No fertilizer P applied.P-40: fertilizer P applied at 40 kg P ha^{-1}. The application rate of 40 kg of P per hectare per annum was selected on the basis of the soil Olsen P level (12 mg kg^{-1}) of the upper 75 mm depth of the soil profile (Roberts *et al*., 1994).

Single super phosphate was used as the fertilizer. The application for the 1999/2000 season was made to the fertilised plots on January, 2000 and the application for the 2000/2001 season was made in the middle of November 2000. Ammonium nitrate was applied as a source of N for the plots planted with ryegrass at the rate equivalent to what was removed in the preceding harvest.

Ceramic suction cup samplers (Grossmann and Udluft, 1991) were used to capture soil water samples for determination of nutrient concentrations in drainage from the experimental plots in this study. Samplers were fabricated using high flow round bottom straight wall ceramic cups which were 75 mm long and 22 mm outer diameter (652x10, Soil-moisture Equipment Corp., Santa Barbara, California 93105). One such soil water sampler was installed near the centre of each plot. To ensure good hydraulic contact between the suction cup and the soil *in situ*, slurry of the material from the soil auger column was made and put back into the hole before the suction probe was inserted. The centre of the ceramic cup was placed at 300 mm depth as suggested by Field *et al*. (1985).

Soil water samples were removed on 2 occasions during the irrigation season, and on 6 occasions between April 14 and July, 31 2001 when heavy rain occurred. The concentrations of nitrate-N and ammonium-N in each water sample were measured using a Technicon II auto-analyser (Downes, 1978).

Dissolved reactive phosphorus, i.e. mainly soluble inorganic P, was measured using the acid ammonium molybdate method (Murphy and Riley, 1962). Even though 384 soil water samples were collected, only 180 samples were of adequate volume to allow sub-sampling for measurement of DRP. Therefore, standard statistical analysis was not carried out for values of DRP concentration of soil water samples.

Estimation of nutrient leaching losses

The amount of nutrient leached per hectare per day was calculated for each treatment as the product of the mean nutrient concentration of soil water samples and the drainage volume estimated using the soil water balance (Sumanasena, 2003). Between 23 November, 2000 and 31 July, 2001, there were nine major rainfall events which recharged the soil profile to field capacity, and generated some drainage.

RESULTS AND DISCUSSIONS

Drainage

Simulated drainage quantity obtained from the site- specific soil water balance model (Sumanasena, 2003) indicated that the irrigation frequency affected the quantity of drainage between November, 2000 and July, 2001 (Table 2). The main drainage period was observed from mid May, 2001 (Day 171) to 31 July, 2001 (Day 251). The cumulative drainage until 12 May 2001 was 140, 60, and 80 mm for irrigation frequency I-20, I-40, and I-60 plots, respectively. Total drainage estimates to 31 July 2001, were 320, 240, and 260 mm for these plots, respectively.

Nitrate-N in soil water

Nitrate-N concentration in soil water was variable (Fig. 1 and Fig. 2). The overall mean nitrate-N concentration of soil water samples taken from plots planted with clover were significantly ($P<0.05$) greater than those from ryegrass plots (Fig. 3). The concentration of nitrate-N in soil water in ryegrass plots approached a plateau (at concentrations that were mostly less than 10 mg nitrate-N L^{-1}) from 14 April, 2001 onwards. In comparison, the nitrate-N concentrations of soil water in the clover plots increased rapidly until the end of May, 2001 and approached a plateau (at concentrations that were mostly greater than 10 approximately 17 mg nitrate-N L^{-1}) from mid June, 2001 onwards.

P fertilizer application did not have a significant effect on the overall mean nitrate-N concentrations in soil water samples under either species. However, for ryegrass, there was a tendency for P-0 plots to have greater nitrate-N ($P<0,05$) concentrations in the soil water samples than P-40 plots (Fig. 1).

Table 1. **Simulated cumulative drainage for the irrigation season and early winter under three irrigation treatments.**

Calendar dates	Day number	Treatment		
		I-20	I-40	I-60
23 Nov., 2000	1	0	0	0
31 Dec., 2000	39	61	21	41
13 Feb., 2001	83	94	34	54
29 Mar., 2001	127	110	50	70
14 Apr., 2001	143	133	53	73
12 May, 2001	171	140	60	80
12 Jun., 2001	202	259	179	199
18 Jun., 2001	208	283	203	223
17 Jul., 2001	237	289	209	229
24 Jul., 2001	244	315	235	255
31 Jul., 2001	251	320	240	260

Estimated nitrate-N leaching losses

For the period November, 2000 to July, 2001, the greatest losses of nitrate-N estimated for ryegrass treatments were 17 and 10 kg nitrate-N ha^{-1} for I-20, P-0 and I-40, P-0 plots respectively (Table 2). These losses were equivalent to 12% and 8% of the N applied in fertilizer. The cumulative nitrate-N losses of all the other ryegrass plots were very similar and within the range of 3 to 6 kg ha^{-1} nitrate-N (2-4% of applied N) (Table 2). Total nitrate-N losses under the irrigation frequency I-60 tended to be smaller than that under the other two irrigation frequencies.

A comparison between cumulative losses up to mid May with cumulative losses up to end July, 2001 reveals that most of the N leaching losses occurred in the period from May to July. This was the period having large drainage volumes and high nitrate-N concentrations in soil water.

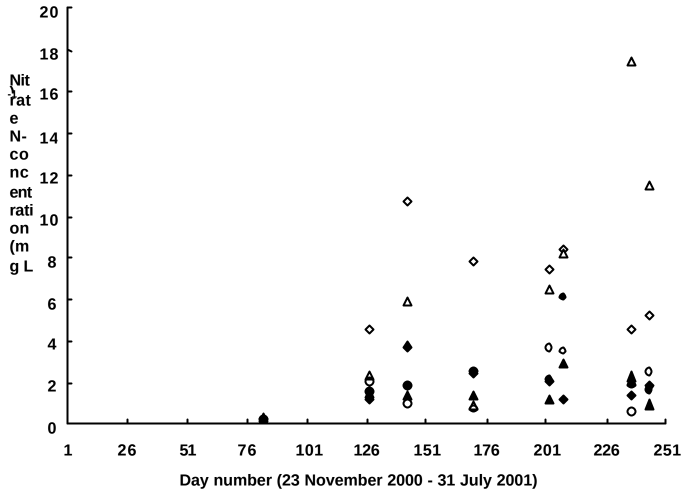

Fig. 1. Nitrate-N concentrations of soil water for ryegrass plots. Symbols; ?, ? , ?, represent irrigation frequencies I-20, I-40, and I-60, respectively. Open symbols represent P-0 plots while closed symbols represent P-40 plots.

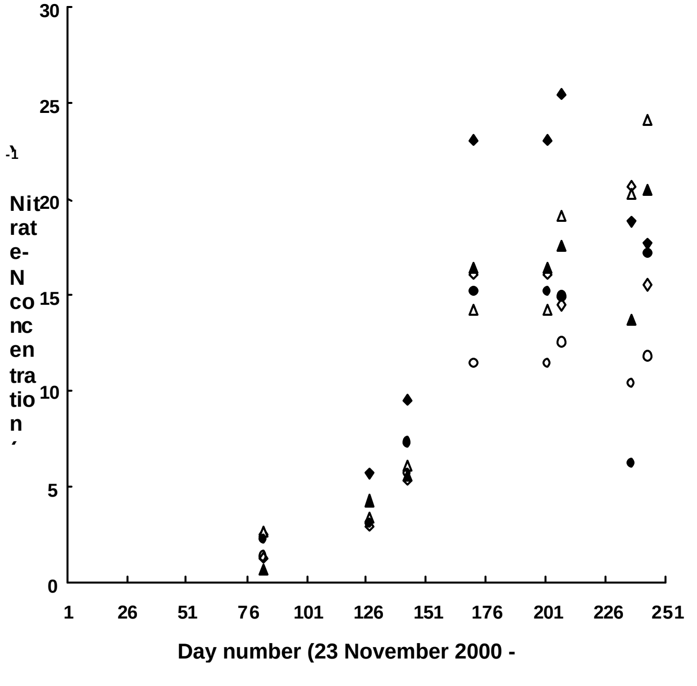

Fig. 2. Nitrate-N concentrations of soil water for clover plots. Symbols; ?, ? , ?, represent irrigation frequencies I-20, I-40, and I-60, respectively. Open symbols represent P-0 plots while close symbols represent P-40 plots

Cumulative nitrate-N losses estimated for clover plots until 31 July, 2001 were at least two fold greater than those estimated for ryegrass plots (Table 3). Nitrate-N losses increased to a marked extent (8 to 15 times) under all treatments having clover between May and July, 2001.

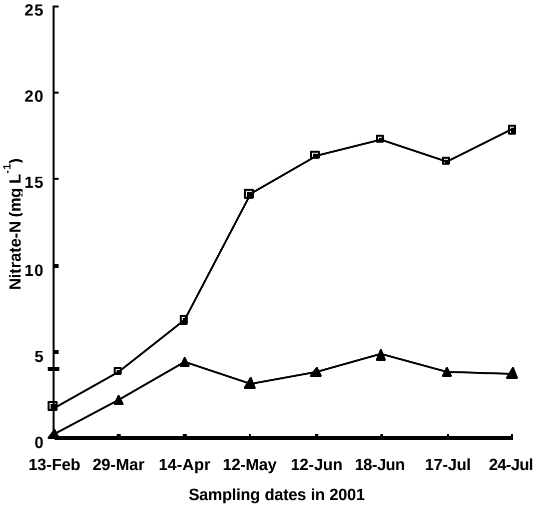

Fig. 3. The effect of species on nitrate-N concentrations of soil water. Symbols ¦ and ? , represent clover and ryegrass, respectively.

Table 2. Summary of the nitrogen balance (kg ha $^{-1}$) for ryegrass plots. Values in parentheses denote the nitrate-N loss as a percentage of applied fertilizer N.

Treatment	Fertilizer N Input	N removal in ryegrass	Leaching loss as nitrate-N	
			23 Nov.2001-14 May 2001	23 Nov.2001-31July 200
I-20 P-0	140	177	5 (4)	17 (12)
I-20 P-40	140	206	2 (2)	5 (4)
I-40 P-0	140	172	1 (1)	10 (8)
I-40 P-40	140	198	1 (1)	4 (3)
I-60 P-0	140	161	1 (1)	3 (2)
I-60 P-40	140	184	1 (1)	6(4)

Dissolved reactive P in soil water

There was no treatment effect for dissolved reactive P concentrations of soil water samples. The range of P concentrations was very narrow, and decreased gradually towards mid winter with increased drainage volumes (Fig. 4).

The range of values reported here for soil water nitrate-N concentrations are comparable with the values given by Cuttle *et al.* (1992) for both ryegrass and white clover. The variability in nitrate-N concentrations increased between late autumn and early winter (12 May to 24 July, 2001). This is a common phenomenon that has been observed by several other workers (White *et al*., 1987; Cuttle *et al*., 1992; Magesan *et al*., 1996). According to these workers, the increased variability in nitrate-N concentration is attributable to the changes in water movement patterns as the profile reaches saturation. Earlier saturation of the root zone and greater cumulative drainage was observed for treatments having irrigation frequency I-20.

A tendency for P-0 plots to have both greater nitrate-N concentrations in soil water samples and less N uptake in harvested material than P-40 plots was observed in for the ryegrass plots (Fig. 1 and Table 2). This may be an indication of more efficient utilization of N fertilizer by ryegrass in the presence of P fertilizer. This trend was not observed for I-60, P-0 plots at the peak of the drainage season.

Table 3. Summary of the nitrogen balance (kg ha $^{-1}$) for clover plots.

Treatment	Fertilizer N Input	N removal in clover	Leaching loss as nitrate-N	
			23 Nov.2001- 14 May 2001	23 Nov.2001- 14 May 2001
I-20 P-0	0	351	4	33
I-20 P-40	0	367	7	41
I-40 P-0	0	291	3	44
I-40 P-40	0	345	2	22
I-60 P-0	0	273	2	19
I-60 P-40	0	314	3	24

The cumulative losses of nitrate-N from plots planted with clover from 23 November, 2000 to 31 July, 2001 were at least two fold greater than losses from corresponding ryegrass plots. Presumably this difference is related to the ability of clover to fix atmospheric nitrogen. The increased concentration of nitrate-N in soil water associated with clover growth may explain, in part, the lower concentration (and loss) of nitrate-N under I-60. As I-60 plots produced less clover than I-20, there was presumably less N_2 fixation and ultimately less nitrate-N at risk to leaching.

Major quantities of nitrate-N were lost from the irrigated plots in May. Workers like Heng *et al*. (1991) and Field *et al*. (1985) have reported similar trends with the commencement of autumn drainage events for the same locality. Heng *et al*. (1991) reported that most of the nitrate-N lost from Tokomaru silt loam was in the first 70 - 80 mm of drainage during late autumn/early winter, and concluded that the drainage during the rest of the winter had a relatively small effect on the total amount of nitrate-N leached.

Overall, nitrate-N leaching losses from ryegrass plots were only 2 to 12% of the N applied as fertilizer. A substantial loss of nitrate-N was measured only for I-20, P-0 ryegrass plots: losses from other plots appeared to be negligible. Comparably, Hack-ten Broeke (2001) reported that different irrigation methods had no significant effect on nitrate-N concentrations in the leachate under pasture in the Netherlands. Moreover, in another part of his study, Hack-ten Broeke (2001) reported that an increase in irrigation water use improved pasture production and reduced nitrate concentrations at 1 m depth. In a recent lysimeter study in Waikato in New Zealand, Burgess *et al*. (2002) observed excess nitrate-N leaching below the pasture root zone under non-irrigated treatments when the autumn drainage flush occurred and they attributed this to the accumulation of nitrate-N in the root zone during the dry season.

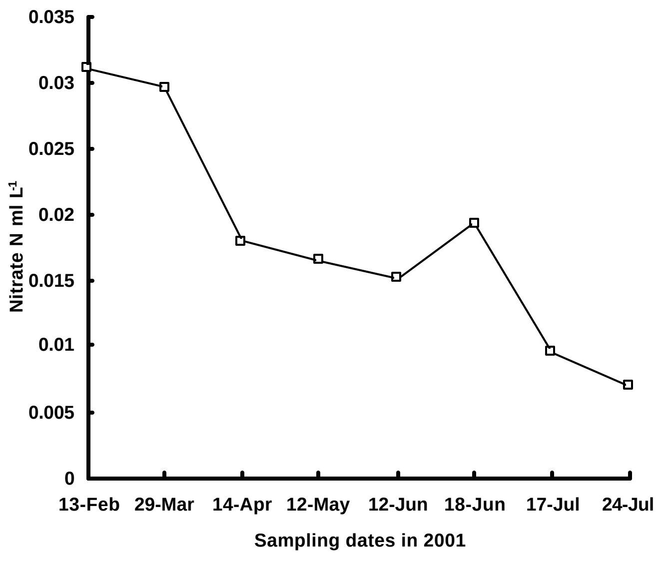

Fig. 4. The mean dissolved reactive P concentrations of free draining soil ater at 300 mm depth following heavy rains in 2001.

The maximum total cumulative nitrate-N loss under ryegrass (I-20, P-40) of 17 kg ha^{-1} is almost half of the value of 37 kg ha^{-1} for a pure sward of ryegrass on Manawatu silt loam estimated by Field *et al*. (1985). However, the study site used by Field *et al*. (1985) was grazed by sheep while the current experiment involved cut swards. The value reported here is closer to estimates reported by Heng *et al*. (1991) on Tokomaru silt loam soil at Palmerston North which was also grazed by sheep.

In general, dissolved reactive P concentrations in soil water samples were in the range of 0 - 0.166 mg L^{-1}. The observations of this experiment are within the range of values reported in the literature (Sharpley and Menzel, 1987; Heckrath *et al*., 1995). The concentration of P decreased from autumn onwards with increased volumes of drainage. This is most likely attributable to dilution of dissolved reactive P with saturation of the profile. The dissolved reactive P measured at 300 mm depth may not be a potential source of environmental pollutant, as this soluble P may be adsorbed onto P-deficient subsoil in the 300- 450 mm depth (Sharpley *et al*. 2001).

CONCLUSIONS

Nitrate-N concentrations in soil water under irrigated swards of clover were large in early winter drainage events irrespective of irrigation frequency treatments. This resulted in relatively large leaching losses of N under clover. Nitrate-N concentrations were not as great in soil water under irrigated ryegrass swards.

Estimated total nitrate-N losses until 31 July, 2001 under each irrigation frequency indicated that changing irrigation frequency of ryegrass within the 'readily available water' range during the previous summer did not have a major effect on the overall nitrate-N leaching pattern during the late autumn/early winter period following the irrigation season. However, there were some indications that irrigation frequency may have affected nitrate-N leaching under clover.

The small dissolved reactive P concentrations recorded under the different irrigation frequency treatments indicate that it is unlikely that there will be a major increase in P leaching as a result of increasing irrigation frequency under pasture in the summer period.

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