Nitrogen fluxes in dairy farm soils in response to fertilizer or “urine”

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Abstract (150 words max)
Eutrophication in the Victorian Gippsland Lakes has been linked to agricultural nitrogen (N) inputs and their potential contribution to leaching losses. Quantifying N fluxes through dairy soils will indicate the importance of leaching to N losses in these systems. Movement of N through the soil profile of a dairy farm in the Gippsland, Victoria, was investigated over a 24-month period. Urine treatments resulted in sizeable yield responses with ~100% increase in pasture dry matter yields above control treatments at first harvest after urine application. Pasture response continued up to four more harvests with N uptake from 19-47%. Fertiliser resulted in almost negligible N leached. The implication of this research is that cow urine is a larger determinant than fertiliser use of N lost from farms.

Key Words
Ryegrass, root zone, soil profile, leaching, pasture uptake.

Introduction

Nitrogen (N), a key nutrient for pastures, can be lost into the atmosphere or leached though the soil into groundwater. Leaching of N into water courses is an issue in Victoria and globally (Galloway et al., 2008). For dairy farms, the rate of emission to the atmosphere, or leaching through to groundwater, is dependent on several factors that include weather conditions, soil characteristics, cultivar response, timing of fertiliser applications, and management of defoliation (Selbie et al., 2015). N inputs in Australian grazed pasture systems has increased over the last 20 years with average annual N fertiliser application rates of 93 kg/ha (Stott and Gourley, 2016). Purchased feed inputs has likewise grown, with mean supplementary dietary N up to 69% of grazed N intake (Aarons et al., 2017). The high N intakes (545 g N/cow per day) of Australian dairy cows is in excess of the recommended 400 g N/cow per day, suggesting that N excretion is likely to be high and will primarily occur as urinary N (Castillo et al., 2000). Dairy cow urinations can apply up to 1000 kg/ha N to the soil surface (Eckard et al., 2004) and as such, urine input loads on an impacted land basis can be an order of magnitude greater than typical fertiliser application loads. These high urinary N loads are likely to exceed plant requirements leading to the potential for losses to the environment.

N can move slowly through the soil profile with research showing that applied N from urine can take up to 6 months to pass through the root zone (Pakrou and Dillon, 2000). Seasonal effects have been shown to significantly change the movement of N (Snow et al.,, 2011). For example, urine applied to pastures towards the end of spring has been shown to remain in the soil until the following autumn, resulting in greater than expected N concentrations stored within the soil profile.

The aim of this experiment was to quantify N use, transformations and losses within a soil profile of a typically managed grazed-dairy pasture. Treatments included artificial cow “urine” or fertiliser N (i.e. urea, calcium nitrate) applied to plots on a pasture paddock on a dairy research farm. N uptake by pasture, soil N concentrations and transformations into mineral and organic fractions, and N losses through leaching within the soil profile were measured.

Methods

Site Description

The research site was located within a paddock at DJPR Ellinbank (38° 14’ 30.1”S, 145° 56’ 12.1” E, http://agriculture.vic.gov.au/agriculture/innovation-and-research/research-centres/ellinbank). The paddock topographically slopes downward (< 5°) from west to east. The site was characterised as a red Ferrosol soil and was selected due to the gradational nature of the soil profile and associated free-draining attributes that are representative of this soil type within the Gippsland.

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Plots

Forty-five plots (1.5 × 2.0 m) were created on an existing paddock and divided into 3 blocks and repetitions using a Latinised randomised complete block design (Figure 1). Soil samples were collected (0-10 cm) from the site to determine existing soil fertility. The entire site was surface broadcast with perennial ryegrass cultivar '*Expedia*,' sown at a rate of 50 kg seed/ha. Maintenance rates of fertiliser were applied based on existing soil fertility levels, estimated net removal per ha from grazing, and soil retention and loss factors. Basal fertiliser applications included P (~50 kg P/ha), applied as triple super, K (~100 kg K/ha) as potash fertiliser (KCl) and S (~50 kg S/ha) applied as gypsum. Copper and zinc were also applied to address any potential soil trace element deficiencies at rates of 2 kg/ha respectively. P, K and S fertilisers were applied in autumn and late spring 2017. Porous ceramic cups were installed in May 2017 at 0.45 m depth on an angle of 60° at 3 locations within each plot (i.e. 135 cups for the site).

block		1	2	3
rep 1				
	1	9	14	2
	2	7	10	5
	3	4	6	8
	4	13	11	1
	5	3	15	12
rep 2				
	1	1	12	9
	2	11	13	15
	3	2	3	14
	4	10	5	7
	5	6	8	4
rep 3				
	1	15	9	6
	2	14	4	11
	3	12	2	13
	4	5	7	3
	5	8	1	10

Cell Colours	
1	Control
2	Urea Fertiliser
3	Nitrate Fertiliser
4	U1 1st application
5	U2 1st application
6	U1 2nd application
7	U2 2nd application
8	U1 3rd application
9	U2 3rd application
10	U1 4th application
11	U2 4th application
12	U1 5th application
13	U2 5th application
14	U1 6th application
15	U2 6th application

U1 = 400 kg/ha N urine solution

U2 = 800 kg/ha N urine solution

Figure 1. Layout of plots

Treatments and applications

Harvesting was determined by the height of grass (i.e. three leaf stage) that a farmer would consider appropriate for grazing. One of four treatments was applied to each plot after each harvest of pasture. Two of the treatments were N fertiliser (50 kg N/ha): Standard urea because of its high N concentration (46%), and widespread usage by dairy farmers in southern Australia; and calcium nitrate which provides a contrasting initial N form and potential for greater N leaching. The other treatments were artificial urine (400 kg N/ha and 800 kg N/ha) to mimic dairy cow urinary N (Shepherd and Phillips, 2011). Potassium bromide was also added as a tracer of water movement in the soil profiles to help identify the source and lag time of sampled soil water. Treatments were applied after each harvest on one group of plots (e.g. U1 and U2, Figure 1), simulating cows eating the pasture. Urine treatments were applied to six plots (2 N loads × 3 replicates). The following harvest, another group of plots was used (e.g. U3 and U4). Fertiliser (2 types × 3 replicates) was also applied to another 6 plots (Plots 1-3, Figure 1).

Sampling

Previous research conducted in Australia to measure soil water and N movement in a soil column has used artificially created/reconstructed soil profiles, intact cores or lysimeters. These configurations can disturb the soil column to such an extent that there is a wide variability in N fluxes and drainage volumes (Pakrou and Dillon, 2000). Therefore, this research used in-situ ceramic porous cups, placed at an angle into an undisturbed soil profile such that the cup is below the root zone. This approach has been shown to measure soil water with minimal disturbance to the soil profile ((Snow et al., 2011).

At each harvest, 200 gm of pasture was collected for dry matter (DM) and nutrient analyses. This was analysed for N(ammonium and nitrate), P, K, S, Ca, Mg, Na, Cl, Mn, Cu, Zn, B and Mb at a commercial facility (Incitec Pivot, Werribee). Prior to a rain event, a vacuum pump was applied to each cup to create negative pressure (-65kPa) for at least 12 hours to collect water from the soil to the cups. Water from the ceramic cups was taken after rain and analysed for pH, EC, nitrate, ammonia, and anions (i.e. bromide). Soil cores were taken at the start and intermittently over the duration of the experiment. Soil mineral N was measured at three depths (0-10, 10-20, 20-30 and 30-50 cm) at five random spots/plot. The soil was analysed for pH, EC, nitrate and ammonium, Olsen P and PBI, sulphur, OC, anions and cations at a commercial facility (Incitec Pivot, Werribee).

Results and Discussion

Pasture

N concentrations increased from around 2.3 to 3% (control treatments) to 3.2 to 4.1% as a result of the fertiliser applications (urea and nitrate). Urine treatments resulted in increases in N concentrations in the ryegrass up to 6.5%, with the largest uptake in spring. Up to a threefold difference in net N removal in harvested pasture above the control treatments was observed, with limited difference between N fertiliser types and urine rates. N uptake after 4 months of application was up to 47% and 28% for 400 and 800 kg/ha N, respectively.

Soil cores

Nitrate N levels were the dominant mineral N form across all treatments and soil depths. There were only small increases in nitrate and ammonium N from the urea and nitrate fertiliser treatment compared with the control, and only at the 10cm depth. Soil nitrate and ammonium N levels declined down the soil profile, potentially due to earlier urine applications.

Soil water (0.45 m)

The volume of water extracted from the porous cups was dependent on two independent variables: treatment type and rainfall prior to extraction. Once the soil profile had started to dry out after winter and was below field capacity, urine applications to the plots becomes evident, with these treatments providing a greater volume of water compared to other treatments.

Nitrate in soil water was the major form of N collected. On average, over the life of the experiment, the fertiliser treated plots leached 3 to 4 times nitrate of the controls, with the 400 kg/ha treatment double that of fertiliser (Table 1). The 800 kg/ha treatment leached 78% more nitrate than the 400 kg/ha treatment, implying that at that concentration the soil profile is saturated with N. Note that the maximum nitrate seen for all treatment was during June 2018 after a particularly dry autumn had broken in late May 2018.

Table 1. Grand means of nitrate (mg-N/L) found in leachate at 0.45 m

	Control	Urea	Calcium Nitrate	400 kg/ha Urine	800 kg/ha Urine
Average	6.74	19.77	22.47	49.00	87.28
SD	11.78	29.75	35.94	69.21	119.92
Max	80.93	146.86	220.87	619.90	1775.40

Nitrate concentrations from the control plots followed a seasonal trend with a declining N concentration as the soil profile recharged with winter rain to negligible levels in late winter when the soil profile was saturated. There was a small increase in N concentrations as biological activity and mineralisation of OM increased in spring/early summer. Nitrate concentrations from the fertiliser applications follow a similar trend. The relatively small nitrate concentrations in extracted soil water below the root zone of the fertiliser treatments is supported by the relatively high pasture N use efficiency (up to 85%) of the applied N fertiliser.

For the urine treatment applications, nitrate reached a peak concentration followed by a gradual decline to background levels (e.g. Figure 2A). However, nitrate concentrations did not rise until a substantial rainfall event occurred. For example, the first application of 400 kg/ha underwent a cycle of reaching peak nitrate concentration (average of 59 mg N/L) and then back to approximately baseline concentrations. The higher rate of 800 kg/ha urine application led to a delayed peak in nitrate (average of: 71 mg N/L). For example, the peak for the 400 kg/ha occurred on the September 9 extraction while the 800 kg/ha peak occurred on September 28, 2017.
In the ensuing dry spring of 2017, the 400 kg/ha treatments resulted in baseline concentrations of nitrate by November 11 but the 800 kg/ha still had a pool of nitrate available in the soil profile with elevated nitrate concentrations continuing through the dry period to the later rain event in December 2017.
Nitrate concentrations measured in extracted soil water following urine application followed similar trends, dropping in concentration after the last rain of 2017 (Figure 2, right).

A late autumn break in 2018 revealed that the N in the soil profile had remained without movement (Figure 2B). The 800 kg/ha rose dramatically after the rains started in May with the 400 kg/ha less so. Sampling during the dry period showed that leaching concentrations for 400 kg/ha and fertiliser applications to be of similar magnitude. The limited rain events between January and April led to increases in soil water N extracted. A large rain event in May 2018 appeared to have flushed much of the N past 0.45 m with concentrations for the urine applications dropping dramatically (e.g. an average drop of 21 and 69 mg-N/L for 400 and 800 kg/ha applications, respectively). Some uptake by plants was also likely prior to the slowdown of ryegrass growth over winter.

Winter 2018 and further applications during that time resulted in higher concentrations of nitrate than the previous year, further evidence that N is being held in the soil until enough water (i.e. rain) can move the N down or solubilise it to make it accessible to plants or microbes (Table 1, Figure 2B). The largest concentrations of N recovered from the porous cups occurred during this time, emphasising how management of herds during winter can be important to reduce N leaching. As per the previous year, the 800 kg/ha peak N concentration occurred later than the other treatments, albeit by only 5 days.

The onset of spring led tothe rate of N reaching 0.45 m dropping dramatically. From August 1 to September 19, all treatments bar the 800 kg/ha returned to baseline concentrations. 800 kg/ha dropped in concentration by 89% from winter highs. Rain events in October produced an increase in concentration for this treatment too, indicating there was more than enough N for plants at this time.

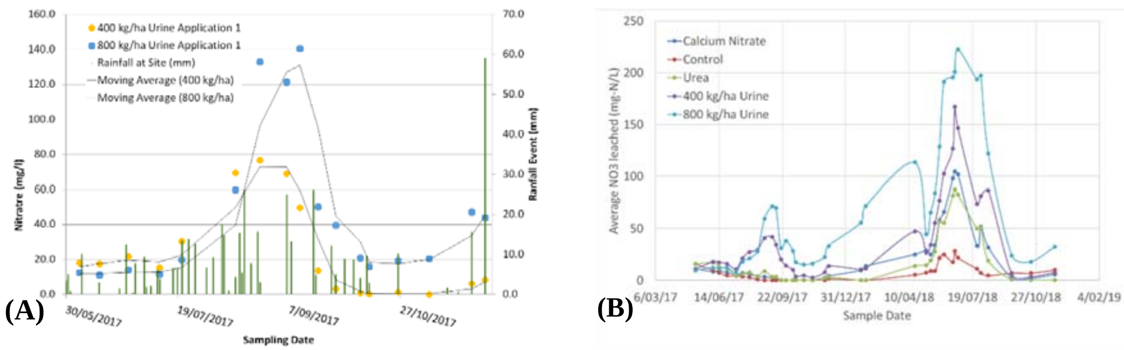

Figure 2. (A) Nitrate concentrations in soil water extracted at 0.45 m. Cow "urine" (400 kg/ha diamonds; 800 kg/ha square) was applied on June 1, 2017. Rainfall events from June 4-December 5, 2017 are shown as orange lines. (B) Average nitrate concentrations for all treatments June 4, 2017-November 26, 2018. Dates are not to scale.

Conclusion

From this experiment, fertiliser applications were not the major source of nitrate leaching with little N reaching 0.45 m. 'Urine' from dairy cows is a more likely source. Neither source of N examined was enough on its own to get past the root zone with rain being needed for N to reach 0.45 m. The pool of N that remains in the soil does so for extended periods without rain, i.e. it is inaccessible to plants and microbes when the soil is dry. Doubling the N concentrations in urine leads both to an increase in peak N concentrations at 0.45 m and a longer period of N moving though the soil profile. Pasture uptake of N decreases in winter due to plant dormancy and summer due to lack of water.

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