Towards a complete nitrogen budget from subtropical dairy farms: three years of pasture nitrogen losses in surface runoff

David Rowlings[1], Martin Labadz[1], Clemens Scheer[1], Peter Grace[1]

[1] Queensland University of Technology, 2 George Street Brisbane, Queensland, 4000, d.rowlings@qut.edu.au

Abstract

Dairy represents one of the most intensive and nitrogen (N) loaded production systems in the high rainfall regions of Queensland, Australia. Fertiliser application rates during the winter rye grass season (April-October) frequently surpass 300 kg N ha^{-1} $year^{-1}$ yet the fate of much of the applied N is uncertain. The high (>1200 mm $year^{-1}$) and intensive rainfall and the proximity to environmentally sensitive areas such as the Great Barrier Reef make losses in surface water run-off of particular interest to the industry. Two run-off plots (416 m^2) were installed on an intensively irrigated and fertilised rye-grass/kikuyu pasture rotation near Gympie, Queensland and monitored over three (1 June to 31 May) measurement years. Runoff was measured using a tipping bucket and nutrients collected via an automated sampler. Runoff and losses were largest during the 2012-13 season when five of the nine runoff events over the measurement period occurred and total runoff exceeded 480 mm, corresponding to 37% of the annual rainfall. Total N load was dominated by NO_3^-, with largest losses during a four day, 448 mm rain event in January 2013 following an extended dry period resulting in 280 mm of runoff and 16.5 kg ha^{-1} of N losses. Total N losses over the remaining periods were typically negligible (< 1 kg ha^{-1} $event^{-1}$), with annual losses of 5.0 and 0.7 kg N ha^{-1} for 2013-14 and 2014-15 respectively. These results indicate that under current management systems intensive pastures contribute only minor nutrient loads, though losses can be high following extended dry periods.

Key Words

Dairy, runoff, N losses, subtropical, pasture

Introduction

An estimated 80% of Australian dairy production is pasture based and is heavily reliant on nitrogen (N) inputs, with the amount of fertiliser and N imported in feed increasing rapidly over the last two decades. The nitrogen use efficiency (NUE) of the dairy industry is amongst the lowest reported from Australian agricultural systems, with N outputs in products at a farm scale representing as little as 14% of total N inputs in fertiliser and feed (Gourley et al., 2012). Recent research using isotopically labelled ^{15}N fertiliser recoveries has demonstrated that direct losses of applied fertiliser from subtropical dairy pastures can be as high as 40% (Rowlings et al., 2016). These losses, which can equate to over 120 kg N ha^{-1} $year^{-1}$, not only contribute to the overall poor NUE reported from dairy farms and the associated economic costs, but depending on the loss pathway, also have the potential to increase environmental pollution to sensitive coastal waterways and the Great Barrier Reef.

Research from southern Australian dairy pastures has shown surface runoff contributes only a small proportion of total losses (<5 kg N ha^{-1} yr^{-1}), with leaching being the major loss mechanism (Burkitt, 2014). However studies from other crops in the tropics such as sugarcane have shown high runoff N losses >16 kg N ha^{-1} (Davis et al., 2016), while N movement down the profile in subtropical dairy soils is limited (Rowlings et al., 2016). Given the geographic concentration of the subtropical dairy industry along the coastal belt, frequent large rain events associated with tropical lows, heavier textured alluvial soils and high soil N loads, the potential for large N losses through surface run-off are high. However very little data currently exists on runoff N losses from dairy systems in the subtropics. This study aimed to quantify runoff losses of N from intensively managed dairy pasture as part of a larger project aimed at improving the N use efficiency of the industry and account for the missing 40% of applied N fertiliser.

Methods

Study site and experimental design

The study was located on a dairy farm 10km due east of Gympie, 180 km north of Brisbane, Queensland (Latitude: 26.19°S; Longitude: 152.74°E). The farm has been used for intensive dairy production over the last 40 years running between 200-240 milking cows under management typical of northern pasture based dairy production systems. The climate is humid subtropical, with a mean annual precipitation of 1,133mm

(1870-2013). Rainfall is summer dominated, with over 55% of the rainfall falling between December and March. Intra-annual rainfall variation is extremely large due to large and sporadic weather systems that result in extremely high daily and weekly rainfall totals. Rainfall is supplemented by up to 200 mm of irrigation annually.
The soil from the pasture sites is a clay loam texture increasing to clay below 250 mm and classified as a Red Dermosol. Management at the site was typical for the region with annual ryegrass (*Lolium multiflorum*) planted in April or May and fertilised and irrigated over the winter and spring before being outcompeted by the kikuyu (*Pennisetum clandestinum*) dominated summer pastures around October and November. The plots were crashed grazed for 12 hours every 3-4 weeks at a stocking rate of >200 cows per hectare. Annual N inputs ranged from 300 -333 kg N ha^{-1} as Urea applied following grazing from May to October, with additional inputs from urine and manure. A full site description is available in Rowlings *et al.* (2016).

Run-off measurements
Surface runoff volume and rates, together with nutrient and sediment loads were investigated from two replicate tipping bucket run-off collectors described by Ciesiolka et al. (1995) installed in December 2011 on a 6º slope. Collection of nutrient concentrations commenced in March 2012, and flow from June 2012 when a 150 mm wide edging was buried 100 mm around each plot leaving a 13 m by 32 m long catchment area (416 m^2). The collectors consisted of a 200 mm deep, 12 m long trough buried perpendicular to the slope flush with the soil surface. The troughs drained through two, 100 mm diameter PVC pipes into a 1.5 m long by 1 m wide by 200 mm high manifold fitted with a slotted 50 mm high overflow to allow even distribution of water into the 10 L PVC tipping bucket. The tipping bucket was connected to a reed-switch and logged via a data logger (Hobo Pendant logger, Onset Computer Corporation, Bourne, MA), and a manual counter.

Water Nitrogen concentration
At the outlet of the PVC tubes, a 200 x 300 mm glass container was placed and the sample hose from a 24 sample autosampler (ISCO 3700, Teledyne Isco, Inc, Lincoln, NE, USA) secured. The autosampler was connected to the tipping buckets reed switch and programmed to take samples at between 20 and 200 tip intervals depending on the season. Once activated, the sampler collected a 700 mL into a polypropylene bottle which were collected the next day when possible and frozen. Nitrate (NO_3^-) concentration was determined by ion chromatography using a Dionex RF2100 ion chromatograph (Thermo Fisher Scientific, Australia) and total Kjeldahl N (TKN) was determined by converting all organic N to ammonium (NH_4^+) which was measured colorimetrically on a discrete analyser (AQ2+, SEAL Analytical, USA). Free NH_4^+ was also measured colorimetrically. Organic N was calculated by subtracting NH_4^+ from TKN. Nutrient loads were derived by multiplying sample concentrations by runoff flow and summing over the event. Annual losses are calculated from June 1 to May 31 for each measurement year.

Results

Climate and runoff and N load
The autumn of 2012 at the commencement of the trial was extremely wet, with 508 mm of rain falling from March to May 2012 resulting in four runoff events. A large daily rain event of 172 mm on 5th March 2012 damaged the plots and prevented good flow data being recorded, though nutrient concentrations were still able to be collected. Surface runoff events were recorded in 9 distinct events from the 1st July 2012 to 30th May 2015 (Figure 1). Most events occurred from January to March, well outside the traditional fertilisation period.

The 2012-13 season was characterised by extreme climatic conditions. A total of 1318 mm of rain was recorded during the measurement year, 18% higher than the 1133 mm mean annual precipitation. Below average rainfall was recorded from all months between August until late January, and was below the 5th percentile for August and December. Rainfall was supplemented with 200 mmm of irrigation to the pasture which ceased in late November due to water shortages. As such plant available water content reached permanent wilting point by mid-December, resulting in poor summer pasture growth with widespread pasture senescence (Rowlings et al., 2016). By comparison, in the 6 weeks from late January to early March over 1000 mm of rain had fallen at the site, 80% of the annual precipitation. This included two large, multi-day rain events where cumulative totals exceeded 440 mm and 220 mm respectively, and maximum daily rainfalls 230 mm (27th January 2013) and 150 mm (25th February 2013). This resulted in runoff losses of 283 mm for January, including the highest daily loss of measurement period of just over 200 mm.

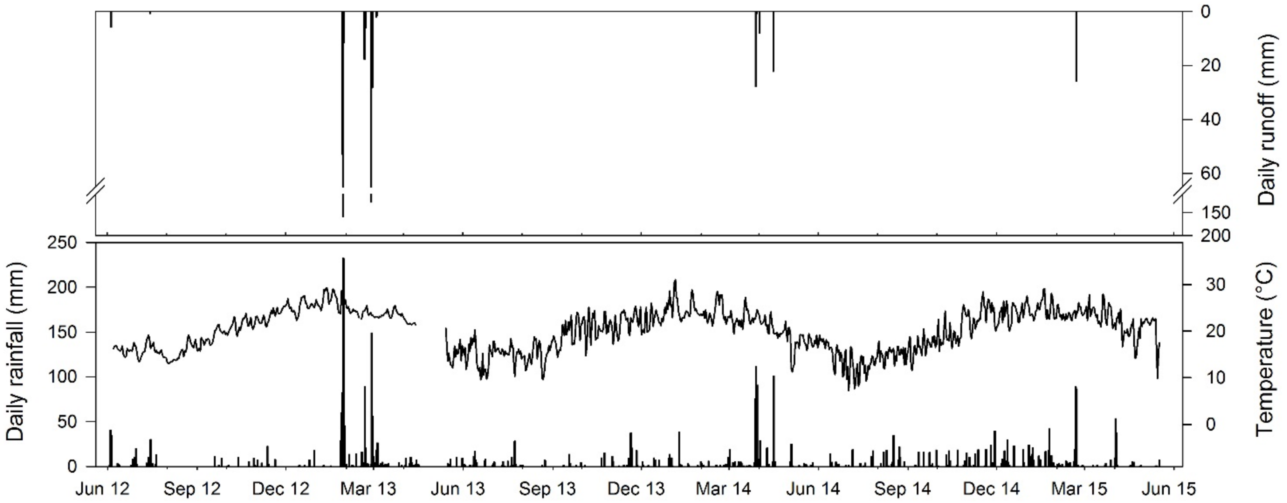

Figure 1. Daily rainfall and mean air temperature for the experimental period June 2012 to June 2015 at Gympie, Queensland.

The January 2013 event also represented the highest N load of the measurement period. Mineral N concentrations during this event increased from 5 to 39 mg L^{-1} of NO_3^--N over the first 14 mm of runoff before decreasing to 25 mg L^{-1} after 24 mm. The total N loss from this single event was estimated to be 16.5 kg N ha^{-1}, with 84% in the NO_3^- form and 15% as organic N. By comparison the second, smaller February event resulted in similar runoff volume (161 mm), but much lower N loads with NO_3^- concentrations <1 mg N L^{-1} and a total load over the event of 1.4 kg N ha^{-1}.

The 2013-14 season precipitation at the site from totalled 1008 mm. March 2014 was the wettest month with 354 mm, the majority (281 mm) of which fell over a 4 day period from the 25/03/14 – 28/03/14. The highest annual daily rainfall of 111 mm recorded during this period resulted in N losses of just over 2.9 kg N ha^{-1}, while a slightly smaller (101 mm) event in mid-April resulted in a further 1 kg of N loss. Rainfall in 2014-15 was evenly distributed across the year with only a single large rain event of 175 mm spread over the 20-21st February 2015 which resulted in only a very minor N loss.

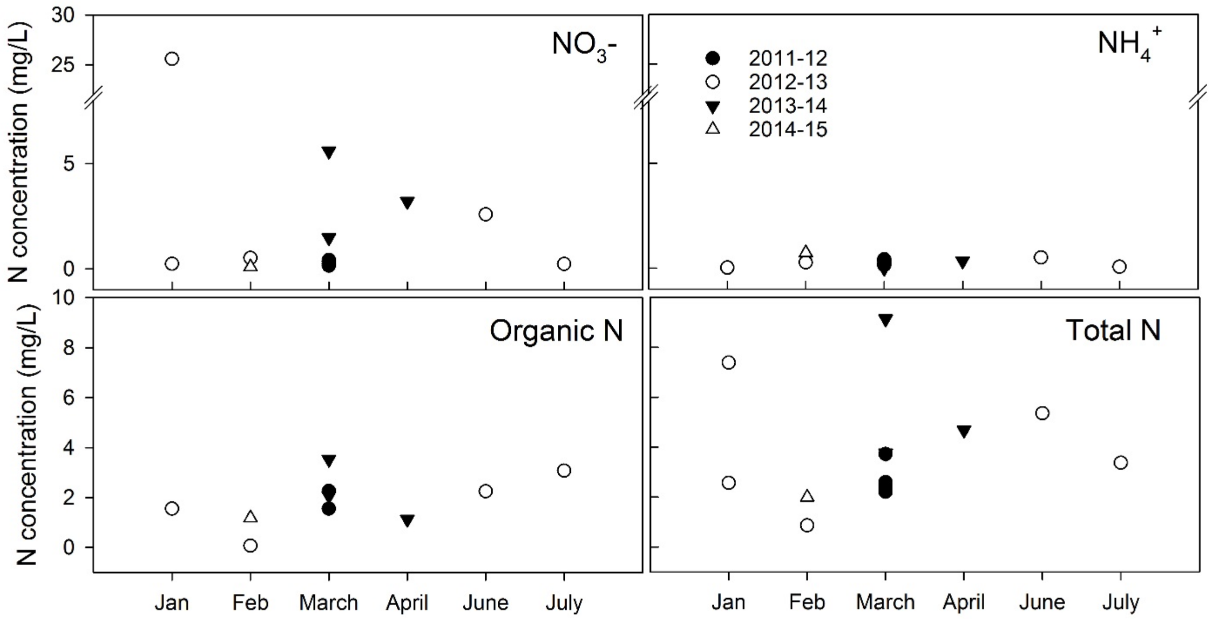

Figure 2. Mean N species concentrations for each runoff event by month at Gympie, Queensland.

Average annual N losses

Average annual losses of both runoff and N were dominated by the large events in January and February of 2013. Runoff intensity had no correlation with N load, with the highest rate of 20 mm hr^{-1} recorded during the February 2013 event, followed by 15.7 and 9.7 mm hr^{-1} for February 2015 and March 2014 respectively. Generally, NH_4^+ and organic N concentrations in the runoff were relatively constant while NO_3^- fluctuated greatly, though there was no relationship with measurement month or event size while (Figure 2). Nitrogen runoff losses from the pasture averaged 7.7 kg N ha^{-1} (Table 1) over the three years with NO_3^- being the most dominant form (76% of total) followed by organic N (20%), although organic N was over 10 times higher than NO_3^- in July 2012 and February 2015 events.

Table 1. Total rainfall, surface runoff and nutrient concentrations and load measured at Gympie, Queensland.

Year	Rain (mm)	Number of events (>1mm)	Total runoff (mm m^2)	% rain as runoff	NO_3^- (kg N ha^{-1})	NH_4^+ (kg N ha^{-1})	Organic N (kg N ha^{-1})	Total N lost (kg N ha^{-1})
2012/13	1318	5	412	31.3	15.0 ± 3.0	0.6 ± 0.4	2.8 ± 0.8	18.5 ± 4.2
2013/14	1008	3	59	5.8	2.4 ± 0.2	0.1 ± 0.0	1.4 ± 0.6	4.0 ± 0.8
2014/15	1222	1	26.6	2.2	0.02 ± 0.01	0.19 ± 0.02	0.31 ± 0.1	0.52 ± 0.1
Average	1211	3	166 ± 124	13.1 ± 9.2	4.3 ± 3.1	0.3 ± 0.2	1.5 ± 0.7	7.7 ± 5.5

Discussion

With the exception of the losses during the 2012-13 summer losses from the dairy pasture were low, and within the 0 - 5 kg N ha^{-1} range reported from southern Australia (Burkitt, 2014). The unusually high losses of NO_3^- during the January 2013 event can be attributed to the unseasonably low rainfall in the 3 months prior which ultimately resulted in pasture senescence, followed by over 400 mm of rain over a four day period. Any readily available N in the microbial biomass, plant material or NH_4^+ mineralised over the dry period would have been rapidly nitrified to NO_3^- under the high soil temperature and moisture conditions of the first two days of the rain event when only moderate rain (<90 mm) fell prior to saturation. A high proportion of the NO_3^- lost during this event most likely originated in the thick surface kikuyu thatch layer which contained >55 kg N ha^{-1} though an increase of more than 30 kg N ha^{-1} in the surface soil was also observed following this event (Rowlings et al., 2016). The slow re-growth of the pasture following senescence would have limited plant N uptake and any NO_3^- near the surface was lost as runoff once the soil reached saturation. In subsequent runoff events, NO_3^- was both much lower and a lesser proportion of total N lost as the rapidly growing pasture consumed any available N.

Conclusions

Despite the high annual N application rates and intense rainfall of subtropical dairy pastures, N losses from surface runoff are generally low and are not a major N loss mechanism. This is largely due to these events occurring during summer, outside the traditional fertiliser application window when excess N in the profile is limited by high pasture uptake. However large losses can still occur after intense rain following unseasonable summer dry periods, an occurrence predicted to increase with increasing climate variability associated with climate change.

References

Burkitt, L.L., 2014. A review of nitrogen losses due to leaching and surface runoff under intensive pasture management in Australia. Soil Research 52, 621-636.

Ciesiolka, C.A., Coughlan, K.J., Rose, C.W., Escalante, M.C., Hashim, G.M., Paningbatan Jr, E.P., Sombatpanit, S., 1995. Methodology for a multi-country study of soil erosion management. Soil Technology 8, 179-192.

Davis, A.M., Tink, M., Rohde, K., Brodie, J.E., 2016. Urea contributions to dissolved 'organic' nitrogen losses from intensive, fertilised agriculture. Agriculture, Ecosystems & Environment 223, 190-196.

Gourley, C.J.P., Aarons, S.R., Powell, J.M., 2012. Nitrogen use efficiency and manure management practices in contrasting dairy production systems. Agriculture, Ecosystems & Environment 147, 73-81.

Rowlings, D.W., Scheer, C., Liu, S., Grace, P.R., 2016. Annual nitrogen dynamics and urea fertilizer recoveries from a dairy pasture using 15N; effect of nitrification inhibitor DMPP and reduced application rates. Agriculture, Ecosystems & Environment 216, 216-225.