Quantifying the supply of plant-available nitrogen from dairy effluents to grow crops

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Abstract

The use of dairy effluent to grow forage and arable crops represents an opportunity to more sustainably reuse shed, feed pad and barn nutrients that are generated from intensive dairy systems. To do so in a profitable and low risk manner requires an understanding of the effect of effluent characteristics on nutrient supply patterns, including both the quantum of release and rate of release. Between 2014 and 2016 we have conducted several assays to investigate the nitrogen (N) supplying power of dairy effluents and link this to effluent characteristics measured at the time of application. This paper reports on Assay 1 where we quantified release patterns for five slurry and six solid dairy effluents collected from commercial farms in the Waikato region of New Zealand. These effluents were applied to a single, low N (0.36 % total N) soil at a target application rate of 100 kg N/ha and subsequently incubated in 500 ml units at 20°C and 90% of field capacity for 182 days. Units were leached a total of 15 times during the assay and the drainage water characterised for inorganic N levels. Estimates of N supply were calculated, corrected for background N supply from a non- effluent control, and relationships with a wide range of effluent characteristics assessed. The assay showed that the pattern and magnitude of N supply across slurry and solid effluent treatments varied considerably, consistent with the large variation in effluent characteristics. Strong positive correlations were found between the water-soluble N and carbon (C) effluent characteristics and the rate of N supply in the first month after effluent addition. There were few clear correlations between effluent characteristics and the rate of N supply during the later stages of the assay (112-182 days). At the end of the assay (182 days), final N supply for respective slurry and solid effluents ranged from 3.7 to 74.2 % and 1.5 to 34.3 % of total effluent N applied. Net N supply values which adjusted for inorganic N in the effluents at application (expressed as either a percentage of total N or organic N) were positive for seven of the eleven treatments (three slurries and four solids) indicating a net N mineralisation effect and negative for the remaining four (two slurries and two solids), indicating a net N immobilisation effect. Work is ongoing to identify the causes of the large variation in N supply.

Key Words

Mineralisation, inorganic N, organic N, effluent characteristics, cropping, APSIM.

Introduction

Intensive dairy farming in New Zealand generates large volumes of effluent that must be sustainably managed. In addition to what is deposited directly in the field, a substantial volume is collected from the milking shed, feed pad and barn areas. These effluents are typically a rich source of nitrogen (N) that can be applied to the soil to grow a wide range of forage and arable crops, reducing the need for synthetic fertilisers.

To optimise crop production and minimise risks associated with N loss requires an understanding of the effect of effluent characteristics on supply patterns, including both the quantum of release and rate of release. Characteristics can vary widely between effluents and this is often related to factors such as animal diet, seasonality, climate, shed management practices and post-collection processing technologies. These factors not only influence the composition of inorganic (i.e. ammonium, nitrate and nitrite forms which are readily available to crops) and organic N, but also the different pools of organic N that are present in each effluent. These organic pools can have a strong influence on mineralisation processes, and interact with soil and climate factors to influence final N release patterns.

Our aim was to characterise a range of dairy effluents and identify links between these characteristics and N supply dynamics. From this understanding we will look to develop simple tools that help farmers to optimise the use of effluents to grow forage and arable crops.

Methods

In May 2014 a selection of slurry (n = 5) and solid (n = 6) effluents were collected from commercial dairy farms in the Waikato region of New Zealand. Farming systems varied widely in intensity (1.5–4.2 cows/ha) and feeding practices (pasture only through to pasture and supplement mixes). Effluents were classified as slurries or solids based on their respective dry matter (DM) ranges of approximately 5−15% and >15%.

A 6-month open incubation assay was then established in a single, low N cropping soil to quantify N supply dynamics and relate these to effluent characteristics. The assay was conducted in 500 mL Millipore Stericup® filter units (0.8 µm filter), allowing routine leaching of the columns over the six month assay. Soil type was a Horotiu silt loam (Typic Orthic Allophanic) which has good drainage characteristics and is representative of cropping soils in the Waikato region. Prior to use, soil was sieved through a 4-mm screen to remove crop residue. Background analyses confirmed that the soil had low residual inorganic N (13.2 mg/kg), moderate N mineralisation potential (46.9 µg/g, as determined by the anaerobically mineralisable N (AMN) test) and total carbon (C) and N levels of 3.58 and 0.36 %, respectively.

Experimental treatments included the five slurry and six solid effluent entries and a non-effluent control. There were five replicates per effluent and ten replicates for the no effluent control. Effluents were mixed into the soil at a target rate of 100 kg N/ha. Rates were calculated using the total N analyses conducted when the effluents were initially collected and a soil bulk density of 0.91 g/cm^3. A second set of effluent analyses were conducted at the time of application to determine the exact amount and composition of N applied to each unit. The measures included: dry matter, total N and C, ammonium-N, nitrate-N, nitrite-N, water soluble N and C components (inorganic and organic), hot water N and C components (inorganic and organic), AMN, pH, basic nutrients (total P, Ca, Mg, K and Na), ash, protein, fat, neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin, hemicellulose, cellulose and carbohydrate content. Actual N application rates calculated using these results averaged at a value of 99 kg N/ha (range was 60 to 167 kg N/ha). Variances between initial and final total N concentrations reflected heterogeneity within the effluent source, or in some cases, possible volatilisation of ammonium during the storage period. Differences in application rates between effluent treatments were not considered to be an issue since the purpose of the assay was to link the characteristics of the applied effluent to net N supply (rather than to compare the magnitude of N release between effluents). Additionally, results were expressed as a percentage of the total effluent N applied.

The assay was conducted in a lab held at 20°C for the duration of the experiment. Soil moisture was maintained at 90% of field capacity using reverse osmosis (RO) water. Units were flushed with one pore volume of RO water at 7, 14, 21, 28, 42, 57, 70, 84, 98, 112, 126, 140, 155, 168 and 182 days after effluent application. Following flushing, a vacuum was applied to remove excess water and bring the soils back to around 90% of field capacity. In total there were 15 leaching events during the course of the assay. The volume of leachate was recorded gravimetrically and a subsample taken for analyses of inorganic N components. After the final leaching event (182 days) soil samples were taken from each unit and analysed for inorganic N still in the soil profiles. Measures of N supply were calculated as the sum of nitrate and ammonium (inorganic N) at each sampling occasion, corrected for background mineralisation from the control treatment.

Three measures of N supply were used in further analyses including *final N supply*, *net N supply* $_{(\% \text{ of total N})}$ and *net N supply* $_{(\% \text{ of organic N})}$. *Final N supply* was calculated as the sum of cumulative inorganic N leached after 182 days and residual inorganic N in the soil after the final leaching event. *Net N supply* $_{(\% \text{ of total N})}$ was calculated as final N supply at 182 days, corrected for the initial amount of inorganic N applied in the effluent and presented as a percentage of applied total N. *Net N supply* $_{(\% \text{ of organic N})}$ was calculated as final N supply at 182 days, corrected for the initial amount of inorganic N applied in the effluent and presented as a percentage of applied organic N.

Results and discussion

A selection of key effluent characteristics are summarised in Table 1. Dry matter contents averaged 13.4 and 38.6 g/100 g (as received) for effluents classified as slurries and solids respectively. Effluents 3 and 5 were classed as slurries (despite elevated DM contents) because their physical characteristics were more closely aligned to slurries. Total N contents averaged 2.15 and 2.36 g/100 g DM for slurries and solids respectively while the respective proportions of N present in inorganic forms averaged 35.1 and 8.3% of total N, most of which was present as ammonium N. Total C contents averaged 37.0 and 38.6 g/100 g DM for slurries and solids respectively. In general, effluents with low dry matter contents (i.e. slurries) tended to have lower C:N ratios and less C present in non-labile forms (hemicellulose, cellulose and lignin). In contrast, effluents with high dry matter contents (i.e. solids) tended to have higher C:N ratios and greater quantities of hemicellulose, cellulose and lignin.

Table 1. Summary of key nitrogen (N) and carbon (C) characteristics for the 11 dairy effluents used in the assay. AMN = anaerobically mineralisable N, CWE = cold water extractable, HWE = hot water extractable.

Effluent number	1	2	3	4	5	6	7	8	9	10	11
Classification	Slurry	Slurry	Slurry	Slurry	Slurry	Solid	Solid	Solid	Solid	Solid	Solid
Dry matter (%)	6.2	12.5	15.6	15.0	17.7	23.4	28.2	25.5	39.1	54.1	61.3
Total N (g/100g DM)	3.04	2.10	2.31	1.66	1.63	2.74	2.57	2.86	1.05	2.49	2.46
Inorganic N (g/100g DM)	1.49	1.32	0.89	0.01	0.06	0.14	0.40	0.38	0.00	0.04	0.21
Organic N (g/100g DM)	1.55	0.78	1.42	1.66	1.57	2.61	2.17	2.48	1.05	2.45	2.25
Total C (g/100g DM)	37.8	37.6	35.2	43.8	30.5	35.8	39.5	41.5	43.1	38.1	33.5
C:N ratio	12.5	18.1	15.3	26.9	19.3	13.5	15.7	14.5	40.9	15.3	13.6
AMN (g/100g DM)	0.73	0.61	0.68	0.23	0.14	0.59	0.51	0.53	0.12	0.29	0.10
CWE N (g/100g DM)	1.63	1.47	1.11	0.03	0.07	0.13	0.55	0.65	0.03	0.07	0.27
CWE C (g/100g DM)	3.57	6.13	3.20	0.18	0.30	0.58	2.44	2.32	0.26	0.56	0.56
HWE N (g/100g DM)	0.93	0.56	0.66	0.20	0.16	0.55	0.61	0.53	0.14	0.41	0.52
HWE C (g/100g DM)	4.7	2.17	2.38	2.36	1.14	2.67	4.28	3.13	1.01	3.16	3.77
Carbohydrates (g/100g DM)	54.9	52.8	51.5	81.5	50.1	44.6	58.5	61.8	85.5	68.9	54.1
Hemicellulose (g/100g DM)	18.2	15.3	15.1	21.3	18.7	13.3	16.2	16.6	26.7	21.6	9.63
Cellulose (g/100g DM)	18.4	16.9	19.4	22.1	37.7	27.1	23.5	19.8	38.9	35.0	28.4
Lignin (g/100g DM)	8.0	7.6	13.3	8.37	13.7	14.8	10.6	18.1	20.7	15.0	24.0

The pattern and magnitude of N supply across slurry and solid effluent treatments varied considerably (Figure 1), consistent with the large variation in effluent characteristics. Despite this variability, effluents were successfully categorised into two distinct patterns of N supply over the initial phase (0-28 days) of the assay; Type 1: initial net mineralisation, and Type 2: initial net immobilisation. After 112 days both types exhibited a consistent net N mineralisation release pattern. These two 'types' were not equivalent to the dry matter classifications, indicating that other effluent characteristics (e.g. N and C forms) were important in determining N release patterns.

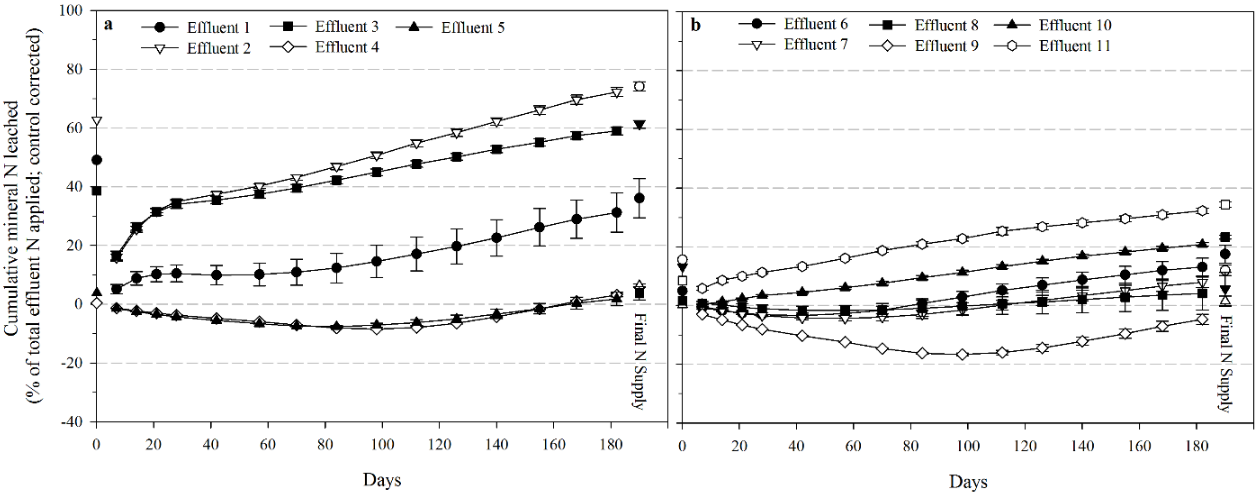

Figure 1. Cumulative inorganic N leached (expressed as a percentage of total effluent N applied and corrected for background N mineralisation from the control treatment) over a period of 182 days for a Horotiu silt loam amended with (a) five effluents classified as slurries and (b) six effluents classified as solids. Each shape series represents an individual effluent. Points at day 0 represent the amount of effluent N applied in an inorganic form. Final N supply represents the sum of cumulative inorganic N leached at 182 days and residual inorganic N in the soil (control corrected). Bars around each point represent the standard error of the mean.

At the end of the assay (182 days) and for respective slurry and solid effluents, *final N supply* ranged from 3.7 to 74.2% and 1.5 to 34.3% of total effluent N applied; *net N supply* *(% of total N)*, which accounted for the amount of inorganic N supplied from new mineralisation (i.e. excluding applied inorganic N and calculated as a percentage of total effluent N applied), ranged from −13.0 to 22.5% and −7.5 to 25.9 %; *net N supply* *(% of organic N)*, which accounted for the proportion of N mineralised from the applied organic pool (i.e. excluding applied inorganic N and calculated as a percentage of organic N applied), ranged from −25.5 to 36.7% and −8.6 to 28.3 %. *Net N supply* values (expressed as % of total N and % of organic N) were positive for seven of the eleven treatments (indicating a net N mineralisation effect) and negative for the remaining four (indicating a net N immobilisation effect). Mineralisation was still occurring at the end of the experiment, 6 months after the addition of effluent, indicating the potential for ongoing N supply to crops.

Strong positive correlations ($r > 0.80$, $P < 0.05$) were found between water-soluble N and C effluent characteristics and the rate of N supply in the 0-28 day period (Table 2). There were fewer strong correlations between effluent characteristics and the rate of N supply in the later stages of the assay (112–182 days). Correlation analyses were not performed for the 28-112 day period because rates of supply over this period were highly variable. Strong positive correlations were found between water-soluble N and C effluent characteristics and *Final N supply* (Table 2). Strong correlations likely reflected the initial leaching of water soluble components rather than mineralisation of organic N forms. There were no statistically significant correlations ($P < 0.05$) observed between effluent characteristics and *net N supply* *(% of total N)* and *net N supply* *(% of organic N)* values.

Table 2. Correlation matrix showing the strength of linear relationships (r value) between effluent characteristics and patterns of supply (slope parameters) and magnitude of supply. Only statistically significant ($P < 0.05$, $n = 11$) r values are presented. Correlations of greater than 0.80 were considered to be strong (bold text) and those between 0.58 and 0.80 weak.

Effluent component applied (µg/g oven dry soil)	Slope 0-28 days[1]	Slope 112-182 days[2]	*Final N supply*	*Net N supply* *(% of total N)*	*Net N supply* *(% of organic N)*
Ammonium N	**0.87**	0.79	**0.88**	-	-
Inorganic N[3]	**0.91**	0.78	**0.91**	-	-
WS[4] inorganic N	**0.93**	0.79	**0.93**	-	-
WS organic N	0.70	-	0.66	-	-
WS organic C	**0.84**	0.74	**0.86**	-	-
HW[5] N	0.76	-	0.75	-	-
HW inorganic N	**0.85**	0.61	**0.82**	-	-
Inorganic N:total N[6]	**0.83**	**0.80**	**0.85**	-	-
WS inorganic N:total N[7]	0.69	-	0.71	-	-
HW C:N[8]	-0.64	-	-0.65	-	-
HW inorganic N:total N[9]	0.76	-	0.74	-	-

[1]Slope of mineralisation curves (Figure 1) between 0 and 28 days. [2]Slope of mineralisation curves (Figure 1) between 112 and 182 days. [3]Sum of nitrate-N and ammonium-N. [4]Water soluble. [5]Hot water extractable. [6]Ratio of inorganic N to total N. [7]Ratio of WS inorganic N to WS total N. [8]Ratio of HW extractable C to HW extractable N. [9]Ratio of HW extractable inorganic N to HW extractable total N.

Conclusions

Results indicate that effluent characteristics can have a strong effect on the quantum and rate of N supply following application to soil. Initial availability correlated strongly with expected effluent characteristics that largely described the inorganic N pool; correlations between effluent characteristics and later supply patterns were less clear and work is ongoing to understand key relationships. The range of release patterns observed will have a large impact on nutrient availability to crops and must be understood in order to ensure effluent use remains profitable and low risk to farmers and the environment.

Acknowledgments

Research was completed as part of the Forages for Reduced Nitrate Leaching programme with principal funding from the New Zealand Ministry of Business, Innovation and Employment. The programme is a partnership between DairyNZ, AgResearch, Plant & Food Research, Lincoln University, Foundation for Arable Research and Landcare Research. We also thank the following people of Plant & Food Research and AgResearch for their technical support: Nathan Arnold, Christina Finlayson, Bob Longhurst.