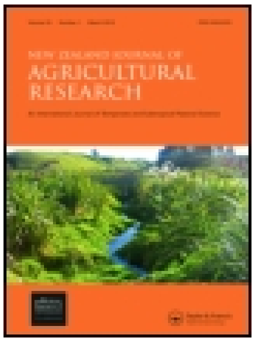

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SHORT COMMUNICATION

Effects of applying dairy wintering barn manure of differing C:N ratios directly to pasture on N mineralisation and forage growth

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ABSTRACT
Two experiments were conducted to examine the effect of applying spent dairy wintering barn bedding (termed 'manure') to a pasture soil. An incubation study compared rates of nitrogen (N) mineralisation of manures of differing storage durations (fresh, 2.5 months and 12 months) and C:N ratios (26:1, 22:1, 17:1 and 12:1), added to soil at a rate of 289 mg N kg^{-1} soil. The second experiment was a field trial, conducted in South Otago in southern New Zealand which compared pasture dry matter responses to applications of stored manure (c. 70 kg N ha^{-1}; C:N of 18:1) or urea (30 kg N ha^{-1}) to an unfertilised control. Incubation results indicated the addition of urea as a N source to the manure product at a rate to reduce the C:N ratio to approximately 12:1 resulted in a large increase in apparent net mineralisation. Field experiment results showed that application to pasture of manure with a high C:N ratio (above 18:1) resulted in a period of net N immobilisation and pasture growth restriction although there was no difference in annual pasture growth or grass N uptake. Knowledge of the C:N ratio of a manure product may help guide farmers in determining the best time to apply manure to soil to both maximise pasture growth and minimise potential nutrient losses to the environment.

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C:N ratio; dry matter yield; immobilisation; incubation; manure; mineralisation; nitrogen; wintering

Introduction

In southern New Zealand, non-lactating, in-calf dairy cows have traditionally been wintered off pasture on brassica crops. Grazing of these crops is a significant source of nutrient loss to waterways (Smith et al. 2012; Monaghan et al. 2013; Orchiston et al. 2013). Wintering barns and standoff pads are increasingly being seen as alternative approaches to wintering dairy cows. However, wintering barns and standoff facilities generate large volumes of manure products that must, at some point, be returned to land (Houlbrooke et al. 2012). The characteristics of the manure and its immediate nutrient value (nitrogen [N], phosphorus [P], potassium [K]) differs between and within systems (Longhurst et al. 2012). The potential fertiliser value of the manure can partially offset the financial cost associated with handling and storing the material (Macdonald et al. 2014). In southern New Zealand, farmers have

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been incorporating loose-housed wintering barn manure directly into the soil during seedbed preparation, without a full appreciation of its agronomic value.

Research on the agronomic effectiveness of organic manures in New Zealand and overseas has largely concentrated on the application of such manures to crop paddocks, as a means of adding organic matter, as well as applying nutrients (Thomsen & Kjellerup 1997; Eghball & Power 1999; Qian & Schoenau 2002; Gutser et al. 2005; Miller et al. 2009; Chatfield et al. 2011). Research has shown that the short-term effect of applying such manures with a high carbon to nitrogen (C:N) ratio was reduced crop production, particularly where existing soil mineral N levels were low and/or the C:N ratio of the manure was high (Thomsen & Kjellerup 1997; Qian & Schoenau 2002). There are conflicting data in the literature regarding N mineralisation rates from manure-amended soil; one incubation study observed a poor correlation between C:N ratio and the rate of N mineralisation (Griffin & Hutchinson 2007), while other studies showed higher rates of N mineralisation from materials that have lower C:N ratios (Chadwick et al. 2000; Qian & Schoenau 2002; Moore et al. 2010). None of these studies evaluated manures with a C:N ratio above 20.

To fully capture the value of manures generated from animal wintering facilities, farmers require information on whether these materials are agronomically effective when directly applied to pastures, or whether additional treatment (e.g. composting) is required prior to application. This paper reports on a soil incubation experiment conducted to measure N mineralisation from manure-amended soil and a field experiment that measured pasture growth response to applied manure. The aim of these experiments was to evaluate the characteristics and fertiliser value of the manure generated by a loose-housed, wintering barn that used woodchip bedding material, and to understand how it influenced subsequent plant N uptake when added to pasture. We tested the hypotheses that: (1) the C:N ratio of the bedding material would influence the rate of mineralisation; (2) high C:N ratios would induce a period of net N immobilisation and restricted pasture growth; and (3) that adding a N source to material to reduce the C:N ratio would increase the rate of net N mineralisation.

Methods

Incubation study

The incubation experiment used soil taken from the 0–10 cm layer of the Tokomairiro deep silt loam (Fragic Perch-gley Pallic soil, NZ Soil Classification [Hewitt 1998]), which was air-dried and sieved (4 mm) prior to use. The field soil is imperfectly drained, has moderate fertility and high plant available water storage capacity. Some chemical characteristics of this soil are as follows: pH 6.1; Quicktest (QT) Ca 12; Olsen P 24 $\mu g\ mL^{-1}$; QT K 7; SO_4-S 17 ppm; total N 0.4 g 100 g^{-1}; total C 4.2 g 100 g^{-1}. These were analysed using standard protocols and methods (Olsen et al. 1954; Yeomans & Bremner 1991; Helmke & Sparks 1996; Suarez 1996; Tabatabai & Frankenberger 1996; Thomas 1996; Rayment & Lyons 2011).

Representative samples of manure were taken from three stacks that differed in storage length (Table 1) and chemical composition (Table 2). A representative sample of each original manure mix was taken and ground to <4 mm prior to mixing with soil.

Table 1. Experimental treatments imposed in the laboratory incubation (soil amended with cow barn manure) and field experiments (pasture growth response to barn manure) using carbon-based wintering barn manure.

Abbreviation	Treatments	Period of manure storage (months)	Manure C:N ratio	Manure N addition kg N ha^{-1}	Fertiliser N addition kg N ha^{-1}
Incubation experiment[a]					
Control	1. Soil only			0	0
Fresh	2. Soil + fresh bedding	0	26:1	300	0
Short	3. Soil + bedding stored for 2.5 months	2.5	22:1	300	0
Long	4. Soil + bedding stored for 12 months	12	17:1	300	0
+N	5. Soil + fresh bedding plus urea	0	12:1	300	342
Field experiment[b]					
Control	1. No N applied			0	0
Manure	2. Manure (single application)	18	18:1	70	0
Urea	3. Urea applied (single application)			0	30

[a]Soil total N 0.4%.
[b]Total carbon 4.2%.

Samples were incubated in the dark at 22 °C in sealed plastic boxes of 2.7 L capacity. The lids of the boxes remained on for the duration of the trial other than for sample collections, water additions and regular venting intervals of 15 min at 2–3 day intervals. Each box contained 500 g of wet soil that was maintained at a moisture content of 24% v/v. Manure was added at a rate of 289 mg N kg^{-1} soil (total N). There were five treatments (Table 1) with six replicates. Urea in the +N treatment was added at a rate of 329 mg N kg^{-1} soil to reduce the C:N ratio from 26:1 to 12:1.

Subsamples of approximately 45 g were removed 1, 3, 7, 14, 21, 28, 42, 56, 69 and 100 days after manure addition and analysed for mineral N and moisture contents. Fifteen grams of moist soil was mixed in a jar with 100 mL of 2 M KCl. This was shaken for 1 h and the extract filtered and analysed for ammonium-N (NH_4^+- N) and nitrate-N (NO_3-N) concentrations using a Skalar SAN^{++} segmented flow analyser (Skalar Analytical). The remaining subsample was used for moisture content analysis. KCl-extractable N

Table 2. Chemical attributes of the three barn bedding manures (stored for different periods of time) used in a laboratory incubation experiment designed to measure net rates of N mineralisation in soil amended with cow barn bedding material.

	Fresh manure	Short-stored manure (2.5 months)	Long-stored manure (12 months)
TN (%)	0.50	0.45	0.51
NH_4-N (%)	0.002	0.004	0.001
NO_3-N (%)	0.008	0.002	0.014
TP (%)	0.11	0.13	0.13
K (%)	0.78	0.53	0.455
TC (%)	12.8	10.0	8.6
DM (%)	35.3	29.2	35.3
pH	8.5	8.7	–
C:N ratio	25.6	22.3	16.8

–, analysis not conducted; TN, total nitrogen; TP, total phosphorus; TC, total carbon.
Analysis conducted at Eurofins Ltd (New Zealand).

values were expressed on a per hectare basis assuming a depth of 10 cm and a soil bulk density of 1040 kg m^{-3}. Apparent net N mineralisation was calculated as the difference between the amount of mineral N (ammonium-N + nitrate-N) extracted from manure treated soils and the soil alone (control) minus any fertiliser N added e.g. fresh manure + urea, and expressed as a percentage of the total manure N added.

Field experiment

The field experiment site was at Telford dairy farm, near Balclutha, South Otago (46°17′S, 169°43′E) on the Tokomairiro soil as described in the incubation study above. An area was fenced off to exclude stock and the pasture mown to 5 cm height prior to treatments being applied by hand on 5 May 2014. Treatments comprised an untreated control and single applications of either stored manure (c. 70 kg N ha^{-1}) or urea (30 kg N ha^{-1}) (Table 1). Plot size was 6 m^2 (4 × 1.5 m) with 12 replicates placed in two rows of six. The manure applied had been composted for approximately 18 months. Some attributes of the manure were 32% dry matter (DM) and 18:1 C:N ratio (total N 15.8 g kg^{-1} dry weight, organic C 280 g kg^{-1} dry weight) and total available (mineral) N of 474 mg kg^{-1} dry weight.

Soil fertility values within the trial area were: pH 6.3; QT Ca 12; Olsen P 43 µg mL^{-1}; QT K 15; SO_4-S 15 µg g^{-1}; total N (TN) and total C (TC) values (0–75 mm) were 4.2% and 0.30%, respectively. Potassium in the form of KCl was applied at the start of the trial and after each harvest at a rate of 50 kg K ha^{-1} to prevent K deficiency due to the clippings being removed at each harvest. Due to very low grass N, P and sulphur (S) concentrations in the October harvest, a basal dressing of 50 kg N ha^{-1}, 50 kg P ha^{-1}, 50 kg K ha^{-1} and 110 kg S ha^{-1} was applied on 14 November 2014. In addition, a lime/fertiliser mix was inadvertently applied (34 kg P ha^{-1}, 34 kg K ha^{-1}, 42 kg S ha^{-1}, 166 kg Ca ha^{-1}) to the paddock, including the trial area, in early February 2015. Pasture production was estimated using a rising plate meter (Thomson et al. 2001), using the equations published by DairyNZ (2008) to convert the meter reading to pasture dry matter, on occasions when the surrounding paddock was grazed. At the same time, a hand-cut sample of pasture (approx. 400 g) was collected from each plot. The grass fraction of this sample was dissected and dried at 60 °C before being sent to a commercial laboratory to be analysed for N content. The pasture was then trimmed off, the clippings removed and each plot replated to provide a residual measurement.

All data were analysed by fitting a repeated measures model with an autoregressive error allowing for heterogeneity between the variances from date to date using REML Genstat v16 (Lawes Agricultural Trust).

Results and discussion

Incubation study

Fresh manure applied directly to soil resulted in net N immobilisation for the duration of the 100 day trial, which was not significantly different from the control (ns) (Figure 1). Manure that had undergone a short storage period prior to application to soil caused an initial period of N immobilisation over the first 14 days of the trial, then a period of

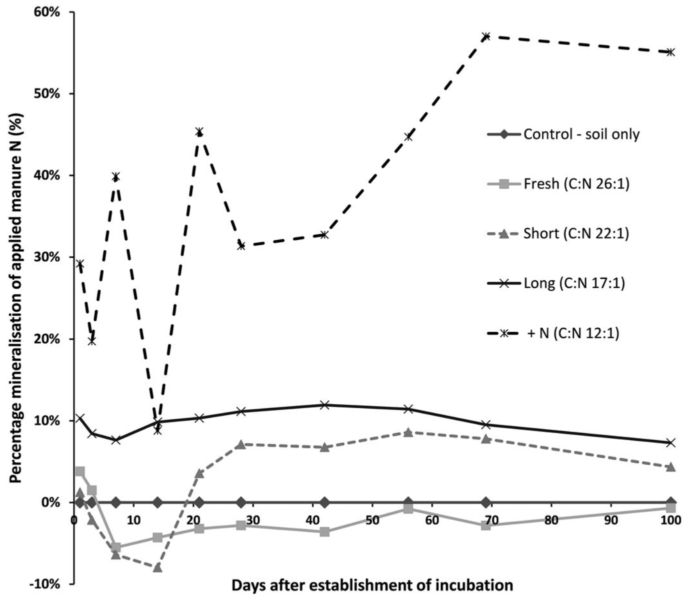

Figure 1. Percentage net mineralisation of applied manure N during laboratory incubation of soil amended with manure that had been applied fresh or stored for periods of 2.5 months (short), 12 months (long) or fresh amended with urea (+N) during trial establishment. Results were adjusted to account for the net mineralisation in the control treatment and for the N added as urea to the +N treatment. Variation in SEM was high over days 1–14 (average 21%) but lower for the remainder of the trial (average SEM was 6% for days 21–100).

mineralisation until day 28; apparent N mineralisation stopped at around 8% of the total N added as manure (ns, $P = 0.721$; Figure 1). The manure that was stored for 12 months prior to application mineralised about 10% of the N applied. This N appeared to be immediately available. Adding urea to the manure to deliver a C:N ratio of 12:1 increased the apparent mineralisation of manure N to nearly 60% by day 70 ($P < 0.001$) (Figure 1).

Field experiment

There were seven pasture harvests over the 12-month period of measurement. The application of urea significantly increased pasture production over the winter months while the manure application decreased pasture production over the same period (Table 3). Over winter and spring, pasture growth rates in the manure treatment were reduced by 14% ($P < 0.05$) and 6% (ns), respectively, compared with the control treatment. It is likely

Table 3. Seasonal and annual pasture production (kg DM ha^{-1}) from field plots amended with cow barn manure (70 kg N ha^{-1}) or urea (30 kg N ha^{-1}). The least significant difference ($LSD_{0.05}$) at the $P < 0.05$ level is given.

Treatment	Winter	Spring	Summer	Autumn	Total growth
Control	1223	2760	4288	992	9260
Manure	1049	2606	4375	946	8975
Urea	1439	2615	4303	919	9280
$LSD_{0.05}$	171	215	286	87	439

Table 4. Grass N concentrations (%) and N uptake (kg N ha^{-1}) from field plots amended with cow barn manure (70 kg N ha^{-1}) or urea (30 kg N ha^{-1}). The least significant difference ($LSD_{0.05}$) at the $P < 0.05$ level is given along with the P value (bold if significant) (optimum grass N is 4.5%–5.0%).

Treatment	9 Sept	21 Oct	19 Nov	18 Dec	22 Jan	26 Feb	4 May	Total grass N uptake
Herbage N (%)								
Control	2.52	1.80	2.79	2.63	2.09	2.44	2.85	
Stored Manure	2.44	1.65	2.96	2.77	2.09	2.43	2.73	
Urea	2.48	1.79	3.28	2.66	2.08	2.40	2.79	
P value	0.52	**0.02**	0.11	0.31	0.95	0.74	0.41	
$LSD_{0.05}$	0.14	0.10	0.47	0.19	0.09	0.10	0.18	
Grass N uptake (kg N/ha)								
Control	31.2	26.5	35.9	64.6	19.5	21.9	28.3	228
Stored Manure	25.8	23.3	36.0	70.7	20.7	20.4	25.8	223
Urea	35.9	26.1	38.3	68.0	19.4	19.8	25.7	235
P value	**0.001**	0.066	0.644	0.368	0.553	0.209	0.212	0.269
$LSD_{0.05}$	4.82	2.96	5.86	8.78	2.80	2.5	1.3	15.9

that a combination of low winter temperatures and the high C:N ratio of the manure limited N mineralisation, thus limiting pasture N responses over this period. The C:N ratio of the manure may have even increased N immobilisation for that treatment in the short term (Qian & Schoenau 2002). The application of basal N to all treatments in mid-November resulted in summer growth rates being 2% greater in the manure plots than the control plots; however, there was no pasture response to the manure applied in the previous autumn. Cumulative annual pasture yield in the manure treatment was 97% of that in the control treatment. Pasture responses in the urea treatment were only evident for the first harvest (September) and were quite low at 7.2 kg DM kg N^{-1} applied.

Grass N concentrations for all treatments were below the optimum range of 4.5%–5.0% (Cornforth & Sinclair 1984) at every harvest (Table 4), despite adequate clover content in the pasture over the late summer and autumn period (average 34% by dissection DM; data not shown). Although no differences in N concentration were evident at the first harvest, the significant yield differences at that time resulted in significantly higher N uptake in the urea treatment and lower N uptake in the manure treatment. The manure treatment had a significantly lower grass N concentration at the October harvest ($P = 0.023$), although this did not translate to a difference in N uptake from the control treatment ($P > 0.05$). Over the 12-month measurement period, the total N uptake by grass was similar for all treatments.

Conclusion

Manure C:N ratio had an important effect on N release from manures that had been stored for different lengths of time. The C:N ratio decreased during manure storage. Applications of fresh manure resulted in an initial period of N immobilisation. This was attributed to the high C:N ratio (26:1). This immobilisation effect appeared to disappear as C:N ratio decreased. In contrast to the fresh manure treatment, application of manure that had a C:N ratio of 17:1 and had been stored for 12 months resulted in a net mineralisation of approximately 8% of the applied manure N. This appeared to be contradictory to findings from the field study, where pasture responses to applications of a stored (18 month) manure (C:N 18:1) were initially nil or low; however, this may be due to the different particle size of the manure products used. This research indicates that spent bedding material (with a high C:N ratio) can be applied directly to pastures although additional fertiliser N may be required to overcome short-term N immobilisation processes. Also the application of stored manures with C:N ratios <15:1 are unlikely to reduce pasture growth rates. Knowledge of the C:N ratio of a manure product will assist decisions made about the supply of N that may become available for plant uptake.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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