NITROGEN AVAILABILITY FROM DAIRY MANURE[1/]

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Introduction

Dairy manure is a valuable source of N for crop production in Wisconsin. Accurate estimates of dairy manure N availability in the first- and subsequent residual-years after application are needed to maximize crop N uptake and reduce N losses to the environment. This study examined dairy manure N availability and mineralization of dairy manure components using various methods. A 6-year field trial estimated the first-, second-, and third-year dairy manure N availability using (1) the apparent recovery method (difference method) (2) the fertilizer N equivalence method and (3) recovery of ^{15}N labeled manure. Manure N release was also studied in the field trial using a mesh litterbag. A laboratory incubation study was conducted in which ^{15}N-labeled or unlabeled feces, urine, and oat straw bedding were incubated in soil for 168 days.

Materials and Methods

Experiment 1

The field experiment, located at West Madison Agricultural Research Station, Madison, WI was conducted on a Plano silt loam (fine-silty, mixed, mesic, Typic Argiudoll) during the 1998 to 2003 cropping seasons. Corn (*Zea mays L.*, c v Lemke 6063) was planted all years of the study. Treatments include five fertilizer treatments (40, 80,120,160, and 200 lb acre^{-1}, applied as NH_4NO_3) applied every year; two manure rates (estimated to provide approximately 80 and 160 lb available N acre^{-1} in the first year) applied at various intervals (every 1, 2, or 3 years) and a no fertilizer or manure control. In addition to the treatments, a starter fertilizer, (9-23-30) was applied to all plots at a rate of 150 lbs acre^{-1} at time of planting. Inorganic fertilizer was broadcast on plots 5 days prior to planting. Manure was hand spread using pitchforks and was disked within 24 hours. Micro plots using manure labeled with ^{15}N were incorporated within the larger unlabeled plots in order to be exposed to the same spatial field elements as the larger plots, but provide the ability to directly measure manure N uptake by corn.

Nitrogen availability was determined in this study using the apparent recovery, fertilizer equivalence, and ^{15}N isotope methods. The apparent recovery method compares treatment whole-plant N uptake from the manure treatments to the amount taken up by the un-manured control plots. This can be seen in Equation 1 (Motavalli et al., 1989):

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$$\text{Apparent N recovery \%} = \frac{\text{Treatment N Uptake} - \text{Control N Uptake}}{\text{Amount of Total Applied N}} * 100$$

The fertilizer equivalence method compares manurial N yield or uptake responses from where a similar response is obtained from a fertilizer N treatment. The derived value divides the fertilizer N rate by the total manurial N rate expressed as a percentage. The percentage is the worth of the manure in terms of fertilizer, which is deemed 100% available in this case. Equation 2 (Motavalli et al., 1989):

$$\text{Nutrient Availability} = \frac{\text{Estimated equivalent fertilizer N rate}}{\text{Total N from manure applied}} * 100$$

The apparent recovery and fertilizer equivalence methods are commonly used for predicting the availability of nitrogen in manures in first year studies. Using the labeled nitrogen method we may be able to obtain better estimates over a longer period of time (Powell et al., 2005).

Nitrogen tracer techniques involve enriching the manure above the natural levels of the ^{15}N isotope and monitoring the movement of this tracer through the soil and crop (Hauck and Bremner, 1976; Powell et al., 2004). This technique is similar to the apparent recovery method as it based on the uptake of isotopic nitrogen rather than a total N uptake. The ^{15}N uptake calculation, Equation 3 (Hauck and Bremner, 1976):

$$\% \; ^{15}\text{N recovered} = \frac{100 \, P(c - b)}{f \; (a - b)}$$

P is amount N in corn silage (manure-amended plots);
f is the amount of manure N applied;
a is the atom % ^{15}N in the manure;
b is natural abundance of ^{15}N in corn silage (control plots);
c is atom% ^{15}N in corn silage (manure-amended plots).

Experiment 2

Litterbag studies have investigated organic matter decomposition and N release from sheep manure (Powell et al., 2004; Rixon and Zorin, 1978) and dried cattle manure (Lupwayi and Haque, 1999). This experiment was conducted inside of the larger field study. In 2000 and 2002, 3.7 x 7.1 inch nylon bags (38 µm mesh) were filled with 21, 31, and 6 g wet weight urine, feces, and bedding, respectively. This represented a typical barn scrape ratio where 42, 36, and 22% of the total manure N came from urine, feces, and bedding, respectively. In 2000, the urine and feces were labeled with ^{15}N using the procedure described in Powell et al. (2004) where dairy cattle were fed ^{15}N labeled forage. Bags were prepared 1 week before burial, closed with a nylon string, placed in individual plastic bags and kept frozen to preserve mineralization characteristics (Van Kessel et al., 1999). On May 15, 2000 and May 22, 2002 bags were randomly buried horizontally (3 inch depth) at 6 inches to the side of the cornrow, spaced 9.8 inches apart. Three bags were not buried and kept frozen to determine N losses before the experiment started. Also, three random bags were buried and sampled approximately 1 hr after burial. The remaining bags were excavated (3 per date) at 7, 14, 21, 28, 35 (2000 only), 42, 56, 84, 98, 126 days after burial and at whole plant harvest at 142 (2002) and 154 (2000) days after placement. Four bags were taken on day 154 in 2000. Sampled bags were placed into individual clear plastic bags and frozen until analysis. The whole sample was thawed, dried at 131°F for 48 hours to determine dry mass and then split for N analysis. The portion of sample to be analyzed for chemical content was ground to 0.5 mm in an Udy mill to achieve homogeneity.

At the time of bag sampling in 2002, corn plants from a non-adjacent row were sampled. Starting June 11, four plants were sampled and starting July 16, only two plants were sampled. Plants were dried at 131°F to a constant mass, ground to 2 mm in a Wiley mill and sub sampled for total N analysis.

Corn samples were digested using the semi-micro Kjeldahl digestion described in Liegel et al. (1980), diluted, filtered and analyzed for total N (QuickChem Method 13-107-06-02D) in an automated colorimeter (Lachat Instruments, Mequon, WI). Mass and N losses were adjusted by subtracting ash content contributions.

Samples of urine, feces, and straw bedding put into litter bags, and litter bag contents after excavation were analyzed for organic matter, NH_4^+(only feces), and total N at the University of Wisconsin- Soil and Plant Analysis Lab at Marshfield using the procedures outlined in Combs et al. (2001). Total ^{15}N of these components was analyzed using a Carlo Erba (Milan, Italy) elemental analyzer coupled with a Europa 20/20 mass spectrometer at the University of California-Davis, Stable Isotope Facility.

Experiment 3

An incubation trial utilized a Plano silt loam (26% sand) with the following initial chemical characteristics: 3.55% total C, 2.56% total organic C, 72 mg kg^{-1} Bray P1, 2220 mg kg^{-1} total Kjeldahl N, and 7.6 pH. Soils were amended with ^{15}N labeled and unlabeled dairy manure components in the following treatments and incubated at 52, 64, and 77°F for 168 days at 60% water filled pore space:

- Treatment 1: ^{15}N-labeled feces; urine and bedding at natural abundance.
- Treatment 2: ^{15}N-labeled urine; feces and bedding at natural abundance.
- Treatment 3: ^{15}N-labeled bedding; feces and urine at natural abundance.
- Treatment 4: ^{15}N-labeled feces; urine and bedding.
- Treatment 5: control (no amendments).

Samples taken at day 168 were analyzed for total and inorganic (NH_4^+ and NO_3^-) ^{15}N.

Results and Discussion

Experiment 1

Manure N availability estimates from this study are shown in Table 1. The apparent recovery and ^{15}N methods had the lowest estimates of manure N availability and the fertilizer equivalence method had the highest estimates. The difference method relies heavily on manure N uptake by corn in the control plots. In this study the control plots had high yields throughout all study years causing low estimates of apparent manure N availability. The recovery of ^{15}N had the lowest variability of all the methods.

This study estimated first-year nitrogen availability from dairy manure to be 19% when averaged across all methods. Currently, the University of Wisconsin Extension recommends that dairy manure N availability (based on total N) during the first year to be 30% when surface applied and 40% when incorporated within 72 hours (Kelling et al., 1998). A review and summary conducted by Beegle et al. (in review) that included 37 studies found that dairy manure N availability during the first year after application averaged 37%. Our estimates appear to be lower than these other sources. One explanation for this may be the use of the 15N isotope where others (Bergström and Kirchmann, 1999; Paul and Beauchamp, 1995) have also found estimates to be lower as result of a phenomena inherent to the method and can be explained by "pool substitution" (Hauck and Bremner, 1976; Jenkinson et al., 1985) whereby soil microorganisms immobilize applied ^{15}N and add ^{14}N to the total N pool.

This study found second- and third-year nitrogen availability to average 9 and 2%, respectively when averaged across all methods. The University of Wisconsin Extension recommends dairy manure residual N availability to be 10 and 5% for the second- and third-year after application. The fertilizer equivalent method produced results that were comparable to University of Wisconsin Extension recommendations for residual dairy manure N availability (Kelling et al., 1998). Estimates using ^{15}N were lower than those obtained using the fertilizer equivalent method and may be considered a minimum residual manure N availability. Based on this and other studies (Kelling and Wolkowski, 1993; Klausner et al., 1994; Paul and Beauchamp, 1993), it is suggested that second and third year residual N availability from a single application of semi-solid dairy manure would be 9 to 12%, and 3 to 5%, of the original manure N application, respectively. Based on our first-year and residual availability estimates for semi-solid dairy manure, producers can be confident in University of Wisconsin recommendations for dairy manure N availability.

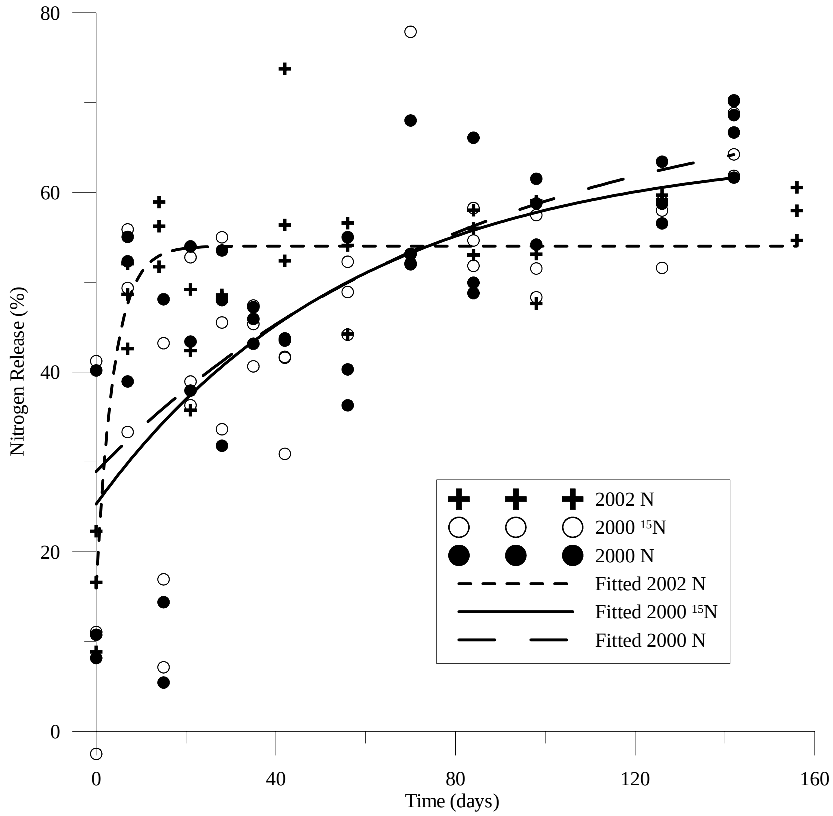
Table 1. Estimates of first-, second-, and third-year manure N availability using various methods.

		Method		
Manure N availability	n†	^{15}N Recovery	Apparent recovery	Fertilizer equivalence
		--%-------------------------------------		
1st year	6	17 (3.1) ‡	14 (4.7)	25 (10.5)§
2nd year	5	6 (1.1)	8 (6.6)	12 (7.9)§
3rd year	4	2 (0.4)	1 (5.8)	3 (9.4) §
† no. of measurement years in parentheses; 4 reps/year				
‡ Average (standard error)				
§ Data from 2002 excluded.				

Experiment 2

Of the total manure N added to the litterbags, an annual average of 67% apparently mineralized (Figure 1). The litterbag released 53 and 86% of the mineralizable N pool by day 21 in 2000 and 2002, respectively. Much of this mineralized N may be attributed to urine, which comprised about 42% of the total manure N. Although, a large majority of the manure N is released in the first year of application, a study conducted by Muñoz et al. (2003) found that 46% of ^{15}N labeled dairy manure N to remain in the soil after 3 years of application, the majority (82%) remaining in the top 12 inches. This may suggest that the 45% of N remaining in litterbags from our study may remain in soil organic pool for some time. This indicates that the manure N during the first year of application may be entering soil N organic pools.

Figure 1. Measured and fitted data for N release from litterbags, 2000 and 2002.



A comparison of ^{15}N and N data from 2000 showed the use of either N form resulted in statistically similar N mineralization rates of release. This suggests that the measured amounts of ^{15}N lost from litterbags were apparently unaffected by an unbalanced dilution of ^{15}N with unlabeled soil N, as has been found in other studies (Bergström and Kirchmann, 1999; Paul and Beauchamp, 1995). The similar results also suggest that expensive ^{15}N is not required for computing N balances in litterbag studies, such as ours.

Experiment 3

In the incubation trial, soil samples taken on day 168 from all temperatures and treatments were analyzed for inorganic ^{15}N to determine individual manure component contributions to mineralized N (Table 2). Net urine mineralization was unaffected ($p<0.05$) by temperature and averaged 55% at the end of the 168 day observation period. Because total ^{15}N recoveries averaged 115% (data not shown), providing evidence that manure N was not lost in this experiment, it is likely that the remaining 45% urine ^{15}N was exchanged with unlabeled N or may have been mineralized and subsequently immobilized. Soil samples taken in 2000 from the larger field experiment showed that a large portion of applied ^{15}N remained in soil 2 to 3 years after application (Muñoz et al., 2003; Powell et al., 2005).

Approximately 19% of applied fecal ^{15}N was mineralized over the 168 d observation period. Fecal ^{15}N mineralization increased significantly with increasing temperature. Other studies have also shown a positive relationship between temperature and manure N mineralization for temperatures 0 to 95ºF (Stanford et al., 1973) and 50 to 75ºF (Griffin and Honeycutt, 2000). Similarly, temperature had a significant effect on bedding N mineralization with N mineralization being lowest (15%) at 52ºC and highest (25%) at 64 and 77ºF. In vessels where all applied manure components were labeled, N mineralization averaged 30% and was unaffected by temperature likely dominated by high N mineralization of urine. This is relatively close to the 35% mineralized N derived by summing the proportionate contribution of individual labeled manure N components.

Table 2. Mineralized ^{15}N recovered from various labeled manure components over all temperatures at day 168.

Temp (°C)	Urine	Feces	Bedding	All components
	------------------------------% of applied ^{15}N--------------------------			
52	44	13	15	24
64	60	18	24	30
77	63	26	25	36
P_t>F	0.054	0.003	<0.001	0.088
LSD, 0.05	16.2	5.7	3.5	10.4

Conclusion

The use of the stable isotope ^{15}N provided direct, and therefore more precise estimates of dairy manure N availability to corn the first, second and third year after manure application. Use of ^{15}N labeled dairy manure confirmed current University of Wisconsin Extension recommendation on dairy manure N availability. Conservation of dairy urine N is key to manure N availability to crops. Most urine N apparently mineralizes during the first few weeks after manure application. A large portion of applied manure N that is not taken up by a crop remains in the soil, and may be available to crops over the long term.

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