COMPARISON OF DAIRY MANURE NITROGEN AVAILABILITY TO CORN USING VARIOUS METHODS

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Introduction

Most dairy farms in Wisconsin continue to produce most of their feed and have sufficient land for recycling manure nutrients through crops. However, to remain economically viable, many dairy farms are increasing herd size and importing more feed. The increased importation of nutrients in the form of feed and fertilizer has resulted in excessive soil nutrient accumulation (Bundy, 1998; Proost, 1999), and has increased the risk of nutrient transfer through surface and subsurface runoff and air pollution.

Federal legislation aimed at controlling farmer practices that potentially pollute surface and ground waters is becoming strict (USDA and USEPA, 1999). The survival of many livestock operations in the U.S, including dairy farms in Wisconsin, will increasingly depend on farmers' ability to comply with environmental standards, especially those associated with the application of manure to cropland. Clearly, alternative manure management strategies are needed if we are to arrest soil nutrient accumulation and loss from dairy farms.

In general, many dairy farmers in Wisconsin continue to consider manure as a waste, something that needs to be disposed of with least economic cost (Nowak et al., 1997). In the last 10 to 15 years there has been a concerted effort to reintroduce manure as a valuable source of plant nutrients. However, even though proper manure management can be profitable through reduced fertilizer costs, many farmers do not credit the nutrients contained in manure (Nowak et al., 1997; Russelle, 1999). The lack of manure nutrient crediting by farmers may be due to many factors that make dairy manure an undependable source of plant nutrients. One of these factors includes the inherent shortcomings of the classical, indirect methods used to estimate manure nutrient mineralization in soils and subsequent crop uptake of manure nutrients.

In Wisconsin, estimates of manure nutrient availability to crops, otherwise known as "nutrient credits" are currently single nitrogen (N), phosphorus and potassium values given for the type of manure applied (solid or liquid), method of application (incorporated or not) and frequency of application (Kelling et al., 1998). The basis for these estimated levels of nutrient availability are results of several studies which used indirect methods, such as the “difference method” and the "fertilizer equivalent approach" to measure manure nutrient availability. For example, using the difference method and the fertilizer

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equivalent approach, from 12 to 63% of dairy manure N has been estimated to be taken up by corn during the first growing season after application (Motavalli et al., 1989; Klausner et al., 1994). These are average N availability values. Variability among the plot values that make up these mean values can be very high. Nutrient availability in the second and subsequent years is even more difficult to predict.

More accurate estimates of manure nutrient availability to crops are needed if we are to expect farmers to improve manure management. This paper reports preliminary results of a long-term study that uses the stable isotope ^{15}N to compare direct and indirect determinations of N flow in various components of the feed-animal-manure-soil/crop continuum of dairy systems. One of the objectives of the studies is to provide information that increases our confidence in manure N credits leading to reductions in N losses from dairy farms.

Study Methods

^{15}N labeling of dairy manure

Under current ration formulation on dairy farms in Wisconsin, only 15 to 20% of feed N is converted into milk. Most of the remaining feed N is excreted in manure. Manure N excretion can be divided into three general pools: 1) urinary N, 2) fecal endogenous N of microbial and gut origin and 3) fecal undigested feed N (Mason and Federiksen, 1979). Manure N (without bedding) is comprised of approximately 55% urine N, 36% fecal endogenous N and 9% fecal undigested feed N for dairy cows fed a forage diet consisting of alfalfa hay and corn silage (Powell and Wu, 1999). Each pool of manure N mineralizes differently in soils (Somda et al., 1994; Sørensen and Jensen, 1998) and, therefore, would potentially have a different availability for crop uptake and propensity for loss in the environment.

Urine N, fecal endogenous N and fecal undigested feed N were labeled with ^{15}N using organic and inorganic labeling techniques (Figure 1). The organic method involves labeling alfalfa (*Medicago sativa* L.) hay and corn (*Zea mays* L.) silage and then feeding these forages to dairy cows for two to four days to label all components of dairy excreta (urine N, endogenous N in feces, and undigested feed N in feces). The inorganic method involves feeding ^{15}N-labeled urea with forage containing ^{15}N at natural abundance. This technique labels only urine N and endogenous fecal N. Feeding inorganic ^{15}N does not label the undigested feed N in feces, since no ^{15}N-enriched forage was fed.

Manure N components were labeled in this way to test the hypothesis that urine N and endogenous fecal N (labeled using the inorganic method) applied to soil are the main manure N components available for crop uptake the first year after manure application. Labeling only urine and fecal endogenous N by feeding urea would be much less time consuming and costly than enriching and feeding forages (the organic method). The undigested feed N in feces, having already undergone degradation by rumen microorganisms, is recalcitrant in soil (Sørensen and Jensen, 1998).

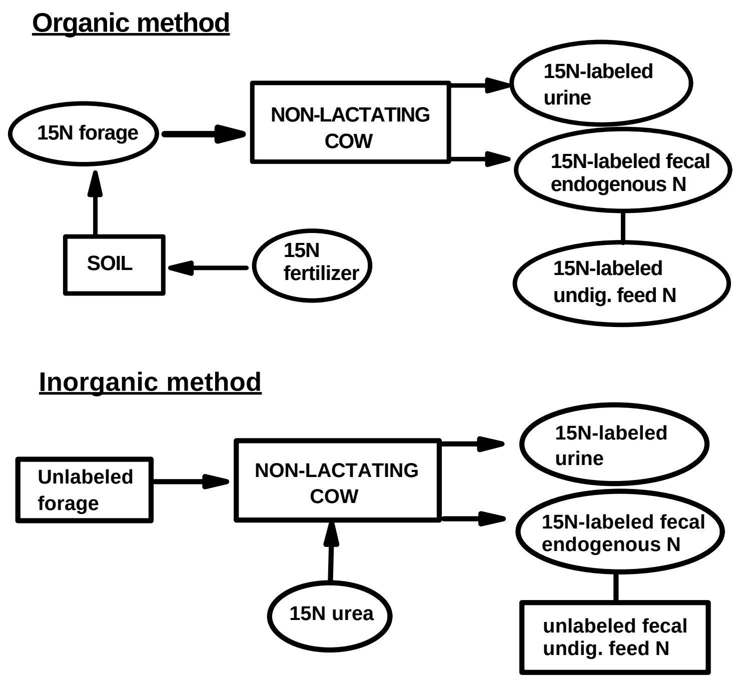

Figure 1: Organic and inorganic methods of ^{15}N-labeling of manure (see Powell and Wu, 1999; Powell et al., (1999).

Field trial

A field trial was established in 1998 on a Plano silt loam (fine-silty, mixed, mesic: Typic Agriudoll) at the West Madison Experiment Station. The trial was designed to (1) examine the effect of manure application rate and frequency on corn silage yield and N uptake and (2) compare manure N uptake by corn silage using direct (^{15}N) and indirect (difference method and fertilizer equivalent approach) measures. Treatments include three manure rates (0, 80 and 160 kg mineral N ha^{-1}), three manure application intervals (every 1, 2 or 3 years) and six fertilizer N levels (0, 50, 100, 150, 200 and 300 kg N ha^{-1}). A strip block design was used with fertilizer N and manure rates applied to blocks and manure intervals applied to sub-blocks. There are 4 replications of each treatment. Manure intervals "every 1 year," "every 2 years," and "every 3 years" have been established, and the intervals continue as follows:

1998	1999	2000	2001	2002	2003
$I_{1(1998)}$	➡	➡	➡	➡	➡
$I_{2(1998)}$	$I_{2(1999)}$	$I_{2(1998)}$	$I_{2(1999)}$	$I_{2(1998)}$	$I_{2(1999)}$
$I_{3(1998)}$	$I_{3(1999)}$	$I_{3(2000)}$	$I_{3(1998)}$	$I_{3(1999)}$	$I_{3(2000)}$

where "I" refers to manure interval, the first subscript number following the "I" refers to the manure interval (i.e., every 1, 2 or 3 years), the second subscript in parentheses refers to the year the interval was established. For example, $I_{1(1998)}$ refers to manure applied every year, this interval established in 1998 (➡ and continuing throughout the project); $I_{2(1998)}$ refers to manure application every 2 years, this interval established in 1998 (receiving manure every 2 years thereafter); $I_{2\ (1999)}$ also refers to manure applications every 2 years, but this interval is established in 1999, etc. By establishing the intervals in this way, we are able to measure the residual effects of manure in every year, beginning in year 3 (2000) of the project. First, second and third year manure N availability are also be available for measurement beginning year 3 of the project.

Unlabeled dairy manure (a mixture of feces, urine and straw bedding scrapped from a barn floor) was applied to blocks using a wagon spreader. During this procedure, duplicate 3.48 m^2 subplots within blocks of the manure N application rate of 160 kg ha^{-1} were covered with a plastic tarp. Manure captured on each tarp was used to calculate exact manure application rates for each plot. These un-manure subplots then received ^{15}N-labeled manure (straw bedding was added to ^{15}N- labeled feces and urine in the same ratio as that determined for unlabeled manure) derived either from the organic or the inorganic methods (Figure 1).

Three approaches are being used to estimate manure-N uptake by crops: (1) the ^{15}N method, (2) the difference method and (3) the fertilizer equivalent approach.

<u>The ^{15}N method</u>

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

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)

Note: Only those subplots amended with ^{15}N-manure derived from the organic method (i.e. all manure N components labeled) were used in the comparison of the ^{15}N method to the difference method and fertilizer equivalent approach.

<u>Difference method</u>

$$\%\ \text{manure N recovery} = \frac{100\ (\text{crop N in manure-amended plots} - \text{crop N in control plots})}{\text{manure N applied}}$$

The difference method assumes that crop N uptake in both manure-amended and control plots is accomplished with the same efficiency. The difference in crop N uptake between manured and non-manured plots is attributed to the addition of manure.

Fertilizer equivalent approach

The fertilizer equivalent approach compares yields and crop N uptake in manure-amended plots to yields and crop N uptake in adjacent fertilizer-amended plots (Klausner and Guest, 1981; Motavalli et al., 1989; Harmsen and Moraghan, 1988). The fertilizer equivalent of manure is the amount of fertilizer N required to achieve the same yield and crop N uptake achieved with manure.

Results and Discussion

Estimates of manure N uptake by corn silage during the first study year (1998) were similar for the ^{15}N and difference methods 1998 (Table 1). These were less than half the estimates of N uptake by corn silage using the fertilizer equivalent approach. These different estimates of manure N uptake by corn silage may be attributed to incorrect assumptions associated with indirect determinations of N credits. Both the difference method and the fertilizer equivalent approach assume that crop N uptake in the manure- and fertilizer-amended plots are accomplished with the same efficiencies. However, whereas approximately half (or more) of manure N is organically-bound and must be mineralized by soil microbes before becoming available for crop uptake, fertilizer N is water soluble and 100% available for crop uptake.

Table 1. Estimates of manure N uptake by corn silage, 1998[(1)]

Measure of manure N availability	Methods of estimating manure N uptake		
	^{15}N-labeled manure (n=12 plots)	Difference method (n=4 plots)	Fertilizer equivalent (n=4 plots)
N uptake (kg/ha)			
Mean	22	22	55
Range across plots	11 to 30	-91 to 122	-161 to 243
% of total N applied			
Mean	10	12	28
Range across plots	4 to 15	-47 to 63	-83 to 125

[(1)]First year of manure or fertilizer N application

Estimates of manure N uptake by corn silage during the second study year (1999) were similar for the ^{15}N method and the fertilizer equivalent method which were somewhat greater than estimates using the difference method (Table 2). Using the ^{15}N method over the first two years of the study, it appears that from 10 to 18% of applied manure N is taken up by corn silage. These preliminary results indicate that the between year variability in manure N uptake by corn silage may be as much a two-fold.

Table 2. Estimates of manure N uptake by corn silage, 1999[(1)]

Measure of manure N availability	Methods of estimating manure N uptake		
	^{15}N-labeled manure (n=4 plots)	Difference method (n=4 plots)	Fertilizer equivalent (n=4 plots)
N uptake (kg/ha)			
Mean	35	32	39
Range across plots	20 to 52	-71 to 149	-68 to 563
% of total N applied			
Mean	18	13	17
Range across plots	10 to 23	-28 to 60	-27 to 225

(1) Plots received manure or fertilizer for 2 consecutive years

Perhaps the most remarkable preliminary result of this study was the much narrower range of N uptake values associated with the ^{15}N method than with the difference method or the fertilizer equivalent approach. The lower variance associated with ^{15}N may greatly improve the precision by which we can estimate manure N uptake by crops. This result may reduce the risk associated with N crediting and improve manure management.

First year comparisons of ^{15}N uptake by corn silage in plots amended with ^{15}N-labeled manure derived by feeding ^{15}N-labeled forage (organic method) or urea (inorganic method) are presented in Table 3. On average, there were no significant differences in estimates of ^{15}N uptake by corn silage using either labeling technique. These preliminary results indicate that ^{15}N-labeling of manure by feeding ^{15}N-enriched urea may be an adequate procedure for studying short-term (one cropping season or less) turnover of manure N in soils.

Table 3. Compared plot (n=6) estimates of manure ^{15}N uptake by corn silage using forage- or urea-derived manure, 1999

Forage-derived manure	Urea-derived Manure	Forage-derived manure	Urea-derived manure
Manure N uptake (kg/ha)		Percent of total manure N applied	
36	44	18	22
13	31	9	21
32	43	16	20
18	36	9	16
33	10	18	9
25	13	16	8
Mean[1] 26	23	14	16

[1]no significant differences in mean values of manure N uptake or percent of total manure N applied using forage- or urea-derived manure

Conclusions

The results of this project should have several theoretical, as well as practical, implications for improving environmental impacts of dairy manure management. We expect that the ^{15}N technique will provide a tool for better understanding N flow in various components of the animal-feed-manure-soil/crop-environment continuum. ^{15}N-labeling of dairy manure using the inorganic method may provide a less expensive and less difficult tool for making direct measurements of short-term (e.g single cropping season) manure N transformations. The field trial is designed to evaluate the effects on N cycling of various manure management strategies, including the current, predominant practice of Wisconsin farmers: the repeated application of large manure amounts to the same field. The long-term nature of the trial (6-yr minimum) and the use of ^{15}N-labeled manure and fertilizer N should provide opportunities for comparing direct and indirect measurements of manure nutrient dynamics under various manure management regimes. It is expected that this information will increase our confidence in manure N credits. Ultimately, these studies may provide the basis for developing alternative, economically viable and environmentally sound manure management practices.

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