Effect of Calcium Intake on Phosphorus Excretion in Feces of Lactating Cows
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Introduction

It is generally considered that ruminants are quite tolerant of varying dietary Ca:P ratios as long as the ratio is between 1 and 7. Concern persists, however, amongst nutritionists and veterinarians regarding the impact of dietary Ca concentration on phosphorus uptake from the gut. The objective of this study was to determine if excretion of P in feces of lactating dairy cows is altered due to Ca intake.

Materials and methods

Eighteen multiparous Holstein cows were utilized in a crossover design. The two treatments were low or high dietary Ca content (0.70 and 1.10%, DM basis), obtained by varying the amount of dietary calcium carbonate (Table 1). Cows were paired based on similarity in milk yield and days in milk, then were randomly assigned in pairs to the dietary treatments. The experiment included two periods, each lasting 3 wk. At the beginning of the second period, cows were switched to the opposite treatment.

Cows were housed in a tie-stall barn and offered a TMR once daily at 1400 h ad libitum (5 to 10% refusal). Actual amounts of feed offered and refused by individual animals were recorded daily to obtain net intake. Milking was at 0500 and 1700 h. Milk yields were recorded, but only the last two weeks in each period were used for analysis.

Results and discussion

The DMI and all measurements of lactational performance were similar between treatments except for milk protein percentage, which was slightly lower ($P=0.06$) for the high Ca diet (Table 2). The similarity in cow performance suggests the cows had adequate Ca. The NRC (1989) recommends 0.58% dietary Ca for cows at a production level similar to that in this experiment.

Fecal concentration of Ca was 1.68 and 2.43%, 45% higher ($P<0.01$) when cows were fed 1.10% Ca than when fed 0.70% Ca (Table 2). Fecal P concentration was 0.89 and 0.94% for the two groups, and was unaffected ($P=.19$) by treatment (Table 2). This result is in agreement with several previous studies with ruminants.

Conclusion

Increasing the concentration of Ca from 0.70 to 1.10% of diets that contained 0.36% P increased fecal Ca concentration but did not change the concentration of P in feces. Because these amounts of Ca encompass the typical range of dietary Ca concentrations used in lactation diets, absorption of P from diets containing as little as 0.36% P does not seem to be affected by dietary Ca concentrations within the range typically fed. A reduction in dietary P for lactating cows does not require a concurrent reduction in dietary Ca concentration to maintain a Ca to P ratio of ~2:1.

Table 1. Ingredient and chemical composition of diets differing in Ca content.

Item	0.70% Ca	1.10% Ca
	--------------------------- % of diet DM -----------------------	
Ingredient		
Alfalfa silage	20.00	20.00
Corn silage	35.00	35.00
High moisture corn	25.85	25.00
Soybean meal, 48% CP	8.00	8.00
Soybean, roasted	10.00	10.00
Dicalcium phosphate	0.15	0.15
Calcium carbonate	0.50	1.35
Salt	0.40	0.40
Mineral and vitamin mix[1]	0.10	0.10
Chemical analyses		
CP, %	18.0	17.9
NDF, %	29.5	29.4
ADF, %	19.9	19.9
Ca, %	0.70	1.10
P, %	0.36	0.36
P in diet refusal, %	0.36 (0.02)[2]	0.37 (0.01)[2]

[1]Contained 0.32 mg/g of Se, 0.43 mg/g of Co, 1.03 mg/g of I, 13.35 mg/g of Cu, 23.99 mg/g of Fe, 51.00 mg/g of Mn, 62.01 mg/g of Zn, 7,000,000 IU/kg of vitamin A, 2,222,000 IU/kg of vitamin D, and 17,630 IU/kg of vitamin E.
[2]Values in parentheses are SD.

Table 2. Lactation performance and fecal Ca and P concentrations when cows were fed diets differing in Ca content.

Item	0.70% Ca	1.10% Ca	SEM	*P*
DMI, kg/d	21.0	20.8	0.3	0.63
Milk, kg/d	29.4	28.8	0.5	0.49
3.5% FCM, kg/d	31.0	30.8	0.89	0.89
Milk fat				
%	3.83	3.93	0.12	0.57
kg/d	1.13	1.13	0.04	0.96
Milk CP				
%	3.38	3.32	0.02	0.06
kg/d	0.99	0.95	0.02	0.21
Lactose, %	4.59	4.53	0.03	0.28
SNF, %	8.95	8.84	0.05	0.14
SCC, 1000^3/ml	173	195	49	0.75
Fecal Ca, %	1.68	2.43	0.13	0.01
Fecal P, %	0.89	0.94	0.03	0.19

Phosphorus Feeding and Manure Nutrient Recycling on Wisconsin Dairy Farms

J.M. Powell, D.B. Jackson-Smith and L.D. Satter

Introduction

The dairy industry in Wisconsin continues to be land-based, that is, many farms produce most of their feed and, therefore, have sufficient land to recycle manure nutrients through crops. However, to remain economically viable, many farms are increasing herd size and importing more feed. The continuous importation of nutrients in excess of on-farm crop nutrient requirements results in excessive soil nutrient accumulation, runoff and the pollution of surface and ground waters. Newly approved federal nutrient management regulations for animal operations have targeted manure management, specifically the phosphorus (P) content of manure and the P recycling capacities of cropland, as key components to the protection of water quality. Very little information exists on how nutrient management in one dairy system component (feed) affects other system components (crops and soils) and the overall impact of livestock numbers and cropland areas on nutrient cycling under farmer conditions. The objectives of this study were to (1) assess the feeding practices of representative dairy farms in Wisconsin, (2) evaluate the relationships between feeding practices, milk production, manure P and a farm's ability to recycle manure P through crops, and (3) offer strategies that may allow dairy farms to attain P balance and conform to environmental regulations targeted at manure management.

Materials and Methods

A total of 98 dairy farms were randomly selected from the top 17 dairy counties in Wisconsin. On-farm interviews were conducted to gather information on dairy cow types, numbers and milk yield, and on feeding practices, the importance of different factors and sources of information in determining rations, etc. The types and amounts of feed being fed on the day of the interview were recorded for each feeding group. Samples were taken of each feed component and freshly deposited feces were sampled from the barn floor. Relationships between apparent dietary P concentration and milk production were determined. The amount of manure P excreted by lactating cows was calculated as the difference in apparent feed P intake and milk P output. Partial P balances (difference between annual crop P harvests and manure P production) were calculated per farm and on a per hectare basis.

Results and Discussion

Herd and cropping system characteristics

Approximately three-quarters of the surveyed farms milked between 30 to 99 cows with an average of 65 cows, 55 of which were in lactation (Table 1). Most of the farms (97%) raised all or some of their replacement heifers. Dairy heifers numbered about 80% of the cows. Of the total manure P produced on a dairy farm, an average of 75% was estimated to come from cows and 25% from heifers. Most of the cultivated area on Wisconsin dairy farms is planted to either alfalfa (56%) or corn (37%; Table 2). Of the total land planted to corn, approximately two-thirds is devoted to grain and one-third to silage. The annual amount of P harvested in crops ranged from 18 to 30 with an average of 23 kg ha^{-1}

Table 1. Herd composition, milk production, stocking rate and annual manure P excretion for 98 dairy herds surveyed in Wisconsin.

	Mean (std dev)	Range
Herd composition (numbers)		
Lactating cows	55 (40)	14 to 281
Dry cows	10 (8)	0 to 46
Heifers	53 (39)	0 to 200
Daily milk production (kg cow^{-1})	26 (8)	7.7 to 43.1
Stocking rate [(1)]		
Animal units ha^{-1}	0.71 (0.27)	0.19 to 1.68
Number of cows (cultivated $ha)^{-1}$	0.64 (0.25)	0.14 to 1.76
Annual manure P (kg)		
Lactating cows	1323 (1042)	163 to 5759
Dry cows	137 (108)	0 to 621
Heifers	400 (296)	0 to 1533

[(1)] Animal unit equals 1000 kg of animal weight (cows and heifers combined).

Phosphorus feeding

The P content of the diet ranged from 2.3 to 8.5 with an average of 4.0 g P kg^{-1}. Approximately 85% of the surveyed farms fed P in excess of current NRC recommendations. Of the total number of lactating cows (5,195) for which there was complete dietary P and associated milk production data, one half (51%) were fed P in excess of the 3.8 g P kg^{-1} DM deemed sufficient for high levels of milk production. Because many of the herds in this survey could not be considered high milk producers, excess feeding of P likely occurred to even a greater extent.

Most dairy producers (70%) reported self-sufficiency in forage (hay plus silage) and grain production. These farms had average stocking rates of of 0.70 cows and 0.54 heifers ha^{-1}. Across all stocking rates (Table 1), there were no apparent herd size differences between those farms that had low and high stocking rates (i.e. farms with the largest herd size did not have higher stocking rates than farms having smaller herd sizes).

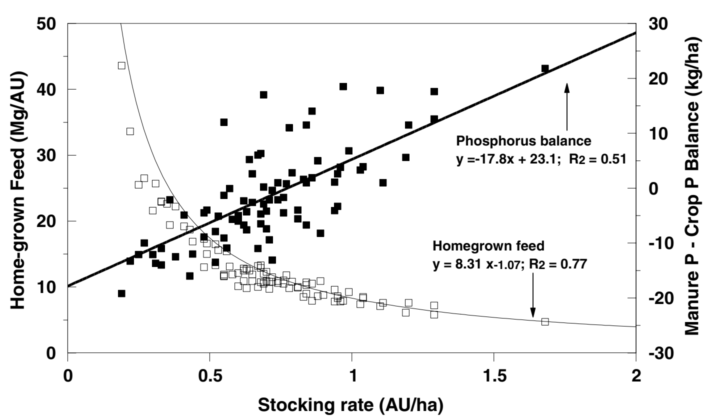
The relationship between homegrown feed (alfalfa, corn silage and grain) production and stocking rate (Figure 1) shows that most Wisconsin dairy farms have stocking rates of less than 1.1 cows ha^{-1}, the threshold value for self-sufficiency in forage (hay plus silage) and grain production. Self-sufficiency in forage and grain production generally means that a farm has adequate land to recycle its manure P through crops. Whereas a farm can attain self sufficiency in forage and grain production up to a stocking rate of approximately 1.1 cows ha^{-1}, all manure P could potentially be recycled through cropland up to a stocking rate of 1.4 cows ha^{-1}. Linking the number of animals to the area of land and cropping system available for manure utilization is critical to proper manure management.

Table 2. Cultivated areas, cropping pattern and annual crop P harvest for 98 dairy farms surveyed in Wisconsin.

	Mean (std dev)	Range
Land use (ha $farm^{-1}$)		
Pasture	6 (5)	0 to 24
Untillable	28 (31)	1 to 172
Cultivated area	97 (68)	18 to 364
Cropping pattern (% of cultivated area)		
Corn grain	23 (13)	0 to 57
Corn silage	14 (10)	0 to 51
Hay	56 (16)	0 to 100
Small grain	3 (6)	0 to 25
Soybean	4 (7)	0 to 27
Annual crop P removal (kg $farm^{-1}$)	2211 (1589)	381 to 8900
Annual crop P removal (kg ha^{-1})		
Corn grain	24 (2.4)	19 to 26
Corn silage	28 (2.7)	24 to 32
Hay	22 (2.2)	19 to 25
Small grain (grain plus straw)	30 (2.6)	24 to 33
Soybean	18 (2.3)	13 to 21

While animal:cropland ratios recognize that soils and their associated cropping systems have a limited capacity to recycle manure nutrients, in practice the impact of stocking rates depends on animal parameters, such as feed inputs, milk and manure outputs, and cropland characteristics that affect a field's ability to effectively recycle manure nutrients. For example, farms that feed recommended levels of dietary P produce less manure P, and therefore, can support more cows per cultivated area than farms that feed P excessively. At similar stocking rates, farms on sloping land and close to surface waters likely pose a much greater threat to water quality impairment than, for example, farms situated on parts of the landscape less susceptible to runoff. On many dairy farms, the P problem originates not so much from excessive stocking rates but rather from a combination of high dietary P levels and inadequate utilization of available cropland for manure spreading. Farms that feed adequate levels of dietary P, and utilize all of their available cropland for manure disposal can maintain higher stocking rates without increasing P losses compared to farms that feed P excessively and spread manure on only parts of their cropland.

Fig. 1. Relationships between stocking rate and sufficiency in forage and grain production and cropland P balance on Wisconsin dairy farms [1 animal unit (AU) equals 1000kg liveweight].



Many of the farms unable to grow all forage and grain are close to self-sufficiency (Figure 2). Approximately 68% of all farms would be able to produce 90% of their herds forage and grain requirements, and 80% of the farms produce 80% of their requirement. Most DM deficits are fulfilled through the purchase of corn grain, which has historically been very inexpensive. This appears to be the strategy of farmers. As stocking rates and feed deficits increase, relatively more forage than grain is produced.

Improving the phosphorus balance on dairy farms by aligning dietary P to milk production

The average diet P concentration (4.47 g/kg) fed on the 32 farms having positive field P balances is on average 25% greater than what the NRC would recommend (3.35 g/kg) for the level of milk production obtained on each farm. The adoption of NRC dietary P recommendations would reduce the number of farms having a positive P balance by 67%, and amount of land in positive P balance by 60% (Table 3). As dairy farms seek to conform to new nutrient management guidelines that restrict manure land-applications to levels that replace crop P removal, the choice of a low-phosphorus mineral and protein supplements could have a major impact on land requirement for manure application, and on-farm accumulation and loss of P.

Fig. 2. Relationship between stocking rates and home-grown feed (alfalfa, corn silage and grain) production on dairy farms not self-sufficient in home-grown feed production [1 animal unit (AU) equals 1000kg liveweight].

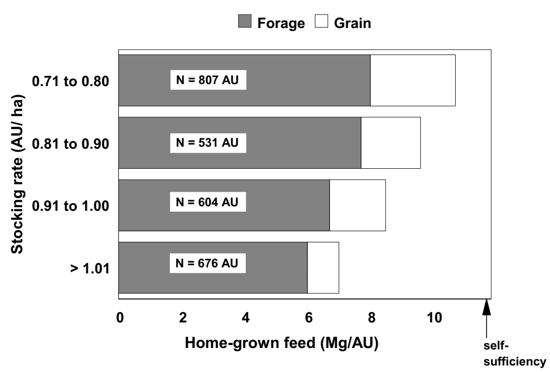


Table 3. Phosphorus balance (manure P - crop P) of dairy farms using current and NRC-recommended (NRC, 2001) feeding practices for phosphorus

Parameter	Actual feeding practice	NRC feeding practice
Number of farms with positive P balance	32	11
(% of total farms)	39	13
Crop area having positive P balance (ha)	2415	1003
(% of total crop area)	30	12
Phosphorus balance (n=82 farms)		
mean (kg farm^{-1})	271	665
range	-3945 to 6970	-1730 to 7103
mean (kg ha^{-1})	1.1	5.6
range	-39 to 19	-20 to 20

Conclusion

Most dairy farms in Wisconsin grow most of their feed and appear to have sufficient land for recycling manure P through crops. However, as land application of manure becomes regulated based on soil test P level and a field's risk to contribute P to surface water, farmers will need to adopt practices that reduce the amount of manure P that needs to be recycled. The manipulation of dairy diets through a more judicious selection and use of imported mineral and protein supplements will be a key practice that aligns manure P with crop P demands. For the many dairy farms that have soils already high or excessive in soil test P, feed management could very well be the most critical element of a farmer's ability to comply with nutrient management regulations Farmers and those influencing their nutrient management decisions (feed consultants, veterinarians) should seek a more holistic understanding of how nutrient management in one production component (e.g., feed) affects nutrient cycling in other production components (e.g., soils and crops) and how various components can be managed to reduce environmental risks while maintaining farm profits.

Acknowledgement

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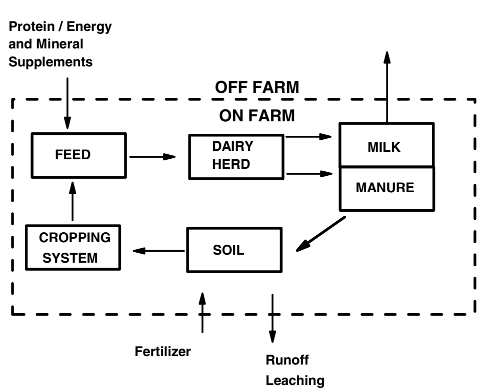
A Systems Approach to Improving Phosphorus Management on Dairy Farms

J.M. Powell, L.D. Satter; L.R. Bundy and D.B. Jackson-Smith

Introduction

The survival of many dairy farms in the U.S. will depend on farmers' ability to comply with increasingly strict environmental regulations, especially those associated with phosphorus (P) management. Many dairy farms consistently accumulate P because imports of P in the form of feed and fertilizer simply exceed exports in the form of milk, cattle, and surplus grain or hay (Fig. 1). In many areas of intensive livestock production the amount of P in manure often exceeds crop requirements. This can lead to a disposal rather than an agronomic use of manure, with a subsequent build-up of soil test P levels, much above what is needed for optimal crop yields. Newly approved nutrient management regulations for livestock operations attempt to reduce P runoff losses by controlling manure P management.

Figure 1. Phosphorus flow on dairy farms



Most efforts to improve nutrient management continue to focus on manure handling, storage, and land application. Such "rear-end" approaches neglect the effects of feeding practices on overall on-farm nutrient balances, manure nutrients and environmental impacts. For example, the newly approved USDA/EPA Unified Strategy for Animal Feeding Operations and proposed Comprehensive Nutrient Management Plan (CNMP) recognize that feed management can be an important tool for achieving a preferred balance of nutrients in manure, but the CNMP does not propose adjustments to feeding practices. Feed management is considered a planning consideration, not a technical standard. However, for farms with high levels of soil test P, feed management could very well be the most critical element of nutrient management. Separate feed, fertilizer and manure nutrient management strategies that do not consider balancing on-farm nutrient inputs and outputs can result in loss of profits through excessive nutrient use, undesirable nutrient accumulation in soil, and increased risk of negative environmental impacts from nutrient runoff, leaching and air pollution.

DFRC scientists and University of Wisconsin collaborators recently completed the first 3-year phase of a USDA-CSREES National Research Initiative-funded project entitled “A systems approach to improving phosphorus management on dairy farms”. The purpose of this report is to summarize the key results obtained during the first 3 study years with an emphasis on how a more judicious use of dietary P would affect farmers’ ability to comply with emerging P-based nutrient management regulations.

Materials and Methods

Strategic feeding trials were conducted to refine the estimate of what amount of dietary P is minimally needed to support high levels of milk production; manure derived from cows fed P adequate and P surplus diets were applied to cropland and runoff P was determined; a study was done to evaluate how excessive dietary P affects the land required for recycling manure P through crops, and the ability of dairy farms to recycle manure P in view of new federal guidelines that limit land application of manure based on crop P requirements; and a study of 98 dairy farms was conducted to learn about relationships between dairy feeding practices and manure P levels under farmer conditions, and between herd size, cropland area and a farm’s ability to recycle manure P through crops.

Results and Discussion

Balancing P inputs and outputs through proper feed, fertilizer and manure management is the first step towards reducing soil P buildup and runoff P losses from dairy farms (Figure 1). Farms that produce manure P in excess of crop P requirements will need to amend feed and/or fertilizer practices, seek additional land for manure application, export manure, and/or reduce animal numbers on their farms if they are to achieve P balance.

Dietary P and milk production. The National Research Council recommends that the typical dairy cow diet contain between 2.7 and 4.0 g P kg^{-1}, depending on milk production (600 kg cow producing 10 to 50 kg of milk per day). A higher level of dietary P (4.8 g kg^{-1}) is recommended for the first 3 weeks of lactation. Many dairy farmers purchase and feed P in great excess of NRC recommendations. On Wisconsin dairy farms, dietary P levels range from 2.3 to 8.5 with an average of 4.0 g P $kg^{-1.}$ Approximately 85% of the surveyed dairy farms fed P in excess of NRC requirements. Over half of all cows were being fed P in excess of 3.8 g kg^{-1}, the level deemed sufficient for high levels of milk production. On these farms, the simple practice of adopting NRC’s dietary P recommendations would reduce the number of farms and amount of land in positive P balance by approximately two-thirds. Perhaps the most immediate and greatest positive impact would come from reductions in the importation of unnecessary P fertilizer and diet supplements.

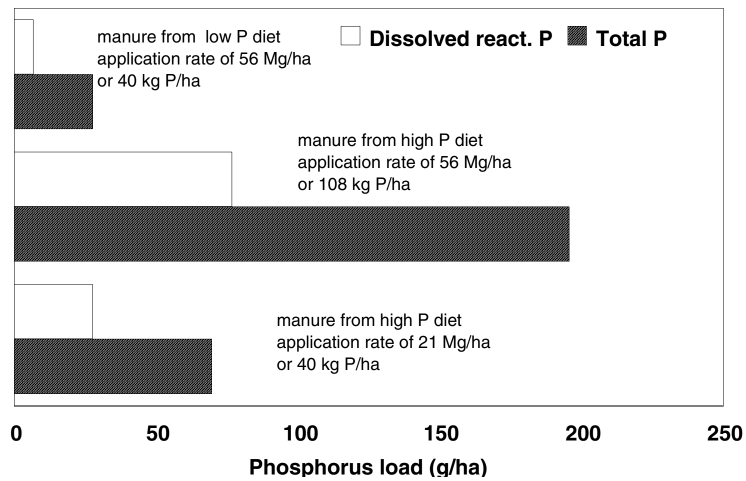
Protein supplements contain a very wide range of P concentrations (Table 1). Selecting a protein supplement with high P levels could have a profound effect on dietary, and therefore, manure P, land requirement for manure application and a farm's accumulation and loss of P. As dairy farms seek to conform to new nutrient management guidelines that restrict manure land-applications to levels that replace crop P removal, the P content of protein supplements will have to be considered.

Table 1. Protein and P concentrations in common dairy protein supplements (NRC, 2001)

Feed	Protein content g/kg	Phosphorus content g/kg	Protein:Phosphorus Ratio
Blood meal	750	3.0	317
Corn gluten meal (dried)	650	6.0	108
Soybean meal (expellers)	463	6.6	70
Soybean (roasted)	430	6.4	67
Brewer's grain (dried)	292	6.7	43
Cottonseed	230	6.0	38
Corn distiller's grain	222	8.3	27
Wheat midds	185	10.2	18
Wheat bran	173	11.8	15
Meat and bone meal	542	47.3	11

Effect of dietary P on runoff P. The type and amount of diet P supplement fed to dairy cows effect the amount and form of P in runoff from manure-amended fields. For example, when manure derived from cows fed a high (4.9 g kg^{-1}) and low (3.1 g kg^{-1}) P diet were applied at equal weights, difference in P runoff between fields amended with high diet P manure was 8 to 10 times greater than from fields amended with low diet P manure (Figure 2). When manure was applied at equivalent rates of P (40 kg P ha^{-1}), the high P manure had P runoff concentrations and loads approximately four to five times those of the low P manure. The higher soluble P in runoff from plots amended with the high P manure at the same P application rate suggests that the forms of P in the manures were different. Excessive diet P supplementation increases both total and water soluble P content of manure.

Figure 2. Soil surface runoff of P from plots amended with dairy manure derived from different dietary P levels (Ebeling et al., 2002)



Effect of dietary P on cropland needed for manure spreading. Excessive dietary P results simply in a greater excretion of manure P. If manure application to cropland becomes restricted to crop P removal, the supplementation of the dairy diet with inorganic P increases the cropland requirement for manure P recycling dramatically (Table 2). Feeding excessive P increases manure P and exacerbates the difference in nitrogen (N):P ratio between manure and crops. This means that manure from cows fed excessively high P diets, when applied to cropland in amounts to meet a crop N demand, will increase soil test P more quickly than the application of manure derived from cows fed P adequate diets. Reducing dietary P not only reduces manure P levels but also improves the N:P ratio of manure to more nearly match the N:P ratio required by plants.

Table 2. Land requirement for recycling the annual fecal P excretion by a cow fed various dietary P levels.

Dietary P level	Fecal P excretion	Cropland area to recycle fecal P	Change in land area due to diet P supplementation
$g\ kg^{-1}$	$kg\ cow^{-1}\ year^{-1}$	ha	%
3.5	19	0.63	0
3.8	21	0.70	11
4.8	30	1.00	59
5.5	35	1.17	86

Conclusion

This interdisciplinary research project showed that the elimination of inorganic P diet supplements and/or the selection of protein supplements of low P content would (1) result in less P imported and excreted in manure, and therefore reduce the cropland area needed for manure P recycling and (2) align the N:P ratio of manure to coincide more closely with N:P ratio of crops, thereby reducing the hazard of over application of P, buildup of soil test P, and runoff from manure-amended fields. The on-farm component and subsequent group meetings with producers clearly showed that any strategy aimed at improving P use must be done in partnership with the feed and fertilizer consultants, veterinarians and manure haulers hired by farmers to make nutrient management decisions. During one of the project's workshops, Wisconsin dairy farmers said that they fully expect these hired services to incorporate any nutrient management regulation into their recommendations. While it has been shown that dairy farms can improve profitability and reduce manure P through diet P manipulation, many in the dairy industry apparently remain unconvinced that lower levels of dietary P will not adversely affect animal performance. The real and perceived risks of reduced animal performance due to diet manipulation need to be defined more clearly. Feed consultants and veterinarians need to know that their dietary P recommendations could very well be the most critical element of a farmer's ability to comply with nutrient management regulations, especially for farmers having limited cropland area upon which they can spread manure. The link between dietary practices and water quality impairment needs to be incorporated into whole-farm nutrient management planning.

Acknowledgement

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Nitrogen Budget and Soil N Dynamics After Multiple Dairy Manure or Fertilizer Applications Using Unlabeled or ^{15}N-enriched Dairy Manure.

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Introduction

Fertilizers, animal manure, and in some cases legumes, are the principal nitrogen (N) sources for crop production in mixed, dairy-crop production systems. Whereas fertilizer N is readily soluble in soils and becomes immediately available for crop uptake, only about half of manure N is inorganic, with the rest present in organic forms that have to be first mineralized to be used by plants or susceptible to losses. Because of its lower N availability, greater amounts of manure than fertilizer N are applied to crops. Continuous manure additions cause a steady accumulation of soil N and may negatively impact groundwater quality.

Excessive soil nutrient accumulation and pollution are pressing environmental challenges facing the dairy and other animal industries. As dairy herds expand to remain economically viable, a larger percentage of the cropland is devoted to corn silage. The effects of shifting more land to corn silage on other systems components, such as N use, buildup and loss remains to be determined. Since only a small part of applied N is ultimately taken up by corn, we wanted to track the fate of the unused portion to see whether it was lost or remained in the soil. The objective of this study was to determine total and inorganic soil N and the N balance of a continuous corn silage cropping system receiving two fertilizer or dairy manure N rates of different application frequency over three years. Unlabeled and ^{15}N-enriched dairy manure was used, and the ability of both techniques to detect trends in soil N levels and account for applied N was compared.

Materials and Methods

A field trial was established in 1998 at the West Madison Agricultural Research Station in Madison, WI (45° 05' N, 89° 31' W) on a Plano silt loam. Initial surface (0–15 cm) soil tests were: pH 6.7 (water); organic matter, 41 g kg^{-1} (loss on ignition); Bray P1 and K levels of 50 and 146 mg kg^{-1}, respectively. Total N, NH_4^+–N and NO_3^-–N levels in the upper 30 cm of soil were 2026, 14, and 8.2 mg kg^{-1}, respectively. Trial treatments consist of two inorganic fertilizer N levels (90 or 179 kg ha^{-1}, as NH_4NO_3), two manure rates (estimated to provide approximately 90 and 180 kg available N ha^{-1} to corn the first year following application), a control receiving neither fertilizer nor manure, and three manure application intervals (every 1, 2 or 3 years). Soil samples were taken in 30cm increments to a total depth of 90 cm just prior to planting and immediately after harvest each of the three study years. Fertilizer N has been applied every year to the same plots. Estimates of soil total- and NO_3^-–N changes due to manure applications were obtained by monitoring soil ^{15}N concentrations in subplots amended with ^{15}N-labeled manure.

Results and Discussion

After three years of continuous fertilizer N or manure application, the lowest and highest NO_3^-–N levels (0 to 30 cm layer) corresponded to control and the high manure rate, respectively. There was usually no difference in soil NO_3^- levels in plots amended with the low manure rate or either fertilizer rate. Manure at the high rate significantly increased NO_3^- -N over the low rate and the control. Although the fertilizer effect on topsoil NO_3^- levels was lower than that of manure, fertilizer increased NO_3^-–N concentrations in lower soil depths (30 to 90 cm) indicating that more fertilizer- than manure-N moves downward as NO_3^-–N during the growing season. This difference in behavior is probably due to the fact that NO_3^-–N applied as inorganic fertilizer is immediately solubilized in soil and therefore more susceptible to downward movement within the soil profile if there is no crop to utilize it. More than half of manure N, on the other hand, is in organic form, and virtually all of the rest is present initially as NH_4^+. Hence, manure N has to be mineralized and/or nitrified before it becomes susceptible to leaching.

There is a clear trend, which can be described by linear regression, towards increased NO_3^- contents (based on ^{14}N plus ^{15}N) with time in the topsoil for both manure rates and for the high fertilizer rate. Equations and statistics are presented in Table 1. It should be noted that the slopes for the manure treatments were generally greater than those for fertilizer, indicating that NO_3^-–N tended to accumulate to a greater degree in the manure- than the fertilizer-amended plots. This also appears to support the argument for greater short-term leaching potential from the fertilizer.

Table 1. **Regression equations used to describe soil NO_3^--N levels to 30 cm depth over time after repeated manure and fertilizer N applications in South-Central Wisconsin, 1998–2000.**

Treatment	Regression equation†	R^2	p-value
Fertilizer high‡	Y = 5.7 + 0.95 X	0.270	0.011
Fertilizer low‡	Y = 8.1	-	-
Manure high§	Y = 1.4 + 2.7 X	0.605	<0.001
Manure low§	Y = 4.4 + 1.1 X	0.407	0.001
Control	Y = 6.9	-	-

†Y is the soil NO_3^--N concentration in mg kg^{-1}, X is the sampling time (1–6 corresponding to spring, 1998 through fall, 2000).
‡Fertilizer rates were 90 and 179 kg N ha^{-1} year^{-1} for the low and high level, respectively.
§Three-year average manure rate were 236 and 459 kg total N ha^{-1} year^{-1} for the low and high level, respectively.

Net total soil N (^{14}N plus ^{15}N) increases in plots that received the low and high manure rates, based on regression analyses, were 2.0 and 2.9 Mg ha^{-1}, respectively, over the three year study period (Table 2). For fertilizer, these values were 1.9 and 2.0 Mg ha^{-1}. It is clear that these measurements are not sufficiently accurate, since they predict soil N increases that represent more than twice the total N applied (0.7 and 1.4 Mg ha^{-1} for manure, and 0.3 and 0.5 Mg ha^{-1} for fertilizer).

Table 2.**T**otal N applied and recovered in harvested corn and soil to a depth of 90 cm for treatments receiving repeated manure and fertilizer applications in South-Central Wisconsin, 1998–2000.

	Initial	Applied				Crop uptake			Final	Recovery†		
Treatment	soil	1998	1999	2000	Total	1998	1999	2000	soil	Crop	Soil	Total
	kg ha^{-1}									%		
Fertilizer	13280	179	179	179	537	390	236	217	15282	46	373	419
Fertilizer	13138	90	90	90	270	301	222	210	15025	51	699	750
Manure	13499	388	501	489	1378	261	194	226	16376	6	209	215
Manure	13073	194	250	233	677	216	197	215	15024	5	288	293
Control	13528	0	0	0	0	257	172	185	13528	-	-	-

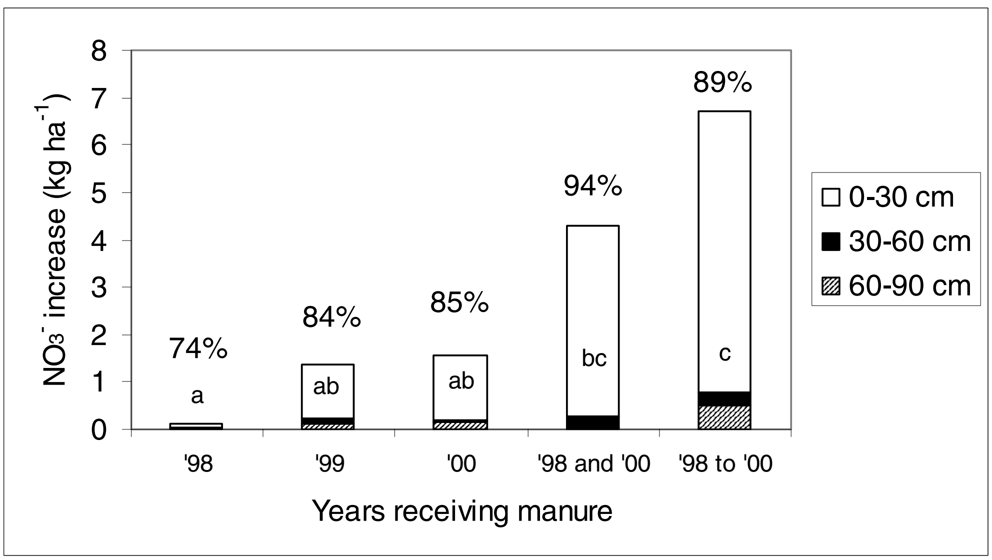
†Cumulative N recovery at the end of the third year, as a percentage of applied N.
‡Fertilizer rates were 90 and 179 kg N ha^{-1} for the low and high level, respectively.
§Three-year average manure rates were 233 and 489 kg total N ha^{-1} for the low and high level, respectively.

According to soil ^{15}N measurements, total soil N increase after three years of continuous manure applications was 289 kg ha^{-1}, or approximately 40% of the cumulative average manure N input of 743 kg ha^{-1}. Soil NO_3^-–N increases due to three years of manure application ranged from 0.1 to 6.7 kg ha^{-1} (Fig. 1). Most (74 to 94%) of this NO_3^- was found in the upper 30 cm of soil. On average, more NO_3^- was found in the 60–90 cm than in the 30–60 cm depth, but the difference was not significant and was likely due to high variability and/or the movement of N from previous year applications. The greatest amounts of NO_3^- in soils occurred in plots receiving more frequent or recent manure applications. According to ^{15}N measurements, manure increased NO_3^- levels in the subsoil only in plots that received three consecutive manure applications, and only to a small degree. These data confirm the large plot trends, that manure applied at the low rate has a low leaching potential, over this three-year period. This is not to ignore that manure could impact N leaching in the future, especially on plots continuously manured.

It might be expected that the downward movement of NO_3^-–N will eventually become a problem even for manure, especially at the high rate. Increases of 0.72 Mg NO_3^-–N ha^{-1} after 11 years of continuous manure application at a rate of 30 Mg ha^{-1} $year^{-1}$, with effects extending to the 150 cm depth. Nitrate in the 0–150 cm depth continually increased with repeated manure applications (20 years) in non-irrigated sites. After three annual manure applications, similar soil NO_3^-–N for fertilizer and manure treatments, that were usually significantly higher than controls at the 60–120 cm depth, after harvest.

Using ^{15}N measurements, from 13 to 22% of applied manure N was recovered in harvested crop during the three-year study period (Table 3). In plots receiving manure every year, 19% of applied ^{15}N was accounted for in harvested corn. The low apparent recovery of unlabeled manure N in crops using the difference method was probably due to the high N uptakes in control plots throughout the experiment. The ^{15}N method provided the best, direct estimate of manure N uptake by corn.

Fig. 1. Soil NO_3^- increase due to manure application frequencies as estimated by ^{15}N measurements in South-Central Wisconsin, 2000.



Numbers above each bar represent the percentage of recovered $^{15}NO_3^-$ present in the top 30 cm only. For NO_3^- increase in the 0-90 cm depth, bars with the same letter are not significantly different at the 0.05 level.

Table 3. ^{15}**Nitrogen recovery to a soil depth of 90 cm for different manure treatments in South-Central Wisconsin, 1998–2000.**

Years receiving manure	N recovery†						
	Soil depths (cm)						
	0-30	30-60	60-90	0-90	Crop	Total	Unaccounted
	-- % --						
1998 to 2000	40	8 (2.4)	2 (0.2)	50	19	69	31 (16)
1998 and 2000	52	6 (1.6)	3 (0.7)	62	13	75	25 (24)
1998	18	4 (1.4)	1 (0.6)	24	17	41	59 (12)
1999	40	5 (0.9)	2 (0.4)	47	21	67	33 (9.7)
2000	37	7 (2.0)	4 (0.9)	48	22	70	30 (5.8)

†Cumulative recovery at the end of the third year, as a percentage of excess ^{15}N applied.
‡Standard errors are given in parentheses.

Approximately one-half to two-thirds of applied manure N was recovered in soil (0–90 cm), with one exception. Only 24% of the manure ^{15}N applied in 1998 was recovered in soil. During this study year manure remained on the soil surface for approximately 20h prior to tillage versus 4h for other study years. This likely resulted in more N loss via ammonia volatilization in 1998 than 1999 or 2000. Nitrogen recovered in the soil probably included slowly-decomposing and recalcitrant fractions of manure (undigested feed N in feces, which accounts for approximately 9% of N excreted by dairy cows), and manure N that was incorporated into new microbial biomass.

The effects of year and frequency of manure application on the amount of applied N recovered in the soil ^{15}N were not statistically significant. Depth differences in ^{15}N recovery were statistically significant ($p < 0.001$), with highest recoveries obtained from the top 0–30 cm depth (38% of applied ^{15}N). No differences in ^{15}N recovery were observed between the 30–60 cm (6%) and 60–90 cm (2%) depths. Unaccounted for ^{15}N (36% on average) was probably lost mainly through NH_3 volatilization and denitrification.

Conclusion

The use of ^{15}N-labeled manure allowed direct tracking of N in the cropping system, and provided more accurate estimates than unlabeled manure of the fate of manure N in the crop-soil continuum. Field plot soil N balances calculated using ^{15}N enrichment of total soil N were much less variable and, therefore, perhaps more reliable than soil N balances based on unlabeled N. Changes in total soil N (unlabeled) are perhaps more useful in determining long-term trends, rather than attempting to account for short-term soil N balances, such as for the three years of this study.

Comparison of Dairy Manure Nitrogen Availability to Corn Using Various Methods
G. Muñoz, K. Kelling and J.M. Powell

Introduction

Dairy manure is a valuable source of crop nutrients and also provides organic matter which improves soil physical conditions. However, when inorganic fertilizers, having a guaranteed nutrient content, readily available to the crop, became available at relatively low costs, they began to be used extensively, replacing manure, which, in turn, was considered more as a waste. Wide variation in manure composition and the difficulty of accurately predicting availability of their nutrients to crops renders manure an undependable nutrient source. Although many farmers acknowledge the beneficial effects of manure on soil quality and nutrient levels, not all of them credit these nutrients, and even less do it in an accurate fashion, although doing so would yield economic benefits through reduced fertilizer costs. The improvement of manure management is, at least, partly, dependent on more accurate, consistent, and reliable estimates of manure N availability in which farmers can have confidence. Making sound use of N resources that ensures adequate crop nutrition while avoiding environmental pollution requires an ability to predict the amount of manure N that will become available and taken up by a crop during a growing season. The objective of this research was to compare dairy manure N availability to corn using direct (^{15}N-labeled manure) and indirect (difference method and fertilizer equivalent) techniques in a field study.

Materials and Methods

A field trial was conducted from 1998 to 2000 at the West Madison Agricultural Research Station in Madison, Wisconsin (45° 05' N, 89° 31' W) on a Plano silt loam. No manure had been applied for at least four years prior to the start of the trial. Treatments consisted of five inorganic fertilizer N levels (45, 90, 135, 179 and 224 kg ha^{-1}, applied as NH_4NO_3); two manure rates (estimated to provide approximately 90 and 180 kg available N ha^{-1} to corn in the first year following application); and a control receiving neither fertilizer N nor manure. The trial was designed to test the effect of different manure application rates and intervals over a longer period of time. This summary reports first-year manure N availability to corn using only a subset of plots (those receiving manure for the first time).

Nitrogen availability and uptake calculations

Fertilizer Equivalence: The FE method compares crop yield or N uptake in the manure treatments with responses obtained from inorganic fertilizer. Each year whole-plant yields and N uptakes were regressed against fertilizer N rate. These relationships were best described by linear functions in all cases, except for whole-plant yield and N uptake in 1999 where data were best fitted to an asymptotic response model [$Y = A - B \exp(-Cx)$] where Y = crop response, A = maximum crop response attainable, B = difference between A and crop response in the unfertilized control, C = constant, x = fertilizer rate. The regression coefficients, R^2 and p-values are presented in Table 1. To solve for FE, crop response values were entered into the regression curves, and the fertilizer rate that would have produced the same response (the FE) was interpolated (Figure 1). Fertilizer equivalents for equal treatments were averaged. Percent N availability (*NA*) was calculated by dividing the FE by total applied manure N:

$$NA\,\% = \frac{FE}{\text{Applied manure N}} \times 100 \qquad [1]$$

Difference method: The difference method assumes that all crop N uptake in the amended (manure or fertilizer) plots in excess of that taken up by the control was the result of the treatment. Apparent N recovery is given by:

$$\text{Apparent N recovery}\,\% = \frac{\text{Tmt N upt- Ctrl N upt}}{\text{Applied N}} \times 100 \qquad [2]$$

In the above equation,
Tmt N upt and *Ctrl N upt* is the N (kg ha^{-1}) contained in the whole plant for a given treatment and control plots, respectively. Applied N is the total amount of N applied (kg ha^{-1}). Apparent recovery can also be compared to fertilizer treatments providing approximately the same amount of expected available N by creating an index of manure N availability, or "relative effectiveness":

$$\text{Rel Eff}\,\% = \frac{\text{Apparent N recovery (manure tmt)}}{\text{Apparent N recovery (fertilizer tmt)}} \times 100 \qquad [3]$$

The fertilizer treatments chosen were the 90 kg ha^{-1} rate for the low manure rate, and 179 kg ha^{-1} for the high manure rate, under the assumption that approximately 40% of newly-applied manure N would be available during the first growing season.

^{15}N Recovery: Apparent manurial N availability was estimated directly by measuring percentage ^{15}N recovered in above-ground corn tissue at physiological maturity:

$$^{15}N\text{ recov}\,\% = \frac{P(c-d)}{f(a-b)} \times 100 \qquad [4]$$

In this equation, P = total crop N, f = total manure N,
a = atom % ^{15}N in the manure applied, b = atom % ^{15}N in the control manure, c = atom % ^{15}N in the treated crop, d = atom % ^{15}N in the control crop.

Results and Discussion

In general, it appeared that: 1) only in a few cases did the high manure rate result in crop responses significantly greater than the control 2) usually both manure rates resulted in similar crop responses 3) the low manure rate almost never significantly increased corn yields or N uptakes over the control 4) there were significant positive correlations between crop responses and fertilizer rates, in all cases (Table 1). The lack of significant positive crop responses to manure (in particular at the low rate) was due to relatively high fertility at the experimental site, as indicated by the high crop responses obtained in the control plots and greater variability associated with the manure treatments. Manure applied at the lower rate appeared to provide sufficient N to the crop.

Table 1. **Regression analysis of corn responses (Y) to fertilizer N rate (X)**

Year	Response†	n‡	Equation	R^2	p-value
1998	WPNU	48	Y = 244.59 + 0.5063 X	0.366	<0.001
1999	WPNU	32	Y = 244.55 - 78.675 exp (-0.0135 X)	0.533	<0.001
2000	WPNU	24	Y = 167.71 + 0.3558 X	0.479	<0.001
1998	WPY	48	Y = 21.46 + 0.0321 X	0.392	<0.001
1999	WPY	32	Y = 21.614 - 2.843 exp (-0.0238 X)	0.246	0.017
2000	WPY	24	Y = 17.455 + 0.0155 X	0.255	0.012

† WPNU: whole-plant nitrogen uptake, WPY: whole-plant yield.
‡Number of points (single plot observations) in the regression.

Manure Nitrogen Availability

Fertilizer equivalence: Fertilizer equivalents of manure using whole-plant N uptake were solved mathematically. For example, in 2000 (Figure 1), the average whole-plant N uptake was 224 kg ha^{-1} at the low manure rate (194 kg total N ha^{-1}). Entering the regression line with this number on the Y-axis, we find that a fertilizer rate of 159 kg ha^{-1} would have resulted in the same whole-plant N uptake. This allows for the calculation of N availability according to Eq. [1]: *N availability %* = 159 kg ha^{-1}/(194 kg ha-1) x 100 = 82%. This means that manure N had approximately 82% the effect of fertilizer N in increasing whole-plant N uptake.

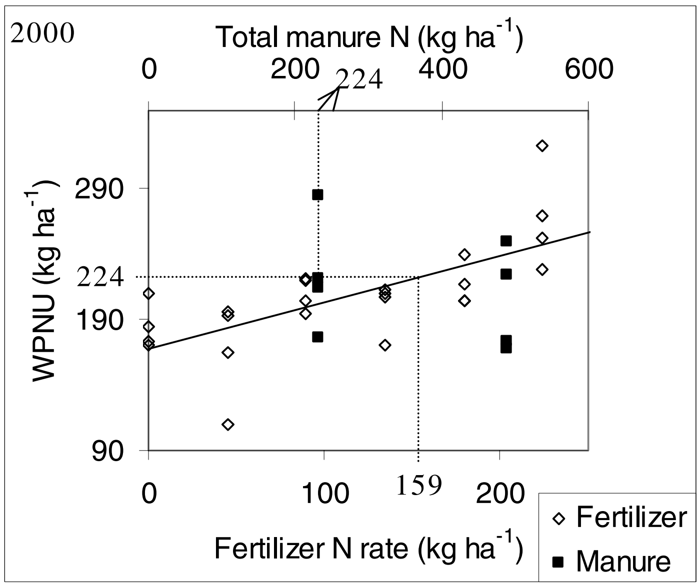
Estimates of first-year manure N availability ranged from 17 to 75%, with an overall mean (across years and crop responses) of 32%. At the high manure rate, manure N availability ranged from 2 to 76% with an overall mean of 26%. First-year dairy manure N availabilities of 27 and 26 % have been reported by Jokela (1992), based on whole-plant yield and N uptake, respectively. Our estimations are slightly higher (34 and 41%, respectively) at a similar manure N rate and are more or less comparable to the 33-60% manure N availability reported by Beauchamp (1983), the 25-100% by Xie and MacKenzie (1986) and 42% by Klausner and Guest (1981). Manure N availabilities appear to be more or less similar across a wide range of soil fertility and environmental conditions, and possibly manure characteristics.

Difference method: According to this method, the amount of N provided by manure or fertilizer was equaled to excess crop N uptake with respect to the control, and referenced to the total N applied. As discussed previously, an N availability measure (relative effectiveness) can be obtained by relating the apparent N recovery from the manure treatments to apparent recovery from a similar fertilizer rate (Eq. [3]). Both parameters for first-year manure and fertilizer treatments are presented in Table 2.

Neither apparent recovery, nor relative effectiveness of manure N were affected by year or manure rate. On average, from 15 to 18% of the total manure N applied at the low manure rate was recovered in the above-ground portion of the crop, with a weighed average of 16% across years. Relative effectiveness of manure N at the low manure rate ranged from 24 to 61% with an average of 32%.

This means that manure N was approximately 32% as effective as a similar rate of fertilizer N in increasing crop N uptake. Consistently lower estimates were obtained at the high manure rate, which ranged from 4 to 27%, with a mean of 15%, approximately half the effectiveness observed at the low manure rate. Apparent N recovery at the high manure rate ranged from 4 to 10% with a mean of 6%, substantially lower than N recovery at the low manure application rate. As discussed for FE, these results were not surprising given the general lack of crop response to the high manure rate due to high soil fertility at the experimental site during the first three study years.

Fig. 1. Corn whole-plant N uptake (WPNU) at various fertilizer and manure N rates after initial manure applications. Central Wisconsin, 2000.



Solid lines represent the relationships ($p < 0.001$) between fertilizer N rate and whole-plant N uptake. Dashed lines illustrate the fertilizer equivalence method.

^{15}<u>N recovery</u>: First-year recoveries of ^{15}N in whole-plant (Eq. [4]) ranged from 10 to 22%, with an average across years of 14% (Table 3). There seemed to be an increasing recovery of ^{15}N with time. An ANOVA with year and replication as main effects indicated that this trend was significant (p-value = 0.024), with recovery in 1998 (10%) being lower than in 2000 (22%).

Comparison of methods

A comparison of the apparent N recovery as calculated by the difference method and ^{15}N recovery showed that for each study-year and the across-years average, estimates were very similar (Table 3). Ranges for ^{15}N recovery are somewhat narrower than for the difference method, particularly in 1998. More importantly, several of the N recoveries, as computed by the difference method were negative (more commonly in 1998), meaning that crop N uptake in control plots exceeded than in manured plots. If during 1998 native N levels were high due to previous alfalfa, then it is reasonable that no extra N was needed. Hence, no extra N uptake was observed in many manured plots, and actually, whole-plant N uptake was not significantly different from the control.

Table 2. First-year apparent manure N recoveries (ANR) and relative effectiveness (RE) of manure according to the difference method for whole-plant N uptakes measured in Central Wisconsin, 1998–2000.

	1998		1999		2000		Mean‡	
Manure N †	**ANR**	RE	**ANR**	RE	**ANR**	RE	ANR	RE
kg ha^{-1}	-- % --							
226	**15**	**24**	**1**8	**2**8	**17**	6**1**	16	32
459	4	4	**10**	**2**7	4	**22**	6	15
Mean¶	9	14	14	27	10	41	11	23

†**Rate is three-year average of total N applied**.
‡**Across years, weighed by number of observations**.
¶**Across manure rates**.

The difference method only compares crop responses in manured plots to those obtained in control plots. This approach has limited applicability in extreme situations, such as when the soil is either high or severely deficient in available N. The ^{15}N method does not require calibration curves or controls (the "control" is ^{15}N natural abundance) and should be, therefore, a more precise and direct estimate of crop N uptake. However, this method does not allow for N availability estimates *per se* (understanding availability as the N that can be potentially used by the crop) unless ^{15}N-enriched fertilizer treatments are included.

Table 3. Estimates of first-year manure N availability and apparent recovery using various methods, for the low manure rate in Central Wisconsin 1998–2000.

		^{15}N method		Difference Method				Fert equiv (WPNU)	
		^{15}N recovery		App recov		Rel Effec		N availability	
Year	n†	mean	range	mean	range	mean	range	mean	range
		---%---							
1998	12	10	4 to 15	15	-31 to 62	24	-51 to 100	31	-60 to 124
1999	8	17	8 to 26	18	9 to 31	28	15 to 49	43	10 to 148
2000	4	22	7 to 42	17	-4 to 43	61	-14 to 156	68	-10 to 142
mean‡		14	4 to 42	16	-31 to 62	32	-51 to 156	41	-60 to 148

†Number of observations.
‡Weighed by number of observations.

In spite of the apparent lower accuracy of the difference method, it provided virtually the same average estimate of manure N recovery estimates as the ^{15}N method. This might suggest that at least for our experimental conditions, the difference method could be the most cost-effective approach for determining manure N availability. However, considering the breadth of the N recovery ranges provided by the difference method, sometimes going from negative to more than 100%, it is somewhat surprising that it has worked out so well. Manure N recovery measurements by the ^{15}N method are invariably more consistent and reliable, although they are costly and involve much more work, from experiment setup to sample analyses.

Conclusions

This field trial was 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 manure 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, over the long-term. The ^{15}N technique appears to provide an effective tool for accurate determination of N flow in the crop/soil-environment continuum. 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.