ESTIMATING SECOND- AND THIRD-YEAR NITROGEN AVAILABILITY FROM DAIRY MANURE [1/]

P.R. Cusick, G.R. Muñoz , K.A. Kelling, and J.M. Powell [2/]

An increased knowledge of the value of manure is needed to increase its value as a fertilizer and to avoid excess nutrient loss to the environment. Since manure is commonly applied to the same fields year after year it is important to understand the cumulative effects of these multiple year applications. Not only do producers and advisors need to understand first-year nutrient availability and losses, they also need to recognize and account for residual effects.

The residual effects of manure N have been examined by a variety of scientists using various manures and methods (Jensen et al., 1999a; Klausner et al., 1994; Pratt et al., 1973). One such method first developed by Pratt et al. in 1973 is the concept of the decay series. The decay series describes the fractional mineralization of manure N over time. It is reported as a series of decimals that represents the proportion of total manure N that is available during the successive numbers of years. Pratt et al. (1973) determined the decay series for available nitrogen in dried dairy manure to be 0.45, 0.15, 0.10, and 0.05 based on experience, not any specific study. The first number, 0.45, represents the 45% available nitrogen in the first year of application. Subsequent numbers, 0.15, 0.10, and 0.05 is the percent nitrogen availability of residual nitrogen in the second, third, and fourth years, respectively.

Klausner et al. (1994) determined the decay series of organic N in dairy manure to be 0.21, 0.09, 0.03, 0.03, and 0.02 based on N uptake using the fertilizer equivalence method. These amounts need to be combined with the amount of inorganic N available and not lost to equal total availability. It should be noted that this study encouraged volatilization of the ammonia fraction of the manure in order to get better estimates of the organic N fractions of the manure. As a result, these numbers may be low estimates for total manure N.

For nitrogen crediting purposes, the University of Wisconsin currently estimates residual N from dairy manure to be 10 and 5% for the second and third year respectively (Kelling et al., 1998). This estimate was based on research reported in Kelling and Wolkowski (1993) where dairy manure was applied to three different locations over three

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[2/] Research Assistant, former Research Assistant, Professor and Extension Soil Scientist, Dept. of Soil Science, Univ. of Wisconsin-Madison; Associate Scientist, U.S. Dairy Forage Research Center, Univ. of Wisconsin-Madison.

years (Table 2). The residual nitrogen availability is determined by the difference of availability between years. By comparing application 1 and 2, the second year availability averaged 4%. By comparing applications 3 and 1, there is a 6% residual availability, 4% remaining from the previous year and 2% remaining from two years back. The decay series for this experiment would be 0.32, 0.04, and 0.02. Many other studies conducted in this area are summarized in Table 1.

Table 2. Nutrient availability as determined by fertilizer equivalence for multiple manure applications.

	Number of Applications		
	1	**2**	**3**
Location	**Average N Availability (%)**		
Fall River	31	39	47
Sun Prairie	48	49	54
Baraboo	18	20	26
Avg	**32**	**36**	**42**

Adapted from Kelling and Wolkowski(1993).

The specific objective of our current work is to estimate residual nitrogen availability from single and multiple manure applications and to determine reliable methodologies to make these estimates.

Methods: The field experiment, located at West Madison Agricultural Research Station, Madison, WI is located on a Plano silt loam (fine-silty, mixed, mesic, Typic Argiudoll) established as a strip block with four replicates. The field experiment was initiated in 1998 and has continued through 2001. Corn (*Zea mays L.*, c v Lemke 6063) was planted to all treatments all years of the study. Treatments include five fertilizer treatments (40, 80,120,160, and 200 lb acre^{-1}, applied as ammonium nitrate) applied every year, two manure rates (estimated to provide approximately 80 and 160 lb available N/acre 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 N uptake from manure.

Nitrogen availability was determined in this study using the difference, fertilizer equivalence, and ^{15}nitrogen isotope methods. The difference method compares treatment uptake of nitrogen either in corn grain or silage from the manure treatments in comparison to the amount taken up by the control plots. This can be seen in Equation 1 (Motavalli et al., 1989):

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

Equations for multiple years of manure application or residual are similar, but account for cumulative applications and residual N from earlier applications.

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):

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

The difference 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.

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). This technique is similar to the difference 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):

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

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).

It is typical for recoveries of labeled nitrogen versus unlabeled nitrogen to be smaller (Bergström and Kirchmann, 1999; Paul and Beauchamp, 1995). This phenomena is inherent to the method and can be explained by pool substitution (Hauck and Bremner, 1976; Jenkinson et al.) or mineralization-immobilization turnover (MIT) (Jannson and Persson, 1982). Labeled pools of fertilizer nitrogen exchange with unlabeled pools of unlabelled pools of nitrogen in the soil and an "artificial" low N recovery is created.

Results: Crop yields for single manure applications in the second and third years after application are illustrated in Table 3 and the fertilizer response curves shown in Figure 1. Generally, manure treatments were not affected by manure rate even though the absolute value tended to be somewhat higher at the higher manure rate. Grain yields were always higher for the high manure rate. Silage yields were also, with the exception of the third year plots where the low rate consistently exceeded the high rate. It is likely the small amount of N available from the low rate by was over-shadowed by the variability existing in the field.

Where the yields were measured for the second and third year following a single manure application (Table 3) apparent residual availability was estimated by the fertilizer equivalence using the response curves shown in Figure 1. Second year residual ranged from –0.5 to 39.5% and averaged 23.3% based on grain yield, whereas the range was -17.9 to 18.9% and averaged 4.3%. When based on whole plant yield. Since the tissue analysis are not complete for 2001, N uptake could not be calculated across all years but Muñoz (2001) found these calculations for second year residual to average 0.0% based on the difference method and 7.4% based on fertilizer equivalence.

Using grain and whole plant yields to estimate third year residuals showed ranges of –2.4 to 16.6% and average of 9.1% based on grain yield and –6.0 to 27.6% and average 8.7% based on whole plant yields. The third year N uptake calculations showed averages of –8 and –2% using the difference and fertilizer equivalence methods. It is clear from these calculations that several components such as the shape of the response curve and the parametric chosen can dramatically influence the value estimated. While it is evident that there is a residual benefit associated with manure applications, it is less obvious what the magnitude of this credit should be.

Direct measurement of residual availability was possible using the ^{15}N enriched manure. Although data are not yet available for 2001, the first years of the study showed more consistent results using this ^{15}N technique. Standard errors were much lower, recoveries were always positive and were in good agreement with other studies (Jensen et al., 1999a; Thomsen et al., 1997a). This method calculated N availability to be 4-5% and 2% for the second- and third-years, respectively.

We also collected data which allowed for the estimate of residual effects by evaluating crop response from multiple versus single manure applications. These cumulative crop responses are shown in Table 4. It is clear from these data that the multiple manure application treatments frequently out yielded the fertilizer treatments upon which the relative response was being based. For this reason it is not possible to estimate manure availability from most of these data. For the first two years Muñoz (2001) did base estimates on N uptakes (Table 5), but in many cases 1st year availability was higher that the estimated availability when 2 consecutive applications were made.

Again in these comparisons, ^{15}N estimates for residual manure N were much smaller than the difference or fertilizer equivalence approach. A decay series based on the ^{15}N study is estimated to be 0.14, 0.04, and 0.02.

Summary: This study emphasizes that field measurement of nutrient availability from manure is difficult and results are highly variable. Using ^{15}N as a tracer greatly reduces this variability. Although there are clear residual benefits from manure applications the magnitude of the amount of nutrients available is likely more than the 25-30% sometimes measured by other techniques. Incorporating a professional judgment into the process suggests that the conservative credits currently being used in Wisconsin of 30, 10, and 5% for years 1 through 3 for dairy manure will rarely over estimate the actual available amount present. Producers and advisors can be comfortable that at a minimum these amounts will be available.

Table 1. Residual nitrogen availability from manure, determined by several methods in field experiments. (Muñoz, 2001)

Method §	Manure type†	N avail. %‡	Residual year	Comments*	Reference
Diff	liquid dairy	8.8	2^{nd}		Paul and Beauchamp, 1993
Diff	solid beef	3.5	2^{nd}		Paul and Beauchamp, 1993
Diff	beef feedlot	18.0	2^{nd}		Eghball and Power, 1999
Diff	liquid dairy	2.3	3^{rd}		Paul and Beauchamp, 1993
Diff	solid beef	7.4	3^{rd}		Paul and Beauchamp, 1993
FE		9	2^{nd}	Based on N uptake	Klausner et al., 1994
FE		10	2^{nd}	Based on yields	Klausner et al., 1994
FE	liquid dairy	10	2^{nd}	Based on N uptake	Kelling and Wolkowski, 1993
FE	liquid dairy	5	3^{rd}	Based on N uptake	Kelling and Wolkowski, 1993
FE		3	3^{rd}	Based on N uptake	Klausner et al., 1994
FE		3	3^{rd}	Based on yields	Klausner et al., 1994
^{15}N	fresh chicken	2-3	2^{nd}	Barley	Thomsen et al., 1997
^{15}N	fresh sheep	3.8	2^{nd}	Barley/ryegrass	Jensen et al., 1999
^{15}N	fresh sheep	4.5-5.7	2^{nd}	Ryegreass	Sørensen et al., 1994
^{15}N	fresh sheep	1.4	3^{rd}	Barley/ryegrass	Jensen et al., 1999

§ Diff: difference method; FE: fertilizer equivalence.

†Dairy manure, incorporated, unless otherwise stated.

‡Percentages are N availabilities according to the fertilizer equivalence method, or apparent N recoveries according to the difference or ^{15}N methods.

*Field experiments, planted to corn, unless otherwise stated.

Table 3. Residual effect of fertilizer and manure N rate on corn whole -plant and grain yields based on single manure applications, at West Madison Agricultural Research Station, WI, 1999-2001.

		1999		2000		2001	
Treatment	N rate	Whole-plant§	Grain‡	Whole-plant§	Grain‡	Whole-plant§	Grain‡
	lbs acre^{-1}	tons acre-1	bu acre^{-1}	tons acre-1	bu acre^{-1}	tons acre-1	bu acre^{-1}
Control	0	8.4	211	8.1	160	6.9	156
Fertilizer	40	9.2	206	7.5	177	7.4	155
	80	9.2	232	9	183	8.6	183
	120	10	230	8.6	202	8	177
	160	9.6	240	8.7	202	9.5	178
	200	9.4	241	9.6	207	9	166
2nd year	191†	8.5	219	7.5	190	6.5	151
Residual	388†	9.4	238	8.2	198	8.2	167
3rd year	201£			7.9	174	8	150
Residual	409£			7.6	183	7.5	165
p-value		0.411	0.011	0.037	0.052	0.052	0.011
LSD		ns*	20	1.3	28	2.2	24

‡Reported at 15.5% moisture content.

§Dry matter at physiological maturity.

† Rate is three-year average of total N applied. Plots received 173 or 223 or 207 lbs acre^{-1} of manure N in 1998 or 1999 or 2000, respectively, at the low rate. Plots manured at the high rate received 345 or 446 or 435 lbs acre^{-1}.

£Rate is two-year average of total N applied. Plots received 173 or 223 lbs acre^{-1} of manure N in 1998 or 1999, respecitively at the low rate. Plots manured at the high rate received 345 or 446 lbs N acre^{-1}.

*Not significant

Table 4. Residual effect of fertilizer and manure N rate on corn whole-plant and grain yields based on multiple manure applications, at West Madison Agricultural Research Station, WI, 1999-2000.

Treatment	N rate	1998		1999		2000		2001	
		Whole-plant§	Grain‡	Whole-plant§	Grain‡	Whole-plant§	Grain‡	Whole-plant§	Grain‡
	lbs acre^{-1}	tons acre-1	bu acre-1	tons acre-1	bu acre-1	tons acre-1	bu acre-1	tons acre-1	bu acre-1
Control	0	9.6	218	8.4	211	8.1	160	6.9	156
Fertilizer	40	9.7	226	9.2	205	7.4	177	7.4	155
	80	11.2	250	9.2	236	9	183	8.6	183
	120	11.2	239	10	230	8.6	202	8	177
	160	13.3	235	9.6	239	8.7	202	9.5	178
	200	11.9	250	9.4	241	9.5	207	9	166
1st year	201†	10.3	227	9.1	216	9	180	-	-
Applic	409†	10.2	259	8.9	244	7.9	177	-	-
2 consec	198†			8.4	236				
Applic	395†			8.2	253				
3 consec	201†					8.7	205		
Applic	409†					8.5	228		
4 consec	185†							9.7	187
Applic	400†							9.2	178
p-value		<0.001	0.001	0.297	0.005	0.329	0.01	0.052	0.011
LSD		1.7	28	ns*	20	ns*	30	2.2	24

‡Reported at 15.5% moisture content.

§Dry matter at physiological maturity.

† Rate is four-year average of total N applied. Plots received 173 or 223 or 207or 138 lbs acre^{-1} of manure N in 1998 or 1999 or 2000 or 2001, respectively, at the low rate. Plots manured at the high rate received 345 or 446 or 435 or 373 lbs acre^{-1}.

*Not significant

Table 5. Estimates of Second- and third-year manure N availability and N recovery using various methods, based on multiple manure applications, at West Madison Agricultural Research Station, WI, 1999 - 2000.

Treatment	Crop Year	Cumulative Manure N	^{15}N method ^{15}N recovery†	Difference method App recov†	Rel Effec†	Fert equiv (WPNU) N availability†
		--- lbs acre^{-1} --	------------------------	-------- % --------	------------------------	------------------------
Single Applic	1999	223	17 (2.3)	18 (3.1)	28 (4.9)	43 (18)
		446	-	10 (3.1)	27 (7.9)	9 (3.0)
		Mean		**14 (2.3)**	**27 (4.5)**	**28 (11)**
Single Applic	2000	207	22 (7.5)	17 (9.8)	61 (35)	68 (27)
		435	-	4 (4)	22 (23)	21 (11)
		Mean		**10 (5.5)**	**41 (21)**	**45 (16)**
2 consec Applic	1999§	395	18 (3.0)	12 (4.0)	20 (6.3)	17 (7.8)
		791	-	6 (3.8)	14 (9.7)	10 (6.6)
		Mean		**9 (2.9)**	**17 (5.5)**	**14 (4.9)**
3 consec Applic	2000††	603	26 (6.8)	13 (4.8)	46 (17)	57 (14)
		1227	-	8 (4.7)	47 (26)	33 (13)
		Mean		**11 (3.2)**	**47 (15)**	**45 (9.8)**

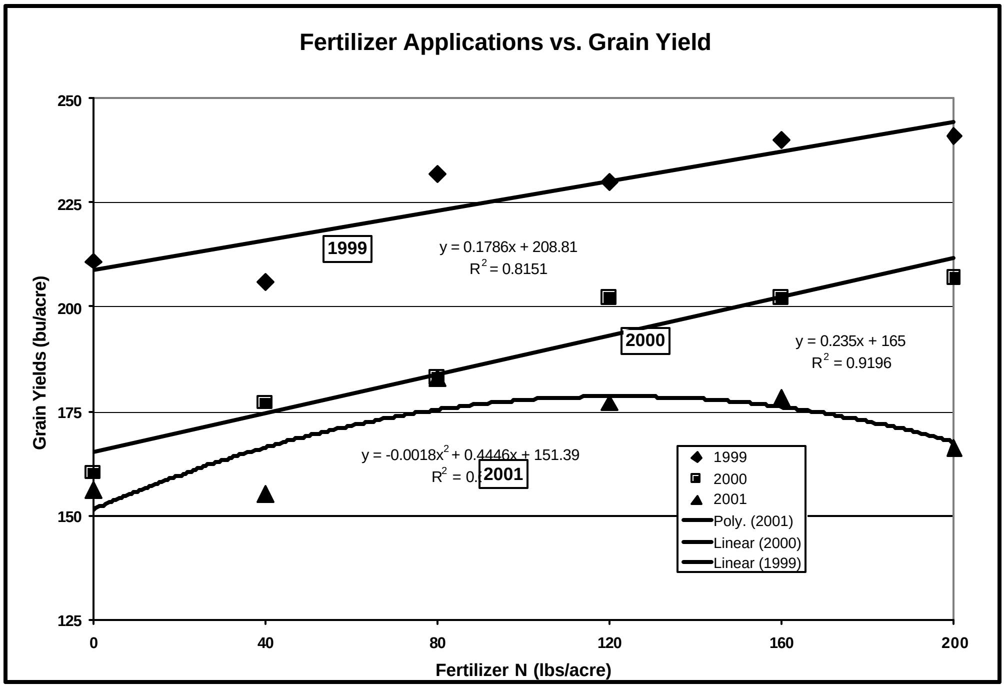
† Values are means across replicates. Standard errors are given in parentheses.

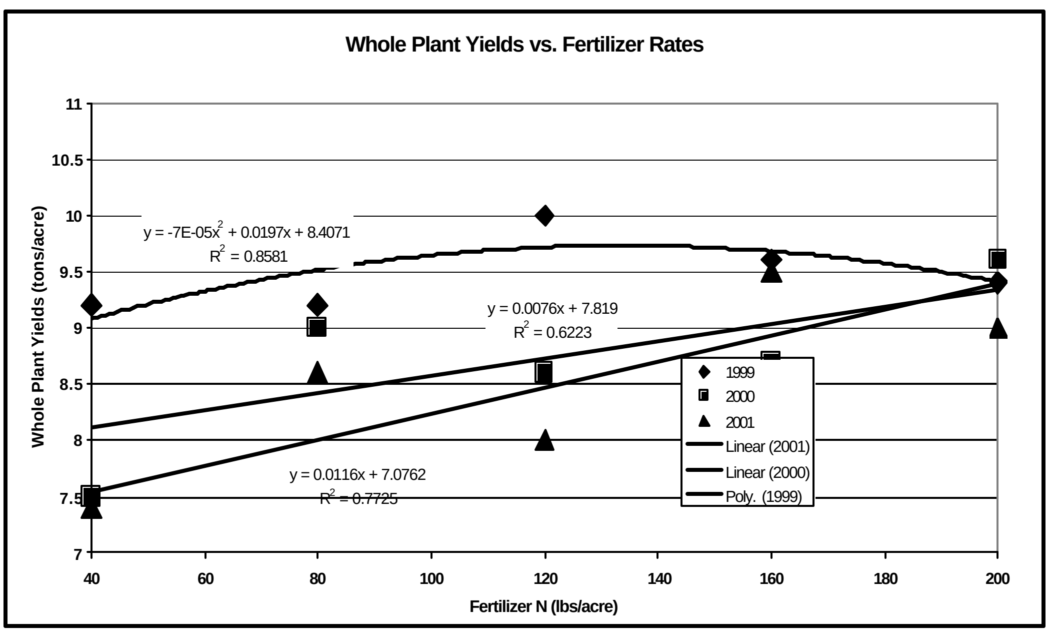
‡Manure was applied in 1998 and 2000.

§Manure was applied in 1998 and 1999.

††Manure was applied in 1998-2000.

Figure 1. Fertilizer Equivalence Charts and Equations for corn grain and silage yields. 1998-2001.





References:

Bergström, L.F., and H. Kirchmann. 1999. Leaching of Total Nitrogen from Nitrogen-15 Labeled Poultry Manure and Inorganic Nitrogen Fertilizer. J. Environ. Qual. 28:1283-1290.

Eghball, B., and J.F. Power. 1999. Composted and noncomposted manure application to conventional and no-tillage systems: corn yield and nitrogen uptake. Agron. J. 91:819-825.

Hauck, R.D., and J.M. Bremner. 1976. Use of Tracers for Soil and Fertilizer Nitrogen Research. Advances in Agronomy 28:219-261.

Jannson, S.L., and J. Persson. 1982. Mineralization and immobilization of soil nitrogen., p. 229-252, *In* F. J. Stevenson, ed. Nitrogen in Agriculture. ASA, CSSA, and SSSA, Madison.

Jenkinson, D.S., R.H. Fox, and J.H. Rayner. 1985. Interactions between fertilizer nitrogen and soil nitrogen- the so-called 'priming' effect. J. of Soil Sci. 36:425-444.

Jensen, B., P. Sørensen, E.S. Jensen, I.K. Thomsen, and B.T. Christensen. 1999a. Availability of Nitrogen in ^{15}N-Labeled Ruminant Manure Components to Successively Grown Crops. Soil Sci. Soc. Am. J. 63:416-423.

Jensen, B., P. Sørensen, I.K. Thomsen, E.S. Jensen, and B.T. Christensen. 1999b. Availability of nitrogen in ^{15}N-labeled ruminant manure components to successively grown crops. Soil Sci. Soc. Am. J. 63:416-423.

Kelling, K.A. 1989. Residual credits from dairy manure applications. New Horizons in Soil Science 2-89. Dept. of Soil Science, Univ. of Wisconsin-Madison.

Kelling, K.A., and R.P. Wolkowski. 1993. Manure agronomic loading rates and nutrient balance., pp. 31-41 *In* Livestock Waste Management Conference, Champagne IL.16 Mar. 1993.

Kelling, K.A., L.G. Bundy, S.M. Combs, and J.B. Peters. 1998. Soil test recommendations for field, vegetable, and fruit crops. UWEX Publ. A2809. Univ. of Wisconsin-Extension, Madison, WI.

Klausner, S.D., V.R. Kanneganti, and B. D.R. 1994. An Approach fo Estimateing a Decay Series for Organic Nitrogen in Animal Manure. Agron. J. 86:897-903.

Motavalli, P.P., K.A. Kelling, and J.C. Converse. 1989. First-Year Nutrient Availability from Injected Dairy Manure. J. Environ. Qual. 18:180-185.

Muñoz, G.R. 2001. Estimate of manure availability using ^{15}N-labeled manure and other techniques., University of Wisconsin, Madison.

Paul, J.W., and E.G. Beauchamp. 1993. Nitrogen availability for corn in sols amended with urea, cattle slurry, and solid and composted manures. Can. J. Soil Sci. 73:253-266.

Paul, J.W., and E.G. Beauchamp. 1995. Availability of manure slurry ammonium for corn using ^{15}N-labelled $(NH_4)_2SO_4$). Can. J. Soil Sci. 75:35-42.

Pratt, P.F., F.E. Broadbent, and J.P. Martin. 1973. Using organic wastes as nitrogen fertilizers. Calif. Agric. 27:10-13.

Sørensen, P., E.S. Jensen, and N.E. Nielsen. 1994. The fate of ^{15}N-labelled organic nitrogen in sheep manure applied to soils of different texture under field conditions. Plant Soil 162:39-47.

Thomsen, I.K., K. V, and B. Jensen. 1997a. Crop uptake and leaching of ^{15}N applied in ruminant slurry with selectively labelled faeces and urine fractions. Plant and Soil 197:233-239.