# NITROGEN AVAILABILITY FROM MANURE IN YEARS FOLLOWING A ONE-TIME APPLICATION

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## INTRODUCTION

The US dairy herd includes 9 million cows which produce an estimated 22 million tons of manure annually. Southern Idaho is a regional dairy center whose herds make up 5.6% of the US total and produce approximately 1.22 million tons of manure annually. The manure is often applied to crop land to supply nutrients to crops, improve soil physical properties, and increase organic carbon (C) concentrations in eroded soils, which are common in this historically furrow irrigated region. To maximize their use of manure and minimize losses of nitrogen (N) to the environment, growers need to know how much N becomes available to crops from manure applications. Though manure is a rich source of plant nutrients, much of its N is in the organic form, only becoming available to crops via the microbially mediated process of mineralization.

*In situ* soil N mineralization measurements better reflect the environmental factors and dynamic conditions that are specific to an individual region or management condition. Lentz et al. (2011) measured seasonal net N mineralization rates for three years after a one-time dairy manure or composted manure application. They reported that 18 to 27% of the 3-yr, cumulative, net N mineralized in manured, southern Idaho soils occurred at the 12-to-24-in depth. Determining how a soil's net N mineralization potential changes in years following a one-time manure application is difficult owing to year-to-year climatic variation, which tends to confound the effect of time on N mineralization (Lentz et al., 2011). Our objective was to determine the effect of year of dairy manure application on net N mineralization in a irrigated, calcareous, southern Idaho soil, while minimizing confounding effects of climate.

## MATERIALS AND METHODS

We conducted the experiment at a site near Kimberly, ID in field plots prepared in Portneuf silt loam soils (coarse silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid). The site last received manure in 1994, 10 yrs before field plot preparations began for the current study. For at least 12-yr prior to the study the field site was planted to a series of crops, which included alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.), wheat/barley (*Triticum aestivum* L./*Hordeum vulgare* L.), and dry bean (*Phaseolus vulgaris* L.).

If one applied manure in one year and measured net N mineralization in the following three years, the comparisons between annual measurements would be influenced not only by the time since application, but also by climatic factors, which vary from year to year. To limit the direct effect of climatic factors during the year in which net N mineralization was measured, we applied manure treatments at a 1x rate (average bulk application rate of 9.7 ton $ac^{-1}$ dry wt. or 277 lbs total N $ac^{-1}$), and a 3x rate (average bulk application of 30.7 tons $ac^{-1}$ dry wt. or 866 lbs total N $ac^{-1}$) once only to a different set of field plots in the fall of each year 2004, 2005, and 2006. Thus, when net N mineralization was measured in 2006, the field plots included a set of two manure-rate treatments that were either 1 or 2 years old (only the two had been included by that date). For the 2007 measurement, the field plots included a completed set of two manure-rate treatments that were either 1, 2, or 3 years old. Finally, when net N mineralization measurements were repeated in the plots for 2009, the manure-rate treatment plots were either 3, 4, or 5 years old. Therefore when net N mineralization was measured in a given year, the included 2- or 3-year application sequence of manure plots had experienced the same climatic conditions in the previous years as well as in the measurement year.

The experimental design was a randomized complete block with 4 replicates of eight treatments (Table 1). The experiment included the six manure treatments and two non-manure treatments, which included, an urea fertilized (Fert) and a control. No N fertilizer was applied to manure treatments, nor was any manure or fertilizer N applied to the control. The Fert treatment received urea-N at recommended rates based on the inorganic N present in the root zone, 0-36 in for beet and 0-24 in for other crops, as measured with a spring pre-plant soil test. No P or K fertilizer was applied to any of the plots. Plots were 30 ft wide by 70 ft long. Manure was always applied in the fall; we obtained solid dairy cattle (*Bos* species) manure that had been stockpiled at a local dairy through the summer. The manure's average total C concentration (standard error) was 21.7% (5.8%), total N was 1.4% (0.26%), and C:N ratio was 15.9 (1.5).

**Table 1. Description of treatments**

| Treatment Name | Treatment ID | Added N source | Bulk Applic. Rate, Dry Wt. (ton $ac^{-1}$) | Year of Application† | Treatment age in yrs when net N mineralization was measured | | |
|---|---|---|---|---|---|---|---|
| | | | | | 2006 | 2007 | 2009 |
| Control | Control | None | 0 | No Applic. | 1 | 1 | 1 |
| Fertilizer | Fert | Urea | 0.13 | Each year | 1 | 1 | 1 |
| | 1x-06 | Dairy Manure | 7.7 | 2006 | -- | 1 | 3 |
| Manure-1x | 1x-05 | Dairy Manure | 14.5 | 2005 | 1 | 2 | 4 |
| | 1x-04 | Dairy manure | 10.2 | 2004 | 2 | 3 | 5 |
| | 3x-06 | Dairy Manure | 25.2 | 2006 | -- | 1 | 3 |
| Manure-3x | 3x-05 | Dairy manure | 34.9 | 2005 | 1 | 2 | 4 |
| | 3x-04 | Dairy manure | 31.9 | 2004 | 2 | 3 | 5 |

Net soil N mineralization was measured in all established plots during the 2006, 2007, and 2009 growing seasons using the buried bag method (described in detail by Lentz and Lehrsch, 2012). This method tracks changes in inorganic N concentration in an isolated soil volume over time. The monitored inorganic N was not subject to leaching or crop removal, and denitrification was minimized. Thus, the obtained Net N mineralization value was equal to the mineralized N less any immobilized. Buried bags were installed at 0- to 12-in depths in all plots and, at 12- to 24-in depths in selected treatments (i.e., control, 1-yr-old manure-3x, and 3-yr-old manure-3x). Each growing season, 3 to 4 buried bags were installed in each plot, starting in the last week in April. Bags were retrieved at six-week intervals, with the last bag recovered in either the third week in September or first week of October. In 2006 an extra bag evaluated the late-fall period. Inorganic N ($NO_3$-N, $NH_4$-N) in the initial and retrieved bag soils was determined using an automated flow injection analyzer. Manure C and N concentrations were determined on a freeze-dried sample with Thermo-Finnigan FlashEA1112 CNS analyzer.

Manure was applied to designated plots on 18 Nov. 2004, 22 Dec. 2005, and 19 Oct. 2006 using a commercial spreader truck equipped with rooster-comb beaters, and was measured in each plot. The field was disked to a depth of 4 in within 48 hours of manure application. The 2005 barley crop was harvested in mid-July. March 2006 soil samples indicated that soil P and K were adequate for the small grain crop. On 13 Apr. 2006 the Fert treatment received 120 lb N $ac^{-1}$ as urea. Barley was planted in late April 2006 and harvested on 20 July. Sugar beet was planted in 2007. Urea was applied to the Fert treatment on 16 Apr. 2007 at the rate of 120 lb N $ac^{-1}$. The field was planted with Poncho-treated sugar beet (cv. BETA 4023R) on 20 Apr. 2007 in rows 22 in apart, with an average in-row spacing of 2.2 in, and later thinned to a population of 47400 plants $ac^{-1}$. The beets were harvested on 10 Oct. 2007. In late May 2008 urea was applied to the Fert treatment at a starter rate of 21 lb N $ac^{-1}$ and the field was planted to bean ('Viva Pink'). The bean crop was harvested on 29 Sep. 2008. In 2009 bean was again planted in the field using the same approach as that used in 2008. Irrigation was supplied via sprinkler to meet the crops' evapotranspiration requirements.

The net N mineralization during the period between burial and retrieval of the buried bags was calculated by subtracting the inorganic N concentration of the initial soil from that of the soil in the retrieved bag. A positive difference indicated net N mineralization, while a negative one indicated net N immobilization during the period. We reported net N mineralization for the *spring* (24 Apr.-15 June); *early summer* (15 June-1 Aug.) and *late summer* (1 Aug.to 17 Sept. or 2 Oct.) periods. The net N mineralized for a 12-in-thick soil layer (termed minN) was reported directly as mg N $kg^{-1}$ soil [multiplying this minN value by 4.0 gives a rough estimate of N in lb $ac^{-1}$]. In addition, net N mineralization values from manure treatments were reported as a percentage (minN%) of the total manure N applied. This was computed for each manure treatment and measurement year as:

$$\text{minN\%} = [(\text{minN}_m - \text{minN}_c) \cdot 10^{-6} \cdot M_{soil}] / TN_m \quad [1]$$

where $\text{minN}_m$ = minN of the manure treatment (mg N $kg^{-1}$); $\text{minN}_c$ = minN of that measurement year's control treatment (mg N $kg^{-1}$); $M_{soil}$ = mass per unit area of a 12-in-thick layer of soil approximated as, $4.48 \times 10^6$ kg $ha^{-1}$; and $TN_m$ = total N applied in the manure (kg N $ha^{-1}$).

We plotted the mean absolute net N mineralization values for 1x and 3x manure rates from each of the three measurement years as a function of time after manure application. To reduce the effect of climate and other factors on the N mineralized each year, data from years 2007 and 2009 were standardized to that of year 2006. To do so, from each of the 2007 amounts we subtracted the difference between the 2006 and 2007 control values. The 2009 data were adjusted in like manner. We also plotted the net N mineralized (as a percentage of total added manure-N) as a function of years since manure was applied. These plotted data were not standardized because the values already accounted for relative differences in measurement-year control values (see Eq. 1).

We examined 0-to-12-in N mineralization data for given reporting intervals separately via ANOVA and pairwise comparisons of treatment means were performed using the Tukey option. Treatment classes, representing a combination of treatments whose responses were averaged together, were compared using orthogonal contrasts. The four class comparisons for the 0-to-12-in N mineralization data were: 1) no manure vs. manure (1x+3x) treatments, where the no-manure class was control+Fert; 2) manure-1x vs. manure-3x treatments across all years; and 3) young manure vs. older manure treatments across both 1x and 3x rates (i.e., manure treatments of year 1 vs. year 2 in 2006, or manure treatments of year 1 vs. those of years 2 and 3 in 2007, or manure treatments of year-3 vs. years 4 and 5 in 2009). For the 12-to-24-in N mineralization data, responses from the control and 3-yr-old manure-3x were similar, so these were averaged together as a class and compared to the 1-yr-old manure-3x responses using an ANOVA. This contrast evaluated the effect of manure treatment age on net 12-to-24-in net N mineralization. All analyses were conducted using a $P$ = 0.05 significance level.

**Table 2. Treatment effects on net N mineralized, expressed as mg N kg$^{-1}$ soil at 0 to 12 in depths for each measurement period and summed across measurement periods for each of three growing seasons (shaded area).**

**2006**

| Source | Treat. Age | 26 Apr-14 Jun | 15 June-1 Aug | 2 Aug-18 Sep | 18 Sep-18 Oct | 26 Apr-18 Oct |
|---|---|---|---|---|---|---|
| | | Net Soil N Mineralized (mg kg$^{-1}$) | | | | |
| Control | 1 | 11.4b† | -0.6a | 3.7ab | -3.2 | 11.4c |
| Fert | 1 | 39.0a | -3.3ab | 8.9ab | -1.8 | 42.8b |
| 1x-06 ‡ | - | - - | - - | - - | - - | - |
| 1x-05 | 1 | 20.2b | -1.3ab | 2.1b | -1.7 | 19.3bc |
| 1x-04 | 2 | 17.6b | -0.3a | 4.1ab | -3.0 | 18.4bc |
| 3x-06 | - | - - | - - | - - | - - | - - |
| 3x-05 | 1 | 51.4a | -4.3b | 13.5a | 0.2 | 60.8a |
| 3x-04 | 2 | 21.7b | -0.4a | 5.6ab | -2.1 | 24.8bc |
| **Contrasts** | | | | | | |
| No Manure | 1,2 | 25.2 | -2.0b | 6.3 | -2.5 | 27.0 |
| Manure | 1,2 | 27.7 | -1.6a | 6.3 | -1.7 | 30.7 |
| Man-1x | 1,2 | 18.9b | -0.8a | 3.1b | -2.4 | 18.8 |
| Man-3x | 1,2 | 36.6a | -2.4b | 9.6a | -1.0 | 42.8 |
| Man y1 | 1 | 35.8a | -2.8b | 7.8 | -0.8 | 40.0 |
| Man y2 | 2 | 19.7b | -0.4a | 4.9 | -2.6 | 21.6 |

**2007**

| Source | Treat. Age | 25 Apr-15 Jun | 15 Jun-1 Aug | 1 Aug-2 Oct | 25 Apr-2 Oct |
|---|---|---|---|---|---|
| | | Net Soil N Mineralized (mg kg$^{-1}$) | | | |
| Control | 1 | 3.8 | 6.8bc | 3.9b | 14.6c |
| Fert | 1 | 8.0 | 6.9bc | 4.7b | 19.6bc |
| 1x-06 | 1 | 8.5 | 12.5a | 11.8a | 32.8ab |
| 1x-05 | 2 | 6.7 | 8.0b c | 9.0ab | 23.7bc |
| 1x-04 | 3 | 6.0 | 8.0abc | 8.5ab | 22.5bc |
| 3x-06 | 1 | 8.8 | 17.6a | 14.9a | 41.4a |
| 3x-05 | 2 | 7.2 | 12.9ab | 8.3ab | 28.5bc |
| 3x-04 | 3 | 8.1 | 10.4abc | 10.6ab | 29.1b |
| **Contrasts** | | | | | |
| No Manure | 1,2,3 | 5.9b | 6.9b | 4.3b | 17.1b |
| Manure | 1,2,3 | 7.6a | 11.6a | 10.5a | 29.7a |
| Man-1x | 1,2,3 | 7.1 | 9.5b | 9.7 | 26.3b |
| Man-3x | 1,2,3 | 8.0 | 13.6a | 11.3 | 32.9a |
| Man y1 | 1 | 8.7 | 15.1a | 13.3a | 37.1a |
| Man y2,y3 | 2,3 | 7.0 | 9.8b | 9.1b | 26.0b |

**2009**

| Source | Treat. Age | 21 Apr-15 Jun | 15 Jun-1 Aug | 1 Aug-17 Sep | 21 Apr-17 Sep |
|---|---|---|---|---|---|
| | | Net Soil N Mineralized (mg kg$^{-1}$) | | | |
| Control | 1 | 7.2b | 6.5 | 4.1 | 17.8b |
| Fert | 1 | 8.2ab | 14.2 | 4.3 | 26.7b |
| 1x-06 | 3 | 10.3ab | 7.8 | 7.1 | 25.2b |
| 1x-05 | 4 | 8.8b | 10.7 | 4.1 | 23.6b |
| 1x-04 | 5 | 8.4b | 9.3 | 5.8 | 23.5b |
| 3x-06 | 3 | 12.0a | 11.7 | 9.2 | 32.9a |
| 3x-05 | 4 | 8.9b | 11.0 | 3.7 | 23.6b |
| 3x-04 | 5 | 9.3b | 10.7 | 5.3 | 25.3b |
| **Contrasts** | | | | | |
| No Manure | 3,4,5 | 7.7b | 10.4 | 4.2 | 22.3 |
| Manure | 3,4,5 | 9.6a | 10.2 | 5.9 | 25.7 |
| Man-1x | 3,4,5 | 9.2 | 9.3 | 5.6 | 24.1b |
| Man-3x | 3,4,5 | 10.1 | 11.1 | 6.1 | 27.3a |
| Man y3 | 3 | 11.1a | 9.8 | 8.2a | 29.1a |
| Man y4y5 | 4,5 | 8.9ba | 10.4 | 4.7b | 24.0b |

† Treatment means or means for individual contrast pairs followed by the same lower case letter are not significantly different ($P$<0.05). Letters are not displayed if ANOVA was not significant.

‡ Treatments: defined in Table 1. Contrasts: Manure y1, y2, y3, y4, y5 = manure fall applied either 1, 2, 3, 4, and 5 years in the past, respectively.

## RESULTS AND DISCUSSION

*0-to-12 in Soil Depth.*

Treatment effects on the absolute net N mineralization response were highly significant for most measurement periods and for the cumulative net N mineralized for the 2006, 2007, and 2009 growing seasons (Table 2). The contrast tests further established that 1) the net N mineralization for manure treatments taken as a group was 1.1 to 2.4x greater than non-manure treatments, although differences were significant only for 50% of the periods monitored; 2) net N mineralization for manure-3x treatments exceeded that for manure-1x, but the difference was greater for young applications (1.9 to 3.1x) than for older (1.2x); and 3) generally the net N mineral-ization from younger manure appli-cations exceeded that of older, but the difference decreased as the average age of the compared treatments increased (e.g. man-y1 produced 1.9x more cumulative net mineralized N than man-y2, but man-y3 produced only 1.2x more than man-y4,y5 (Table 2).

The control generally produced 25 to 80% less net mineralized N during the growing season than either the Fert or manure treatments (Table 2). Fur-thermore, the cumulative growing-season mineralized N produced by manure treatments generally did not differ from the Fert treatment. The exception was the 1-year-old manure-3x

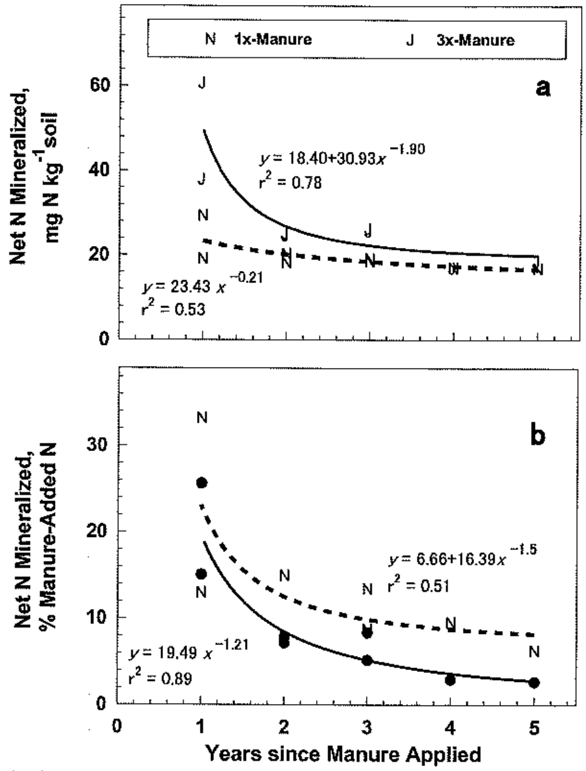


**Fig. 1. The effect of the applied-manure age on the net N mineralized at the 0-to-12 in. depth during the growing season, as measured in 2006, 2007, and 2009. Net N mineralization is presented as mg N mineralized per kg soil—standardized relative to the N mineralized in 2006 (a), or relative to the total amount of manure-N applied (b)**

treatment, which pro-duced 1.4 to 2.1x greater net mineralized N across the growing season than Fert.

The season-long net N mineralization for the control treatment was greater in 2007 and 2009 compared to 2006 (Table 2), most likely due to differences in temperature, moisture, and crop conditions, which influenced microbial activity. In addition, the pattern of net N mineralization produced by all treatments across the measurement periods differed for 2006 relative to 2007 and 2009. In 2006, net N mineralization peaked during spring followed by immobilization in early summer, whereas in subsequent measurement years net N mineralization amounts were more evenly distributed over the growing season. We attribute the 2006 spring mineralization maximum to the combined effect of abundant precipitation (1.4x average value) and warmer-than-normal temperatures in spring 2006. In contrast, spring precipitation in 2007 and 2009 was below normal.

*Effect of Application Year.*

After the one-time manure application the growing-season net N mineralization decreased with time, although the pattern of this decrease varied depending upon whether the net N mineralization was reported in absolute (Fig. 1a) or relative terms (Fig. 1b). The absolute net N mineralization declined as a exponential or power function in time, with the fitted curve for the manure-3x starting at a greater value for year 1 and declining more steeply than the manure-1x application (Fig. 1a). After the 3$^{rd}$ year the curves are much closer but offset such that the predicted (or fitted) manure-3x values consistently exceed those of manure-1x by approximately 3 mg N kg$^{-1}$.

The fitted curves in Fig. 1b describe the effect of application time on net N mineralization given as a percent of total manure-N applied. They indicate that a greater proportion of total manure-N became available in 1x- than in 3x-manure treatments. The fitted slopes of 1x- and 3x-manure treatments at year five suggest that net N mineralization might either continue to slowly decline or possibly plateau in subsequent years. For both sets of curves (Fig. 1a,b), the smaller $R^2$ values associated with 1x-manure treatments indicate that other factors besides application year have a substantial impact on net N mineralization after application. These may well be related to differences in manure characteristics that influence short-term mineralization and immobilization rates, particularly in the first year after manure application.

From the functions describing the change in relative net N mineralization (Fig. 1b) we derived a five-year decay series for each of the two manure rates applied in this study. These decay series represent the fraction of total manure-N applied that would be available for crop use in year one through five after a single manure application. The decay series was 0.23, 0.12, 0.10, 0.09, and 0.08 for the manure-1x, and 0.20, 0.08, 0.05, 0.04, and 0.03 for the manure-3x.

*Net N Mineralization at 12-to-24 in Soil Depth.*

The 3-yr-old manure-3x and control treatment responses were more similar to each than to the 1-yr-old manure-3x. The contrast test indicated that the early summer net N mineralization for the 1-yr-old manure-3x was -3.3 mg $kg^{-1}$ vs. 0.8 for the combined control and 3-yr-old manure-3x treatment class ($P$=0.03). As a result, during the growing season, the 1-yr-old 3x manure produced only about 1/10$^{th}$ the net mineralized N as that produced by the control and older manure treatment class (0.6 mg $kg^{-1}$ vs. 6.4, $P$=0.05). The fresh manure contained more soluble, readily metabolized organics than did the 3-year-old manure or control soils. When this soluble carbon was leached into the C-poor soils at 12-to-24-in depth, it was metabolized and much of the available inorganic N was incorporated into microbial tissue. In the older manure and control plots, less soluble C leached into the deeper soils and immobilization processes were inhibited.

The net N mineralized in the 12-to-24-in soil during the growing season for 1-year-old 3x manure was -1.7% of the total manure-N applied compared to 2.4% for the 3-year-old 3x manure (data not shown). Therefore, the contribution of the 12-to-24-in soil layer to overall net N mineralization in the entire uppermost 60-cm of the profile during the growing season was -9% for the 1$^{st}$ year after application and 28% for the 3$^{rd}$ year (data not shown). This confirms an earlier observation made by Lentz et al. (2011), namely that the 12-to-24-in depth plays a substantial role in both the immobilization and mineralization of N in these soils.

## CONCLUSIONS

Growers in semi-arid, irrigated regions can better estimate the quantity of N available to crops grown in fields treated with stock-piled dairy manure using this study's findings. A decay series was derived for each of two one-time manure application rates, 1x (9.7 ton $ac^{-1}$ dry wt.) and 3x (30.7 ton $ac^{-1}$). The fraction of applied manure-N that became available from net N mineralization in the years after application differed between the two manure rates, revealing that N mineralization efficiency varied inversely with manure application rate. Uncertainties related to net N mineralization prediction were greatest for the lesser application rate, particularly in the first year after application. These differences may be related to variations in manure characteristics, such as C, N, or labile, soluble organic carbon concentrations that affect short-term manure mineralization and immobilization dynamics. At greater application rates variation in manure characteristics have a lesser relative effect, which may partially explain the greater uncertainties associated with 1$^{st}$ year 1x-manure application relative to the 3x-manure. A single decay series describing the fraction of applied manure N that becomes available to crops in succeeding years is often used to predict N availability. Our results indicate, however, that a single decay series would not accurately predict N availability over a range of manure application rates.

## REFERENCES

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