IMPACT OF MANURE CHARACTERISTICS AND MANAGEMENT ON NITROGEN MINERALIZATION

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ABSTRACT

Estimation of N mineralization rates from manure is essential for calculation of agronomic rates of manure application. The objectives of this research include prediction of the rate and amount of N mineralized from manure based on its physical and chemical characteristics, and evaluation of the impact of manure management practices on N mineralization. In incubation studies, mineralization rate was better predicted than the potentially mineralizable N. In addition to the C:N ratio of the manure, its acid detergent fiber content was shown to be an important predictive variable in both laboratory and field studies. Field studies showed that applying manure in the fall provided over six times the amount of mineral N for crop needs at corn's six-leaf stage (the beginning of rapid N uptake) than spring application. Crop residue on the soil surface resulted in greater mineralization rates, probably due to a mulching or insulating effect that resulted in higher soil temperature and greater soil moisture. Incorporation did not significantly affect N mineralization rates in an irrigated system with spring-applied manure. Irrigated plots had higher mineralization rates than that of dryland systems, especially between six-leaf stage and tassel. Although our ability to predict N mineralization rates is improved based on these studies, it is still essential to follow-up on manure application with subsequent soil testing to factor in the remaining uncertainty.

OBJECTIVES

Farmers often over-apply manure to cropland due to uncertainty about N mineralization rates from animal manures. Improving our ability to predict N mineralization based on manure characteristics and management practices could improve farmer confidence in published mineralization rates and lead to more accurate estimates of manure application rates that meet crop needs without causing water quality problems. The objectives of this research include:

1) prediction of the rate and amount of N mineralized from manure based on its physical and chemical characteristics, and
2) evaluation of the impact of manure management practices on N mineralization.

METHODS

Laboratory Incubations

A large-scale manure survey (n=137) was completed throughout Colorado in order to compare actual nutrient values with published table values (Davis et al., 2002). A variety of chemical and physical assays were conducted on all manure samples: inorganic N, soluble organic N and C, total N and C, lignin, acid detergent fiber, neutral detergent fiber, cellulose, and hemicellulose. Twenty of these manure samples (including dairy, beef, horse, pig, turkey, chicken, sheep, and llama manures) were selected for this incubation study to obtain a wide range in physical and chemical manure characteristics (Smith, 2002).

Two soils were used: Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustoll) and Valent sand (mixed, mesic, Ustic Torripsamment). Fifteen grams of soil were mixed with 0.23 g (~10 tons dry manure/acre) of each manure (oven dried at 60°C), mixed with 15 g of acid-washed sand, and packed into 60 mL leaching tubes using the method of Vigil and Kissel (1995) as modified from Stanford and Smith (1972). Leaching tubes were placed in a humidity chamber inside a precision incubator at optimal microbial conditions of 30°C and near a soil water-filled-porosity of 55%. Each treatment and controls (soil without manure) were replicated four times. Leach tubes were periodically leached with 0.01 M $CaCl_2$, and NO_3-N and NH_4-N were analyzed in the leachate. The incubations lasted at least 127 days. Net N mineralization (N_{min}) was calculated by subtracting the N_{min} from unamended soil from the N_{min} in amended soil. The cumulative N mineralized was fitted to a single exponential model:

$$N_{min} = N_o(1-e^{-kt}),$$

where N_o=potentially mineralizable N, k=rate constant, and t=time.

***In situ* N mineralization**

Five of the 20 manures used in the incubation study were selected for a field study, in addition to a control with no manure applied (Jakubowski, 2001). Each manure was kept frozen, then run through a meat grinder twice and mixed well to provide a homogenous sample. The ground manures were weighed out wet to simulate application rates of 26.4 Mg dry manure ha^{-1} (12 dry tons per acre) to be applied to aluminum conduit tubes measuring 5 cm in diameter by 15 cm long, filled with 12.5 cm Weld silt loam.

Bags were installed in the bottom of each tube to capture ions leaching from the soil core. These bags were made from Lycra® material and filled with 20 mL of ion-exchange resin, consisting of equal amounts of Na-saturated cation (US Filter C-211) and Cl-saturated anion (US Filter A-464) exchange resin.

Each treatment was replicated three times in an irrigated corn field with five sub-samples per replicate. The manures were applied after the tubes were driven into the soil and then withdrawn. The manure was mixed into the top 2.5 cm of the soil, and the resin bag was placed in the bottom 1.5 cm of the tube and held in place with a nylon retainer cloth. The tubes were then reinserted into the soil with approximately 1 cm of the tube remaining above the surface.

Removal times of 3, 6, 20, and 45 weeks after tube installation were scheduled. Both soils and resin bags were extracted with 2 N KCl and analyzed for NO_3-N and NH_4-N concentration. Net mineralization on a soil mass basis was then calculated as:

Net manure N mineralized = (treatment soil inorganic N + treatment resin inorganic N) - (control soil inorganic N + control resin inorganic N)

The experiment was set up as a split plot in time design with three replications and five sub-samples per replicate. The manure treatments were designated whole plots, and the removal dates were sub-plots.

A second field study evaluated manure management impacts on N mineralization under irrigated and dryland conditions on a Weld silt loam. Treatments were designed to evaluate manure application timing, the presence of crop residue, manure incorporation, and dryland vs. irrigated conditions. There were 10 replicates each for the irrigated and dryland plots. In each replicate, one manured tube and one control tube for each treatment were inserted into the soil in the corn rows.

Soil core removal and tube installation was performed in the same manner as in the first experiment. The beef feedlot manure was applied at a rate of 26.4 Mg dry manure ha^{-1} (12 dry tons per acre) and 496 kg N ha^{-1}. To simulate residue, wheat stubble was collected, cut into 0.5 cm lengths and applied at a rate of 5500 kg ha^{-1}. To simulate surface manure applications, the manure sample was stirred into the upper 1.5 cm of the soil core. For incorporated manure simulations, the soil core was emptied into a bucket, mixed with the manure sample and repacked. Tubes were installed in November and April to evaluate fall and spring manure applications. Growth stages for the corn plants dictated when the tubes were removed from the field. This was done to determine the availability of inorganic N at critical stages (V6 and tassel) of the plants' growth cycle. The pre-plant date was intended to help quantify N_{min} rates over the winter months.

RESULTS AND DISCUSSION

Manure Characteristics

The single-pool, first-order model applied to the incubation study resulted in R^2 values ranging from 0.75 to 0.99. However, the mean square errors were high for many of these models. The N_o values ranged from 74 to 516 mg/kg in the Weld soil and 22 to 261 mg/kg in the Valent soil. The k values ranged from -0.076 to -0.002 in the Weld soil and -0.163 to -0.005 in the Valent soil. Several of the samples became anaerobic during the initial incubations and were re-run. Then R^2 values increased to range from 0.89 to 0.99, and mean square errors were lower, but would still be considered high. The ranges in N_o and k were also narrowed in the repeat incubations. The single-pool, first-order equation did not fit nine out of the 40 manure:soil combinations in the original incubation, but did fit nine out of ten of the re-run incubations.

Next, we attempted to predict N_o and k from all incubations as a function of manure characteristics. In every case, regressions were significant at $p<0.0001$. The highest R^2 values were obtained by analyzing data separately for each soil. However, the best-fit models often had C_p values that were considerably higher than the number of parameters in the model, indicating that the models were poor. A three or four parameter model cannot explain the variability in potentially mineralizable N (N_o) from two soils and a variety of manures as used in this incubation study ($R^2<0.50$). The rate constant k was better predicted, resulting in 55% and 59% of the variability explained using three and four parameter models, respectively. The parameters of importance in the k predictions included C:N ratio, soluble C, soluble N, total N, and acid detergent fiber.

We also evaluated carbon mineralization in these incubations, and both the rate of C mineralization and the total pool of mineralizable C were predictable with R^2 values of 0.85 and 0.83, respectively, using only total C and N, NDF, and ADF as independent variables. Therefore, the predictability of C mineralization under ideal conditions was considerably greater than that for N mineralization.

Our field study demonstrated mineralization patterns similar to those of Chae and Tabatabai (1986) with an immobilization or lag period of 6 weeks, a sharp increase of N_{min} between 6 and 20 weeks, and minimal change in the release of mineral N from 20 to 45 weeks. It is known that higher C/N ratios result in lower N_{min} rates. In this study, C/N was significantly correlated with N_{min} ($p = 0.0001$, $r=-0.24$). However, other factors may help to develop better predictive relationships with N_{min} on manure-amended soils. Acid detergent fiber (ADF) was highly correlated with N_{min} ($p=0.0001$, $r=-0.33$), and ash content could possibly be used to predict N_{min} ($p=0.18$, $r=-0.08$), as well. Neutral detergent fiber (NDF) did not correlate as well with N_{min} as the other factors (p=0.38, r=0.05). Thus, ADF was shown to be an important predictive variable in both the laboratory and field studies.

To illustrate this, a beef manure had a slightly lower C/N ratio (10.9) than the hog manure (11.7), but net N_{min} was significantly lower for the beef manure. Fiber and ash content may help explain the differences. The beef manure's ADF content (65%) was higher than the hog manure (38%), and the beef manure also had a higher ash content (56% as compared to 44%). Utilizing C/N, ADF and ash content may enable researchers to make more accurate predictions of N_{min} at the field scale.

Manure Management

Application timing did not have a significant impact on N_{min} in the irrigated plots at either V6 or tassel. However, for the dryland plots, the overall comparison was significant at α=0.05 (p=0.0009) at V6. We measured 83 kg ha^{-1} more N_{min} for the fall applied manure than the spring applied manure (p=0.0004) at V6. At tassel, the difference in N_{min} was only 15 kg ha^{-1}, with no statistical significance (p=0.44). Nitrogen mineralization for the fall applied manure in both the dryland and irrigated plots reached a maximum near V6 then leveled off after that. Conversely, the spring applied manure had relatively low N_{min} at V6, then increased sharply between V6 and tassel, especially under dryland conditions. Applying manure in the fall is better than applying manure in the spring, from a crop nutrition point of view. Applying manure in the fall provided over 6 times the amount of mineral N for crop needs at V6 than the spring application. This is important because, V6, which occurs about 1 month after emergence, marks the beginning of rapid growth and increased N uptake by the roots of the corn plant. However, high N availability in the spring may lead to greater N transport to water bodies through leaching and runoff.

The effect of wheat stubble residue on N_{min} was evaluated on spring-applied manure in a dryland system. Overall, the N_{min} from wheat residue vs. no wheat residue treatments was not significantly different at α=0.05 (p=0.18). At V6, we measured a difference of 9 kg ha^{-1}, but this was not significant. At tassel, however, the difference of 46 kg ha^{-1} was significant (p=0.02). Over time, however, the residue treated manured soils demonstrated a significant increase of N_{min} from V6 to tassel (+55 kg ha^{-1}, p=0.006), while the non-residue treated incubations did not (-1 kg ha^{-1}, p=0.97). Our initial expectations for this experiment were different than the results. Instead of greater immobilization rates occurring because of the large carbon source of the residue, greater mineralization rates resulted. Greater N_{min} rates may have occurred due to the mulching effect that the residue may have had. The residue may have insulated the manure from extreme temperatures and environmental conditions (e.g. wind and heavy rain). The residue may have also enhanced soil moisture storage (Aiken et al., 1997). Both of these factors could have provided an environment favorable for microbial growth and activity, which in turn mineralized the manure at an increased rate. Therefore, in a dryland situation, having residue on the surface would be beneficial for more efficient breakdown of land applied animal wastes and greater release of NO_3-N and NH_4-N for crop uptake.

We examined how incorporating spring-applied manure into the soil affected N_{min} in an irrigated system. The irrigated surface application vs. incorporation comparison was not significant overall (p=0.36). The two treatments had an estimated difference of 50 kg ha^{-1} at V6 (p=0.18) and converged at tassel with an estimated difference of 1 kg ha^{-1} (p=0.98). The data suggests that in an irrigated system, the overall difference in N_{min} rates may not be greatly affected by incorporation.

This study compared dryland and irrigated plots, both with spring, surface applied manures and no wheat residue. At V6, the two treatments were quite similar ($p=0.74$). However, we measured a difference in N_{min} of 55 kg ha^{-1} at tassel which was significant ($p=0.03$). The data suggests that irrigated systems, which demonstrated an increase of 75 kg ha^{-1} from V6 to tassel ($p=0.052$), will have higher N_{min} rates than that of dryland systems, particularly in the latter stages of mineralization.

These *in situ* measurements ranged from 20-25% N_{min} within the first field season after manure application, considerably less than the 40% as published in our extension publications (Waskom and Davis, 1999). Overall, the studies indicate that N_{min} rates for manure-amended soils are variable and are affected by many factors: manure characteristics, soil temperature, soil water content, tillage practices (conventional or no-till), manuring practices (surface applied or incorporated), and residue content. It is essential to follow-up on manure application with subsequent soil testing to factor this variability into the following year's recommendations.

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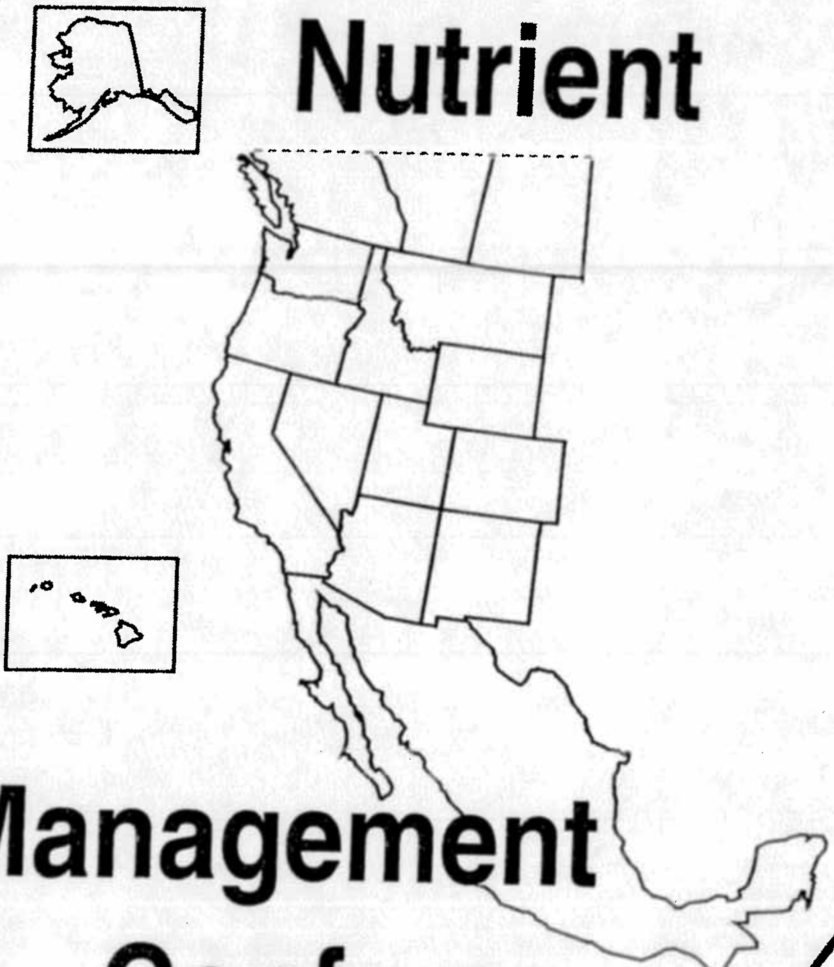

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