Evaluation of Nitrogen Availability from Raw and Treated Dairy Manures

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Abstract
There is minimal information on the composition of and amounts of potentially available nitrogen from treated manures. Knowing how nitrogen (N) availability differs with manure treatment will result in better N crediting guidelines. Twenty different dairy manures were sampled from five dairy farms and include raw, anaerobically digested before and after liquid-solid separation, non-digested separated liquids and solids, and composted bedded pack manures. The manures were incubated with five representative Wisconsin soils for 112 d. Manure potentially available N (PAN) differed by manure type and by soil. Generally, the treated liquids had significantly more (P<0.05) PAN than the raw liquids and the solids had significantly less (P<0.05) PAN than the raw liquids. N was immobilized in several of the solid manure types evaluated. The manure characteristics best correlated with PAN were acid detergent fiber (ADF) to total N (TN) ratio, neutral detergent fiber (NDF):TN, and NH_4-N:TN (r=-0.94, -0.93, and 0.90, respectively, p<0.0001). Using linear regression, PAN was best predicted by a model including NH_4-N:TN and organic N concentrations in manure as terms. This equation may assist in refining current University of Wisconsin-Extension first-year N availability estimates of treated, untreated, solid and liquid manures.

Key words
Potentially available nitrogen, dairy manure, nitrogen mineralization, nitrogen immobilization

Introduction
On-farm manure treatment systems are increasing in popularity among producers in the USA for various reasons, including more efficient transportation and storage along with reduced odor and lower pathogen levels in treated manure. Such treatment systems (anaerobic digestion, composting, and liquid-solid separation) alter the chemical and physical properties of manure, from nutrient concentrations to particle size and moisture content (Castellanos and Pratt 1981; Douglas and Magdoff 1991; Gordillo and Cabrera 1997; Shi *et al*. 1999; Chantigny *et al*. 2008; de Boer 2008). These properties have the potential to affect plant available nutrients when the manure is applied to agricultural fields.

Research on N availability of emerging dairy manure treatment systems is sparse. Additional research is necessary to determine if nitrogen availability guidelines should be modified to consider manure treatment or manure characteristics. The objectives of this study were: 1) to determine how much potentially available nitrogen (PAN) and N mineralization differs between raw and treated manures, 2) to assess manure compositional effects on PAN and N mineralization, and 3) to construct a model to predict potential N availability with various manure characteristics.

Methods
A laboratory incubation was conducted where five soils (four silt loams and one sand) were amended with 20 different raw and treated manures from five farms. Selected manure properties are provided in Table 1. Each manure was mixed with 40 g of each soil at a rate of 150 mg total N/kg with four replications except for two treatments, RW-RL and RW-SeL, where manure was applied at 100 mg total N/kg soil, because the large amount of liquid manure needed at the 150 mg total N/kg application rate would have created soil conditions greater than 60% water filled pore space. There was also an untreated control for each soil. Treated soils were incubated at 25°C for 112 days; moisture was maintained between 40 and 60% water filled pore space. At the end of the incubation soils were immediately air-dried. Ground soils samples were extracted with 2 M KCl in a 1:10 soil to solution ratio for one hour, filtered through Whatman no. 2, and analyzed for NH_4^+-N (Keeney and Nelson 1982) and NO_3^--N (Doane and Horwáth 2003).

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Table 1. Selected manure characteristics and percent of total manure N that is potentially available averaged over five soils.

Farm-manure	Manure type	Total N	NH_4-N	Dry matter	NDF†	Total C: Total N	$\%PAN_m$ ‡
		—— (g/kg dry matter) ——					(%)
5S-RL	Raw liquid	37.7	16.2	67	542.6	11.4	33.4 b§
5S-DL	Digest liquid	51.0	25.1	47	453.2	7.6	43.5 ab
5S-DSeL	Digested separated liquid	71.3	38.4	31	210.9	5.4	52.2 a
5S-DSeStL	Digested separated stored liquid	67.1	36.1	33	261.7	5.7	48.1 a
5S-DSeS	Digested separated solid	15.7	0.5	326	804.8	29.9	-14.6 d
5S-DSeCuS	Digested separated cured solid	21.7	1.7	323	790.3	20.5	0.4 c
CH-RL	Raw liquid	39.7	20.7	49	450.7	9.7	38.9 b
CH-DL	Digested liquid	79.3	52.5	26	200.9	4.6	57.6 a
CH-DSeL	Digested separated liquid	38.5	20.4	75	474.8	8.3	48.6 ab
CH-DSeS	Digested separated solid	21.8	5.4	262	721.9	19.9	17.0 c
RW-RL	Raw liquid	51.7	30.1	25	448.1	9.3	46.4 b
RW-SeL	Separated liquid	114.5	87.3	10	154.8	3	59.4 a
RW-SeStL	Separated stored liquid	112.1	32.1	28	517.6	5.2	46.1 b
RW-SeS	Separated solid	15.5	2.8	167	847.9	30.3	-15.6 d
RW-SeCoS	Separated composted solid	28.4	1.2	247	734.7	14.9	9.5 c
NP-CBP1	Compost bedded pack 0-30 cm	19.8	0.6	397	814.0	23.4	-13.3 b
NP-CBP2	Compost bedded pack 31-60 cm	23.1	5.4	377	814.0	18.7	9.3 a
NP-CBP3	Compost bedded pack 61-90 cm	21.3	4.6	383	725.4	18	12.5 a
MRS-RS	Raw solid-Scrape alley	30.7	15.0	138	780.6	2.2	41.8 a
MRS-RSA	Raw solid-Approachment	16.1	5.0	243	602.3	7.4	-2.8 b

† NDF, neutral detergent fiber.
‡ $\%PAN_m$, percent of total manure N that is potentially available N.
§ Within a farm, $\%PAN_m$ is significantly (P<0.05) different between manures with different letters.

Because two N application rates were used, all results were converted into percentages of total N applied. PAN from the soil and manure as a percent of total N applied ($\%PAN_{m+s}$) was calculated as the sum of the NH_4^+-N and NO_3^--N concentrations divided by the application rate by the equation:

$$\%PAN_{m+s} = [(NH_4^+\text{-N} + NO_3^-\text{-N})_{treated,}/ \text{total N applied}] \times 100 \qquad \text{Eq. [1].}$$

$\%PAN_{m+s}$ includes mineral N added with the manure and manure organic N that mineralized during the incubation as well as N that mineralized from the soil. PAN from the manure only ($\%PAN_m$) is given as a percent of total N applied and was calculated as the inorganic N concentration in a treatment minus the inorganic N concentration in the control samples divided by the total N applied, as given the equation:

$$\%PAN_m=\{[(NH_4^+\text{-N} + NO_3^-\text{-N})_{treated} - (NH_4^+\text{-N} + NO_3^-\text{-N})_{control}]/\text{total N applied}\}\text{x}100 \qquad \text{Eq. [2].}$$

Note $\%PAN_m$ includes both mineral N added with the manure plus the manure organic N that mineralized.

A mixed model for a completely randomized design was used to assess the affect of manure treatment and soil type on PAN_m at the end of the incubation (PAN_m) with manure considered a fixed effect and soil a random effect. Mean separations were performed using Tukey's HSD with α=0.05. A t-test was used to determine if means of $\%PAN_m$ were significantly (P<0.05) different than 0 or 40%. Relationships between $\%PAN_m$ and manure characteristics were assessed by correlations. Stepwise multiple linear regression was used to determine the equations that best predicted $\%PAN_m$. Mallow's Cp statistic was calculated to determine the best number of parameters to include in the linear regression equations.

Results

The $\%PAN_m$ was analyzed for all soils combined at each dairy individually. At the 5S Dairy digested separated liquid (5S-DSeL) and digested separated stored liquid (5S-DSeStL) manure had significantly (P<0.05) greater

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

%PAN_m (52.2 and 48.1%, respectively) compared to the raw liquid (5S-RL; 33.4%); while %PAN_m for the digested liquid (5S-DL) prior to separation (43.5%) was not different than the raw or digested separated liquids (Table 1). The digested separated solid (5S-DSeS) manure immobilized N as evidenced by the negative value for %PAN_m (-14.6%). Curing (not active composting) the digested separated solid (5S-DSeCuS) reduced the total C (TC):TN ratio and resulted in %PAN_m of 0.4%, which was not significantly different than zero. Atallah *et al.* (1995) found that increasing storage time of cattle manure decreased N immobilization by increasing the stability of organic matter, explaining why curing of digested separated solids increased %PAN_m in the present study.

Percent of PAN_m from the digested liquid at the CH Dairy (CH-DL) was significantly greater than the raw liquid (CH-RL) (57.6 and 38.9%, respectively). Unlike the 5S Dairy, %PAN_m from the digested separated solid at CH dairy (CH-DSeS) (17.0%) was significantly less than %PAN_m from the raw liquid but was significantly greater than zero which is in contrast to the 5S Dairy. The digested separated solids immobilized N at 5S Dairy but not at CH Dairy. This difference might be attributed to 5S Dairy adding 10% fats to the anaerobic digester to improve biogas yield; addition of high C, low N material such as fat would decrease %PAN_m if the fat were not completely digested.

The treatment system at the RW Dairy consisted of a liquid-solid separator only. The separated liquid sampled immediately after separation (RW-SeL) had the greatest %PAN_m at 59.4%. The raw liquid (RW-RL) and separated stored liquid (RW-SeStL) had nearly identical %PAN_m, which is not surprising considering the neutral detergent fiber (NDF), dry mater, and NH_4^+-N concentration were similar as well. The separated solids (RW-SeS) initially immobilized N, but after composting (RW-SeCoS), %PAN_m was 9.5%. During the composting process the TC:TN ratio of the solid was reduced by 50% and the NDF was reduced.

In a composted bedded pack system, bedding is added to the barn daily and the pack is actively composted by aerating it daily to a depth of about 30 cm. The pack was sampled in 30 cm increments prior to cleaning the barn. Percent of PAN_m from the bottom two depths of the pack (NP-CBP2, and NP-CMP3) were not significantly different from each other and were significantly less than 40%, but were significantly greater than %PAN_m from the first depth (NP-CBP1) where N was immobilized. The composting process for the first depth was not as complete as the lower two depths as evidenced by the greater TC:TN ratio and lower NH_4-N concentration.

Two raw solid manures from MRS Dairy were also evaluated with %PAN_m from the scrape alley (MRS-RS) (41.8%) being significantly greater than manure from the approachment (MRS-RSA) which immobilized N (%PAN_m of -2.8%). The large difference in %PAN_m with these two raw solid manures is related to the large amount of straw that was visible in the approachment manure (MRS-RSA).

Manure separation is very influential on %PAN_m with or with anaerobic digestion as a pre-treatment. Liquid-solid separators are effective in creating a separate liquid that has significantly lower dry matter, NDF, and TC:TN ratio along with greater NH_4^+-N concentration as a percent of TN compared to raw manure, which results in increased %PAN_m, while the separated solids have opposite properties and reduced %PAN_m. Using correlation analysis for all manures, %PAN_m was significantly (P<0.05) correlated to dry matter, NDF, TN, ADF, and NH_4^+-N (r = -0.83, -0.82, 0.81, -0.80, and 0.78, respectively) along with other parameters however correlation coefficients were less. The negative correlations between %PAN_m and NDF and ADF indicate that the greater the concentration of lignin, cellulose, and hemicellulose in manure creates greater microbial demand for N, subsequently reducing %PAN_m.

In an effort to provide a better prediction of %PAN_m, which could be used by farmers to credit manure N against crop needs, multiple regression analysis was used to develop a predictive model. A two-term model was determined to be superior to either a one or two term model. There were three good two-term models; parameters and R^2 values were: 1) ADF:TN + TC:organic N (ON) (R^2=0.913), 2) NDF:TN + TC:ON (R^2=0.915), and 3) NH_4^+-N:TN + ON (R^2=0.875). These three models were evaluated in a method similar to Doerge and Gardner (1988) to evaluate error and bias of predicted vs actual %PAN_m. While the third model had the lowest model R^2, predicted values with this model had the greatest correlation coefficient (r=0.93) with

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actual values compared to the first (r=0.90) and second (r=0.84) models. In addition, the first two models included parameters, NDF and ADF, which are not routinely analyzed for manure. The third equation might be a more practical estimation of $\%PAN_m$ because all the parameters are routinely analyzed on manure samples and the predicted $\%PAN_m$ most closely matched actual $\%PAN_m$. The complete third equation is: $\%PAN_m = 92.6* NH_4^+\text{-N:TN} + ON - 30.3$.

Conclusions

Manure treatment significantly affects $\%PAN_m$ compared to raw manure; in general, treated liquid manures have greater and treated solid manures have lesser $\%PAN_m$. University of Wisconsin-Extension guidelines assume that 40% of TN is available if manure is incorporated, regardless of manure type, handling, and/or treatment. These data suggest that manure N availability guidelines should be updated to be applicable for all manure types. Results from this study suggest that $\%PAN_m$ might be predicted using NH_4^+-N:TN and ON. Further research is required to validate this research in a field setting.

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