

# **Nitrogen Dynamics in Manured Saskatchewan Soils**

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## **Introduction**

The behavior of manure nitrogen in Saskatchewan soils is of agronomic and environmental interest. The value of manure as a fertilizer is most often considered in its role as a nitrogen source for crop growth, although other nutrients such as phosphorus can also contribute to crop response (Schoenau et al., 1999; Olson and Papworth, 1999). Concerns surrounding the use of manures as fertilizers include the fate of excess nitrogen lost from the soil through leaching and gaseous evolution. The objective of this paper is to consider our current state of understanding of the behavior of manure nitrogen added to Saskatchewan soils.

## **Manure Nitrogen**

Knowing the amounts and forms of nitrogen in manure is critical when attempting to predict its behavior in the soil environment. Both inorganic nitrogen (immediately plant available nitrogen) and organic nitrogen (total minus inorganic) concentrations should be known and are a key measurement made by laboratories involved in manure testing.

The inorganic nitrogen in manure potentially exists in the forms of ammonium ( $\text{NH}_4^+$ ) and nitrate ( $\text{NO}_3^-$ ). This inorganic nitrogen is immediately available for plant uptake, similar to commercial inorganic nitrogen fertilizers. Ammonium tends to dominate over nitrate, with little or no detectable nitrate present in the liquid swine effluent and solid cattle manures used in our field trials in Saskatchewan (Schoenau et al., 1998), consistent with observations of other researchers (Chang and Entz, 1996; Paul and Beauchamp, 1994). Dominance of ammonium as the inorganic nitrogen form in manures

can be attributed to low rates of conversion of ammonium to nitrate (nitrification) and the instability of nitrate in anaerobic storage conditions. For liquid swine effluents, we have encountered a range of total nitrogen contents from about 15 lbs total N / 1000 gallons to upwards of 50 lbs total N / 1000 gallons in some high solids effluents. Of this total N, from 90% to about 30% is found to be comprised of ammonium, with the lowest proportions in effluents with high solids content (Table 1).

Table 1. Nitrogen composition of two liquid swine effluents sampled from two earthen storage units during application in spring 1999.

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	<b>High Solids</b>	<b>Low Solids</b>
Total N	30 lb / 1000 gal	19 lb / 1000 gal
Ammonium N	18 lb / 1000 gal	15 lb / 1000 gal
Organic N	12 lb / 1000 gal	4 lb / 1000 gal
% of Total N as Ammonium	60 %	79 %

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For solid manures such as cattle manure, the proportion of total nitrogen comprised of ammonium tends to be lower, in the range of 10% to 20% of total N (Charles, 1999; Beauchamp, 1986). Therefore for all manures, particularly solid manures, only a portion of the nitrogen is present as the plant available ammonium form. The ammonium present in manure can undergo several fates when added to the soil: 1) be absorbed by plant roots; 2) be absorbed by microorganisms (immobilized); 3) be volatilized by conversion to  $\text{NH}_3$  (high pH); 4) be converted to nitrate (nitrification) by microorganisms. Ammonium is rendered immobile in the soil by sorption to soil clays and colloids. However, when ammonium is converted (nitrified) to nitrate, the nitrogen

becomes mobile. In Saskatchewan soils, the conversion of ammonium to nitrate is quite rapid (Qian and Schoenau, 2000). The conversion of the manure organic N is more difficult to predict as it is related to microbial decomposition processes. Owing to the preponderance of organic N forms in some manures, it plays an important role in the overall behavior of manure nitrogen in the soil.

### Decomposition of Manure Organic N

Figure 1 depicts the general pathway by which organic nitrogen in manure is ultimately converted into the available forms of ammonium and nitrate. Factors influencing the rate of this conversion include temperature and moisture as they influence microbial activity, with higher decomposition rates associated with higher temperatures and soil moisture contents near field capacity (Scheppers and Mosier, 1991).

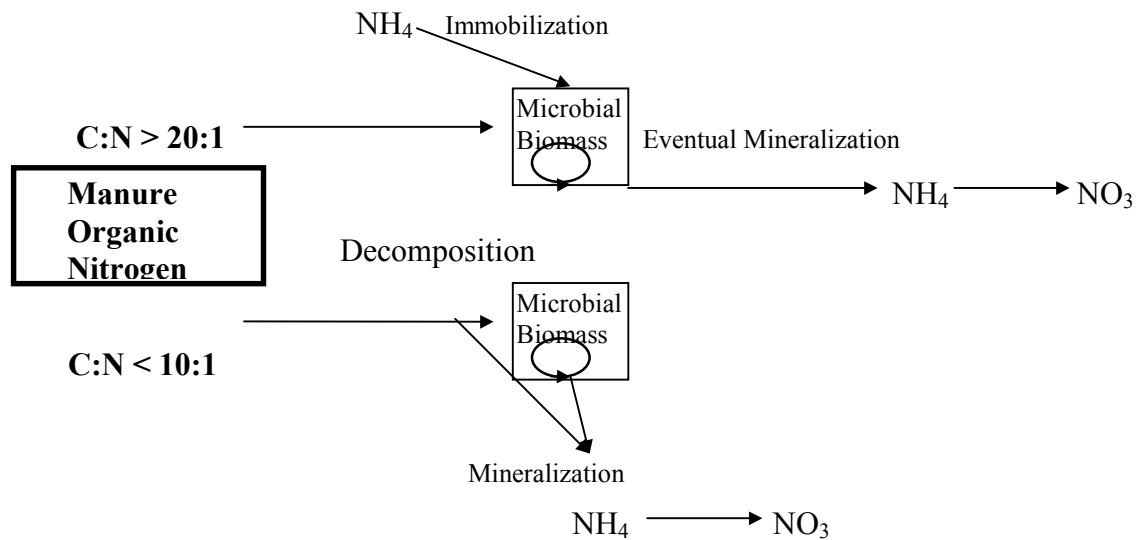


Figure 1. Decomposition pathway of manure organic nitrogen.

The composition of the organic matter in the manure will have a great impact on the rate at which organically bound nitrogen is converted into plant available inorganic forms (mineralization). A key attribute of the organic matter in the manure influencing nitrogen availability is the carbon to nitrogen (C:N) ratio of the organic matter. When the carbon to nitrogen ratio is high (> 20:1) decomposing microorganisms may initially use

all of the nitrogen in the organic matter plus the inorganic nitrogen to construct cell material (immobilization). This can result in little or no increase in available nitrogen observed in the first few weeks or months following application of manures with high C:N ratios, or even a net decrease if the C:N is high enough. After an initial period of decomposition in which carbon is lost as carbon dioxide, the C:N ratio becomes smaller and eventually inorganic nitrogen in excess of microbial needs is released (mineralization). Consistent with this, Charles (1999) observed limited impact of fresh feedlot pen cattle manure (C:N ~ 20:1) on soil nitrogen availability and crop nitrogen uptake in the year of application at two sites near Humboldt, Sask. However, as decomposition proceeded in the second and third year after application of cattle manure, increases in nitrogen availability became apparent. The high organic matter content of cattle manure - bedding mixtures contributes to the build-up of a pool of mineralizable humus in the soil which contributes to tilth and available nitrogen supply that is evident even several years after the application ceases (Vitosh et al., 1973).

Paul and Beauchamp (1996) observed that net N mineralization decreases when the C:N ratio is greater than about 9:1. Immobilization of available N has been observed in cattle manures with C:N ratios of about 16:1 (Beauchamp, 1986; Sommerfeldt and MacKay, 1987). It is important to recognize that the C:N ratio of the organic matter in solid manures is variable and should be measured in order to more accurately predict effects on soil available nitrogen in the short-term. For example, manure from feedlots which has much straw bedding (high C:N ratio) incorporated into it will collectively have a higher C:N ratio and be less effective as a source of available nitrogen in the year of application than manure which is predominantly fecal material or which has been piled and composted such that carbon has been removed as CO<sub>2</sub> and the C:N ratio decreased.

The C:N ratio of organic matter in liquid swine effluent samples tends to be lower, with values ranging from 5:1 to 10:1 reported for samples collected in Saskatchewan (Charles, 1999). These ratios are low enough such that upon initial decomposition, nitrogen is present in excess of the microbial needs and there is a net release of inorganic N, increasing the supply of available nitrogen (Qian and Schoenau, 2000). Current estimates of the availability of liquid swine effluent organic nitrogen (net

mineralization) in the year of application in prairie soils is 20-30%. These values, which are incorporated in manure application recommendation systems, appear reasonable. The effects of swine manure on increasing availability of nitrogen in the soil may not always be evident in large increases in extractable inorganic nitrogen levels in the soil. In forage grasses, significant recycling of applied manure nitrogen appears to take place through mineralization of nitrogen initially sequestered in biomass (microorganisms, roots and exudates) in these systems (Pastl et al., 2000).

The organic matter in liquid swine effluent is more rapidly decomposed than organic matter in solid cattle manure (Charles, 1999). Because of its low C:N, easily decomposed nature and high proportion of ammonium, it is usually observed that liquid swine effluent has a consistent and significant effect on increasing soil available nitrogen and crop nitrogen uptake immediately following application (Schoenau et al., 1999, Qian and Schoenau, 2000). Some workers have suggested that long-term application of liquid swine manure will have relatively little direct impact on increasing soil organic matter as compared to solid manure since the low C:N ratio may stimulate oxidation of native soil organic matter (Eiland, 1980). However, these predicted effects do not take into account the long-term effect of increased crop residue carbon additions associated with stimulation of plant growth from the nitrogen and other nutrients in the manure.

### **Crop Utilization of Manure Nitrogen and Potential Loss Mechanisms**

As expected, because of incomplete mineralization of the manure organic N, the crop recoveries of applied manure N tend to be lower per unit of total N applied as compared to commercial inorganic fertilizer. In trials on a loam soil in the Black soil zone near Humboldt, we found apparent crop recoveries of injected liquid swine manure nitrogen in the year of application to be 60% to 70% of that observed for urea. For cattle manure at this site we found apparent recoveries of manure N in the crop to be much lower in the year of application, with recoveries for cattle manure N about 7% to 10% of the recovery observed for urea. These findings are consistent with a much higher proportion of the total N in the cattle manure comprised of organic N and a high C:N of this organic matter as compared to the liquid swine effluent. In the second year

following application of the manure, the apparent recovery was still slightly higher for the liquid hog manure than the cattle manure (Wen and Schoenau., 1999). It is clear that in the case of solid manures with much organic matter of high C:N ratio, it may take several years for the nitrogen to be liberated into an inorganic plant available form. However, when the manure nitrogen is retained in the organic form it is much less susceptible to losses by leaching or gaseous escape if not used by the crop.

Potential loss mechanisms for manure nitrogen in Saskatchewan soils include leaching, denitrification and volatilization. Similar to any ammoniacal fertilizer, the inorganic nitrogen added in animal manures as ammonium will be converted to nitrate (nitrified) if not used by plants. If application rates result in available nitrogen amounts in the soil that exceed the crop's nutrient uptake potential, the excess nitrogen is at risk for loss to the environment. The accumulation of nitrate is of concern owing to groundwater contamination risks. Chang et al (1991) observed accumulations of excess nitrate in soils in southern Alberta following annual applications of beef cattle manure at high rates. Similarly, Charles (1999) observed that a high rate of liquid swine effluent (790 kg total N / ha) produced crop injury and excess soil nitrate ( $> 400 \text{ kg NO}_3\text{-N / ha}$  0-60 cm) at the end of the growing season.

Repeated yearly applications of manure at rates which greatly exceed the ability of the crops grown to use the nitrogen will increase the risk of movement of nitrate below the root zone. For a single application of liquid swine effluent made in 1997 at low, medium, and high rates at a research site near Dixon, no elevation in soil nitrate contents below the root zone (60-90cm, 90-120cm) was observed in plots sampled in fall of 1999 as compared to the unfertilized control (Table 2). For lower annual application rates of liquid swine effluent (~75 - 150 kg total N / ha) there was also no evidence of elevated deep soil nitrate levels above the control at the end of three years (Table 2). However, at the high annual rates there was some evidence of downward movement of nitrate. At rates of ~300 kg total N / ha each year from 1997 to 1999, in the fall of 1999 the soil nitrate content was significantly increased over the control in the 60-90 cm and 90-120 cm depth. Urea applied at high rates (200 kg N / ha) every year also showed a similar trend (data not shown). For the cattle manure treatments, for single application made in

1997 and for annual applications (97,98,99) at all rates (~100 to 400 kg total N / ha), no significant increases in soil nitrate above the unfertilized control were observed in the fall of 1999 in the 30-60 cm, 60-90 cm and 90-120 cm depths. This lack of effect of cattle manure additions on increasing nitrate deeper in the profile after three years is consistent with the slow conversion of organic N to plant available inorganic N with this type of manure. It is important to remember that especially with high organic matter content manure where the nitrogen persists in the organic form, there can be continued release of available N through mineralization for several years after the application ceases.

Table 2. Deep soil profile nitrate contents in samples taken in fall 1999 from manure application research plots at Dixon, Sask.

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***Liquid Swine Effluent Plots***

<b>N Rate (kg total N / ha)</b>			<b>Soil NO<sub>3</sub>-N (kg/ha)</b>	
<u>'97</u>	<u>'98</u>	<u>'99</u>	<u>60-90 cm</u>	<u>90-120 cm</u>
0	0	0	1.4 a	2.6 b
75	50	100	2.4 a	6.3 ab
150	100	200	3.5 a	8.2 ab
300	200	400	21.5 b	13.0 a
300	0	0	1.8 a	3.6 b

***Solid Cattle Manure Plots***

<b>N Rate (kg total N / ha)</b>			<b>Soil NO<sub>3</sub>-N (kg/ha)</b>	
<u>'97</u>	<u>'98</u>	<u>'99</u>	<u>60-90 cm</u>	<u>90-120 cm</u>
0	0	0	1.1 a	2.0 a
120	100	70	0.6 a	1.8 a
240	200	140	2.2 a	4.3 a
480	400	280	1.9 a	3.5 a
480	0	0	3.0 a	4.5 a

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For a manure type, values in a column followed by the same letter are not sig. different p< 0.05.

The process of denitrification, in which the nitrate is reduced to nitrous oxide and dinitrogen gas, is another potential loss for manure nitrogen. Microbial denitrification is

carried out by soil microorganisms and is favored by poor aeration, abundance of organic carbon, and warm temperatures. Conversion of nitrate to nitrous oxide is of particular concern as nitrous oxide is a greenhouse gas. Manures provide carbon for denitrifying microbes and in the case of liquid manures, much soluble carbon and water, which can create anaerobic microsites where denitrification occurs. Residual unused nitrate left in the soil is especially susceptible to denitrification losses in fall or spring before the next period of crop nitrogen demand. Potential for denitrification losses are greater in clayey soils than sandy soils. Recent studies of denitrification on field plots in east central Saskatchewan have shown higher potential denitrification activity with injected manure than the equivalent N rate of urea fertilizer (Farrell et al., 1999). As application rates increased, the denitrification potential increased. Denitrification tends to be episodic, with pulses of nitrous oxide gas production observed after application and when the soil is saturated immediately following snowmelt or heavy rainfall. The significance of this process as a loss mechanism deserves continued attention.

Volatilization refers to the loss of manure nitrogen via the escape of ammonia ( $\text{NH}_3$ ) gas. As is the case with ammonia producing commercial nitrogen fertilizers like urea, placement of manure in the soil through injection or incorporation tends to result in less volatilization losses and greater crop nitrogen recovery than broadcasting. Placement of the manure into the soil gives any ammonia an opportunity to react with the soil, forming ammonium ions which are retained. Broadcasting of liquid manures without incorporation can result in volatilization losses as high as 30% (Beauchamp et al., 1982) while injection (banding) into the mineral soil can reduce volatilization losses to less than 2%. A similar effect of placement of liquid swine manure was revealed in field plots in east central Saskatchewan where injection has consistently resulted in greater soil available N following application than broadcast and incorporation. For cattle manure we have observed little difference in nitrogen availability between broadcast and immediate incorporation versus broadcast and 24 hour delayed incorporation. It is clear that placement of manure on the soil surface, without incorporation or injection, is less desirable from a nitrogen retention standpoint as well as increasing concerns over odor and contamination from surface runoff.



## **Conclusion**

Good management of the nitrogen in manure involves knowing the amounts and forms of nitrogen present in the manure and accounting for the effects of important processes in the soil nitrogen cycle that will influence the behavior of the manure N as a source of plant nutrients. These are essential factors in the sound management of any fertilizer nitrogen source as this knowledge will enable selection of the best application rate, timing and method of placement to maximize agronomic benefit and minimize nutrient pollution concerns. This knowledge of manure nitrogen behavior in prairie soils is being integrated into manure application recommendations systems. While ammonium nitrogen contained in animal manures will behave in a similar fashion to ammonium derived from commercial inorganic fertilizers, the content and composition (C:N) of the organic nitrogen will be an important factor governing how the manure behaves as a source of plant available nitrogen in both the short and long-term. As with commercial nitrogen fertilizers, manure application rates that result in available nitrogen in excess of plant needs will create concerns over excess nutrient losses to the environment.

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