

# The Role of Manure Application in Maintaining Air, Water & Soil Quality

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## ▪ **Manure is Amazing Stuff!**

When we read about manure in the popular press it is seldom to sing its praises. Both producers and the public at large are often unaware of the value of manure to agriculture. The return of animals, and the manure they produce, to the prairies has the potential to significantly increase the sustainability of prairie agriculture. For decades the organic matter and nutrient content of prairie soils has been declining as rates of removal under annual cropping and grain export have outpaced the return of organic matter and nutrients to the soil. Animal manure, an excellent source of nutrients and organic matter, provides the opportunity to replenish the soil and increase soil fertility

Manure contains all of the major crop nutrients (nitrogen, phosphorus and potassium) as well as many, if not all of the minor nutrients needed by plants. Manure has an additional benefit beyond its nutrient content. Manure contains many organic compounds. These compounds help to build and maintain soil structure which in turn helps to maintain soil tilth, water holding capacity, soil aeration and reduces soil erosion. The organic compounds in manure are food for the soil microbial population which may enhance nutrient availability, residue decomposition or in some cases the removal of nitrate from the soil.

To realize the positive aspects of manure we must ensure that we have minimized any negative impacts. The challenge is to design cost effective systems which can take advantage of all of the positive aspects of manure while minimizing negative impacts. The primary design considerations for manure management systems have traditionally been convenience and cost effectiveness. Few producers would debate their importance. Increasingly however, nutrient recovery and environmental impact are emphasized. Many jurisdictions have begun to require detailed manure management plans to ensure efficient and safe manure utilization. This is due in-part to public concerns over sustainability of agricultural systems and environmental impact

of intensive animal production. While reduced environmental impact represents an indirect benefit to the farmer, the value of the nutrients recovered from the manure provides direct economic benefit.

Effective manure management strives to balance the amount and timing of nutrient supply with plant demand. Applying the correct amount of manure, at the right time, to the most appropriate crop in the most effective manner. In this paper I will attempt to summarize some of the processes which help to define the most effective approaches to manure application to crop land.

### ▪ **More of the Good Stuff**

We should not gloss over the benefits of animal manure. Animal manure was once considered a critical nutrient resource in agriculture. But with the advent of chemical fertilizers, which provide a more concentrated and more easily regulated source of nutrients, manures came to be considered a waste product of animal production. We are beginning to return to our view of manure as a critical soil amendment. This is, in part, due to the realization that maintaining soil productivity is not just adding the N, P & K, but also involves the maintenance of soil organic matter. The positive impacts of manure on soil are now better understood.

The organic matter contained in the manure is food to the soil microbial population. The activity of this microbial population helps to produce the glues that cause soil particles to stick together in what is known as soil structure. A good soil structure improves the aeration of the soil, the soil water holding capacity and the soil as a rooting medium for plants. The enhanced structure of the soil also makes soil easier to till, improves seed bed preparation and reduces soil erosion. Another aspect of the return of manure to the soil that has, until recently, been over-looked is the increased amount of carbon stored in soils receiving manure. The signing of the Kyoto Protocol has caused all aspects of Canadian industry to examine their greenhouse gas emissions and look for potential mitigating practices. The storage or "sequestration" of carbon in the soil has been identified as a key potential mitigation strategy. Some estimates suggest that agricultural soils in Canada could potentially sequester several million metric tonnes of carbon each year. The role of manure in enhancing soil carbon sequestration is the subject of on-going research.

Another major benefit of land application of manures is the recycling of nutrients. Not only is this a cost saving to the producer but it also reduces fossil fuel consumption associated with the synthesis and transportation of nitrogen fertilizers. This also has a significant positive impact on agricultural greenhouse gas production.

## ▪ **Potential Adverse Impacts of Animal Manures**

To understand how to best manage manure we must understand the potential impacts it may have on the environment and consider these impacts in the design of our manure management systems. These include losses during handling and storage of manure, losses during land application and losses of nutrients once they are in the soil.

### **Atmospheric Impacts**

Animal manures have several significant impacts on our atmosphere. The impact we are most aware of, and our neighbours are most aware of, is odour. A wide array of compounds contribute to odour. Most of these compounds are produced during anaerobic bacterial metabolism. Odour is generally considered a nuisance issue and there have been relatively few reports of adverse health impacts. One of the components of odour is of greater concern and that is ammonia. Ammonia is the predominant form of available nitrogen in most manures. It can readily be lost from animal manure in the barn, from storages or during land application. In some situations ammonia loss may reduce the nitrogen content of the manure by as much as 50%.

Currently focus has been directed at the role of manure in the production of greenhouse gases. It has been estimated that manure is the source of 14% of Canada's total human-induced greenhouse gas production (AAFC, 1998). Manure is a source of all three of the major greenhouse gases – carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ). Manure is not one of the major sources of  $\text{CO}_2$  and, as indicated earlier, manure may actually have a positive influence on the storage of carbon in soil. Methane production is normally associated with ruminant animals. Anaerobic manure storages have been shown to be significant sources of  $\text{CH}_4$ . It has been estimated that 60% of the  $\text{CH}_4$  produced from animal manures is associated with anaerobic storages (Cole, 1996). Nitrous oxide is the most potent of these three greenhouse gases and has approximately 300 times the effect on the atmosphere as  $\text{CO}_2$ . Agriculture is one of the most significant sources of human-induced  $\text{N}_2\text{O}$  production and manure is one of the major sources of nitrous oxide in agriculture. Following application to soil, the carbon and nitrogen in manure increases the activity of the microbial population and in so doing increases  $\text{N}_2\text{O}$  production.

## ▪ Management – Understanding The Processes

### Loss During Storage & Handling

Significant losses of nitrogen, primarily as ammonia, can occur during the handling and storage of manure. Undiluted animal urine, whether on the barn floor or animal pastures, is the source of significant ammonia loss. The longer urine remains in a concentrated form in the animal barn the greater the potential for loss. Rapid transfer to storage has been shown to enhance nitrogen conservation (Table 1). Once manure is transferred to storage its exposure to the atmosphere is minimized and the material is diluted by wash water and other constituents contained in the system.

**Table 1: Ammonia losses as influenced by the duration of retention in swine housing (Burton and Beauchamp, 1986).**

Management System	Approximate Retention on Barn Floor	NH <sub>3</sub> Loss
Slotted floor over pit	~1 hour	5-9%
Daily scrapping to pit	~1 day	19-21%
Gravity incline to pit	~1 week	27%

The method of storage is also of importance. Storage conditions which minimize exposure to the atmosphere generally reduce ammonia loss. Biological activity in unstirred containment is usually sufficient to consume all of the oxygen contained in stored manure. These storages are referred to as being anaerobic. Anaerobic storages have been shown to conserve ammonia to a greater extent than lagoons. Continuously mixed or aerated manure treatment, designed to convert ammonia to nitrate, can result in nitrogen losses in excess of 50% (Vanderholm, 1975). Ammonia loss from anaerobic storage ranges from negligible, in storages where surface crusts form, to as much as 50-60% (Meyer, 1973; Vanderholm, 1975).

### Loss During Land Application

Once manure has been applied to the soil there are a number of fates which will influence how much of the nitrogen remains in the soil in a form available to the plant. These include:

- ▶ Ammonia Volatilization
- ▶ Runoff
- ▶ Nitrogen Immobilization
- ▶ Denitrification

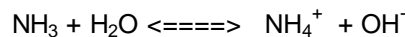
- ▶ Nitrate Leaching
- ▶ Plant Uptake

Soil conditions, land management and climate will all interact to influence the relative magnitude of these fates. In the following paragraphs I will briefly discuss each of these processes and how management can minimize their impact on nitrogen loss.

### **Ammonia Volatilization**

#### ***Process***

Ammonia volatilization is the gaseous loss of ammonia from the soil. In the presence of water, ammonia gas (NH<sub>3</sub>) is in equilibrium with the ammonium ion (NH<sub>4</sub><sup>+</sup>).



Soil pH is commonly near neutrality (6-8) or slightly acidic and thus ammonia does not tend to accumulate and ammonia losses are small. Significant amounts of ammonia loss may occur from soils with a high pH or when high NH<sub>4</sub><sup>+</sup> concentrations are present. Examples include urine patches in pastures, surface applied urea and anhydrous ammonia applied to dry soils. Ammonia volatilization from manure occurs when excessive amounts of manure is applied or when manure high in ammonium is applied.

Volatile losses of ammonia are greatest for application technologies which involve extensive contact with the atmosphere. It has been estimated that approximately 50% of the manure nitrogen produced in the U.S. is lost via ammonia volatilization (Porter, 1975). Losses of the ammonia, as great as 40%, occur as a result of the irrigation of manures containing a high ammonium content such as swine manure (Pote et al., 1980). Drying can result in significant ammonia loss as well. Heck (1931) observed 40-50% of total manure N could be lost on drying. Lauer et al. (1976) observed that losses of 61-99% of the ammonium in manure could occur if manure was allowed to remain on the soil surface for periods ranging from 5 to 25 days.

#### ***Management***

Since some manures, particularly liquid swine manure, contain high concentrations of ammonium and in some cases may be alkaline (high pH), there is the potential for ammonia loss. Most soils have a high pH buffering capacity which act to neutralize the addition of alkaline materials like manure. Minimal contact with the atmosphere and rapid incorporating manure into the soil allows the manure to react with the soil, reducing the pH of the material and binding the ammonium ions to prevent their loss as ammonia. Further any

ammonia produced has the opportunity to dissolve in soil water and be converted to ammonium and thereby be retained in the soil.

## **Nutrient Runoff**

### *Process*

When the amount of rainfall exceeds the infiltration capacity of the soil there is the potential for runoff of excess water to adjacent areas in the landscape or into surface water bodies. This runoff water can carry significant amounts of nutrient, particularly when manures have not been incorporated into the soil following application. In the early spring, the infiltration capacity of the soil may be very low because of ice contained within the soil. The potential for runoff is greatest at this time. The potential for runoff is also increased on sloping land. The runoff from manured fields can contain significant amounts of nitrogen and phosphorus and organic compounds. In the receiving water bodies this can cause eutrophication and damage to the aquatic habitat.

Klausner et al. (1976) found that solid dairy manure application during thawing periods resulted in significant nitrogen and phosphorus movement to surface water bodies. Young and Mutchler (1976) found, under conditions in Minnesota, that up to 20% of nitrogen and 16% of orthophosphate was lost during spring runoff when manure was applied to frozen soil. In the same study, losses of less than 3% of nitrogen and 4% of phosphorus were observed when the manures were incorporated into the soil in the fall following application. In general, application procedures which introduce the manure directly into the soil matrix or incorporate it as soon as possible after application reduce nutrient loss. Application of manure to frozen soil when it cannot be incorporated and is subject to drying should be avoided.

### *Management*

The most effective means for reducing the runoff of the nutrients contained in manure is to incorporate the manure into the soil as soon as possible after application. Leaving standing stubble in the field in the fall will reduce soil erosion and the runoff of nutrients during the spring period. Manure should not be applied to frozen land. Manure applied to frozen land cannot be incorporated and remains on the soil surface during spring period when the potential for runoff is at its greatest. Designing animal operations with at least 6-9 months manure storage capacity insures that manure need not be applied to frozen land.

## Nitrogen Immobilization

### *Process*

In addition to mineral nitrogen and phosphorus, manure contains a wide range of organic compounds, most of which are partially degraded feed constituents. Once applied to the soil these compounds become food for the soil microbial population. Eventually the soil community will degrade these and release the organic nutrients they contain in inorganic, plant available forms. If the amount of nitrogen or phosphorus contained in the feed materials is not sufficiently high, the soil microbial population may temporarily remove either nitrogen or phosphorus from the plant available pool for use in decomposition. This process is referred to as immobilization. It is important to note that this is not a loss *per se* but rather a temporary removal or storage of the nutrients. This temporary storage can interfere with the supply of nutrients to the crop if it occurs at the wrong time.

The immobilization of nutrients following manure application only occurs when the carbon content of the organic materials is much higher than its nutrient content. For nitrogen, immobilization will only occur when the carbon to nitrogen (C:N) ratio is greater than approximately 20-30:1. This primarily occurs in manures with high bedding content.

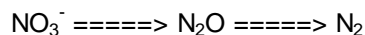
### *Management*

In manures where the CN ratio is sufficiently high that immobilization is of concern, the negative impacts of immobilization can be avoided by applying the manure in the early fall. This provides sufficient time for the manure to be degraded and the period of nitrogen immobilization to occur. When the crop is planted in the spring the manure will be a source of nitrogen to the crop and the rate of nitrogen fertilizer application should be adjusted to reflect this contribution. For manures high in ammonium and with relatively low C:N ratios in the organic fraction such as liquid swine manure there will be no period of net nitrogen immobilization and these manures will be an immediate source of plant available nitrogen.

## Denitrification

### *Process*

Denitrification is a microbial process occurring in the soil which results in the conversion of a plant available nitrogen, nitrate ( $\text{NO}_3^-$ ), to gaseous non-available form.



In moist to wet soils, biological activity consumes oxygen at a rate greater than it can be supplied. When oxygen is depleted, bacteria use nitrate in place of the oxygen. This process requires substrate (organic matter), the presence of nitrate, and sufficient water to restrict the supply of oxygen to the soil. Manure application can create ideal conditions for denitrification and can result in significant loss of plant available nutrients. Note that one of the intermediates of this reaction,  $N_2O$ , is an important greenhouse gas. The production of  $N_2O$  associated with manure application is currently an area of interest as its implications for our total greenhouse gas production are assessed. The sporadic nature of the denitrification process makes estimation of the rates of  $N_2O$  production difficult. It has been assumed that on a global basis, 1-3% of manure nitrogen is released as  $N_2O$ , although there is insufficient data to assess the reliability of this estimate. Plot studies have suggested that animal manures may have much greater  $N_2O$  production than inorganic fertilizers. In particular solid manures have been shown to stimulate large losses of  $N_2O$ . Further research is needed before we are able to say with any certainty whether the  $N_2O$  production from manure is sufficient to offset the enhanced sequestration of carbon in the soil, making manure a net greenhouse gas emitter. There is also the potential for the development of technologies which reduce  $N_2O$  emissions from manure.

### *Management*

The key to managing denitrification losses from manure amended soil is to avoid accumulation of  $NO_3^-$ . When the soil is wet, primarily in the spring and fall, accumulated  $NO_3^-$  will be lost as a result of denitrification. Most manures contain mostly ammonium and very little  $NO_3^-$ . Following land application,  $NO_3^-$  is formed from ammonium by the process of nitrification. The nitrification of late fall and early spring applied manure will be relatively slow and thus little nitrate will accumulate during these periods and there will be little loss from denitrification. Early fall application of manure can result in significant nitrification and during a wet spring much of this nitrogen could be lost as a result of denitrification. The accumulation of  $NO_3^-$  in the soil can also be limited by applying manure to high N demanding crops and applying the recommended rates of manure the majority of the nitrate produced from the manure will be utilized by the crop. Also avoid application of large amounts of manure to wet areas of the landscape. The use of nitrification inhibitors for delaying nitrate production is being examined.

## **Nitrate Leaching**

### *Process*

When  $NO_3^-$  accumulates in the soil it can be carried with draining water through the soil profile, beyond the plant root zone and into groundwater. This process is known as  $NO_3^-$  leaching and can impair groundwater quality. Soils with high potential for  $NO_3^-$  include soils able to conduct water rapidly (course texture) to

which high rates of manure or nitrogen fertilizer have been applied. Manure contains little or no  $\text{NO}_3^-$  but rather, contains ammonium which is converted to nitrate by soil organisms. The potential for  $\text{NO}_3^-$  leaching loss from manure is no greater, and most cases is less, than equivalent rates of a fertilizer such as urea (Beauchamp, 1983; Younie et al., 1994). When applied in excess of that required by the crop, manure application can result in significant  $\text{NO}_3^-$  leaching.

### ***Management***

The most effective approach to minimizing the risk of  $\text{NO}_3^-$  associated with the application of manure is to apply appropriate rates of manure. Appropriate rates are generally defined in relation to crop nitrogen demand. If manure is not applied at excessive rates, large amounts of  $\text{NO}_3^-$  do not accumulate in the soil and there is low risk of  $\text{NO}_3^-$  movement to groundwater. Time of manure application is also important. Where possible manure should be applied close to the time of crop nitrogen demand. This minimizes the time period where nutrients accumulate in the soil, in a form susceptible to loss, prior to crop uptake.

## ▪ **Manure Management for Maximal Gain and Minimal Risk**

While manure is potentially a tremendous resource, in the wrong place these same nutrients can pose a serious environmental threat. To ensure that these nutrients remain a resource and not a liability the land application of manure must be carried out prudently and judiciously. Much is known about the effective management of animal manures. The following management approaches can help to ensure manure is effectively used in crop production.

### **Rates of application... how much is enough?**

While we have discussed the positive aspects of manure application to soil, this is one of those situations where there can clearly be “too much of a good thing”? The intent of manure application is to provide for crop nutrition and to avoid contamination of groundwater. Manure application guidelines are usually based on the nitrogen content of the manure. This has been for two reasons:

- ▶ Nitrogen is the nutrient most often limiting crop production,
- ▶ Nitrogen is the element which poses the greatest environmental threat in most cases, whether it be in terms of nitrate contamination of groundwater or the increased atmospheric concentrations of the greenhouse gas nitrous oxide.

In some situations the accumulation of phosphorus from repeated applications of manure can pose an environmental threat and in those situations manure applications should be based on acceptable phosphorus loading rates.

So how much manure is that? As an example in the Manitoba 1998 Farm Practices Guidelines for Hog Producers. Manitoba Agriculture recommends in general terms, that manure application rates should match crop nutrient requirements. Depending on the crop that may range from 65 - 250 kg N/ha. Application rates on sandy soils are lower than medium to fine textured soils. Manure application rates should also reflect anticipated loss rates associated with the chosen method of application. Calibration of manure spreaders is also an important aspect in applying manure at the appropriate rates.

### **Timing of application**

In addition to knowing how much to apply, it is important to know when to apply the manure. Clearly the timing of manure application will be a compromise between the optimal date for nutrient utilization and the date most convenient for the operator. From a nutrient utilization perspective, the closer to the time of maximum plant nutrient demand the manure can be applied the greater the likelihood that the nutrients will reach the crop and the less opportunity there is for nutrient loss. Thus spring is better than fall. Winter applications should be avoided as the manure cannot be incorporated and significant losses of ammonium to the atmosphere and nitrogen and phosphorus in runoff are likely to occur. Summer application to fallow land is also not recommended because nitrates can accumulate in the soil during the fallow period and begin leaching to groundwater in the fall and spring rains.

### **Where should manure be applied?**

Manure should be applied to the land that needs it the most. High rates of manure should not be applied to the same land year after year. If manure is applied to the same land each year the rate of nitrogen mineralization will soon exceed crop demand, allowing for the accumulation of  $\text{NO}_3^-$  and the potential for loss.

### **To what crops should manure be applied?**

Manure should be applied to high nitrogen demanding crops wherever possible. This allows for the greatest amount of immobilization of the nitrogen by the plant.

### **▪ Conclusions**

In conclusion, manure is a resource to be utilized effectively and not a waste for disposal. Effective manure management can provide for plant nutrient

demands with little or no risk to the environment. The following general guidelines should be followed in planning a manure management strategy.

- ▶ Use appropriate manure application rates based on plant nitrogen demand.
- ▶ Incorporate manure as soon as possible after application.
- ▶ Do not apply manure to frozen soils.
- ▶ Test the nutrient content of manure regularly.
- ▶ Have routine soil tests performed on soils to which manure has been applied.

## ■ References

- Agriculture and Agri-food Canada.** (1998) Health of our Air. Draft Document.
- Beauchamp, E.G.** (1983) Response of corn to nitrogen in preplant and sidedress applications of liquid dairy cattle manure in the field. *Can. J. Soil Sci.* 63: 377-386.
- Burton, D.L. and E.G. Beauchamp** (1986) Nitrogen loss from swine housing. *Agricultural Wastes* 15: 59-74.
- Cole, V.** (1996) Agriculture options for mitigation of greenhouse gas emissions. *In: Climate Change 1995. IPCC report*, Cambridge University Press, Cambridge. pp. 747-771.
- Heck, A.F.** (1931) Conservation and availability of the nitrogen in farm manure. *Soil Sci.* 31: 335-363.
- Klausner, S.D., P.J. Zwerman and D.F. Ellis.** (1976) Nitrogen and phosphorus losses from winter disposal of dairy manure. *J. Environ. Qual.* 5: 47-49.
- Lauer, D.A., D.R. Bouldin and S.D. Klausner** (1976) Ammonia volatilization from dairy manure spread on the soil surface. *J. Environ. Qual.* 5: 134-141.
- Porter, K.S.** (1975) Nitrogen and Phosphorus: Food Production Waste and the Environment. Ann Arbor Science Publishers, Inc. Ann Arbor, MI.
- Pote, J.W., J.R. Miner and J.K. Keolliker** (1980) Ammonia loss during sprinkler irrigation of animal wastes. *Trans. Amer. Soc. Agric. Eng.* 23: 12202-12206, 1212.
- Vanderholm, D.H.** (1975) Nutrient losses from livestock wastes during storage, treatment, and handling. *In: Proc. 3rd Int. Conf. on Livestock Wastes.* American Society of Agricultural Engineers. St. Joseph, MI. pp. 21-24.
- Younie, M.F., D.L. Burton, R.G. Kachansoki, E.G. Beauchamp and R.W. Gillham.** (1994) Impact of livestock manure and fertilizer application on nitrate contamination of groundwater. Final Report to the Ontario Ministry of the Environment and Energy.