AMMONIA EMISSIONS FROM FIELD-APPLIED MANURE:
MANAGEMENT FOR ENVIRONMENTAL AND ECONOMIC BENEFITS

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Livestock manure has the potential to provide significant benefits for soil health and crop nutrient supply; but it also can contribute to a range of environmental problems, including ammonia emission. In particular, maximizing crop utilization of manure N requires careful management to control N losses.

Manure N can be lost by several different processes—nitrate leaching, gaseous denitrification, and surface runoff of N. But the process that commonly has the potential for the greatest N loss from manure – and the one most readily controlled by management – is ammonia volatilization (Fig. 1). Besides the obvious economic loss requiring replacement with purchased fertilizer N, there are potential environmental concerns as well. Ammonia emission can contribute to eutrophication of surface waters (esp. marine and estuarine) via atmospheric deposition. The decreased amount of available N in manure reduces the N:P ratio and leads to a more rapid build-up of P in the soil for a given amount available N. And ammonia in the atmosphere can form fine particulates that lower air quality.

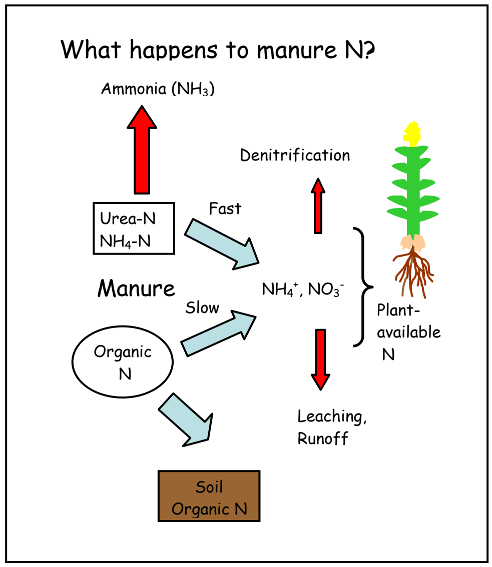

Figure 1. Processes that contribute to losses or crop availability of manure N.

Most ammonia emissions are from livestock production, with cattle farming, especially dairy, regarded as the largest source (Bussink & Oenema 1998). Land application of manure contributes the most ammonia emissions from cattle in the UK, with animal housing a close second (Fig. 2; Misselbrook et al., 2000). This article will focus on ammonia volatilization of manure N, in particular the management practices to control ammonia loss and increase the benefits for crop production. Most examples will be with dairy manure.

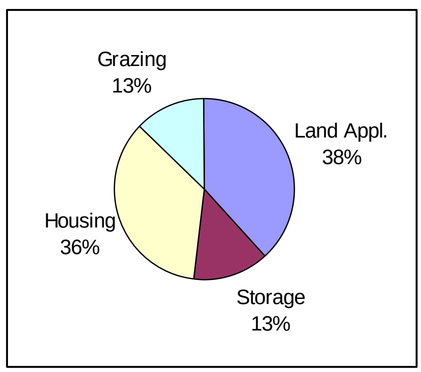

Figure 2. Ammonia emission from different segments of cattle farming in the UK (Misselbrook et al., 2000.

Nitrogen Content of Manure

Improving the management of manure N starts with knowing the N content of manure and the relative amounts of the different forms. The total ammoniacal N (ammonium-N plus ammonia-N plus urea-N) is the portion of manure N that is immediately susceptible to loss. We

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will refer to the combination of these forms as simply ammonium-N, or NH_4-N. The NH_4-N fraction is readily available to plants or quickly mineralizes to plant-available ammonium (NH_4^+) in the soil, so it is essentially equivalent to fertilizer N. As manure left on the soil surface dries and the pH rises, NH_4^+ can rapidly convert to ammonia gas (NH_3), which is readily lost to the atmosphere.

The nitrogen content of manure varies greatly from farm to farm depending on animal diet, amount and type of bedding added, water added from rain or milk house waste, etc. For example, a random set of 30 liquid dairy manure samples from Vermont farms showed greater than a four-fold range of both ammonium and total N (Fig. 3: Jokela and Meisinger, 2004). As is typical for liquid dairy manure, the ammonium fraction comprises about 50% of the total N. Despite the wide range of values, the average approximates typical book values. Because of the great variability in manure nutrient content, the only way to know the nitrogen content of the manure on your farm is to sample it and have it analyzed. Then it can be used as the basis for determining the manure rate to meet the crop N need.

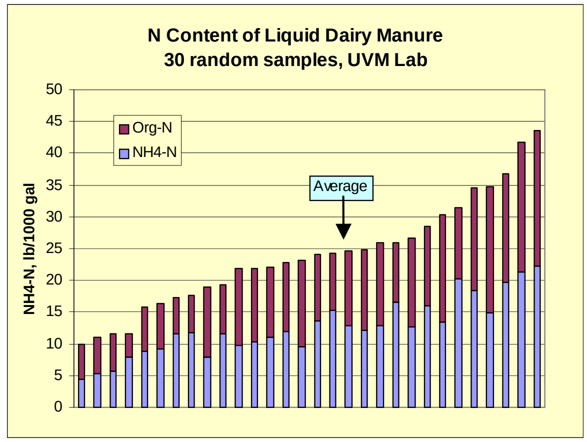

Figure 3. Nitrogen content (NH_4-N and organic N) of 30 random dairy manure samples analyzed by the Agricultural and Environmental Testing Lab, University of Vermont (Jokela and Meisinger, 2004).

Pattern and Magnitude of Ammonia Volatilization

Ammonia volatilization occurs because ammonium-N (NH_4^+-N) in manure or solution is converted to dissolved ammonia gas (NH_3), by the reaction:

$$NH_4^+ \rightleftarrows NH_3 + H^+$$

The reaction produces more NH_3 as pH or temperature increases, and as the NH_4-N concentration increases.

Ammonia volatilization losses vary greatly under field conditions depending on soil and environmental conditions and on management. Ammonia losses can range from over 90% of the applied NH_4-N for surface application under high loss conditions, to only a few percent when manure is injected or incorporated immediately into the soil. Under typical conditions, losses from dairy manure left on the soil surface are commonly 30 to well over 50%. The ammonia volatilization rate is usually greatest during the first few hours after application, as shown in an example from Vermont where dairy slurry (9% DM) was broadcast at 7000 gallons per acre on silage corn stubble (Fig. 4: Jokela and Meisinger, 2004). This temporal pattern emphasizes the importance of timely incorporation of manure to prevent substantial losses of N.

The extent of ammonia volatilization depends on a number of factors: a) manure characteristics (dry matter content, NH_4-N content, pH), b) soil conditions (soil moisture, soil chemical properties, plant/residue cover), c) environmental factors (temperature, wind speed, rainfall), and d) application management (especially incorporation and timing). For example, manure dry matter content affects ammonia emission, slurries with higher dry matter content generally showing greater ammonia loss (Meisinger and Jokela, 2000; Jokela et al., 2004). This is due to the fact that slurries with lower solids tend to infiltrate more readily into the soil where ammonium is protected from volatilization by adsorption onto soil colloids. This explains why solid manures tend to volatilize a higher percentage of the NH_4-N than liquid manures, although solid manures lose less N the first day. While all of the manure, soil, and environmental factors play a role in determining the ammonia loss, application management is probably the biggest factor. It also offers the greatest potential for reducing NH_3 loss and improving N utilization by the crop. (For a more comprehensive discussion of the factors affecting ammonia volatilization, see Meisinger and Jokela (2000)). Management practices designed to reduce ammonia loss from manure provide other benefits too, such as controlling odor and incorporating phosphorus, which limits runoff losses. These benefits are often as important to livestock producers as the nitrogen savings.

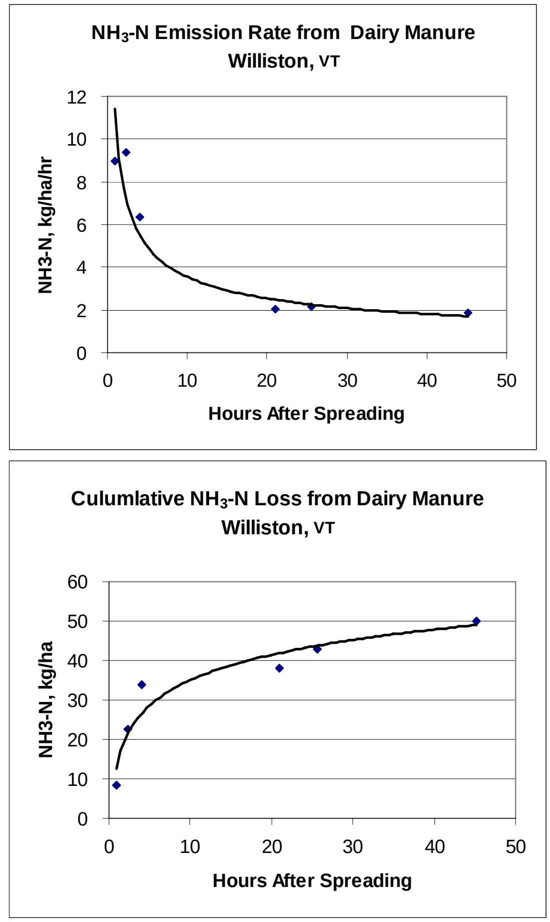

Figure 4. Rate of NH_3 emission from dairy slurry surface-applied at 7000 gal/acre. Williston, VT. (Jokela and Meisinger, 2004).

Manure Incorporation by Tillage

If manure is mixed into the soil, ammonium-N is adsorbed onto the exchange complex of the soil and retained. The rapid initial loss of ammonia from dairy slurries (Fig. 4) emphasizes the need for timely incorporation. Even a one-day delay in incorporating manure slurries can lead to loss of over 50% of the NH_4-N. Most common tillage methods will effectively control ammonia losses from manure if done immediately after manure is applied. In general, the effectiveness of tillage in controlling ammonia emissions is a function of how thoroughly the manure is covered and mixed with the soil. Research with dairy slurry in Maryland showed reductions in NH_3 loss of 80 to 97% from immediate tillage with chisel, disk, or moldboard plow (Fig. 5; Thompson and Meisinger, 2002). Cultivating before slurry application can also reduce ammonia emissions because of increased infiltration into the soil.

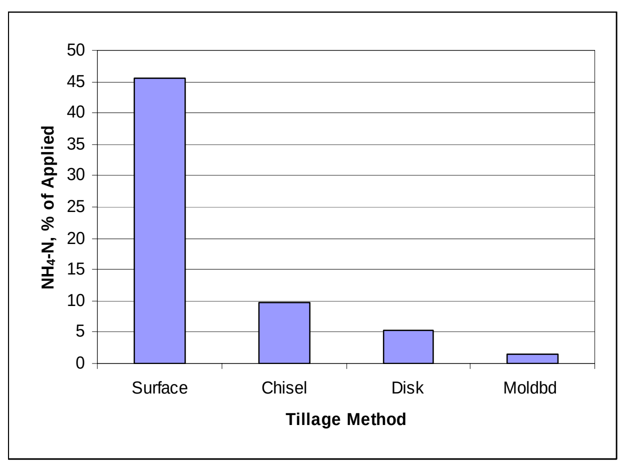

Figure 5. Ammonia loss from dairy slurry after immediate tillage by several common implements on a silt loam soil, Beltsville, MD. (Thompson and Meisinger, 2002).

Reduction of ammonia loss by timely tillage greatly improves N availability, which can be reflected in increased yields or lower fertilizer N need. For example, in a field study in Vermont, semi-solid dairy manure incorporated by plowing within a few hours of application supplied adequate N for a 25 ton/acre corn silage crop; but when the same manure rate was surface-applied in the no-till system an additional 50 lb/acre of fertilizer N was needed (Fig. 6.; Jokela, 2004a). The difference can be attributed to N loss via ammonia emission in NT and conservation of N where manure is incorporated by tillage.

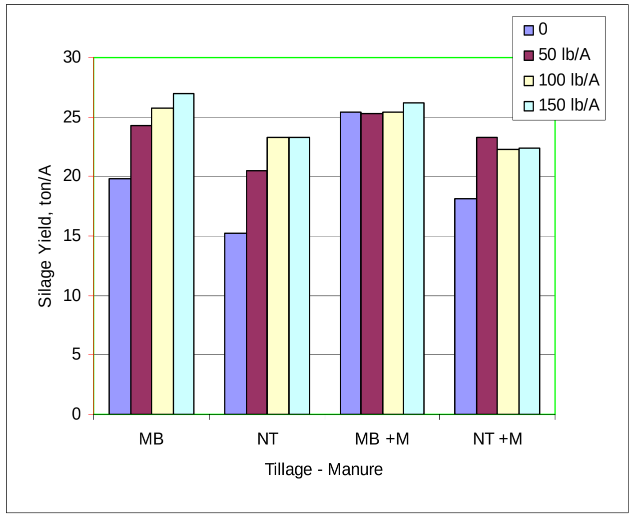

Figure 6. Corn silage yields as affected by tillage, manure, and N fertilizer rate. MB=moldboard plow, NT=No-till, +M=manure applied at 25 ton/acre. Fertilizer N rate in legend; all treatments received 20 lb N /acre as starter. (Jokela, 2004a)

For solid manures, a separate tillage operation is the main avenue for incorporation, but for slurries there are several other application options for conserving ammonia.

Direct Incorporation Methods

Annual Cropping Systems

A range of equipment options are available for direct incorporation of liquid manure. Direct incorporation refers to any method that incorporates manure directly into the soil without a separate tillage operation, most commonly with knives, chisels, disks, or other tillage tools mounted in the front or rear of a tank spreader (Jokela & Côté, 1994). Injection of manure below the soil surface is an effective method for controlling ammonia volatilization since there is no exposure of manure to the atmosphere (assuming no surfacing of slurry) and NH_4+ is adsorbed onto soil colloids; but there are also other equipment systems for use in annual cropping systems (Fig. 7). Deep injection with a knife or chisel (6 or more inches) has produced large reductions in ammonia emissions from slurries applied to corn in the US (Hoff, et al., 1981). The reduced ammonia volatilization is generally reflected in improved N utilization and increased yields. Higher corn yields and improved N efficiency were reported in Ontario from liquid cattle manure when it was injected at either pre-plant or sidedress time compared to

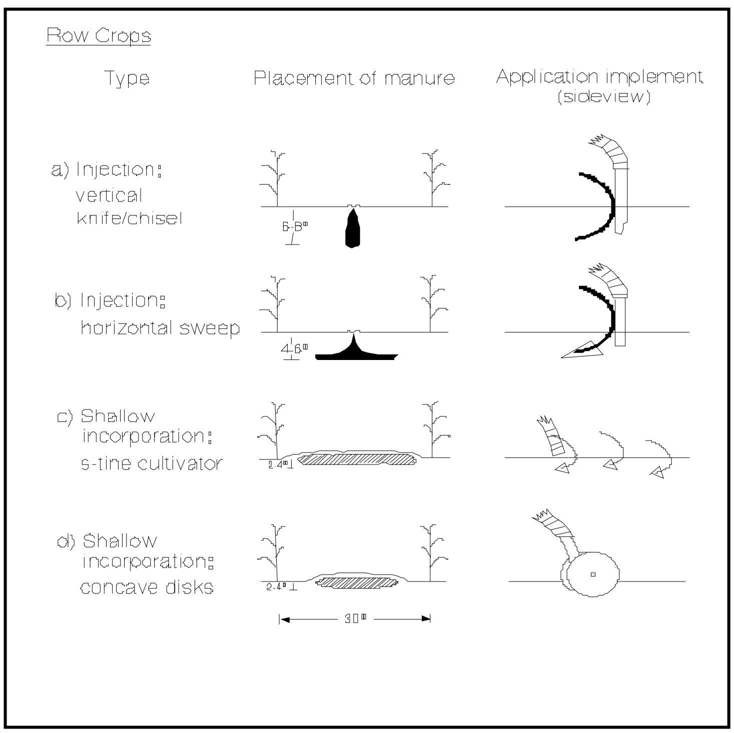

Figure 7. Equipment options for direct incorporation of liquid manure in row crops or on bare ground (Jokela & Côté, 1994).

surface application (Beauchamp, 1983). Increased corn yields from sidedressed injected dairy manure were observed in New York (Klausner and Guest, 1981).

In recent years a horizontal sweep injector that operates at a shallower depth (4 to 6 inches; Fig. 7b) has become more popular because it provides more even distribution of manure, improves N availability, and requires less power (Schmitt et al., 1995). Increased N availability has been reflected in higher Pre-sidedress Nitrate Tests (PSNT) and higher corn grain yields**.** A relatively new design, now available commercially from a few companies in Canada and the U.S., does not actually inject the manure but mixes and covers it with soil using either "s-tine" cultivator shanks or pairs of concave covering disks. (Figs. 7 c, d) These shallow incorporation methods require less power than deep injection tools, can be operated at faster ground speeds, and have fewer problems in stony soils.

In a two-year trial in Vermont we compared application of liquid dairy manure in the fall (surface-applied, sweep injection, and s-tine cultivation) and spring (s-tine cultivation). Nitrogen availability, as indicated by PSNT values (Figure 8: Jokela et al., 1999), was higher for the incorporated treatments, with spring greater than fall application. Fall manure left on the surface was the same as the no-manure treatment. Corn silage yields followed similar trends.

Another option that has seen some use, especially in Canada, is direct incorporation of liquid manure at sidedress time (12 to 24 inches corn height). Advantages are that the timing is closer to the time of increased corn N uptake, thus avoiding potential N loss early in the season from denitrification or leaching, and it allows use of the PSNT (pre-sidedress nitrate test) to estimate N need and, therefore, manure rate. Researchers in Ontario (Ball-Coelho et al., 2005) sidedressed liquid swine manure on corn with a coulter-injector shank-disk hiller system. They obtained excellent yields and found that the PSNT was an effective tool for determining optimum manure rates. They used similar equipment to combine manure injection and zone tillage, maintaining residue cover and creating a good seedbed in a conservation tillage system (Ball-Coelho and Roy, 2004). Another study that sidedressed liquid swine manure on corn in Quebec (Côté et al., 1999) showed better utilization of N from manure applied with "s-tine" incorporation than with deep injection. Dairy manure sidedressed with s-tine cultivation in Vermont gave equivalent corn silage yields as fertilizer N at similar rates of NH_4-N (Jokela et al., 1995).

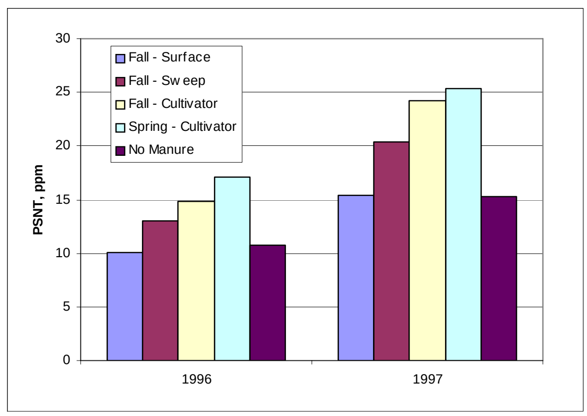

Figure 8. PSNT as affected by manure timing and tillage incorporation method. Sheldon, VT. (Jokela et al, 1999).

An ongoing study in Wisconsin (Powell and Misselbrook, unpubl.) compares two direct incorporation methods – narrow-shank injection, and broadcast incorporation with aeration tines (AerWay)[3] – to surface broadcast of liquid dairy manure on no-till silage corn stubble. Preliminary results, which include only one of three application periods for each year, show a typical pattern of ammonia emission with most of the loss occurring in the first day (Fig. 9). Both direct incorporation methods reduced ammonia losses significantly; but the magnitude of

[3] Equipment name is used for informational purposes only and does not imply the endorsement of the USDA-ARS or the University of Wisconsin.

ammonia emissions and the relative effectiveness of the two direct incorporation methods varied with each study period. This likely reflects differences in the specific soil, manure, and weather conditions during each application day. For the three-year period, injection showed the lowest NH_3 loss, surface broadcast the highest, and AerWay intermediate (Fig. 10).

Perennial Forage Systems

There are situations where standard injection or incorporation by tillage is not practical, e.g., manure applied to grasslands or to a no-till field. In these situations modified application equipment is needed. Because of root damage and yield reductions with deep injection, shallow injection systems (2-inch depth) have been developed (Fig. 11d) which reduce ammonia emissions but produce less soil disturbance and crop damage, although some yield reductions have been observed (Misselbrook et al., 1996). Ammonia volatilization has been reduced by 40 to 95% by shallow injection in various trials in the Netherlands and the UK (Misselbrook et al., 1996; Huijsmans et al., 1997). An approach that avoids soil disturbance entirely, while still reducing ammonia losses, is application of slurry in narrow bands either directly from the spreader hose or through a sliding shoe that rides along the soil surface (Fig. 11 b, c). The intent is to place the manure in a band close to the ground below the crop canopy, providing less surface exposure and some wind protection and preventing contamination of foliage with slurry. This equipment reduces ammonia volatilization, especially in the first few hours after application, though not as effectively as with injection. Most studies in Europe have reported volatilization reductions of 30 to 70% compared to surface application (Huijsmans et al., 1997; Pain & Misselbrook, 1997).

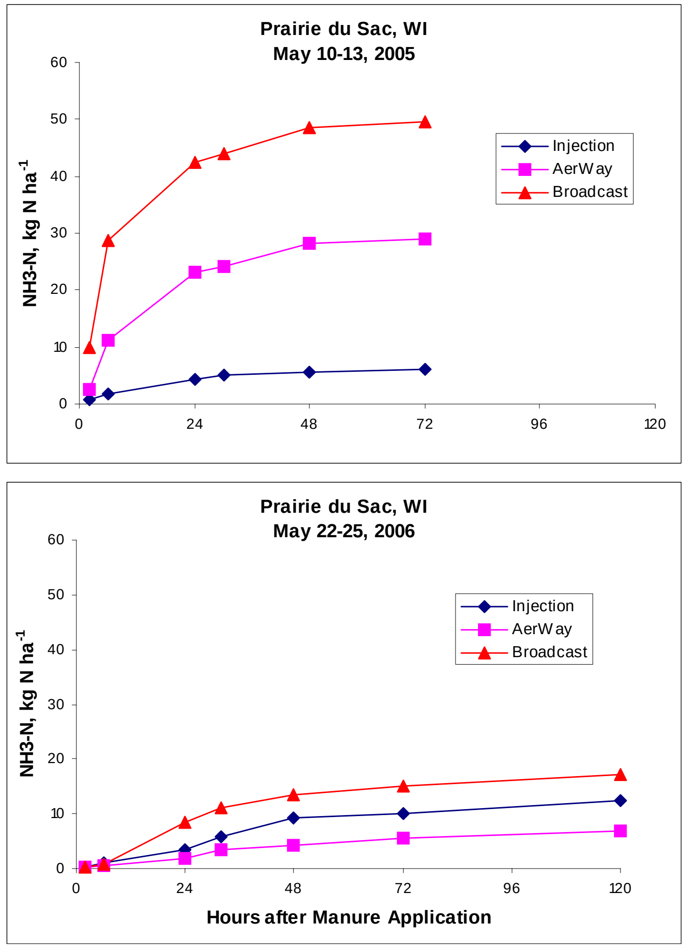

Figure 9. Cumulative loss of NH_3-N as affected by method of manure application (Powell and Misselbrook, unpubl.).

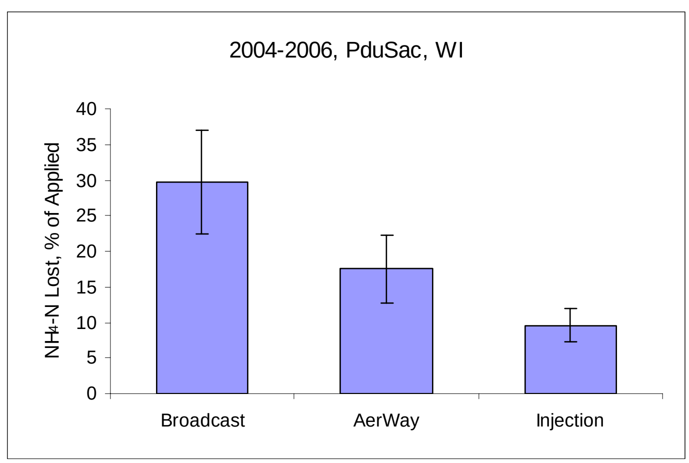

Figure 10. Total loss of NH_3-N as a percent of applied NH_4-N as affected by method of manure application (Powell and Misselbrook, unpubl.).

Research with a trailing foot application system in Vermont gave ammonia loss reductions of 30 to 90% compared to broadcast application, most of the difference occurring in the first several hours after application (Fig. 12; Jokela et al., 1996). Small, but significant, yield increases of 6 to 14% resulted from band application in two of four site-years (Carter et al., 1998). A three-year study in British Columbia showed greater grass yields and N recovery from a sliding shoe system (Bittman et al., 1999), the difference attributed to reductions in ammonia emissions. The same researchers applied dairy slurry to grass using a new implement, an AerWay SSD (sub-surface deposition applicator), which applies manure in narrow bands directly over vertical slots created by the aerator tines (Bittman et al., 2005). They reported ammonia emission reductions of over 50% compared to surface broadcast, as well as decreased odor and nutrient runoff losses. They also found the system effective for reduced-till annual crops, since it caused minimal residue disturbance (Bittman et al., 2004).

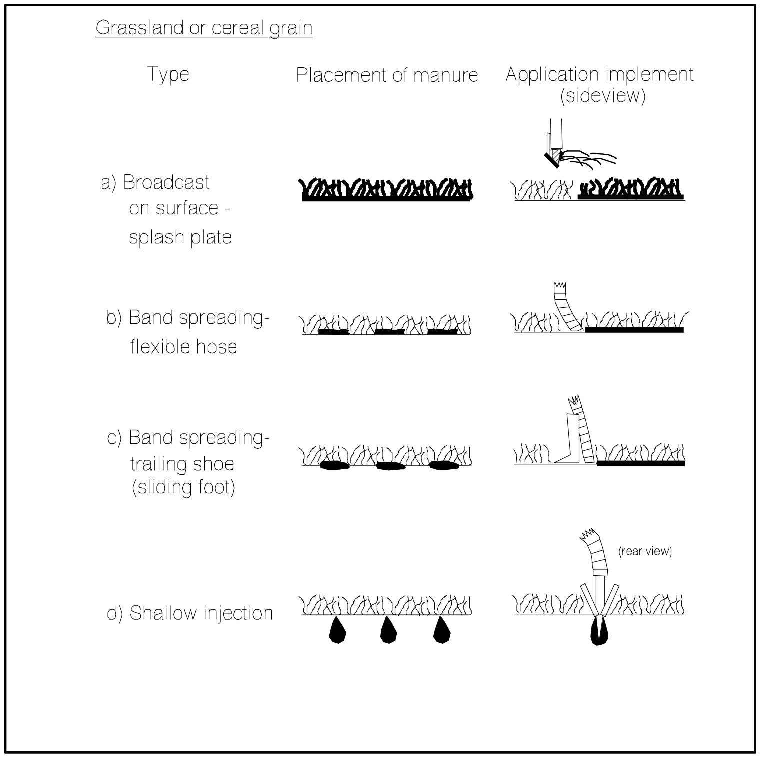

Figure 11. Equipment options for injection or direct incorporation in grassland or no-till crops (Jokela & Côté, 1994).

Matching Manure Application Rate to Crop Nutrient Need:
How much difference does manure incorporation make?

Let's look at an example of two scenarios for manure management for corn production – spring-applied dairy manure incorporated either within one hour (or injected) (Case 1) or after seven days (Case 2). See text box for other specifics (Jokela, 2004b).

Based on university recommendations (a composite of several north central and northeast states), manure in the example would provide approximately 13 lbs of available N (fertilizer equivalent) per 1000 gallons if incorporated immediately; so 7900 gallons per acre

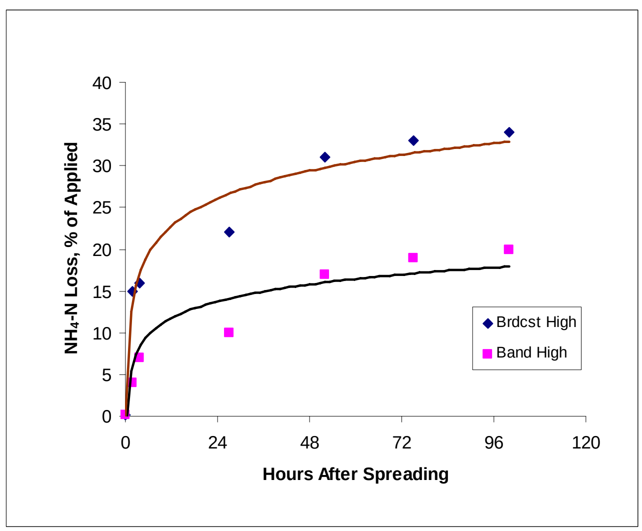

Figure 12. Cumulative NH_3 emission from dairy slurry applied as broadcast or banded with a trailing foot (Jokela et al., 1996).

would be required to meet the crop need of 100 lb N per acre. Because of the greater ammonia loss with delayed incorporation, the second scenario would require about 14,500 gallons per acre to meet the same N need. If there is additional land available with N and P need, the difference in application rates (6600 gallons/acre) would have a potential nutrient value of about $67/acre ($42 for N and $25 for P_2O_5). Both management options supply excess phosphorus, but only 39 lb P_2O_5 /acre in the first case compared to 105 lb lb P_2O_5 /acre in Case 2.

Example: Comparison of Time of Manure Incorporation for Silage Corn

- Nutrient Recommendation: 100 lb N, 40 lb P_2O_5 /acre (after accounting for starter N, previous crop, and past manure N)
- Dairy Manure Analysis, lb/1000 gal.
  - Total N: 23; NH_4-N: 11; P_2O_5: 10
  - 8% DM
- Fertilizer prices: N $.50/lb, P_2O_5 $.38/lb

While manure has historically been applied to meet the crop need for N, concerns about runoff of phosphorus from fields into surface waters has led to a need to apply manure on a P basis on some fields. How would the two scenarios compare in this regard? In both situations the manure rate required to meet the P recommendation would be the same – 4000 gallons per acre (assuming 100% fertilizer equivalent for manure P). In scenario 1 (quick incorporation) 49 lb/acre of additional fertilizer N would be needed; but in the delayed incorporation case 72 lb N/acre would be required. The difference in cost would be about $11 per acre, based on a price of $.50/lb N.

Summary

Ammonia volatilization can be a major nitrogen loss pathway for field-applied manure, and can have both economic and environmental consequences. Fortunately, there are effective and practical management practices to address these concerns – manure analysis as a basis for application rate, timing manure application to better coincide with crop N uptake, and timely incorporation of manure by tillage or one of several direct incorporation methods. Because of the temporal pattern of ammonia emission, most loss occurring in the first few hours after application, incorporation of manure immediately or shortly after application is particularly important to cut N losses, thereby saving fertilizer expense and minimizing undesirable environmental impacts.

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