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Advanced Application Techniques

Making the Most of Your Manure Responsibly

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Dairies, swine operations, beef cattle feedlots, and poultry houses generate substantial amounts of manure. This by-product is an excellent source of nutrients that can be used to feed plants. The manure also adds organic matter to soil that improves its nutrient retention, water-holding capacity, infiltration, and porosity. When properly managed, manure can be a valuable resource. However, applying manure to the land can also create nuisance odors, contaminate surface and groundwater, and cause nutrient imbalances in the soil.

Research demonstrates that advanced manure application techniques that incorporate manure into the soil are superior to traditional surface application in terms of retaining nitrogen and reducing negative environmental impacts. These advanced methods vary in their ability to reduce nitrogen loss from ammonia volatilization, nitrate runoff and leaching, and nitrous oxide emissions. Therefore, farmers must consider cost, nutrient efficiency, and environmental risks when choosing an application method. Understanding the nitrogen cycle and environmental impacts is essential to choosing application techniques that are most compatible with specific manure characteristics, land use and cropping regimes, and farm management practices.

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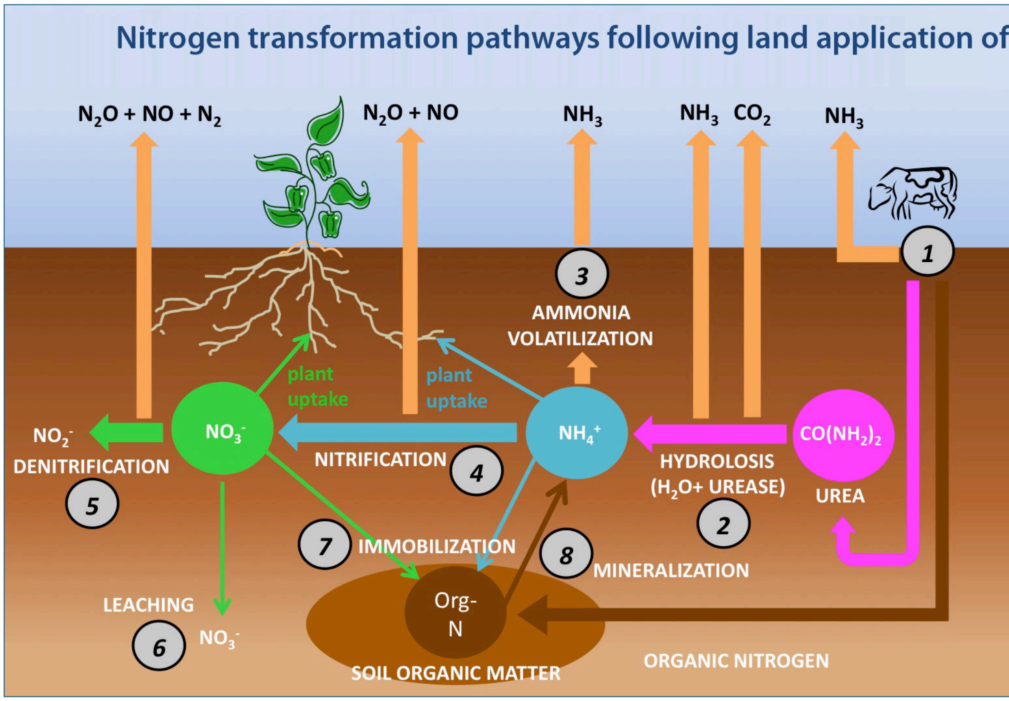
Manure-nitrogen transformations

Animals convert a portion of feed nitrogen into milk and meat protein; the remainder is excreted in urine and feces as organic and inorganic nitrogen. This manure is treated/stored, then applied to crop or forage land, where the nitrogen (as urea and organic nitrogen compounds) undergoes various chemical transformations. These manure and subsequent nitrogen transformations are directly affected by:

- animal species
- source of feed/dietary inputs
- type of manure treatment
- soil moisture
- nutrient levels
- soil pH and the temperature
- humidity
- wind conditions

Figure 1 illustrates how the nitrogen in manure is transformed in the soil through hydrolysis, nitrification, denitrification, immobilization, and mineralization. It also illustrates nitrogen loss to volatilization and leaching.



Symbol	Name
$CO(NH_2)_2$	Urea
CO_2	Carbon dioxide gas
NH_4+	Ammonium
NH_3	Ammonia gas
NO_3-	Nitrate
NO_2-	Nitrite
N_2O	Nitrous oxide gas
NO	Nitric oxide gas
N_2	Nitrogen gas
Org-N	Organic nitrogen, various forms

Figure 1. Nitrogen transformation in the soil, with chemical compounds identified above.

Transformation processes

① **Manure application:** Nitrogen is excreted in livestock and poultry urine as urea (in mammals) or uric acid (in birds), and as urea, ammonia, and organic nitrogen (proteins, organic acids, and amino acids) in feces.

② **Urea hydrolysis:** Hydrolysis of urea by urease (produced by microorganisms in feces and soil) converts urea into ammonia, ammonium, and carbon dioxide gas. Soil pH greater than seven favors ammonia volatilization and enhances this process.

③ **Ammonia volatilization:** This process is the conversion of liquid ammonium into ammonia gas that is lost to the atmosphere. High soil pH and temperature favor ammonium to ammonia conversion. Losses are greatest when this conversion occurs at the soil surface when manure is spread and not incorporated into the soil immediately.

④ **Nitrification:** Ammonium has a positive charge that binds it to negatively charged clay particles that can be taken up by plant roots. Under aerobic conditions (oxygen present) nitrifying bacteria in the soil converts ammonium to nitrite and then to nitrate in a few days or weeks. In process, nitrous oxide and nitric oxide gases are lost to the atmosphere. Nitrate is highly soluble and plants take it up more rapidly than ammonium–ammonium is bound to clay particles in the soil where roots must reach it.

⑤ **Denitrification:** The process by which soil bacteria convert nitrate and nitrite into gaseous nitrous oxide and nitric oxide, and eventually to nitrogen gas, which are lost to the atmosphere. This process occurs under anaerobic conditions (e.g., oxygen-poor soils due to water logging).

⑥ **Leaching:** Nitrate is leached mainly during rainy seasons and fallow periods, when percolating rainfall washes it from the plant root zone.

⑦ **Immobilization:** This process occurs when soil organisms take up nitrate and ammonium and temporarily lock up the nitrogen. When these organisms die, the organic nitrogen in their cells is mineralized into ammonium, which is again available to plants.

⑧ **Mineralization:** This process is the reverse of immobilization. Microbes in the soil convert organic nitrogen from manure and organic matter to ammonium. The rate of mineralization increases with soil temperature, moisture, and oxygen.

Health and environmental concerns

Applying large quantities of manure without a proper nutrient management plan can damage soil, water, and air quality. Ammonia, nitrate, and nitrous oxide are the nitrogen compounds that pose the greatest concern for human health and the environment. Nitrous oxide and methane, which emit from stored manure, are potent greenhouse gases.

Ammonia (NH_3)

Ammonia is a colorless pungent gas that is detectable at 5 to 18 parts per million (ppm). It is lighter than air and highly soluble in water. Ammonia is released from urine, uric acid, and feces while manure is stored and following land application. At elevated concentrations, ammonia contributes to respiratory problems in humans and animals.

Ammonia is one of the only basic (pH > 7) compounds in the atmosphere. It readily reacts with strong acidic compounds, such as nitric and sulfuric acids to form ammonium salts. These salts are among the constituents of fine particulate matter (PM) or dust particles that are less than 2.5 microns in diameter (designated PM2.5). They can remain airborne for up to 15 days leading to haze or smog.

When rain removes ammonia from the atmosphere and deposits it on land, it is converted into ammonium and absorbed by soil particles. Ammonium is eventually converted to nitrite or nitrate by bacteria, and releases hydrogen ions into the soil. Hydrogen ions that are not taken up by biomass eventually cause an acidic soil environment. Ammonia deposition can increase nitrogen levels to the point that it impairs an ecosystem's natural balance and enables non-native or nitrogen-responsive species to replace fragile plant and animal species.

Nitrate (NO_3)

Runoff, leaching, and soil erosion from agricultural land can transport nitrate and phosphorus, into lakes, ponds, rivers and streams, and cause eutrophication. Eutrophication is nutrient enrichment that causes excessive algae blooms, which rob water of dissolved oxygen. In extreme cases, this can change water clarity and color, kill fish, change aquatic plant diversity to forms that thrive in nutrient-rich water, and promote growth of harmful bacteria and toxins.

Nitrate-nitrogen that is not taken up by plants, immobilized by bacteria, or converted to atmospheric gases, can leach below the root zone and contaminate ground and surface water. Nitrates in food and water can be converted to nitrite by human digestion and can interfere with red blood cell's capacity to carry oxygen. This interference can cause *methemoglobinemi* (blue baby syndrome), a condition that primarily affects newborns and infants up to six months old. High nitrate levels in drinking water can also cause skin rashes and hair loss.

Nitrous Oxide (N_2O)

Nitrous oxide gas (laughing gas) is a byproduct of nitrification and denitrification. It is not available to plants and is a potent greenhouse gas. Nitrous oxide is about 300 times more effective at trapping heat in the atmosphere than carbon dioxide. Some estimates suggest nitrous oxide emissions are about 1.25 percent of the total nitrogen applied as manure.

Methane (CH_4)

Methane is also a potent greenhouse gas. It is 21 times better at trapping heat in the atmosphere than carbon dioxide. Some treatment systems capture or flare off methane before the manure is applied to land; however, some methane potential generally remains. Under aerobic conditions, soil microbes use methane as a source of carbon, but when methane concentrations exceed the metabolic capacity of the soil or soil microorganism metabolism is inhibited by manure application, methane emission may occur. Aerating the soil and treating manure before applying it can reduce net methane emissions.

Manure characteristics and application techniques

The choice of manure application equipment is largely determined by the solids content of manure–whether it is applied as a solid, slurry, or liquid. Figure 2 shows the breakdown of raw manure solids content for dairy and beef cattle, swine, and poultry.

There are several options for land application of manure. Each method varies in terms of nutrient efficiency, gaseous emissions, and environmental protection. Applicator design, soil moisture at the time of application, dry matter content, and application rate will determine how much nitrogen is lost from the soil surface.

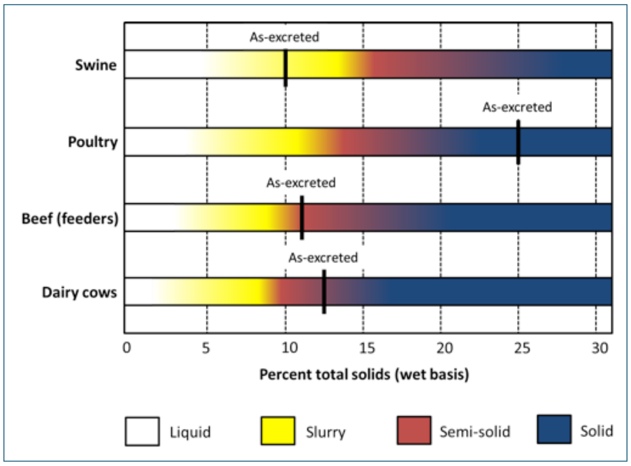


Figure 2. Relative handling characteristics of raw manure for various livestock species (adapted from Fulhage et al., 2001).

Solids

Most solid manure (15 percent or more dry matter) and compost are spread using broadcasting equipment then tilled into the soil. The most common equipment for applying solids is a rear-discharge, box-type spreader that distributes manure over swaths of varying widths. Some spreaders have a side discharge; most of these have V-shaped hoppers and feed the material with augers. Flail-type spreaders have a semicircular hopper bottom and a rotating shaft with chain-suspended hammers to fling the material from the hopper.

Manure spreaders may be tractor-drawn or mounted on a truck. Moving manure from storage to field is faster with truck-mounted box spreaders and shortens the time required to apply stockpiled manure. Soil compaction can be a problem, but using dual or flotation tires, or delaying application until fields are dry can help. However, delaying incorporation can lead to increased odor, and loss of nitrogen/nutrients to volatilization and runoff.

The recent development of a subsurface applicator for poultry litter is an important technological advance. This machine is the first subsurface applicator available for solid manures. Poultry litter has an inconsistent texture and relatively low moisture content, which makes it extremely difficult to inject.

The subsurface applicator overcomes this challenge by grinding the litter with augers above the chutes through which it drops into furrows in the soil. Poultry litter is dryer and more nutrient dense than slurry and liquid manure, so less volume needs to be applied. Subsurface applicators need to cut a slit only about 2 inches deep, apply the litter, and then close the opening.

Slurry

Surface application of manure slurry (4 to 10 percent solids), with equipment such as a splash plate applicator, has been the primary choice of farmers because it is faster and less expensive than other methods. However, traditional surface application risks include: uneven coverage (particularly in windy conditions), nuisance odor, damage to forage, ammonia volatilization, and runoff. Another disadvantage is that slurry broadcasting can only be used before the forage is growing or immediately after harvest.

Advanced manure application techniques that address these risks and limitations are becoming a more viable option for today's farmer. A growing

number of commercial applicators, concern for environmental protection, the high cost of synthetic fertilizers, and the need to improve nutrient retention are driving these new technologies. Equipment now allows manure to be applied to crops during the growing season at intervals that more closely match their specific nitrogen requirements. This flexibility also helps farmers save money by reducing needed storage capacity.

Band-type or **trailing-hose** spreaders apply manure slurry at or just above the ground through a series of hanging or trailing pipes. The application is typically 39 to 40 feet wide with about 12 inches

between bands. This technique can be used to apply slurry to growing forage stands and between rows of growing crops. The width of the machine makes this method unsuitable for small, irregularly shaped fields or steeply sloping land. The hoses may also become clogged if the slurry contains too much fibrous material (e.g., straw).

Trailing shoe or **sleigh-foot** machines are mainly suited to applying slurry to grassland. A narrow shoe or foot over the soil surface parts grass leaves and stems. Slurry is then placed in narrow bands on the soil surface at 8 to 12 inches apart—

slurry penetration into the root zone is enhanced by the parts. Placing manure below the forage canopy decreases ammonia volatilization and increases nitrogen recovery by using grass cover to protect it from wind. To limit ammonia loss, apply the slurry bands to grass that is at least 3 inches tall. These machines are 23 to 26 feet wide so their use is limited by the size, shape, and slope of fields and by stones on the soil surface.

The **open slot injection** technique is mainly for use on grassland. This technique uses knives or disc coulters to cut vertical slots 2 to 4 inches into the soil, and places slurry into them. The slots are typically 8 to 16 inches apart with a working width of approximately 20 feet. Application rate must be adjusted so slurry does not spill out of the open slots. Because

this technique depends on the knives or disc coulters cutting to a uniform depth, it is less effective on stony, shallow, or compacted soils.

Chisel injectors vary across manufacturers and models, but a significant common development is the sweep that can be placed on the bottom of the knife. This sweep mixes the manure horizontally within the soil profile. This horizontal tillage also seeks to reduce nitrogen leaching by disrupting macropores.

The **closed slot injection** technique can place manure as shallow as 2 to 4 or as deep as 6 to 8 inches below the surface. After the slurry is injected, it is covered completely by press wheels or rollers located behind the injection tines. Shallow closed-slot injection decreases ammonia emission more efficiently than open-slot applications when soil type and moisture conditions allow slots to close well. Deep injectors usually consist of a series of tines fitted with lateral wings or goosefeet to aid lateral dispersion of slurry into the soil. This allows relatively high application rates. Tine spacing is typically 10 to 20 inches with a working width of 7 to 10 feet.

Although this technique promotes ammonia retention, it is generally restricted to tillable land because the lateral wings can decrease yields on grassland. Soil depth, clay and stone content, uneven topography, and the need for a large tractor also limit this technique. Since the injection point is deeper, in many cases below the plant root zone, there is a greater risk of nitrous oxide emissions and leaching of nitrates.

Shallow incorporation involves tilling (e.g. plowing) in manure that has been spread on the surface. This method effectively decreases ammonia emissions. **Shallow disk injectors** minimize soil disturbance and incorporation of surface residues; they are compatible with no-till and forage systems. Plowing is mainly applicable to solid manures on tillable soils. The technique can also be used for slurries when injection techniques are not possible. Similarly, shallow incorporation can be used when rotating grassland to arable land or when reseeding.

Manure loses ammonia rapidly following spreading; incorporating the manure immediately after spreading reduces emissions. This requires a second tractor with incorporating equipment close behind the manure spreader. If a second tractor is not available, incorporating manure the same day it is spread will still reduce emissions.

Surface application with aeration uses core and solid tine aeration to incorporate liquid and dry manures into the soil. Aerators punch holes into the ground and can be used as manure is spread or afterward. When aeration and liquid manure are used together, manure can be broadcast or placed in bands over the aeration holes so more of it enters the soil profile and less is left on the surface. Though aerators require less draft energy than disk or chisel injectors,

they do not seal manure under the soil surface. Consequently, they are less effective at reducing ammonia volatilization.

Liquid

Liquid animal manure (up to 4 percent solids) is applied with center pivot and solid-set spray irrigation, tanker, towed-hose surface spreading, and shallow subsurface injection. Because liquid manure has relatively low nutrient concentration, it is generally applied at high rates. However, it should be applied evenly and at a rate that allows it to infiltrate and not run off. Center pivot and traveling gun sprinklers allow liquid manure to be applied rapidly, but can produce odors that travel beyond the application area

if they atomize the manure when shooting it into the air. Ammonia emissions and nitrogen loss will depend on how the manure is treated, the water dilution ratio, method of dispersal, weather conditions, and soil moisture at time of application. Injecting liquid manure during periods of low evaporation reduces loss from ammonia volatilization. Injection can also reduce runoff and produce greater crop yields.

Rewards and risks across advanced application methods

Advanced manure application techniques vary in how well they minimize ammonia volatilization, increase crop nitrogen uptake, improve forage and crop quality, and reduce emission of nitrous oxide. These measures differ according to manure consistency and nutrient loading, application rate, timing of application, weather conditions, land cover and topography, soil structure and moisture content. All of these manure application techniques, particularly for slurry manure, reduce ammonia and nitrous oxide emissions compared to conventional surface application methods. Table 1 summarizes research on reduction in ammonia loss for advanced application techniques.

Other research findings include:

- Subsurface manure applications with disks, knives, or chisels can reduce ammonia emissions by about 40 percent compared to traditional surface application methods. Well-designed manure injectors that close the injection slot can reduce ammonia emissions by more than 90 percent.
- Plowing in liquid or solid manure immediately after application is the most effective way to reduce ammonia volatilization. Delays of as little as 4 to 6 hours will lead to significant ammonia losses.
- Manure injection techniques can increase nitrate leaching because more nitrogen is applied directly into the soil profile. Nitrate leaching is more likely when excess nitrogen is applied and in areas with high rainfall rates, and soils that are sandy or have preferential flow paths.
- Advanced slurry application methods cause more nitrogen to be retained in the soil, so nitrous oxide emissions will usually increase. However, these increases are not absolute and should not eliminate use of ammonia-reducing techniques.
- Subsurface manure application can increase denitrification and lead to nitrogen loss as nitrous oxide. Adding readily metabolized carbon compounds, such as sugars, starches, and proteins, may decrease soil oxygen by increasing microbial activity in the injection slots; anaerobic conditions promote denitrification.
- Subsurface injection techniques are the best choice for reducing ammonia loss, but they are not suitable for when the terrain is rocky or uneven. In these situations, trailing shoes are a good alternative.
- Ammonia volatilization decreases as manure infiltration increases. Injecting or incorporating manure minimizes exposure to the air by placing manure within the soil.
- Incorporating solid manure reduces ammonia and nitrous oxide emissions. Banding slurry under a growing crop allows less ammonia to volatilize than applying it to fallow soil.

Table 1. Reductions in ammonia loss with advanced manure application techniques compared to surface application without incorporation.†

Application method	Type of manure	Land use	% NH_3 reduction	Nitrous oxide (N_2O) emissions
Incorporation (immediate)	solid & slurry	crop land	80–90[a,b]	Impacts on nitrogen loss due to N_2O emissions are mixed. Studies show either no difference or increased N_2O emissions due to subsurface application of manure compared to surface application. Conditions that favor N_2O emissions include saturated, anaerobic soils and injection slots containing readily metabolized carbon compounds that encourage denitrification.[b,c]
Incorporation (same day)	solid & slurry	crop land	40–90[a]	
Band spreading (trailing hose)	slurry	grass land	10[a]–74[b]	
Band spreading (trailing hose)	slurry	crop land	30[a]–75[b]	
Band spreading (trailing shoe)	slurry	grass land	40–70[a,b]	
Band spreading (trailing shoe)	slurry	crop land	38–90[b]	
Open slot injection	slurry	grassland	20–80[a,b,c]	
Closed slot injection	slurry	grass/crop	50–97[a,c]	
Deep injection	slurry	crop land	95–99[b]	

†Adapted from FAO (2009)[a]; Webb (2010)[b]; Dell (2011)[c].

For more information

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