Chapter 9. Manure as a Nutrient Source

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Introduction

Manure is an unavoidable byproduct of animal production. Manure can be a valuable source of nutrients for crop production when properly managed; however, improper management of manure can result in environmental degradation, damage to crops, and conflicts with neighbors and the public because of odors, pests, or other nuisances.

Proper management of manure must consider all aspects of the operation, including how and where manure is generated, how it is stored, and how it is ultimately used. Although there are various alternative uses for manure (e.g., biogas generation), this chapter will address the issues of manure production, storage, and land application for managing manure as a nutrient source for crops.

Manure production and composition

Quantity of manure produced

The quantity (volume or mass) of manure produced and its nutrient content are the most critical factors that govern its use as a nutrient source. The quantity of manure produced varies considerably among species because of differences in animal diets and metabolism and within species due primarily to differences in management (e.g. bedding, feed source, etc.). Estimates of dry and semi-solid manure production by species have been summarized by Tetra Tech, Inc. (Table 9.1).

Variation in manure NPK content among species

Animals are relatively inefficient in their utilization of N, P, and K from feed, with more than 50% commonly passing through to the feces. These nutrients may end up in the manure and, in the case of N, be lost to the atmosphere. In addition to variability in feed conversion efficiency, the amount and type of bedding (if any) will also influence the nutrient content of the material.

As might be expected, the quantity of nutrients in the manure varies considerably by species (Table 9.2). For example, broiler litter may contain four to five times as much N, and ten times as much P, as horse manure.

Table 9.1. Annual manure production estimates for various species (Tetra Tech, Inc., 2004).

	Animals per AU[a]	**Annual manure production per AU**
	-1000 lbs-	---tons---
Beef cattle	1.00	11.50
Dairy cattle	0.74	15.24
Swine (breeders)	2.67	6.11
Swine (other)	9.09	14.69
Hens (laying)	250.00	11.45
Pullets (over 3 months)	250.00	8.32
Pullets (under 3 months)	455.00	8.32
Broilers	455.00	14.97
Turkey (slaughter)	67.00	8.18

[a]**AU** = animal unit

Table 9.2. Nutrient content of various types of manure.

Manure Type	**Nitrogen** (total)	**Phosphorus** (P_2O_5)	**Potassium** (K_2O)
	----------lb / ton ----------		
Broiler litter[b]	59	63	40
Turkey (fresh)[a]	27	25	12
Layer[a]	35	42	28
Horse[b]	9	6	11
	----------lb / 1000 gal ----------		
Swine[b]	40	37	23
Dairy[b]	28	19	25

[a] Zublena et al., 1990.
[b] Bandel, 1990.

Table 9.3. Poultry litter moisture and nutrient values from 2,054 samples in Arkansas (Van Devender et al., 2004).

	Moisture Content	**Nitrogen** (Total)	**Phosphorus** (P_2O_5)	**Potassium** (K_2O)
	------%------	----------lb / ton ----------		
Minimum	2	22	18	23
Maximum	47	98	96	80
Mean	23	60	58	52

Improving the digestibility of P

Deviations from the nutrient content values listed above may occur for a number of reasons. One of the most important reasons is diet manipulation. Cereal grains (such as corn and soybeans) are major feed ingredients in poultry and swine diets (National Research Council, 1994). Approximately two-thirds of the P in these grains is in the form phytic acid, or phytate, that is poorly-digested by non-ruminants. This results in inefficient use of most of the grain-P, which subsequently passes through the animal in the manure. Because of this poor utilization, non-ruminant diets commonly are supplemented with more digestible forms of P, such as calcium phosphate (Angel et al., 2001).

One technique to increase the digestibility of P in feed grains is to add phytase to the feed. Phytase is an enzyme that helps the birds utilize more of the “indigestible” P, which reduces the need for supplemental P. Research has shown reductions in P excretions of 25 to 50% when phytase is added to poultry or swine diets and supplemental P (e.g., calcium phosphate) is reduced (Maguire et al., 2005; Nahm, 2002). Hansen et al. (2005) found that the recent adoption of phytase has lowered the P content of poultry litter in Delaware by 30 to 40% compared to traditional values.

Other nutrients in manure

Manure is usually managed to provide the three major plant nutrients (N, P, and K). However, varying amounts of other essential elements, including Ca, S, B, Mg, Mn, Cu, Mo, Fe, Na, and Zn, enhance the value of manure as a balanced nutrient source. Tables 9.4 and 9.5 contain “typical” concentrations of secondary and micro-nutrients of various poultry and swine manures, respectively.

Table 9.4. Typical content of secondary and micronutrients in poultry manures (Zublena et al., 1990).

Manure Type	Ca	Mg	S	Na	Fe	Mn	B	Mo	Zn	Cu
		----------lbs/ton----------								
Layer										
Undercage scraped	43.0	6.1	7.1	4.5	0.5	0.27	0.05	<0.01	0.32	0.04
Highrise stored	86.0	6.0	8.8	5.0	1.8	0.52	0.05	<0.01	0.37	0.04
Broiler litter										
Broiler house	41.0	8.0	15.0	13.0	1.3	0.67	0.05	<0.01	0.63	0.45
Roaster house	43.0	8.5	14.0	13.0	1.6	0.74	0.05	<0.01	0.68	0.51
Breeder house	94.0	6.8	8.5	8.6	1.3	0.57	0.04	<0.01	0.52	0.21
Stockpiled	54.0	8.0	12.0	6.2	1.5	0.59	0.04	<0.01	0.55	0.27
Turkey litter										
Brooder house	28.0	5.7	7.6	5.9	1.4	0.52	0.05	<0.01	0.46	0.36
Grower house	42.0	7.0	10.0	8.4	1.3	0.65	0.05	<0.01	0.64	0.51
Stockpiled	42.0	6.8	9.5	6.4	1.5	0.62	0.05	<0.01	0.56	0.34
		----------lbs/1000 gallons----------								
Layer										
Liquid slurry	35.0	6.8	8.2	5.3	2.9	0.42	0.04	0.02	0.43	0.08
Lagoon sludge	71.0	7.2	12.0	4.2	2.2	2.3	0.08	0.01	0.80	0.14
		----------lbs/acre-inch----------								
Layer										
Lagoon liquid	25.0	7.4	52.0	51.0	2.0	0.24	0.4	0.02	0.70	0.19

Table 9.5. Typical content of secondary and micronutrients in swine manures (Zublena et al., 1990).

Manure Type	Ca	Mg	S	Na	Fe	Mn	B	Mo	Zn	Cu
		----------lbs/ton----------								
Fresh	7.9	1.7	1.8	1.6	0.39	0.04	0.07	<0.01	0.12	0.03
Paved lot scraped	12.0	2.3	2.2	1.6	1.03	0.19	0.02	<0.01	0.35	0.15
		----------lbs/1000 gallons----------								
Liquid slurry	8.6	2.9	4.7	3.7	0.7	0.15	0.07	<0.01	0.39	0.11
Lagoon sludge	15.8	4.5	8.3	2.9	1.8	0.28	0.02	0.01	0.67	0.23
		----------lbs/acre-inch----------								
Lagoon liquid	25.5	8.3	10.0	57.7	2.4	0.34	0.18	<0.01	1.50	0.30

Manure sampling and testing

It is important to realize that actual manure nutrient content can be dramatically different from typical values. Testing of manure from specific operations is critical to accurately assess nutrient concentrations for the purpose of calculating manure application rates to supply crop nutrient needs.

A manure sample must be collected for laboratory analysis in order to determine the exact nutrient content. Proper collection of this sample is critical to ensure that it accurately represents the manure to be used.

Detailed sampling and handling procedures

In practice, it is difficult to obtain a truly representative sample because of the inherent variability in manure within a stockpile, a lagoon, or other storage facility. The following guidelines (adapted from Hermanson, 1996) will help to assure the best sample possible:

- **Semi-solid lot manure:**
  - Scraped directly from lot into spreader:
    a) Collect about 2 lbs of manure using nonmetallic collectors from different locations within a loaded spreader.
  - From storage:
    a) Collect manure using nonmetallic collectors from under the surface crust while avoiding bedding materials.

- **Liquid manure slurry:**
  - From under-slotted-floor pit:
    a) Extend a 1/2-in nonmetallic conduit open on both ends into manure to pit floor.
    b) Seal upper end of conduit by placing a thumb over open end to trap manure, remove and empty slurry into plastic bucket or nonmetallic container.
    c) Take subsamples totaling at least 1 quart from 5 or more locations.
  - From exterior storage basin or tank:
    a) Ensure that manure has been well mixed with a liquid manure chopper-agitator pump or propeller agitator.
    b) Take subsamples from 5 pit locations from agitator pump or from manure spreader, and place in a plastic bucket.

- **Lagoon liquid:**
  - Recycled liquid:
    a) Collect recycled lagoon liquid from inflow pipe to flush tanks in a nonmetallic sample container.
  - From lagoon:
    a) Place a small bottle (1/2 pint or less) on end of 10 to 15 ft pole.
    b) Extend bottle 10 to 15 ft from bank edge.
    c) Brush away floating scum or debris.

d) Submerge bottle within 1 ft of liquid surface.
e) Empty into a plastic bucket, repeat 5 times around lagoon, and mix.

- **Broiler or turkey litter:**
  - House litter:
    a) Visually inspect litter for areas of varying quality (e.g., areas around feeders and waterers), and estimate percent of floor surface in each area.
    b) Take 5 litter subsamples at representative locations representative of overall litter characteristics.
    c) At each location, collect litter from a 6-in by 6-in area to earth floor and place in a plastic bucket.
    d) Mix the 5 subsamples in the bucket transfer to a nonmetallic sample container, such as a 1-gallon freezer bag, and seal.
  - From stockpile:
    a) Collect subsamples from 5 locations at least 18 in into pile.
    b) Mix, transfer 2 to 3 lbs to nonmetallic sample container, and seal.

Manure samples should be either refrigerated or sent immediately to the testing laboratory. Glass containers should never be used because pressure from developing gases may fracture the glass.

Manure storage and handling

Nutrient loss

The nutrient content of manure, particularly nitrogen, can change during storage; therefore, sampling and analysis should be performed as close to the time of application as possible. Changes in nutrient content can occur due to dilution (e.g., rainwater entering a liquid storage system), settling (e.g., phosphorus precipitation and accumulation in lagoon sludge), or gaseous loss (e.g., nitrogen volatilization).

Some typical storage-related losses of N, P, and K for various manure systems are presented in Table 9.6. The losses were calculated by subtracting the nutrient contents after storage from “as-excreted” values so they include both storage and handling losses. Handling losses likely account for a consistent, but small, amount of nutrient loss.

Except for lagoons, losses of P and K during storage are relatively low and are likely due more to handling than actual storage. Large losses occur in lagoon systems as solids settle from the slurry to the bottom of the lagoon. By contrast, N losses during storage can range from 15% to as much as 90%. Note that the ranges can be fairly broad and actual losses may exceed the tabulated ranges due to differences in management, weather, mitigation strategies, etc.

Table 9.6. Typical manure losses during handling and storage (Fulhage and Pfost, 2002).

Manure System	Nitrogen	Phosphorus (P_2O_5)	Potassium (K_2O)
	----------percent lost----------		
Solid			
Daily scrape and haul	20-35	5-15	5-15
Manure pack	20-40	10-20	10-20
Poultry, deep pit or litter	25-50	5-15	5-15
Solids on open lot			
Scrape once/year	40-55	20-40	30-50
Daily scrape and haul	20-35	10-20	15-25
Separated solids, 90 days storage	30	10-20	10-20
Liquid (slurry)			
Anaerobic pit	15-30	5-20	5-20
Aboveground storage	10-30	5-15	5-15
Manure basin or runoff pond, 120-180 days storage	20-40	5-50	5-50
Liquid- lagoon	70-85	50-80	30-80
Lagoon, 365 days	90	50-80	30-80

Estimating nutrient loss during storage

Nutrient losses during storage are commonly estimated with the use of a standard loss factor for each type of storage (Table 9.7). Such calculations can be helpful for planning purposes, but it is best to test the manure before using it to supply plant-available nutrients.

Note: Determining the storage needs of the various types of operations is beyond the scope of this manual; however, there are some general factors that should be considered in essentially any situation where manure is stored before being applied to land. These considerations include the characteristics of the land (i.e., slope, vegetation, soil type, proximity to water) and the type of manure to be used (i.e. liquid, semi-solid, or solid).

Information regarding siting and sizing of storage facilities can be found in the Natural Resources Conservation Service (NRCS) Field Office Technical Guide available in electronic form for individual states at: http://www.nrcs.usda.gov/technical/efotg/.

Table 9.7. Estimating annual nutrient availability after losses from open lot, storage or lagoon[a]. Enter total manure nutrients produced (from Table 9.2) in columns 2, 5, and 8 and multiply by the relevant factor for your storage or management system.

Manure Storage/ Treatment System	**Nitrogen**			**Phosphorus (P_2O_5)**			**Potassium (K_2O)**		
	N Pro-duced	**Factor[b]**	**Avail-able N**	**P Pro-duced**	**Factor[b]**	**Avail-able P**	**K Pro-duced**	**Factor[b]**	**Avail-able K**
Example: poultry manure on sawdust; per ton (from Table 9.3)	*60*	** 0.50*	*30*	*58*	** 1.0*	*58*	*52*	** 1.0*	*52*
Open lot or feedlot		* 0.50			* 0.95			* 0.70	
Storage (slurry manure, bottom loaded storage)		* 0.85			* 1.0			* 1.0	
Storage (liquid manure, top loaded storage)		* 0.70			* 1.0			* 1.0	
Storage (pit beneath slatted floor)		* 0.75			* 1.0			* 1.0	
Poultry manure in pit beneath slatted floor		* 0.85			* 1.0			* 1.0	
Poultry manure on shavings or sawdust held in house		* 0.50			* 1.0			* 1.0	
1-Cell anaerobic treatment lagoon		* 0.20			* 0.35			* 0.65	
Multi-cell anaerobic treatment lagoon		* 0.10			* 0.35			* 0.65	

[a] Source: http://ianrpubs.unl.edu/wastemgt/graphics/g1334t1.pdf
[b] Multiplication factor: the portion of nutrients retained in the manure or effluent.

Land application of manure

Introduction

Most manure generated in the Mid-Atlantic region is applied to soils as a nutrient source for crop production. Manure has also been found to improve certain soil properties, including soil structure, water-holding capacity, and populations of beneficial organisms.

It is critical both from crop production and environmental perspectives that the application rates provide adequate nutrient levels while avoiding the application of excess nutrients that can leave the field via runoff or leaching. Overapplication of manure has been linked to environmental problems, including eutrophication.

Manure is usually managed to provide the three major plant nutrients: N, P, and K. The goal of proper manure management for crop production is to apply the manure using appropriate methods and rates to maximize the amount of land-applied nutrients that are taken up by plants.

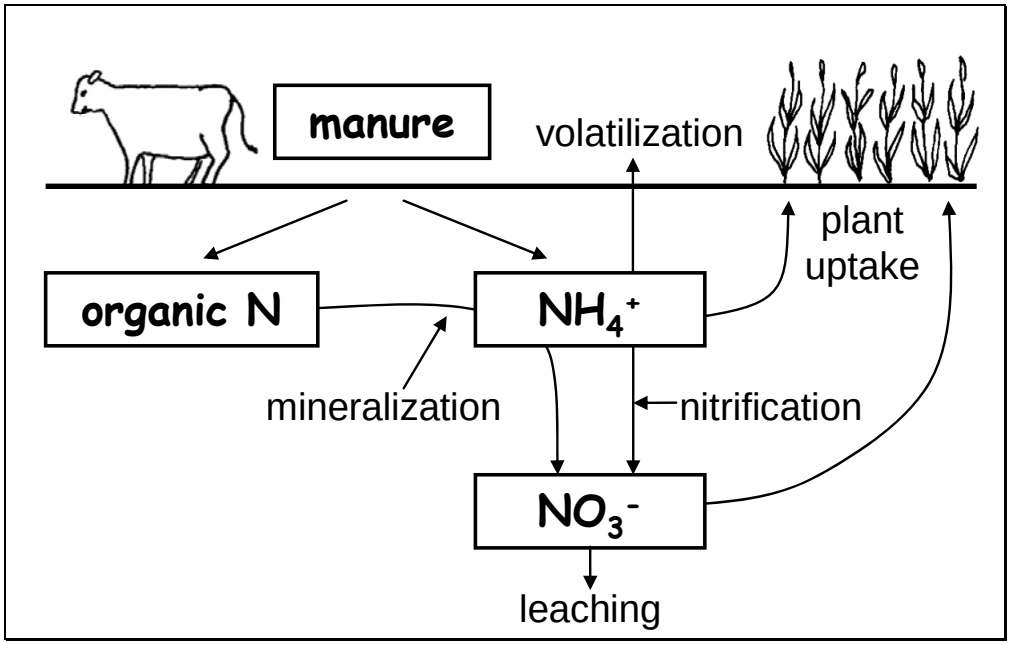
Availability of manure nutrients to plants

The plant-availability of the P and K in manure is commonly assumed to be similar to the availability of these nutrients in commercial fertilizer because most of the P and K in land-applied manure are present in inorganic forms. Determining the availability of P and K is a relatively simple matter of determining the P and K content of the manure. By contrast, determining the availability of N in manure is more complicated.

Forms of N in manure

Nitrogen in manures is found in two forms: organic and inorganic (Figure 9.1). Organic N is the fraction in dead plant and animal material and is found primarily in amine groups ($-NH_2$) and uric acid. Inorganic manure N can be either ammonium (NH_4^+) or nitrate (NO_3^-). The most common form of inorganic N in manure is ammonium, which is specified in most laboratory analyses.

Figure 9.1. Partial N cycle showing the forms and transformations of nitrogen in manure.



Estimating N mineralization rate

The inorganic fraction, which can comprise 20 to 65% of the total quantity of N in manure (Table 9.8), is considered immediately available to plants. The organic fraction must first be converted to inorganic N: a process termed *mineralization*. The rate at which the organic N is mineralized is highly variable and influenced by factors such as temperature, moisture, and C:N ratio of the manure. Despite this variability in mineralization rate, researchers have adopted some general mineralization factors that are commonly employed to estimate N availability for various types of manure during the season following the application (Table 9.9). These factors represent the percentages of the organic fraction that are expected to become available to plants during the first year after application of manure.

Table 9.8. Average percentage of forms of nitrogen in different types of manure in Virginia (Virginia Department of Conservation and Recreation, 1993).

Manure type	Organic N	Inorganic N (NH_4^+)
	---------- % ----------	
Dry poultry	77	23
Liquid poultry	36	64
Semi-solid dairy	70	30
Liquid dairy	58	42
Semi-solid beef	80	20
Swine lagoon	47	53
Mixed swine	35	65

Table 9.9. Fraction of organic N mineralized from various manure types and application scenarios in the year of application. (Virginia Department of Conservation and Recreation, 2005.)

Manure type	Spring or early fall applied[a]	Winter topdress or spring residual[b]	Perennial grass
	----- N mineralization factor -----		
Dairy or beef	0.35	0.20/0.15	0.35
Swine	0.50	0.25/0.25	0.50
Poultry	0.60	0.30/0.30	0.60

[a] Factors for manure applied in spring for summer annual crops or in early fall for small grain crops.
[b] Factors for manure applied in early winter/available in spring.

Sources of volatilizable N

Volatilization is the loss of N as ammonia gas (NH_3). There are two major pathways for this loss in agriculture: conversion of ammonium-N (NH_4^+-N) to NH_3 and the conversion of urea ($CO(NH_2)_2$) to NH_3. Urea is a nitrogen-containing compound that is readily converted to ammonia upon catalysis by the ubiquitous enzyme urease via the following reaction:

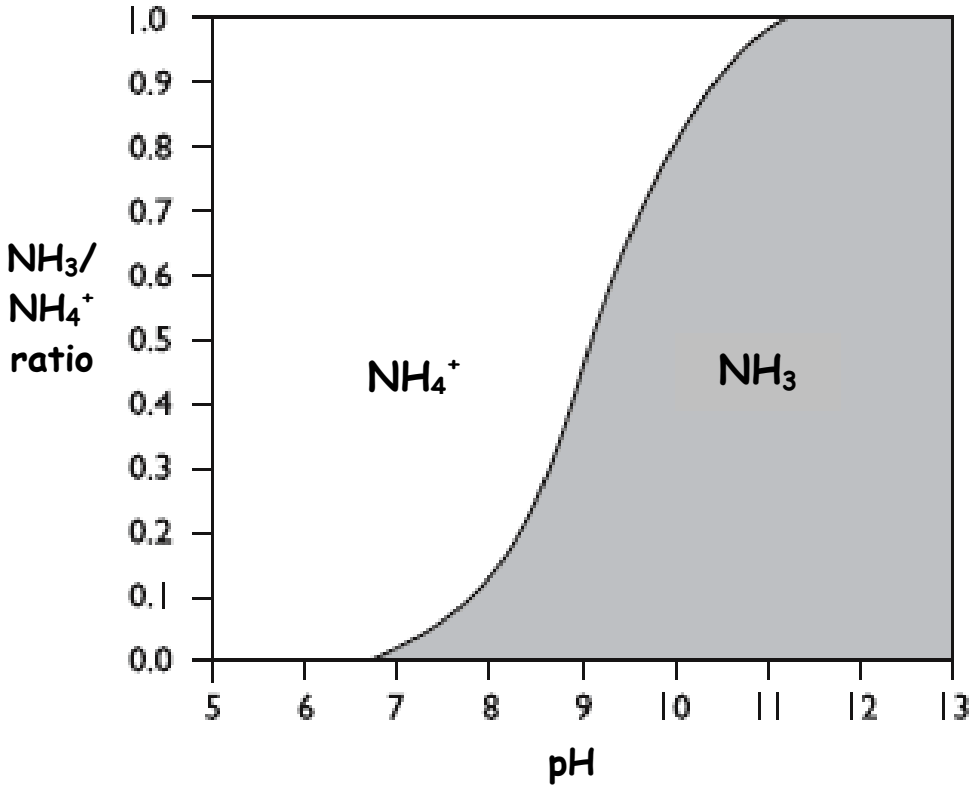
$$\mathbf{CO(NH_2)_2 + H_2O + urease \rightarrow 2NH_3 + CO_2}$$

Effect of soil pH on N volatilization

The most important factor influencing nitrogen volatilization of reduced inorganic N (i.e., ammonium and ammonia) in manure is pH (Fig. 9.2). Nearly all of these N forms are present as ammonium at pH levels typically encountered in Mid-Atlantic soils (i.e., <6.5). The percentage of ammonia

increases and volatilization losses are more likely to occur as pH rises. This equilibrium is typically shifted toward ammonia in freshly excreted manures, which have higher pH values than soil.

Figure 9.2. The NH_3/NH_4^+ (ammonia to ammonium) ratio as a function of pH (adapted from Gay and Knowlton, 2005).



Effect of incorporation on N volatilization

The best way to minimize N volatilization losses from applications of manure is incorporation. Table 9.10 shows the volatilization factors that can be used to predict losses of ammonia under three different application scenarios. This factor should be multiplied by the manure ammonium/ammonia content to predict plant-available N.

Table 9.10. Manure ammonium-N availability factors for Virginia. (Virginia Department of Conservation and Recreation, 2005.)

Application method	Semi-solid manure	Liquid slurry	Lagoon liquid	Dry litter
	---------- N availability factor ----------			
Injection	-----	0.95	0.95	-----
Broadcast with immediate incorporation	0.75	0.75	0.90	0.90
Incorporated after 2 days	0.65	0.65	0.80	0.80
Incorporated after 4 days	0.40	0.40	0.60	0.65
Incorporated after 7 days or never incorporated	0.25	0.25	0.45	0.50
Irrigation without incorporation	-----	0.20	0.50	-----

Calculating plant-available N (PAN)

The amount of nitrogen available to crops during the first year following application of manure is referred to as *plant-available nitrogen*, or *PAN*. PAN is the total of the inorganic nitrogen (primarily ammonium, or NH_4^+-N) and the percentage of the organic nitrogen that will mineralize during the growing season.

The first step in calculating PAN is to **determine the amount of organic and inorganic N in your manure**. Most manure analyses do not provide this information directly. Instead, they give the total amount of N (usually as total Kjeldahl N, or TKN) and the inorganic N (NH_4^+-N) present (as pounds of nutrient per ton or per 1,000 gallons) in the sample. To determine the organic fraction, simply subtract the NH_4^+-N value from the TKN value, as follows:

Step 1: TKN - NH_4^+-N = Organic N

The second step is to **estimate the amount of organic nitrogen that will mineralize during the first year**. This is calculated by multiplying your value for organic N by a mineralization factor. Table 9.9 can be used to obtain a mineralization factor that matches a particular manure type.

Step 2: Organic N * Mineralization Factor = Organic N Available First Year
(from Step 1) (from Table 9.9) (lbs/ton or lbs/1000 gallons)

The third step is to **estimate the amount of NH_4^+-N that will be available**

following land application. This can be estimated using the volatilization factors from Table 9.10.

Step 3: NH_4^+-N (from lab analysis) * volatilization factor = available NH_4^+-N (lbs/ton or lbs/1000 gallons).

Then, to **calculate PAN**, simply add the organic N available the first year (from Step 2) to the available ammonium-nitrogen (NH_4^+-N) available (from Step 3).

Step 4: Available NH_4^+-N + Organic Available First Year = PAN (lbs/ton or lbs/1,000 gallons)

Equipment calibration

The information in the preceding sections will be useless if the manure is not applied uniformly and at a known rate. Proper calibration of manure application equipment is a critical part of manure and nutrient management.

Regardless of the design of the equipment or type of manure, manure application equipment can be calibrated in one of three basic ways (Koelsch, 1995):

- The *tarp* method:
  Place a tarp flat on the field, spread manure on the tarp, weigh the manure, and calculate the application rate.
- The *swath and distance* method:
  Determine the swath width and distance traveled to empty the spreader and calculate the rate based on area covered and the weight of the load.
- The *loads-per-field* method:
  Simply count the number of loads of manure applied and divide by the numbers of acres.

For each of the calibration methods, it is critical that all of the controllable variables (i.e., equipment speed, gate settings, type and consistency of manure) remain constant!

Calibrating with the tarp method

The tarp method consists of placing a tarp (or plastic sheet) on the ground and using the manure spreader to spread the manure on the tarp. The collected manure is weighed, and the application rate is determined from the weight of the manure collected and the area of the plastic sheet or tarp used. This measurement should be repeated at least three times and the results averaged to ensure a consistent application rate.

Table 9.11 provides conversion factors to easily calculate the application rate based on the quantity of manure collected and some common tarp sizes.

Alternately, the rate can be calculated by simply dividing the number of pounds of manure collected by the area (in square feet) of the tarp. The result will be the pounds of manure per square foot. This number can be multiplied by 21.78 to give the tons per acre.

Example: You have an 8 ft by 8 ft tarp and you collect 8.8 lbs of manure on the tarp. The calculation would be:

8.8 lbs / 64 sq ft *(8 ft * 8 ft = 64 sq ft)* = 0.1375 lbs/sq ft
0.1375 lbs/sq ft * 21.78 = 3 tons/acre applied

Table 9.11. Application rate in tons per acre (T/A) for four common tarp sizes (Mancl, 1996).

Pounds (lbs) of waste collected	**----------Tarp dimensions----------**			
	6 ft by 6 ft	**8 ft by 8 ft**	**10 ft by 10 ft**	**10 ft by 12 ft**
	----------Application rate (T/A) ----------			
1	0.61	0.34	0.22	0.18
3	1.82	1.02	0.65	0.54
4	2.42	1.36	0.87	0.73
5	3.03	1.70	1.09	0.91
10	6.05	3.40	2.18	1.82
15	9.08	5.10	3.27	2.72
20	12.10	6.81	4.36	3.63

Calibrating with the swath and distance method

Calculations for determining application rate for the swath and distance method are similar to those used for the tarp method above. First, determine the weight of a “load” of manure either by direct measurement (i.e., weighing) or by converting from volume measurement. (Many applicators are rated by bushel or cubic foot capacity). Second, determine the width of the application swath and the distance required to apply the load. From this point, the calculations are identical to those used above.

Example: You have a spreader that holds 7000 lbs of manure (3.5 tons). Your application width is 35 ft and the equipment travels 1200 feet along a field to empty the load. The calculation would be:

7000 lbs / 42,000 sq ft (35 ft * 1200 ft = 42,000 sq ft) = 0.1667 lbs/sq ft
0.1667 lbs/sq ft * 21.78 = 3.63 tons/acre applied

Calibrating with the loads-per-field method

The loads-per-field method is the easiest to calculate. The major drawback of this method is that it is an “after the fact” calculation so that the applicator does not have the opportunity to make adjustments in the application rate for the particular field. This method may best be used as a method of monitoring application rates during the clean-out of a storage facility, using the first two methods described to actually calibrate the spreader before the full scale application of manure begins.

First, determine the weight in tons of a load of manure. Second, determine the size of the field in acres. It is then a simple matter of counting the number of loads applied to the field, multiplying that number by the weight in tons of a single load, and then dividing that number by the acreage of the field.

Example: You have a spreader that holds 7000 lbs of manure (3.5 tons). Your field is 55 acres and you apply 35 loads to the field. The calculation would be:

35 loads * 3.5 tons/load = 122.5 tons
122.5 tons / 55 acres = 2.23 tons/acre applied

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