CHAPTER 3

Swine Manure Production and Nutrient Content

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INTRODUCTION

Knowledge of the amount of manure and plant nutrients produced on a swine farm is the first step in the proper operation of a swine manure handling, treatment, and utilization system. The nutrient and volatile solids content of swine manure will vary with the digestibility of the ration, animal age, amount of feed wasted, the amount of water wasted, and the amount of water used to remove manure from the building. The data provided in this chapter is to be used for general planning purposes. South Carolina regulations (Standards for the Permitting of Agricultural Animal Facilities: R.61-43) require swine producers to have manure samples analyzed annually to establish land application rates.

MANURE PRODUCTION

The quantity of fresh swine manure (including feces and urine) produced each day is shown in Table 3.1. The quantity of manure, total solids, and volatile solids produced per day are given per animal unit (AU). An animal unit is equal to 1,000 pounds of live animal weight. The quantity of manure produced is given in pounds (lb), cubic feet (ft^3), and gallons (gal).

The total and volatile solids content in swine manure is given in lb/AU/day since these are the units often used to size an anaerobic lagoon or digester (see chapter 4 for more details). The total solids content is the combination of the solids than can be broken down by bacteria and the solids that will never degrade. Volatile solids are the solids that can be decomposed by biological treatment.

Table 3.1. Daily production of fresh manure, total solids, and volatile solids for typical swine farms (adapted from MWPS-18, 1993; ASAE standard D384.1, 1998; and Barker, 1990).

Farm Type	Average Weight lb/PU [2]	Manure Production per AU [1] lb/day	ft^3/day	gal/day	Total Solids lb/AU/day	Volatile Solids lb/AU/day
Farrow-to-Wean	433/sow	60	0.97	7.26	5.9	4.5
Nursery	30/pig	84	1.35	10.1	11.0	8.5
Farrow-to-Feeder	522/sow	64	1.03	7.70	6.7	5.1
Feeder -to- Finish	135/hog	84	1.35	10.1	11.0	8.5
Farrow-to-Finish	1,417/sow	77	1.24	9.28	9.3	7.2

[1] AU = 1,000 lb of live weight.
[2] PU = production unit. The production unit is a sow, pig, or hog as shown.

CALCULATION OF AVERAGE PRODUCTION LIVE WEIGHT AND NUMBER OF ANIMAL UNITS

The manure and solids production data are given as the pounds or volume per animal unit per day. The average production unit depends on the type of swine that are kept on the farm. For example, the production unit on a farrow-to-wean farm is the sow. The animal weight per sow includes the weight for all pigs produced, gestating and breeding sows, boars, and replacement animals. On a swine farm with only one type of animal, such as a feeder-to-finish farm, the average weight is simply the average weight of the hogs at any time. For example, if the average weight of a feeder pig that is placed in the building is 50 lb and the average weight of a market hog is 220 lb the average weight per hog is (50 + 220)/2 = 135 lb.

Some of the facility and lagoon site selection requirements in the South Carolina regulations depend on the size of the operation. The average production live weight on the farm is used to define farm size. Swine operations with more than 420,000 pounds of average live weight fall under the regulations for large swine facilities. The values in Table 3.1 can be used to calculate the average production live weight using the following equation:

Average Production Live Weight = Number of Production Units x (lb / PU). (3.1)

Example 3.1 Determine the total average production live weight for a 1000 sow, farrow-to-feeder swine farm using equation 3.1. Is this farm subject to the regulations for large swine facilities?

From Table 3.1 the average weight per PU for a farrow-to feeder farm is 522 lb/sow. The average production live weight for a 1,000 sow farm is: 1,000 sows x 522 lb/sow = 522,000 pounds. In the South Carolina regulations a large swine farm is defined as any farm that has a production live weight that is greater than 420,000 pounds. Therefore, a 1,000 sow, farrow-to-feeder farm comes under the regulations for large swine farms.

Example 3.2 What is the largest farrow-to-feeder farm that *does not* come under the regulations for large swine facilities?

Calculate the number of production units that will give an average live weight of 420,000 pounds as follows:

420,000 lb ÷ 522 lb/sow = 804.6 sows.

Therefore, the largest number of sows that can be kept on a farrow-to-feeder farm and still come under the regulations for small swine facilities is 804 sows.

The daily manure production data given in Table 3.1 is given per animal unit (AU). The number of animal units on a farm is calculated as:

Number of Animal Units (No. AU) = Average Production Live Weight ÷ 1000. (3.2)

Example 3.3 Calculate the number of animal units for a 1,000 sow farrow-to-feeder farm. The average production live weight of a 1,000 sow farrow-to-feeder farm was calculated in example 1 and was found to be 522,000 pounds. The number of animal units is: 522,000 ÷ 1,000 = 522.

MANURE VOLUMES FOR DIFFERENT MANURE HANDLING SYSTEMS

The manure production data given in Table 3.1 is for undiluted manure as excreted from the animals. However, the actual volume that must be collected, handled, treated, and stored varies with the methods used to remove manure from the building. In addition, wasted water from waterers and building washdown can increase the manure volume by 10 to 30%.

The volume of manure and wasted water is compared with the amount of liquid manure that flows from pit-recharge and flush buildings in Table 3.2. The manure and wasted water volumes in the table are good estimates of the volume of fresh manure, waterer wastage, and washdown water that is added to a manure handling system each day. This volume is used to calculate the manure storage volume when a lagoon or liquid storage structure is sized.

In South Carolina, most swine facilities use a flush or pit-recharge system with a lagoon or storage pond (chapter 4). The water used to remove manure from a pit-recharge or flush building is typically recycled from the lagoon. Pit-recharge systems are gaining popularity over flush systems because less water volume is required to clean the building.

Table 3.2. Variation of swine manure volume depending on type of manure handling system (to convert to gallons multiply ft^3 by 7.48).

Farm Type	Average Weight lb/PU	Manure and Wasted Water [1] ft^3/AU/day	Pit-Recharge [2] ft^3/AU/day	Flush [3] ft^3/AU/day
Farrow-to-Wean	433 lb	1.16	9.3	9.4
Nursery	30 lb	1.62	9.4	17.6
Farrow-to-Feeder	522 lb	1.24	9.4	10.7
Feeder -to- Finish	135 lb	1.62	6.8	17.6
Farrow-to-Finish	1,417 lb	1.49	7.8	14.9

[1] Dilution water from waterer wastage and washdown was assumed to be 20% of the manure volume. Does not include water for flushing or pit-recharge.
[2] Includes wasted water and water used to remove manure from buildings. Total solids content for pit-recharge systems varies from 1.5% to 2.6%.
[3] Includes wasted water and water used to remove manure from buildings. Total solids for flush systems can vary from 0.5 to 2%. A value of 1% was used to calculate the volumes shown.

The actual amount of manure handled per day on a given farm will vary with farm size and the type of manure handling system used. A flush system will remove manure from a building 4 to

12 times a day. A pit-recharge system is typically emptied every 5 to 7 days. These daily values can be used to estimate weekly or annual volumes once the manure removal schedule is established.

Example 3.4 A feeder-to-finish swine farm has 6 pit-recharge buildings that are designed to house a maximum of 880 hogs. The manure from one building is emptied every 7 days. What is the volume of manure that must be handled by the waste system? Give the volume in cubic feet and gallons.

Step 1. The average weight per PU for a feeder-to-finish farm is 135 lb/hog (Table 3.2). Calculate the number of animal units in a single building as:

$880 \text{ x } 135 \text{ lb/hog} \div 1{,}000 \text{ lb/AU} = 118.8 \text{ AU / building}$.

Step 2. From Table 3.2, the total manure and wasted water produced per AU per day is 6.8 ft^3/AU/day. Calculate the manure volume per day as follows:

118.8 AU/building x 6.8 ft^3 / AU / day x 7 days = 5655 ft^3 of manure/building.

Step 3. The volume in gallons is

5655 ft^3/day x 7.48 gal/ft^3 = 42,299 gal/building.

NUTRIENT CONTENT OF SWINE MANURE

Swine manure contains all 13 of the essential plant nutrients that are used by plants. These include nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), chlorine (Cl), boron (B), iron (Fe), and molybdenum (Mo). Plant nutrients originate from the feed, supplements, medications, and water consumed by the animals. Using swine manure as a fertilizer for crops or trees may provide a portion, or all, of the plant requirements. The amount of nutrients provided depends on the nutrient content of the manure (lb of nutrient / 1,000 gal of manure) and the amount of manure applied (gal of manure / acre). The amount of manure applied per acre (called the ***application rate***) is typically based on the nitrogen needs of the plants. However, phosphorous requirement can also be used to determine the application rate (for more details see Chapter 5, Waste Utilization). South Carolina regulations can also limit the land application rate of swine manure based on the copper or zinc content of the manure.

The nutrient content (lb / 1,000 gal) in swine manure varies depending on the age of the animals, ration, temperature, methods used to collect and store manure, and the moisture content. The amount of water used to remove manure from the building has a large effect on the moisture content. Flush systems generally add more water to the manure than do pit-recharge systems. Dilution water is also added to manure from waterers, and from building washdown.

The variation in the nutrient content of fresh swine manure and manure from several types of storage and treatment alternatives is compared in Table 3.3. These values were developed from a database that combines data taken on South Carolina swine farms with mean values from North Carolina State (Barker, 1990). The values for fresh manure were taken from the ASAE Standard D384.1 (1998).

The nutrient content in a lagoon or storage will vary by depth. A large fraction of the solids in swine manure will settle to the bottom of a storage structure. As a result, the nutrient composition of the top layer of water in a lagoon or storage will be reduced by the settling process alone. Most of the nitrogen in the top layer of water in a lagoon or storage is in the ammonium form. Ammonium nitrogen (NH_4^+-N) can be readily converted to ammonia gas and be lost from the surface of lagoons and storage ponds by volatilization. Organic nitrogen (organic-N) and phosphorous (P_2O_5) is concentrated in the solids that settle to the bottom of a lagoon.

Anaerobic decomposition will occur in most storages and lagoons. The volatile solids in manure are broken down by anaerobic bacteria. During this process the organic nitrogen is converted to ammonium nitrogen. Over a period of time, the ammonium nitrogen from decomposed volatile solids is converted to ammonia and can be lost to the atmosphere.

Table 3.3. Comparison of the nutrient content of the common forms of swine manure on South Carolina farms (as-sampled or wet basis).

Moisture	90.8%	98.0%	99.63%	90.0%	97.8%	99.5%
Total Solids	9.2%	2%	0.37%	10%	2.2%	0.5%
Manure Type	Fresh [1] Manure	Manure [2] from Building	Lagoon Surface Water	Lagoon Sludge	Agitated Water & Solids [7]	Storage Pond Surface Water
	lb / 1000 gal					
NH_4^+-N	28.6	11.4	3.4	6.1	3.9	4.3
Organic - N	22.7	5.6	1.4	15.5	4.1	2.0
Total - N [3]	51.3	17.0	4.8	21.6	8.0	6.3
ESTIMATES OF AVAILABLE NITROGEN [4]						
Incorporated	36.5	12.5	3.6	14.2	5.6	4.6
Surface	27.9	9.1	---	12.3	4.4	---
Direct Injection	---	14.8	4.2	---	6.4	5.5
P_2O_5 [5]	40.4	13.4	2.8	47.3	11.3	3.6
K_2O [6]	34.5	14.2	6.1	6.3	6.1	7.9
Ca	32.6	3.7	0.86	32.3	6.8	1.1
Mg	6.9	2.4	0.46	11.0	2.5	0.57
Zn	0.49	0.28	0.03	1.8	0.37	0.04
Cu	0.12	0.26	0.02	0.75	0.16	0.03
Mn	0.19	0.12	0.01	0.65	0.13	0.02
S	7.5	1.3	0.31	6.6	1.5	0.39
Na	6.6	2.5	1.8	1.6	1.8	2.2

[1] Nutrient content of manure as excreted (from ASAE Standard D384.1, 1998). All other values based on database compiled by the authors.
[2] The total solids content from flush and pit-recharge buildings will vary from 1.5% to 2.6% depending on building design and animal weight. A mean value of 2% is shown.
[3] Total-N = Organic-N + (NH_4^+- N)
[4] Estimates based on recommendations from the Clemson University Agricultural Services Laboratory.
[5] Total phosphorus expressed as P_2O_5. To get elemental P multiply by 0.44.
[6] Total potassium expressed as K_2O. To get elemental K multiply by 0.83.
[7] Use these values as an estimate of the nutrient content of agitated liquid storage structures and lagoons.

The nutrient values in Table 3.3 can be used for general planning before a lagoon or manure storage is constructed, or prior to the expansion of an existing farm. In the case of an existing lagoon or storage pond, sample analysis from the structure must be used to perform nutrient balances for land application.

Estimation of Plant Available Nitrogen

Not all of the nitrogen in swine manure is immediately available for plant use. The nitrogen that is available for plant use is called the plant available nitrogen (PAN). Nitrogen (N) can be present in manure as ammonium-N, organic-N, and nitrate-N.

Ammonium Nitrogen and Volatilization Losses
A large portion of the nitrogen in liquid swine manure is in the ammonium (NH_4^+) form. Ammonium (NH_4^+) and ammonia (NH_3) can interchange rapidly depending on the pH. Ammonium will convert to ammonia at a pH that is greater than 6.5. Increasing the pH (more alkaline or less acid) increases the amount of ammonia and decreases the amount of ammonium. Most manure has a pH close to 7.0. Therefore, both ammonium and ammonia are present. The Clemson University Agricultural Services Laboratory reports a single value for the ammonium nitrogen content of manure. This value includes both ammonical forms of nitrogen (NH_4^+ and NH_3). Therefore, whenever the term ammonium nitrogen (also abbreviated NH_4^+-N) is used in this book it should be understood that both ammonia and ammonium are included.

Ammonia (NH_3) is a gas and can be readily lost to the air by ***volatilization***. Volatilization is a process that is similar to evaporation. Volatilization losses can occur from the surface of manure whenever it is exposed to air. Ammonia-N can be lost from manure on concrete lots, from the surface of liquid manure in a pit, from the surface of a lagoon or storage structure, and during land application. The nutrient content of manure is typically measured using a representative sample of the form of manure that is to be land applied. Therefore, volatilization loss resulting from handling and storage of manure has already occurred, and only an estimate of the application loss is used to estimate the amount of ammonium-N that is available.

The amount of ammonium nitrogen that is lost from swine manure depends on the method of land application as shown in Table 3.4. If manure is spread on the ground without being mixed into the soil by a tillage operation (called ***incorporation***) then a large portion of the ammonia nitrogen can be lost to the atmosphere. Ten to fifteen percent of the NH_4^+-N is lost from surface applied manure each day if rain does not fall on the field. In addition, a fraction of the ammonium-N can be lost during the application process. A significant rain (0.25 inches or more) will carry most of the ammonium nitrogen into the soil. All of the NH_4^+ can be converted to ammonia and can be lost if it does not rain for several weeks.

Incorporation of manure on the same day it is applied can reduce the volatilization losses to 30%. Direct injection (using a tank injector or towed-hose direct injector) can reduce volatilization losses to zero. Incorporation of manure conserves valuable nitrogen and increases the precision of using manure as a fertilizer.

Table 3.4. Estimates of ammonia nitrogen loss based on land application method.

Application Method	Loss of Ammonia Nitrogen Range	Recommended Value
Surface application without incorporation	10 - 100%	50%
Surface application with incorporation the same day or irrigation of liquid manure	5 - 30%	20%
Direct injection below the soil surface	0 - 2%	0%

The ammonium-N availability factor is calculated from the ammonia loss as follows:

$$NH_4^+\text{-N Availability Factor} = (100 - \text{Percent Loss}) \div 100. \qquad (3.3)$$

Although NH_4^+-N and NH_3-N both exist in manure and soil they have extremely different properties. Ammonium (NH_4^+) is a charged molecule dissolved in the soil water and can be readily used by plants. Ammonia (NH_3) is a gas and is not significantly taken up by plants. Ammonium does not leach from soil except for extremely coarse sands. However, ammonium typically is converted in the soil to nitrate-N (NO_3^-) which can be easily leached from soil.

Organic Nitrogen and Mineralization

Organic nitrogen (organic-N) is the most abundant form of nitrogen in animal manure with a high solids content (10% total solids or more). Organic-N is not available to plants until it has been decomposed by microbes to ammonium-N. The process of converting organic nitrogen to ammonium-N is called ***mineralization***. Conversion of organic-N to ammonium-N does not occur immediately, and not all of the organic-N is mineralized. Sometimes animal manure with a high solids content is referred to as a slow-release N source because the organic-N is made available over time and not all at once. How fast and how completely this occurs depends on a number of factors including: temperature, soil moisture, soil pH, type of manure, and the extent of incorporation.

The amount of organic-N that is available during the first growing season can range from 30 to 80%. Field measurements taken at the Pee Dee Research Station (Quisenberry, 1998) indicate an average of 60% of the organic-N is mineralized regardless of application method. This is the value used to estimate the plant available nitrogen by the Clemson University Ag. Service Laboratory. However, since many factors effect mineralization the conversion of organic-N to NH_4^+-N may be more or less than 60%.

Organic-N does not leach from soil. Erosion is the only way that organic-N can be lost from the soil.

Nitrate Nitrogen

Most swine manure storage structures store manure in a predominantly anaerobic condition. ***Anaerobic*** means oxygen is excluded. Therefore, very little nitrate nitrogen is present in the manure and is generally not measured. However, interest is increasing in the use of aeration or aerobic treatment systems to control odor. ***Aerobic*** treatment systems maintain elevated levels of oxygen in the manure through natural or mechanical aeration. The process of aeration will result in increased nitrate nitrogen in the manure. Therefore, swine manure that is aerated must also be analyzed to determine the nitrate -N content (Section 100.60 (A) 2, e). All of the nitrate-N is available to the crop and is an important component of some commercial fertilizers (ammonium nitrate for example).

Even though nitrate is not typically present in a significant amount in swine manure it is still an important form of nitrogen. Nearly all of the ammonium-N and organic-N will eventually be converted to nitrate in the soil. Although nitrate is readily taken up by crops, it can be easily lost from the soil. Rainfall or irrigation that results in the movement of water through the root zone of the crop will result in the loss of nitrate by leaching. When soil is saturated, and leaching does not occur, nitrate can be converted to nitrogen gas and be lost to the air. Both of these processes can occur rapidly. Therefore, it is best to apply manure or fertilizer nitrogen very close to the time when the crop's requirement for N is the greatest.

Calculation of Plant Available Nitrogen

The plant available nitrogen (PAN) is the sum of the available ammonium nitrogen, the available organic nitrogen, and the nitrate nitrogen. The estimate of PAN is used to calculate the amount of manure that is needed to satisfy the nitrogen needs of a crop. The equation used to estimate the plant available nitrogen is:

$$\begin{aligned}\text{Plant Available Nitrogen (PAN)} \quad = \quad & [NH_4^+\text{-N Availability Factor x } NH_4^+\text{-N Content}] \\ + \quad & [0.60 \text{ x Organic-N Content}] \\ + \quad & [\text{Nitrate-N Content}]. \qquad (3.4)\end{aligned}$$

The use of equation 3.4 is explained in the following example.

Example 3.5 A swine producer had the surface water of his swine manure storage pond tested for plant nutrients by a laboratory. The laboratory results indicated that the water contained 5.4 lb NH_4^+-N /1,000 gal and 1.68 lb organic-N /1,000 gal. The storage pond water will be applied to cropland using a traveling gun irrigation system. Calculate the amount of plant available nitrogen per 1,000 gal. Compare the PAN with the total-N.

Step 1. Determine the NH_4^+-N availability factor from Table 3.4 and equation 3.3.
The recommended ammonia nitrogen loss factor for irrigation is the same as for incorporation and is 20%. The NH_4^+-N availability factor is calculated using equation 3.3 and is 0.80 ((100-20%) ÷ 100).

Step 2. The plant available nitrogen (PAN) is calculated using equation 3.4 as follows:
0.80x 5.4 lb NH_4^+-N/1,000 gal + 0.60 x 1.68 lb organic-N/1,000 gal = 5.33 lb /1,000 gal.
Note that nitrate-N was not considered since the storage is not aerated.

Step 3. The total-N is the sum of the organic and ammonium nitrogen. In this case, total-N = 5.4 + 1.68 = 7.08 lb /1,000 gal. The estimate of PAN is 75% of the total-N for this manure analysis.

Using an Animal Waste Analysis Report

South Carolina regulations require swine producers to have manure samples analyzed at least annually to determine the amount of manure that can be applied to cropland. A sample laboratory report is shown in Table 3.5. This report is for a swine finishing farm that uses a pit-recharge system to collect manure below a slotted floor. The manure is stored in a storage pond (see chapter 4 for description). The surface water of the storage pond is applied using a traveling gun irrigation system. Solids are agitated and removed with the water at least once each year.

Selection of a Sample Number
The first step in the proper use of a laboratory report is the selection of the sample number. The sample number is determined by the person who sends in the sample. The sample number can be any combination of letters or numbers (up to 5 letters or numbers). Select a sample number that helps to identify the type of manure analyzed. In Table 3.5 the sample number is SSW5. This sample number is an abbreviation for Storage Surface Water 5. The number 5 indicates that this is the fifth sample of storage surface water that has been sent to the laboratory for analysis. Therefore, the rolling average for PAN, P_2O_5, K_2O, or other nutrients is the average of 5 values.

LAB NO
The LAB NO (100498 in Table 3.5) is assigned by the Agricultural Service Laboratory. This number is needed if you have a question concerning your waste analysis report. The phone number of the Clemson Agricultural Service Laboratory is 864-656-2068.

Moisture Content
The nutrient content results are given on an as-sampled or wet basis. The moisture content of the manure sample has a large effect on the nutrient content. The moisture content is determined by the laboratory and is given near the bottom of the report. In this case, the manure contains 99.58% water. The solids content of the sample is 0.42% (100-99.58).

Nutrient Content
The contents of all forms of nitrogen, phosphorous, potassium, and the other nutrients are given in two columns. The first column is in either percent (%) or parts per million (ppm). The second column gives the nutrient content in pounds per 1,000 gallons of manure (lbs/1,000 gal). In most cases, nutrient management calculations use the units pounds per 1,000 gallons for liquid manure. If the manure has a high solid content then the results in the second column are given in pounds per ton (lbs/ton).

Estimates of Plant Available Nitrogen
The animal waste report provides up to five different values for manure nitrogen. It is very important for animal waste managers to be able to interpret and use these nitrogen results correctly. The ammonium-N, organic-N, and nitrate-N given on the report are the three basic forms of nitrogen that were discussed previously in the section called Estimation of Plant

Table 3.5. Sample animal waste analysis report for the surface water of a storage pond for swine manure (finishing buildings with a pit-recharge manure handling system)

A N I M A L   W A S T E   A N A L Y S I S   R E P O R T
Clemson University
Cooperative Extension Service
Agricultural Service Laboratory
Clemson, S.C. 29634-03921

LAB No. 100498

NAME	Farmer, J.Q.	ACCOUNT	CASH MONEY
ADDRESS	312 Sunny Acres Road	DATE	12-2-1998
CITY	Any Where, SC		
ZIP CODE	29341		

SAMPLE NO. SSW5 MANURE: SWINE STORAGE: STORAGE

--------------------------------------RESULTS REPORTED ON AN AS-SAMPLED BASIS------------------------------------

			lbs/1,000gal
Ammonium Nitrogen	0.061	%	5.40
Organic Nitrogen	0.019	%	1.68
Nitrate Nitrogen			
INCORPORATED AVAILABLE NITROGEN ESTIMATE			5.33
SURFACE AVAILABLE NITROGEN ESTIMATE			3.71
Phosphorous as P2O5	0.0286	%	2.53
Potassium as K2O	0.1070	%	9.47
Calcium	0.0055	%	0.49
Magnesium	0.0011	%	0.10
Sulfur	0.0048	%	0.42
Zinc	1.03	ppm	0.01
Copper	0.80	ppm	0.01
Manganese	0.52	ppm	0.00
Sodium	279.13	ppm	2.47
Arsenic			
pH			
Moisture	99.58	%	
Calcium Carbonate Equivalency			

INCORPORATED PLANT AVAILABLE NITROGEN ESTIMATE - 80% of ammonium-N, 60% of organic-N, and 100% of nitrate-N (if determined). Assumes some loss of ammonium-N during application and prior to incorporation.

SURFACE PLANT AVAILABLE NITROGEN ESTIMATE - 50% of ammonium-N, 60% of organic-N, and 100% of nitrate-N (if determined). Assumes the manure will be left on the surface of the soil with no incorporation by plowing or irrigation.

Available nitrogen calculations are estimates and the actual amount received may be more or less than the estimate depending on the composition of the manure, soil type, and environmental conditions.

All of the potash in the animal waste should be plant available in the first year of application. Although not all of the phosphorous is available in the first year, its availability should be comparable to that in commercial fertilizers.

The rate of animal waste to apply for crop production is dependent on the nutrient content of the waste, method of application and incorporation, soil test, crop to be grown, and previous manure applications. In most cases, the plant available nitrogen content of the waste is used to determine the rate of application. Your County Agent can assist you in determining the proper application rate. APPROVED BY ________________

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Available Nitrogen. The other two values given are estimates of the plant available nitrogen (PAN) based on the method of application. The incorporated available nitrogen estimate of PAN should be used in the following cases:

- when manure will be mixed with the soil by a tillage operation the same day it is applied (disking, plowing, but not no-till drilling),
- when liquid manure is spread using an irrigation system, or
- during the planning stages when the exact method of application is yet to be decided.

In Table 3.5, the incorporated PAN estimate is 5.33 lbs/1,000 gal. This value was previously calculated using equation 3.3 in example 3.4. Therefore, the incorporated PAN estimate can be obtained from the waste analysis report if the Clemson University Agricultural Service Laboratory is used. If another laboratory is used, use equation 3.3 and Table 3.4 with the results for ammonium-N and organic-N.

The surface available nitrogen estimate should only be used when manure with a high solids content is spread on the surface without being incorporated. Separated solids, slurry manure, and thick lagoon solids are examples of the types of swine manure that could be spread without incorporation. In Table 3.5 the surface applied estimate of PAN is given as 3.71 lb/1,000 gal. However, this value should never be used when the surface water of a lagoon or storage pond is land applied. The high moisture content (99.58%) of this type of manure will cause the ammonium-N to be carried into the soil with the water regardless of application method.

Direct injection of liquid manure is a technology that may become widely used in South Carolina in the future. However, it is not currently a common practice. Direct injection eliminates the ammonia loss associated with irrigation or surface application of liquid or slurry manure. If direct injection is to be used, the PAN estimate is calculated using equation 3.3. For the data shown in Table 3.5, the PAN estimate for direct injection is 6.41 lbs/1,000 gal (5.40 + 0.60 x 1.68) which is 20% higher than the PAN estimate used for irrigation.

Manure Sampling Frequency and Rolling Average

South Carolina regulations require a manure analysis to be obtained for each form of manure that is land applied as indicated below.

100.100 (B) 6 The producer shall be responsible for having representative samples of the swine waste collected and analyzed at least once per year and when the feed composition significantly changes. The amount of swine waste to be land applied so that the permitted application rate (normally the agronomic rate) is met will be determined using a rolling average of the previous analyses. The Department shall establish minimum requirements for the proper method of sampling and analyzing of swine waste.

In most cases, swine manure is applied to crop or pasture land in the following forms: lagoon surface water, storage pond surface water, and agitated water and solids. As shown in Table 3.3, the nutrient content of the swine manure can vary significantly depending on the form that is applied.

The laboratory results from the most recent analysis should be averaged with all previous manure analyses for a particular form of manure. This is what is meant by a ***rolling average***. Each time manure is collected and sent to a laboratory for analysis errors always occur due to: sampling differences in the field, and experimental errors associated with laboratory procedures. Therefore, the best value for the nutrient content of a particular form of swine manure is the average of as many analyses as possible. Separate, representative manure samples must be collected and analyzed for each form of manure applied each year. Most swine producers will need to keep a rolling average for surface water of the lagoon or storage structure, and for agitated manure.

South Carolina regulations require the analysis of a representative sample at least one time per year. However, more frequent sampling is recommend. The need for more frequent sampling can be easily demonstrated using data taken from a swine manure storage pond located in South Carolina.

Sample Data Used to Establish a Rolling Average for Nitrogen and Phosphorous
Surface water samples were collected from a liquid storage pond on a swine finishing farm in July, August, September, October, and November in 1998 (see chapter 7, Manure Sampling Procedures). The samples were analyzed by the Clemson University Agricultural Service Laboratory. The surface water is land applied using a traveling gun irrigation system. Therefore, the incorporated available nitrogen estimate given on the laboratory report (see Table 3.5 for explanation) was used to develop a rolling average for PAN. A rolling average was also maintained for phosphorous (expressed as P_2O_5). The variation in the sample analyses and rolling averages for PAN and P_2O_5 are shown in Figures 3.1 and 3.2. The solid lines in the graphs is the historical rolling averages. Each time a new sample was collected the new value for PAN and P_2O_5 was averaged with all of the previous values. The dashed line is the current average of all 5 samples. It is important to note that the PAN and P_2O_5 measurements came from the same samples.

The phosphorous content, Figure 3.2, did not vary greatly over the sampling period. The rolling average began at a value of 2.2 lb P_2O_5/1,000 gal and decreased to 2.1 lb P_2O_5/1,000 gal. The relatively small amount of variation in the P_2O_5 data suggests that the sampling methods were consistent from month to month. However, the concentration of phosphorous can be effected by rainfall, frequency of pumping, and variations in the amount of manure added.

The plant available nitrogen, PAN, varied from month to month more than the phosphorous content (Figure 3.1). The greater variation in nitrogen content in liquid manure is due to variations in the volatilization losses. Rainfall, pumping frequency, and variations in the amount of manure loaded each day can also effect PAN.

The variation in ammonium-N is the greatest source of fluctuation in PAN. Most of the sources of variation in PAN can not be controlled. Therefore, a rolling average of several samples provides the best value for fertilization calculations.

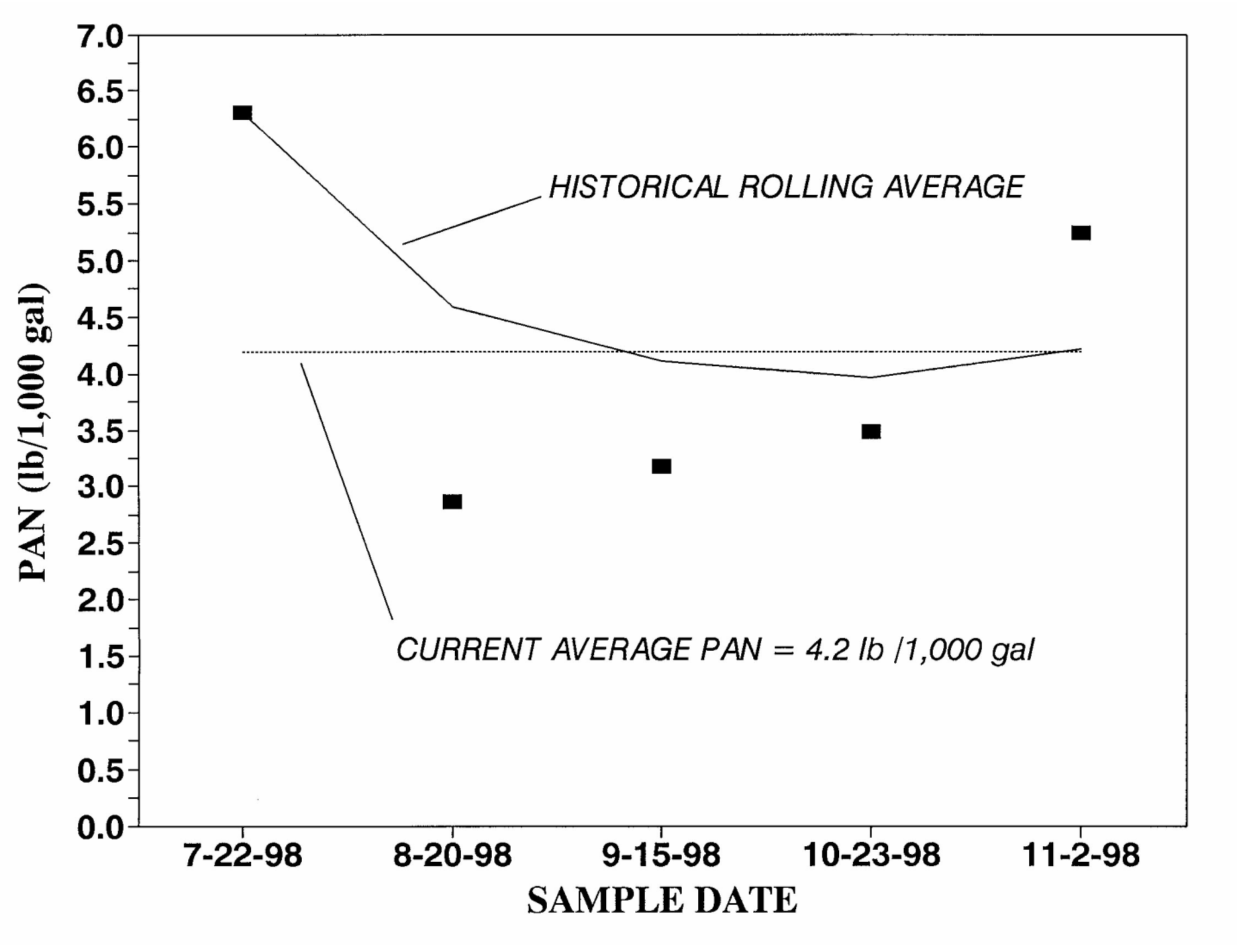

Figure 3.1. Variation in the plant available nitrogen in the top layer (1 ft) of a storage pond used to store liquid swine manure.

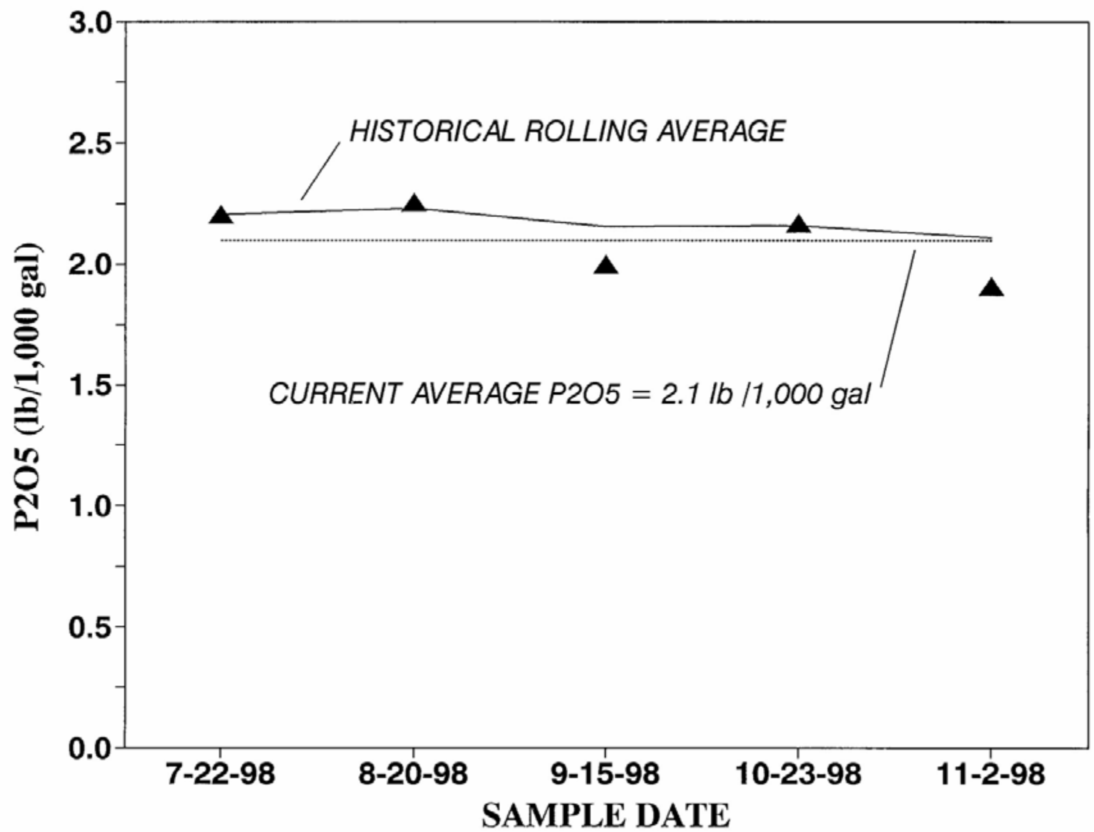

Figure 3.2. Variation in total phosphorous in the top layer of a swine manure storage pond (same samples as Figure 3.1).

Recommended Sampling Frequency

The data shown in Figure 3.1 suggests that a reasonable estimate of the nitrogen content in dilute manure can be obtained with three samples. The variation in the rolling average is relatively small after obtaining five samples. Taking more samples during the first 2 to 3 years of operation will allow a stable rolling average to be established quickly. Specific recommendations on sampling frequency are listed below.

- Lagoon or storage pond surface water is often land applied several times per year. Collect a sample prior to each application during the first two years. Reduce the sampling frequency to 2 to 3 times per year after a stable estimate of the rolling average has been obtained.
- The frequency of solids removal will vary depending on the type of structure used to store manure (see chapter 4). Solids are removed from a storage pond by agitation and pumping 1 to 4 times per year. Sludge removal from a lagoon may take place every 3 to 5 years. Collect a representative sample of agitated solids and liquids whenever possible since it often takes longer to obtain 5 to 10 samples.
- Mechanical or gravity solid-liquid separation yields manure with a relatively high solids content (3 to 30% total solids). Collect three samples from solid-liquid separation processes during the first 2 years of operation. Sampling frequency can be reduced to 1 or 2 times per year after a consistent rolling average is established.

When to Begin a New Rolling Average

A new rolling average is begun only when a major change occurs that would be expected to alter the average plant nutrient content of the manure. Examples of these types of changes are:

- addition of a new manure treatment process (such as liquid solid separation or aeration),
- change in the animal population (such as converting nursery buildings to farrowing buildings, or increasing the total number of swine), or
- making a major change in the ration that will influence nutrient content (such as changing feed sources, reducing nitrogen in the feed by feeding selected amino acids, or feeding phytase to reduce phosphorous).

Copper and Zinc Limits for Land Application of Swine Waste

In most cases, the ***agronomic rate,*** or the amount of nitrogen needed to grow a particular crop (see glossary for complete definition), is used to determine how much swine manure can be applied per acre. However, South Carolina law also requires swine producers to consider the concentrations of copper (Cu) and zinc (Zn) in the manure as part of the land application requirements. The criteria that must be satisfied are as follows.

100.100 (B) Constituent Limits for Land Application of Swine Waste

1. Swine Waste. The Department may establish constituent limits in permits on a case-by-case basis on swine waste to be land applied. Swine waste containing only the standard constituents at normal concentrations as given by commonly accepted reference sources, such as Clemson University, American Society of Agricultural Engineers, Midwest Planning Service Document, or NRCS, can be land applied at or below agronomic rates without any specific constituent limits in a permit. When the swine waste analysis indicates there are levels of copper, or other constituent of concern, the Department will establish constituent limits in permits for each constituent of concern to ensure the water quality standards of Regulation 61-67 are maintained. For these cases the producer must comply with the following criteria:

a. Constituent Limits. If swine waste subject to a constituent limit is applied to land, either
   i. the cumulative loading rate for each constituent shall not exceed the cumulative constituent loading rate for the constituent in Table 1 of Section 100.100; or
   ii. the concentration of each constituent in the swine waste shall not exceed the concentration for the constituent in Table 2 of Section 100.100.

b. Constituent concentrations and loading rates.
   i. Cumulative constituent loading rates.

TABLE 1 OF SECTION 100.100
CUMULATIVE CONSTITUENT LOADING RATES

Constituent	*Cumulative Constituent Loading Rate (kilograms per hectare)*	*(pounds per acre)*
Copper	1500	1339
Zinc	2800	2499

   ii. Constituent concentrations.

TABLE 2 OF SECTION 100.100
CONSTITUENT CONCENTRATIONS

Constituent	*Monthly Average Concentrations (milligrams per kilogram) Dry weight basis*
Copper	1500
Zinc	2800

   iii. Annual constituent loading rates.

TABLE 3 OF SECTION 100.100
CONSTITUENT CONCENTRATIONS

Constituent	*Annual Constituent Loading Rate (kilograms per hectare per 365 day period)*	*(pounds per acre per 365 day period)*
Copper	75	67
Zinc	140	125

c. Additional constituents may be required, from the application information or subsequent monitoring in a permit thereafter, but such needs will be assessed on an individual project basis.

In most cases the regulatory requirements for the application of zinc and copper can be satisfied by demonstrating that the concentrations of zinc and copper are below the threshold values given in TABLE 2 OF SECTION 100.100 (see box below). <u>The concentration of zinc in swine manure</u>

must be less than 2800 milligrams per kilogram of dry solids (mg/kg) to be excluded from further consideration. The maximum copper concentration is 1500 mg per kg of solids.

The concentrations of zinc and copper provided by the Clemson University Agricultural Service Laboratory (see Table 3.5) are given on an as-sampled basis. Concentrations are given ppm (parts per million) and in pounds per 1,000 gallons (lb/1,000 gal). The moisture content is given in percent. The following equation can be used to convert the as-sampled copper (Cu) and zinc (Zn) contents, in ppm, to the dry basis concentration:

$$\text{mg / kg (dry basis)} = [\text{Cu or Zn Content in ppm}] \div (\text{Solids Fraction}). \qquad (3.5)$$

(Note: 1 L of liquid manure has a mass very close to 1 kg.)

The solids fraction needed in equation 3.5 is calculated from the percent moisture as shown below:

$$\text{Solids Fraction} = (100 - \%\ \text{Moisture}) \div 100. \qquad (3.6)$$

The nutrient content of manure with a high total solids content is typically given by the Agricultural Services Laboratory in ppm and lb/ton. Equation 3.5 can also be used for dry manure as long as the as-sampled copper and zinc concentrations are given in ppm.

Some laboratories may report the copper and zinc content on a dry weight basis (mg/kg). Therefore, it is very important to read all reports carefully to know how the data is presented.

The use of equations 3.5 and 3.6 is demonstrated in the following example.

Example 3.6 Calculate the Zn and Cu concentrations for swine storage pond water using the manure analysis given in Table 3.5. Are the Zn or Cu concentrations greater than the concern levels as defined by the regulation (TABLE 2 OF SECTION 100.100)?

Step 1: Calculate the solids fraction using equation 3.6.
The average moisture content in Table 3.5 is 99.58% . The solids fraction is
(100 - 99.58) ÷ 100 = 0.0042.

Step 2: Calculate the dry matter Zn concentration using equation 3.5.
The Zn content from Table 3.5 is 1.03 ppm wet-basis. The dry matter concentration is calculated using the solids fraction from step 1 as follows.
1.03 ppm Zn ÷ 0.0042 = 245 mg Zn / kg (dry basis). Since 245 mg/kg is less than the concern level of 2800 mg/kg we do not need to keep records of the amount of Zn applied to cropland to satisfy regulatory requirements.

Step 3: Calculate the Cu concentration in the same way as for zinc.
0.80 ppm ÷ 0.0042 = 190 mg Cu / kg (dry basis).
The dry matter Cu concentration is also below the concern level of 1500 mg Cu/kg. Therefore, Copper will not be a limiting constituent for land application either.

The zinc and copper concentrations for all forms of swine manure that are typically used to fertilize crop or pasture land are shown in Table 3.6. These values were calculated based on the data given in Table 3.3. The results indicate that the concentrations of Zn and Cu (dry basis) are below the level of concern in all cases. However, all swine producers will need to test manure from their farm to prove that the Zn and Cu concentrations are below the established limits.

Table 3.6. Concentrations of zinc and copper (dry basis) in swine manure that is land applied.

	Lagoon Surface Water	Lagoon Sludge	Agitated Lagoon Water & Solids	Storage Pond Surface Water
Moisture (%)	99.63%	90.0%	97.8%	99.5%
Zinc, mg/kg	965	2143	2002	952
Copper, mg/kg	644	893	866	714

If manure analysis indicates that zinc or copper dry matter concentrations exceed the regulatory limits then the requirements given in TABLE 1 and TABLE 3 OF SECTION 100.100 must be satisfied. Records must be kept to show that the annual application rate (loading rates in regulation) of copper and zinc do not exceed the limits given in TABLE 3. Also, the cumulative application of copper and zinc must not exceed 1339 pounds of Cu per acre or 2,499 pounds of Zn per acre.

SUMMARY

Knowledge of the nutrient content of swine manure is an essential element in the design and operation of a swine manure management system. Manure volume and nutrient data have been provided that can be used for design and planning purposes. South Carolina regulations require each swine producer to sample each form of swine manure that is land applied at least annually. A rolling average is used for each form of manure applied to cropland to determine application rates. Additional details on nutrient balancing, and lagoon and storage sizing will be presented in other chapters.

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