CHAPTER 3a

Dairy Manure Production and Nutrient Content

John P. Chastain, and James J. Camberato

INTRODUCTION

Knowledge of the amount of manure and plant nutrients produced on a dairy farm is the first step in the proper operation of a manure handling and utilization system. The nutrient content of dairy manure will vary with the digestibility of the ration, animal age, amount of feed wasted, the amount of water wasted, the amount of bedding used, and the amount of water used to remove manure from the buildings. 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 dairy producers to have manure samples analyzed annually and to determine manure volumes to establish land application rates.

CALCULATION OF AVERAGE PRODUCTION LIVE WEIGHT AND ANIMAL UNITS

The South Carolina Standards for the Permitting of Agricultural Animal Facilities (R. 61-43) uses the average animal live weight to determine the size of a dairy farm. The ***average animal live weight*** is defined as:

Average Animal Live Weight = (Entry Weight + Exit Weight) / 2. (3.1)

This definition applies to dairy animals that are housed in a confinement facility or feedlot that requires the collection and utilization of manure in a permitted manure handling system. Dairy animals that are kept entirely on pasture, such as replacement heifers, are not included in the calculation of the average production live weight. In most cases, the average production live weight on a dairy farm is simply the average weight of the cows that can be obtained from farm records.

The ***normal production animal live weight*** is calculated as:

Normal Production Animal Live Weight =
Average Animal Live Weight x Number of Animals in Confinement. (3.2)

<u>Dairy operations with more than 500,000 pounds of total normal production animal live weight fall under the regulations for large facilities.</u>

Example 3.1 What is the normal production animal live weight for a dairy farm that houses 300 Holstein cows in a freestall barn if the average 1st lactation heifer weighs 1,200 lb and the average cow that exits the herd weighs 1,500 lb?

Step 1: Average Animal Live Weight = (1,200 + 1,500) / 2 = 1,350 lb / cow
Step 2. Normal Production Animal Live Weight in the barn
= 1,350 lb / cow x 300 cows = 405,000 lb.

Example 3.2 A dairy producer has a freestall barn that houses a milking herd of 400 Jersey cows. The milking herd records indicate that the average cow weight is 880 lb. Calculate the total normal production animal live weight in confinement on this farm.

Normal Production Animal Live Weight = 880 lb/cow x 400 = 352,000 lb.

Another definition that is used in manure management calculations is the animal unit. In this manual, ***an animal unit (AU) is equal to 1,000 lb of normal production animal live weight***. The total number of animal units on a farm is:

Total Number of Animal Units = Normal Production Animal Live Weight / 1,000. (3.3)

Example 3.3 Calculate the total number of animal units for a dairy farm with a normal average production animal live weight of 405,000 lb.

Total AU = 405,000 lb ÷ 1,000 lb/AU = 405 AU.

MANURE PRODUCTION

Dairy animals produce about 1.61 ft^3 (12.0 gal) of fresh manure (feces and urine) per 1,000 lb average live weight per day. The manure contains 14.4 lb of total solids per AU per day. The volatile solids production is 11.9 lb per AU per day.

The actual volume of manure that must be handled on a dairy is typically more than 1.61 ft^3/AU-day. Additional solids can be added from wasted feed, freestall bedding, and soil tracked in from outside lots. Additional water is often added from waterer wastage, milking center waste water, water used to clean floors, and flushing of alleys. The variation of manure production for dairy facilities will vary with the solids content (TS) as shown in Table 3.1.

Table 3.1. Variation of dairy manure production (ft^3 / AU - day) depending on consistency of removed manure.

Manure Removed As:	**Total Solids Content (TS)**							
	1%	2%	4%	6%	8%	10%	12%	14%
Thick Slurry – minimal water						2.31 [a]	**1.92** [b]	1.65
Slurry + Milking Center Waste				3.85	**2.88**			
Slurry + Parlor Flush			**5.77**	3.85				
Alley Flush		**11.54**	5.77					
All Facilities Flushed	**23.07**	11.54						

Milking Center Only [c]	**TS**	**ft^3/AU-day**
Twice-a-day (2X) milking	1.7%	1.02
Milking 3 times per day (3X)		1.53
2X milking with flush	0.6%	2.88
3X milking with flush		4.32
Manure and Sand Bedding	20 to 38%	1.6 [d]

[a] Volume (ft^3 /AU/day) = 14.4 lb TS/AU-day x 1.6021 ÷ TS (%). To convert to gal./AU-day multiply ft^3/AU-day by 7.48

[b] Typical volume and TS indicated in bold.

[c] Volume (ft^3 /AU/day) = (0.54 lb TS/AU- milking x No. Milkings/day x 1.6021) ÷ TS (%)

[d] Varies with sand usage per freestall. References: Stowell and Bickert (1995) and Fulhage (2003)

Example 3.4 A dairy producer has a freestall barn that houses 300 Holsteins. Manure is scraped with a skid-steer loader into a reception pit near the center of the barn. All of the wash water and waste from the milking center is also collected in the reception pit with the manure. How much manure will be generated each day? What volume of manure will be generated in 1 year?

Step 1. Assuming that the average cow weights 1,350 lb, the total number of animal units in the barn is:

300 x 1,350 ÷ 1,000 lb/AU = 405 AU.

Step 2. Assuming that the total solids content of the manure is 8%, 2.88 ft^3 of manure is produced per AU per day (Table 3.1). The volume of manure that must be handled each day is:

2.88 ft^3/AU-day x 405 AU = 1,166.4 ft^3/day or 8,725 gal/day.

Step 3. The total manure volume that will be produced in 1 year is:

1,166.4 ft^3/day x 365 days/year = 425,736 ft^3/year or 3,184,505 gal/year.

Example 3.5 A dairy producer grazes 120 Jersey cows intensively and the only facility that requires collection and storage of manure is the milking center. The cows are milked twice each day and a high-pressure hose is used to clean the parlor and holding area floors. Estimate the volume of milking center waste that must be collected and stored each day.

From Table 3.1, 1.02 ft^3 of milking center waste is generated per AU per day. The number of animal units in the milking herd is 108 (900 lb/cow x 120 / 1,000). The daily volume of milking center waste is

108 AU x 1.02 ft^3/AU-day = 110.2 ft^3/day or 824.3 gal/day.

Example 3.6 Sand bedding is used in a 4-row drive through freestall barn that contains 100 stalls. Typically 110 Holsteins are housed in the barn. The dairy producer plans on building a concrete manure storage to contain 90 days of sand-laden manure. Milking center waste will not be included. What is the required manure storage capacity?

Step 1. Assuming that the average cow weights 1,350 lb, the total number of animal units in the barn is:

110 x 1,350 ÷ 1,000 lb/AU = 149 AU.

Step 2. Allow 1.6 ft^3/AU-day for sand-laden manure as shown in Table 3.1. The required sand-laden manure storage capacity is:

149 AU x 1.6 ft^3/AU-day x 90 days = 21,456 ft^3or 160,491 gal.

NUTRIENT CONTENT OF DAIRY MANURE

Dairy 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 dairy 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 / ton or lb of nutrient / 1,000 gal) and the amount of manure applied (ton / acre or gal/acre). The amount of manure applied per acre is called the ***application rate*** and 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 dairy manure based on the copper or zinc content of the manure.

The nutrient content of dairy manure from several types of dairy facilities is compared in Tables 3.2 and 3.3. The nutrient values in these tables can be used for general planning before a new dairy farm is constructed or prior to the expansion of an existing farm. In the case of an existing dairy farm, sample analysis from the dairy manure on a particular farm should be used to perform nutrient balances for land application. These values were compiled from a database that combines data taken on South Carolina dairy farms with mean values from North Carolina State (Barker, 1990).

Table 3.2. Comparison of the nutrient content of solid and semi-solid dairy manure.
Nutrient data complied from Barker (1990) and data compiled from South Carolina farms.

Manure Type	Fresh Manure	Scraped Paved Outside Lot	Solids From Settling Basin	Solids From a Stationary Screen
Moisture	86%	67%	89%	80%
Total Solids	14%	33%	11%	20%
	---------- lb / ton ----------			
NH_4-N	1.7	2.0	0.4	0.2
NO_3-N	0.02	0.10	---	---
Organic - N	8.28	13.0	5.8	4.7
Total - N [1]	10.0	15.1	6.2	4.9
P_2O_5 [2]	5.0	7.9	4.0	3.1
K_2O [3]	8.1	14.1	1.0	1.9
Ca	3.7	24.6	5.5	5.0
Mg	1.7	3.0	0.7	1.2
Zn	0.043	0.10	0.19	0.06
Cu	0.010	0.03	0.14	0.10
Mn	0.044	0.08	0.07	0.04
S	1.2	2.0	1.1	0.8
Na	1.2	1.5	0.2	0.5

[1] Total-N = (Organic-N + NH_4- N + NO_3-N)
[2] Total phosphorus expressed as P_2O_5. To get elemental P multiply by 0.44.
[3] Total potassium expressed as K_2O. To get elemental K multiply by 0.83.

Table 3.3. Comparison of the nutrient content of slurry and liquid dairy manure.
Nutrient data complied from Barker (1990), and data compiled from South Carolina farms.

Manure Type	Fresh Liquid Manure	Slurry	Milking Center Manure and Wastewater	Lagoon Surface Water	Lagoon Sludge	Agitated Lagoon Liquid & Sludge
Moisture	96.2%	93%	98.3%	99.4%	93.9%	97.0%
Total Solids	3.8%	7%	1.7%	0.6%	6.1%	3.4%
	---------- lb / 1,000 gal ----------					
NH_4-N	5.5	9.4	6.3	3.2	6.2	4.7
Organic - N	6.5	13.6	3.8	1.8	8.8	5.3
Total - N [1]	12.0	23.0	10.1	5.0	15.0	10.0
P_2O_5 [2]	7.8	14.0	3.4	2.8	22.0	12.4
K_2O [3]	7.7	21.0	7.7	7.2	7.9	7.6
Ca	8.0	10.0	2.7	0.3	12.0	6.2
Mg	2.8	4.8	1.1	1.3	4.5	2.9
Zn	0.12	0.21	0.04	0.07	0.39	0.23
Cu	0.09	0.05	0.01	0.01	0.36	0.19
Mn	0.10	0.18	0.03	0.05	0.30	0.18
S	1.5	3.1	0.55	0.9	3.6	2.3
Na	2.4	3.2	1.3	1.8	1.4	1.6

[1] Total-N = (Organic-N + NH_4- N)
[2] Total phosphorus expressed as P_2O_5. To get elemental P multiply by 0.44.
[3] Total potassium expressed as K_2O. To get elemental K multiply by 0.83.

ESTIMATION OF PLANT AVAILABLE NITROGEN

Not all of the nitrogen in dairy 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 portion of the nitrogen in dairy 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 manual 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 while it is in the house, while it is in storage, and after 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 dairy 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. A significant rain, 0.25 inches or more, or irrigation of liquid manure will carry most of the ammonium nitrogen into the soil. All of the NH_4^+ can be converted to ammonia and can be lost from surface applied solids of slurry manure if it does not rain for several weeks. Incorporation of manure on the same day it is applied can reduce the volatilization losses to 5 to 30%. 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.

	Loss of Ammonia Nitrogen	
Application Method	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:

$$NH_4\text{-N Availability Factor} = (100 - \text{Percent Loss}) \div 100. \qquad (3.4)$$

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^-) that 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 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: soil 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. 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

If dairy manure is stored in a predominantly anaerobic condition then very little nitrate nitrogen will be present and is generally not measured. ***Anaerobic*** means oxygen is excluded. ***Aerobic*** treatment systems, like composting, maintain elevated levels of oxygen in the manure through natural or mechanical aeration. The elevated oxygen levels will result in a significant amount of nitrate nitrogen in the manure. Therefore, dairy manure that receives a significant amount of aeration must also be analyzed to determine the nitrate-N content. 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 always present in a significant amount in dairy 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:

$$\text{Plant Available Nitrogen (PAN)} = [NH_4\text{-N Availability Factor x } NH_4^+\text{-N Content}] + [0.60 \text{ x Organic-N Content}] + [\text{Nitrate-N Content}]. \quad (3.5)$$

The use of equation 3.5 is explained in the following example.

Example 3.7. A producer had dairy manure from a storage tested for plant nutrients by a laboratory. The laboratory results indicated that the manure contained 6.4 lb NH_4-N /1,000 gal, and 9.5 lb organic-N/1,000 gal. The manure will be applied to cropland using a side-discharge manure spreader. Calculate the amount of plant available nitrogen per 1,000 gal of manure. Compare the PAN with the total-N.

Step 1. Determine the NH_4-N availability factor from Table 3.4 and equation 3.4.
The recommended ammonia nitrogen loss factor for surface application is 50%.
The NH_4-N availability factor is calculated using equation 3.4 and is:
(100-50%) ÷ 100) = 0.50.

Step 2. The plant available nitrogen (PAN) is calculated using equation 3.5 as follows:
0.50 x 6.4 lb NH_4-N/1,000 gal + 0.60 x 9.5 lb organic-N/1,000 gal = 8.9 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, ammonium nitrogen, and nitrate-N.
In this case, total-N = 6.4+ 9.5 + 0 = 15.9 lb /1,000 gal. The estimate of PAN is 56% of the total-N for this manure analysis.

Using an Animal Waste Analysis Report

South Carolina regulations require dairy 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 agitated dairy lagoon sludge.

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 DLS3. This sample number is an abbreviation for Dairy Lagoon Sludge 3. The number 3 indicates that this is the third sample of agitated lagoon sludge 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 3 values.

LAB NO

The LAB NO (40225 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 96.03% water. The solids content of the sample is 3.97% (100-96.03).

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 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 8.39 lbs/1,000 gal. 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 3.5 with the results for ammonium-N, organic-N, and nitrate-N if needed.

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 lagoon sludges are examples of the types of dairy manure that could be spread without incorporation. In Table 3.5 the surface applied estimate of PAN is given as 7.82 lb/1,000 gal. However, this value should never be used when the surface water of a lagoon is land applied.

Table 3.5. Sample animal waste analysis report for agitated dairy lagoon sludge.

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. 40225

NAME	Farmer, J.Q.	ACCOUNT	CASH MONEY
ADDRESS	312 Sunny Acres Road	DATE	4-29-2003
CITY	Any Where, SC		
ZIP CODE	29341		

SAMPLE NO. DLS3 MANURE: Dairy STORAGE: Agitated Sludge

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

			lbs/1,000gal
Ammonium Nitrogen	0.023	%	1.92
Organic Nitrogen	0.137	%	11.41
Nitrate Nitrogen	1.24	ppm	0.01
INCORPORATED AVAILABLE NITROGEN ESTIMATE			8.39
SURFACE AVAILABLE NITROGEN ESTIMATE			7.82
Phosphorous as P2O5	0.1072	%	8.93
Potassium as K2O	0.0386	%	3.21
Calcium	0.0875	%	7.29
Magnesium	0.0197	%	1.64
Sulfur	0.0355	%	2.96
Zinc	16.47	ppm	0.14
Copper	3.83	ppm	0.03
Manganese	14.28	ppm	0.12
Sodium	121.06	ppm	1.01
Arsenic			
pH			
Moisture	96.03	%	
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 _________________

The high moisture content (99.4%) 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 surface application of liquid or slurry manure. If direct injection is to be used, the PAN estimate is calculated using equation 3.5. For the data shown in Table 3.5, the PAN estimate for direct injection is 8.78 lbs/1,000 gal (1.92 + 0.60 x 11.41 + 0.01).

ESTIMATION OF MAJOR PLANT NUTRIENTS PRODUCED

Calculation of the cropland needed to properly use dairy manure for fertilizer requires an estimate of the total amount of nutrients produced, an appropriate estimate of the plant available nitrogen, and the fertilization requirements for the desired crops based on realistic yields. Dairy manure systems can be configured in many ways. Therefore, determination of the exact manure volumes for a system prior to construction can be difficult and is beyond the scope of this chapter. However, a reasonable estimate for general planning purposes can be made for most dairy farms using the nutrient production values given in Table 3.6. The values given for slurry or liquid storage will provide a close estimate if manure is scraped from the building and hauled daily or is stored prior to land application. If an anaerobic treatment lagoon is used the nutrients in the irrigated lagoon water (supernatant) and the sludge that is stored for several years must be considered in the planning process. On some dairy farms, the milking center waste is collected and stored in a separate system from the majority of the cow manure. Such systems are common on grazing and open lot dairy farms. The use of the table is demonstrated in the following examples.

Table 3.6. Estimates of the major plant nutrients produced on dairy farms per year. (1 AU = 1,000 lb live weight)

	NH_4-N	Organic-N	Total-N	P_2O_5	K_2O
Type of Manure System			lb / AU – year		
Slurry or liquid storage	88	116	204	128	158
Anaerobic Lagoon Liquid	31	17	48	27	69
Lagoon Sludge[1]	14	20	34	51	18
Milking Center Only					
Milking 2X/day	18	10	28	9.5	21
Milking 3X/day	26	16	42	14	32

[1] Annual nutrient production in the sludge that should be removed periodically to maintain lagoon function. Typically every 3 to 5 years. Multiply tabulated values by sludge storage period.

Example 3.8. Determine the total amount of PAN and P_2O_5 produced per year on a 300 Holstein dairy that uses a slurry type handling system and incorporates the manure on the day of application.

Step 1. Calculate the total number of animal units.

300 cows x 1,350 lb/cow ÷ 1,000 lb/AU = 405 AU

Step 2. Calculate the total pounds of PAN produced per AU per year.

0.80 x 88 lb NH_4-N + 0.6 x 116 lb Organic-N = 140 lb PAN/AU-year

Step 3. Calculate the amount of PAN and P_2O_5 that will be land applied each year.

140 lb PAN/AU-year x 405 AU = 56,700 lb PAN/year

128 lb P_2O_5 /AU-year x 405 AU = 51,840 lb P_2O_5/year.

Example 3.9 How many acres of cropland are needed for this 300-cow dairy if the annual nitrogen needs of all crops in the rotation is 180 lb N/ac? How many acres are needed per cow?

56,700 lb PAN/year ÷ 180 lb N/ac = 315 acres/year or 1.05 ac/cow.

Example 3.10 Most crops use much less phosphorous than nitrogen. In fact, the desired N/P_2O_5 ratio for many crops is in the range of 2.0 to 3.0. Assume that the average N/P_2O_5 ratio of the crops in the rotation is 2.5. How many pounds of P_2O_5 are needed per acre? If regulations require manure to be spread based on the P need of the crop how many acres will be needed for a 300 Holstein dairy and per cow?

Step 1. To determine the fertilization rate for P_2O_5 divide the N rate by the N/P_2O_5 ratio.

180 lb/ac ÷ 2.5 = 72 lb P_2O_5/ac.

Step 2. The total land area needed if land application is based on P is:

51,840 lb P_2O_5/year ÷ 72 lb P_2O_5/ac = 720 ac/year or 2.4 ac per cow.

Example 3.11 If a 300 cow dairy treats and stores dairy manure in an anaerobic lagoon determine the following:

1. How many acres are needed per year if manure is applied based on N?
2. How many acres are needed per year if manure is applied based on P?
3. If lagoon sludge is agitated and removed every 5 years how much additional cropland is needed if application is based on N or P?
4. How does this compare with the slurry system described in the previous examples?

Assume the annual fertilization needs are 180 lb N/ac and 72 lb P_2O_5/ac.

Lagoon liquid is typically applied using a traveling gun or center pivot irrigation system. Therefore, the PAN estimate is 0.80 x 31 lb NH_4-N + 0.6 x 17 lb Organic-N = 35 lb PAN/AU-year. The amount of P_2O_5 produced / AU - year = 27 lb.

PAN / year = 35 lb PAN/AU-year x 405 AU = 14,175 lb PAN/year.

P_2O_5 / year = 27 x 405 = 10,935 lb P_2O_5 / year.

Land area needed based on 180 lb N/ac =

14,175 lb PAN/year ÷ 180 lb N/ac = 79 ac/year or 0.26 ac/cow

Land area needed based on 72 lb P_2O_5/ac =

10,935 lb P_2O_5 / year ÷ 72 lb P_2O_5/ac = 152 ac/year or 0.51 ac/cow.

It is assumed that the agitated lagoon sludge will be incorporated on the day of application. Therefore the amount of PAN produced per year is:

0.80 x 14 lb NH_4-N + 0.6 x 20 lb Organic-N = 23 lb PAN/AU-year.

The total amount of PAN that will be applied ***every 5 years*** is:

23 lb PAN/AU-year x 5 years x 405 AU = 46,575 lb PAN.

Also the amount of P_2O_5 that will be applied ***every 5 years*** is:

51 lb P_2O_5/AU-year x 5 x 405 = 103,275 lb P_2O_5.

The land area requirement for sludge ***every 5 years*** based on N is:

46,575 lb PAN ÷ 180 lb N/ac = 259 ac or 0.86 ac/cow.

The land area requirement for sludge ***every 5 years*** based on P is:

103,275 lb P_2O_5 ÷ 72 lb P_2O_5/ac = 1,434 ac or 4.78 ac/cow.

Use of an anaerobic lagoon reduces the amount of land needed each year to 29% of that required for a slurry system if application is based on N. However, application of sludge every 5 years will require almost the same amount of land as the slurry system requires each year (1.05 ac/cow versus 0.86 ac/cow). If the land area needed for application on N is annualized for the lagoon system then the total acres needed per cow is 0.43 ac/cow (0.26 + 0.86/5) which is less than half the land area needed for the slurry system. If land application is based on P then an extra 4.78 ac / cow must be available every 5 years. Therefore, the traditional lagoon system has only a marginal advantage over the slurry system due to the logistical difficulties in finding additional cropland for lagoon sludge. A method to process the sludge into a low-moisture soil amendment could help to reduce this problem.

MANURE SAMPLING FREQUENCY AND ROLLING AVERAGE

South Carolina regulations require a manure analysis to be obtained at least once each year for each form of manure that is land 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 dairy 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. That is, manure from a slurry storage and manure from a pile of lot scrapings will need a different rolling average if both forms are land applied for the same farm.

Recommended Sampling Frequency

South Carolina regulations require the analysis of a representative sample at least one time per year. However, more frequent sampling is recommended. Collect a sample prior to each application during the first two years. Reduce the sampling frequency to 1 to 2 times per year for each form of manure that is land applied after a stable estimate of the rolling average has been obtained.

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, anaerobic digestion, composting, etc),
- a major change in the ration is made that will influence nutrient content (such as feeding less phosphorous).

COPPER AND ZINC LIMITS FOR LAND APPLICATION OF DAIRY 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 manure can be applied per acre. However, South Carolina law may require producers to consider the concentrations of copper (Cu) and zinc (Zn) in the manure as part of the land application requirements.

In most cases the regulatory requirements for the application of zinc and copper can be satisfied by demonstrating that the concentrations of these elements are below the threshold values given in Table 3.7. In general, a dairy producer will only need to regularly test for zinc and copper if it is specified in the permit document. The concentration of zinc in dairy manure must be less than 2,800 milligrams per kilogram of dry solids (mg/kg) to be excluded from further consideration. The maximum copper concentration is 1500 mg per kg of dry solids.

Table 3.7. Critical dry matter concentrations of copper and zinc in dairy manure (Standards for the Permitting of Agricultural Animal Facilities: R.61-43).

Constituent	Monthly Average Concentrations milligrams per kilogram dry weight
Copper	1,500
Zinc	2,800

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

$$\text{mg/kg (dry basis)} = [\text{Copper or Zinc content in ppm}] \div (\text{Solids Fraction}). \qquad (3.6)$$

The solids fraction needed in equation 3.6 is calculated from the percent moisture as shown below:

$$\text{Solids Fraction} = (100 - \%\ \text{Moisture}) \div 100. \qquad (3.7)$$

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

The use of equations 3.6 and 3.7 is demonstrated in the following example.

Example 3.12 Calculate the Zn and Cu concentrations for agitated dairy lagoon sludge 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 3.7)?

Step 1: Calculate the solids fraction using equation 3.7.
The average moisture content in Table 3.5 is 96.03%. The solids fraction is (100 – 96.03) ÷ 100 = 0.040.

Step 2: Calculate the dry matter Zn concentration using equation 3.6.
The Zn content from Table 3.5 is 16.47 ppm wet-basis. The dry matter concentration is calculated using the solids fraction from step 1 as follows.
16.47 ppm Zn ÷ 0.040 = 412 mg Zn / kg (dry basis). Since 412 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.
3.83 ppm ÷ 0.040 = 96 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 different forms of dairy manure that are typically used to fertilize crop or pasture land are shown in Table 3.8. 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.

Table 3.8. Concentrations of zinc and copper (dry basis) in dairy manure that is land applied.

	Liquid	Slurry	Lagoon Water	Lagoon Sludge
Moisture (%)	96.2	93	99.4	93.9
Zinc, mg/kg	372	353	1373	752
Copper, mg/kg	279	84	196	694

<u>If manure analysis indicates that zinc or copper dry matter concentrations exceed the regulatory limits then the requirements given in Tables 3.9 and 3.10 must be satisfied</u>. Records must be kept to show that the annual loading rates do not exceed the limits given in Table 3.9. Also, the application of copper, and zinc must not exceed 1,339 pounds of copper per acre or 2,499 pounds of zinc per acre for the life of the application site (Table 3.10).

Table 3.9. Maximum annual loading rates for copper and zinc in dairy manure (Standards for the Permitting of Agricultural Animal Facilities: R.61-43).

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

Table 3.10. Maximum cumulative loading rates for copper and zinc (Standards for the Permitting of Agricultural Animal Facilities: R.61-43).

Constituent	Cumulative Constituent Loading Rate	
	(kilograms per hectare)	(pounds per acre)
Copper	1,500	1,339
Zinc	2,800	2,499

SUMMARY

Knowledge of the nutrient content of manure is an essential element in the design and operation of a dairy 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 producer to sample each form of dairy 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.

References

ASAE D384.1, 1998. Manure Production and Characteristics. In: ASAE STANDARDS, ASAE. St. Joseph, MI 49085-9659.

Barker, J. 1990. Unpublished manure nutrient data. Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, NC.

Fulhage, C.D. 2003. Sizing and Management Considerations for Settling Basins Receiving Sand-Laden Flushed Dairy Manure. in Proceedings of the 9th International Symposium on Animal, Agricultural and Food Processing Wastes, pp 456-462, Oct. 12-15, Research Triangle Park, ASAE, 2950 Niles Road, St. Joseph, MI 49085 USA.

MWPS-18, 1993. Livestock Waste Facilities Handbook. Midwest Plan Service, Iowa State University, Ames, Iowa 50011-3080.

Stowell, R.R. and W.G. Bickert. 1995. Storing & Handling Sand-Laden Dairy Manure. Extension Bulletin E-2561, Michigan State University Exyension, East Lansing, MI 48824-1039.

Quisenberry, V.L. 1998. personal communication. Professor of Soil Science, Clemson University, Department of Crop and Soil Environmental Science, Clemson, SC.