

OHIO LIVESTOCK MANURE MANAGEMENT GUIDE



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Preface

Agriculture in Ohio is ever-changing and includes both large farms and many smaller farms. However, in most cases, the basic principles of manure management have not changed. Livestock animals produce manure, and people spread it. Usually the goal is to utilize the fertilizer nutrients in manure for crop production, while avoiding harm to the environment. Properly utilized manure can augment or replace purchased commercial fertilizer. Improperly managed manure can pollute soils, air, lakes, wells, and streams and cause substantial community conflict.

This revised edition of the *Ohio Livestock Manure Management Guide*, Ohio State University Extension Bulletin 604, updates and expands information provided in previous editions. The editorial committee acknowledges the contributions made by previous editorial committees and writers. In a break from the past, this edition's editorial committee included individuals from other agencies and organizations who frequently work with farmers on manure-management issues along with The Ohio

State University writing committee. It is hoped that this inclusive approach will provide a more unified single document for manure management recommendations. In addition, the editorial committee would like to thank the Ohio Livestock Coalition's Educational Committee for reviewing the draft document.

Livestock manure can be either a valuable resource or an environmental pollutant. The whole purpose of this *Ohio Livestock Manure Management Guide* is to help farmers utilize manure as a resource while at the same time protecting our shared environment. A guiding principle for the writers of this edition of Bulletin 604 was to address the needs of both large and small livestock producers. This edition contains new and expanded sections, and the total length of the document is increased. We hope this new format will improve the guide's usability and value for all of those involved in livestock manure management in Ohio.

Fundamentals

Chapter 1—Manure Characteristics

The quantity, composition, and consistency of manure influence the selection and the design of manure-handling facilities. In its strictest definition, animal manure refers only to feces and urine. However, bedding, feed wastage, rain, soil, milk-house wastes or wash, and more are mixed with the feces and urine on many farms. This results in a manure that has properties considerably different from fresh manure. To minimize confusion in this chapter, the term *fresh* will be added to manure when talking only about feces and urine mixtures.

Fresh Manure

Table 1 lists fresh manure (feces and urine) production and its characteristics by livestock types, weights, and production levels. Values in the table are averages for individual animals being fed according to National Research Council Guidelines (2001). Variations of $\pm 20\%$ can occur and are highly dependent on feed digestibility and nutrient feeding levels of the animal. Recent studies have shown nitrogen (N), phosphorus (P), and potassium (K) can be reduced in many feeding programs without reducing animal productivity. The result is manure with N, P, and K levels lower than those given in Table 1. Laboratory analysis of fresh manure is the most reliable way to determine its chemical content. Procedures for sampling manure are discussed at the end of this chapter.

The first part of Table 1 gives the ratio of fresh manure weight generated daily per animal body weight, along with moisture and dry solids level. Also included are ash, N, P, and K concentrations as a percentage of dry solids (all water removed). Results show that manure production per unit of body weight varies with production level (dry vs. lactating), diet (high energy vs. high roughage), sex, age, and stage of production, as well as with species. Also, N, P, and K concentrations vary with these same factors. Thus, the quantity and properties of manure depend on:

- Animal—species, age, productivity.
- Levels of nutrients fed and ration digestibility.

Two properties of fresh manure are relatively constant, namely water content and density. For fresh manure, water content is consistent at 88 to 92% for non-poultry species and 73 to 75% for poultry. Thus, unless an animal is sick or is being fed excessive levels of salt (in which case, moisture increases), these moisture ranges can be expected. Manure in the 88 to 92% range should be handled as a liquid, while manure in the 73 to 75% range should be handled as a solid. Figure 1 shows graphically how manure moisture affects its handling characteristics. Chapter 3 on Manure-Management Systems describes manure-handling systems and the range of manure water contents they will handle.

Density of fresh manure is similar for all species at 62 to 65 lb/ft³ (water has a density of 62.4 lb/ft³). At these densities, a gallon of manure would weigh approximately 8.3 lb. **Therefore, to convert fresh manure weights to gallons, divide weights by 8.3.**

The second part of Table 1 gives the weight and volume of fresh manure, solids, and quantities of N, P₂O₅, and K₂O produced daily per animal type. N, P₂O₅, and K₂O concentrations were calculated by multiplying:

fresh manure produced daily x dry matter
content x chemical level (dry basis)

This information can be used to estimate the quantity of total nutrients generated daily per animal on a farm. For example, a dairy cow producing 90 lb milk per day generates daily 153 lbs (18.4 gal.) of fresh manure containing 1.00 lb N, 0.30 lb P₂O₅, and 0.56 lb K₂O.

Table 2 shows the dollar value of nutrients in 1 ton (or 241 gallons) of fresh manure and 1 ton of dry manure at 15% moisture for each animal type. The results show how moisture impacts the value of a ton of manure. For example, a semitruck-load (25 tons) of fresh turkey manure might be worth \$481. However, if the manure were dry (15% moisture), it could be worth \$1,635 for the same NPK analysis on a dry basis.

Table 1. Fresh Manure Production and Characteristics per Animal Type.

Animal Type	Animal Size	Nutrient Content					Daily Manure weight volume	Daily Nutrients								
		Ratio	Water	TS	VS	N		P	K	TS	VS	N	P ₂ O ₅	K ₂ O		
	lb	Wm/Wa	% wb	% db	% db	% db	% db	lb/day	cu ft/day	lb/day	lb/day	lb/day	lb/day	lb/day	lb/day	
Dairy Cattle																
	Calf	150		88	12	85.7	3.21	0.64	2.56	13	0.200	1.56	1.34	0.0500	0.0100	0.0400
	Young Stock	250	0.084	88	12	82.6	3.17	0.79	2.78	21	0.323	2.52	2.08	0.0800	0.0200	0.0700
	Heifer	750	0.087	88	12	85.3	2.95	0.90	2.82	65	1.00	7.80	6.65	0.2300	0.0700	0.2200
	Dry Cow	1,000	0.082	88	12	85.3	3.66	0.55	2.36	82	1.32	9.84	8.39	0.360	0.123	0.280
	Dry Cow	1,400	0.082	88	12	85.0	3.62	0.55	2.41	115	1.85	13.80	11.72	0.500	0.173	0.400
	Lactating Cow—50 ^a	1,400	0.091	88	12	85.0	5.45	0.71	2.50	128	2.06	15.31	13.02	0.834	0.247	0.461
	Lactating Cow—90 ^a	1,400	0.110	88	12	85.0	5.44	0.80	2.50	153	2.48	18.41	15.65	1.002	0.335	0.555
	Veal	250	0.036	96	4	43.8	11.11	8.33	16.67	9	0.145	0.360	0.16	0.0400	0.0300	0.0600
	Beef Cattle															
Calf	450	0.058	92	8	84.7	6.73	4.81	5.29	26	0.413	2.08	1.76	0.1400	0.1000	0.1100	
High Forage	750	0.083	92	8	89.7	8.27	2.82	5.04	62	0.984	4.96	4.45	0.4100	0.1400	0.2500	
High Forage	1,100	0.084	92	8	89.4	8.29	2.85	4.89	92	1.48	7.36	6.58	0.6100	0.2100	0.3600	
High Energy	750	0.072	92	8	92.9	8.80	3.24	5.09	54	0.871	4.32	4.01	0.3800	0.1400	0.2200	
High Energy	1,100	0.073	92	8	91.9	8.44	3.28	5.00	80	1.29	6.40	5.88	0.5400	0.2100	0.3200	
Cow	1,000	0.063	88	12	77.9	4.10	2.51	3.44	63	1.00	7.56	5.89	0.3100	0.1900	0.2600	
Swine																
Nursery	25	0.108	89	11	81.5	6.73	3.37	3.37	2.7	0.0435	0.297	0.24	0.0200	0.0100	0.0100	
Grow-Finish	150	0.063	89	11	80.0	7.66	4.78	3.83	9.5	0.153	1.05	0.84	0.0800	0.0500	0.0400	
Gestating	275	0.027	91	9	85.5	7.41	5.93	5.93	7.5	0.121	0.675	0.58	0.0500	0.0400	0.0400	
Lactating Sow	375	0.060	90	10	90.2	8.00	5.78	6.22	22.5	0.357	2.25	2.03	0.1800	0.1300	0.1400	
Boar	350	0.021	91	9	89.4	7.72	6.17	6.17	7.2	0.114	0.648	0.58	0.0500	0.0400	0.0400	
Sheep																
Ewes	100	0.040	75	25	82.7	4.00	2.00	4.00	4.0	0.0635	1.000	0.83	0.0400	0.0200	0.0400	
Poultry																
Layer	4	0.065	75	25	75.4	5.38	4.15	2.46	0.26	0.00400	0.065	0.05	0.0035	0.0027	0.0016	
Broiler	2	0.090	74	26	72.3	4.91	2.99	2.35	0.18	0.00286	0.047	0.03	0.0023	0.0014	0.0011	
Turkey	20	0.045	75	25	76.0	5.60	4.80	2.40	0.90	0.0143	0.225	0.17	0.0126	0.0108	0.0054	
Duck	6	0.055	73	27	59.6	5.16	4.26	3.14	0.33	0.00532	0.089	0.05	0.0046	0.0038	0.0028	
Equine																
Horse (all forage)	1,100	0.051	85	15	85.0	2.34	0.34	0.71	55.7	0.884	8.36	7.10	0.196	0.0646	0.0715	
Horse (50% grain)	1,100	0.051	85	15	85.0	3.29	0.66	1.21	55.7	0.884	8.36	7.10	0.275	0.1254	0.1220	

Reference: Adapted from MWPS -18, unpublished OARDC data, Lawrence *et al.* (2004). Wm = daily weight of manure, Wa = average weight of animal during this stage of production, TS = total solids, VS = volatile solids, % wb = percent wet basis, and % db = percent dry basis. To convert manure weights to gallons, divide by 8.3. P₂O₅ = 2.273 x P and K₂O = 1.205 x K. ^a lbs of milk/day.

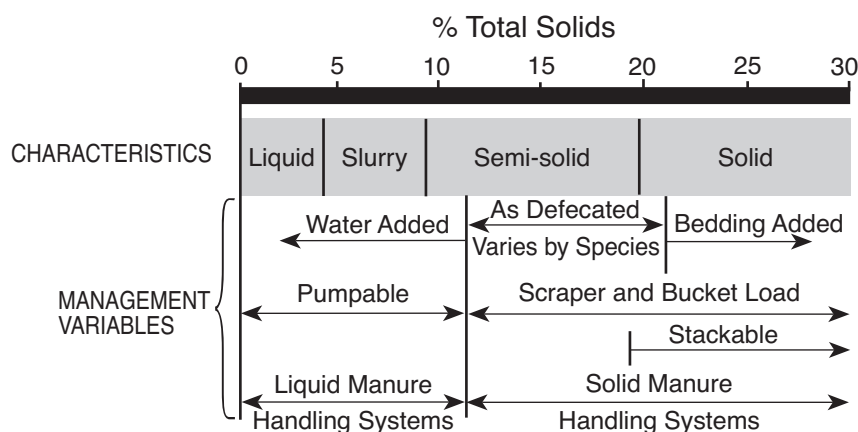


Figure 1. Physical manure characteristics and handling requirements. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Table 2. Manure Nutrient Concentrations and Value per Ton.

		Fresh Manure (75% to 92% moisture)				Manure @ 15% Moisture			
Animal Type	Animal Size lb	N lb/ton	P ₂ O ₅ lb/ton	K ₂ O lb/ton	Value \$/ton	N lb/ton	P ₂ O ₅ lb/ton	K ₂ O lb/ton	Value \$/ton
Dairy Cattle									
Young Stock	250	7.6	1.9	6.7	3.06	54.0	13.5	47.2	14.57
Heifer	750	7.1	2.2	6.8	3.00	50.1	15.3	47.9	14.08
Dry Cow	1,000	8.8	3.0	6.8	3.56	62.2	21.3	48.4	17.93
Dry Cow	1,400	8.7	3.0	7.0	3.56	61.6	21.3	49.3	17.81
Lactating Cow—50 ^a	1,400	13.1	3.9	7.2	4.73	92.6	27.4	51.2	25.86
Lactating Cow—90 ^a	1,400	13.1	4.4	7.2	4.83	92.5	30.9	51.2	26.54
Veal (96% moisture)	250	8.9	6.7	13.3	5.29	188.9	141.7	283.3	69.89
Beef Cattle									
Calf	450	10.8	7.7	8.5	5.18	114.4	81.7	89.9	41.52
High Forage	750	13.2	4.5	8.1	5.02	140.5	48.0	85.7	40.51
High Forage	1,100	13.3	4.6	7.8	5.00	140.9	48.5	83.2	40.70
High Energy	750	14.1	5.2	8.1	5.36	149.5	55.1	86.6	43.92
High Energy	1,100	13.5	5.3	8.0	5.22	143.4	55.8	85.0	42.71
Cow	1,000	9.8	6.0	8.3	4.61	69.7	42.7	58.5	23.88
Swine									
Nursery	25	14.8	7.4	7.4	5.85	114.5	57.2	57.2	36.63
Grow-Finish	150	16.8	10.5	8.4	7.07	130.1	81.3	65.1	44.90
Gestating	275	13.3	10.7	10.7	6.67	125.9	100.7	100.7	47.85
Lactating Sow	375	16.0	11.6	12.4	7.70	136.0	98.2	105.8	49.56
Sheep									
Ewes	100	20.0	10.0	20.0	9.40	68.0	34.0	68.0	21.76
Poultry									
Layer	4	26.9	20.8	12.3	11.92	91.5	70.6	41.8	34.26
Broiler	2	25.6	15.6	12.2	10.57	83.5	50.9	40.0	28.55
Turkey	20	28.0	24.0	12.0	12.76	95.2	81.6	40.8	37.26
Equine									
Horse (all forage)	1,100	7.0	2.3	2.6	2.40	39.9	13.1	14.5	11.40
Horse (50% grain)	1,100	9.9	4.5	4.4	3.73	56.0	25.5	24.8	17.41

^a lbs of milk/day. N = 0.22 \$/lb; P₂O₅ = 0.20 \$/lb; K₂O = 0.15 \$/lb. Calculations based on Table 1.

Bedding and Water Additions

Bedding should be considered in many manure-handling systems. An estimate of the amount of bedding used can be obtained by measuring the amount used for a small number of animals and expanding it to the whole herd. Table 3 provides characteristics of common bedding materials as related to water absorption and fertilizer nutrients. This information can be used in calculating nutrient value of fresh manure and the bedding when laboratory analysis is unavailable.

Bedding, water additions, handling and storage losses alter manure's characteristics; therefore, the data given in Tables 1 and 2 are only the place to begin for analyzing nutrient loading rates on farms and calculating the value of manure.

Volume of Manure

Estimating the total volume of manure produced is accomplished by adding the volume of fresh manure from the animal, plus half the volume of the dry bedding used, plus the volume of water additions. Only half the volume of bedding is used

to allow for void spaces in the bedding which are filled with the fresh manure during mixing.

Moisture and Composition

Figure 2 shows the ratio of bedding to fresh manure needed to achieve a specific moisture ratio of manure. For example, free-stall fresh manure (88% moisture, liquid) would require about 0.05 lb of dry bedding at 10% moisture to be added per 1.0 lb of fresh manure to produce a semi-solid manure with a moisture of 84%. For a dairy cow producing 90 lb of milk per day, this would be about 7.7 lb per day of bedding (153 lb manure per day x 0.05). If the bedding was wheat straw, this would have added 0.038 N, 0.014 P₂O₅, and 0.069 K₂O lbs per day of nutrients or a 3.8%, 4.7%, and 12% increase above fresh manure values, respectively. When bedding with straw or corn stalks, nutrient values should be considered for nutrient management planning (NMP) on a farmstead. However, for sawdust or sand bedding, nutrient additions will generally be less than 3% for N, P₂O₅, and K₂O.

Table 3. Bedding Characteristics.

Type	Water Absorbing Capacity	Density	Water	Solids	Nutrient Concentrations		
					N	P ₂ O ₅	K ₂ O
	lb/lb, bedding	lb/ft ³	% wb	% wb	% db	% db	% db
Straw ^a							
Wheat, Oat	2.2	5 to 8	10.0	90.0	0.55	0.20	1.00
Cornstalks ^a							
Shredded	2.5	4 to 5	10.0	90.0	0.75	1.40	0.90
Hardwood ^a							
Shavings or Sawdust	1.5	9 to 12	10.0	90.0	0.20	0.10	0.20
Sand ^b							
Clean Sand (dry)	0.16	80.6	6.2	93.8	0.00	0.00	0.00
Clean Sand (wet)	0	91.6	19.4	80.6	0.00	0.00	0.00

^a Adapted from Ohio State University Extension Bulletin 604, 1992 Edition. Material wetted from 10% moisture to 65 to 70% moisture.

^b Unpublished Ohio Agricultural Research and Development Center (OARDC) data.

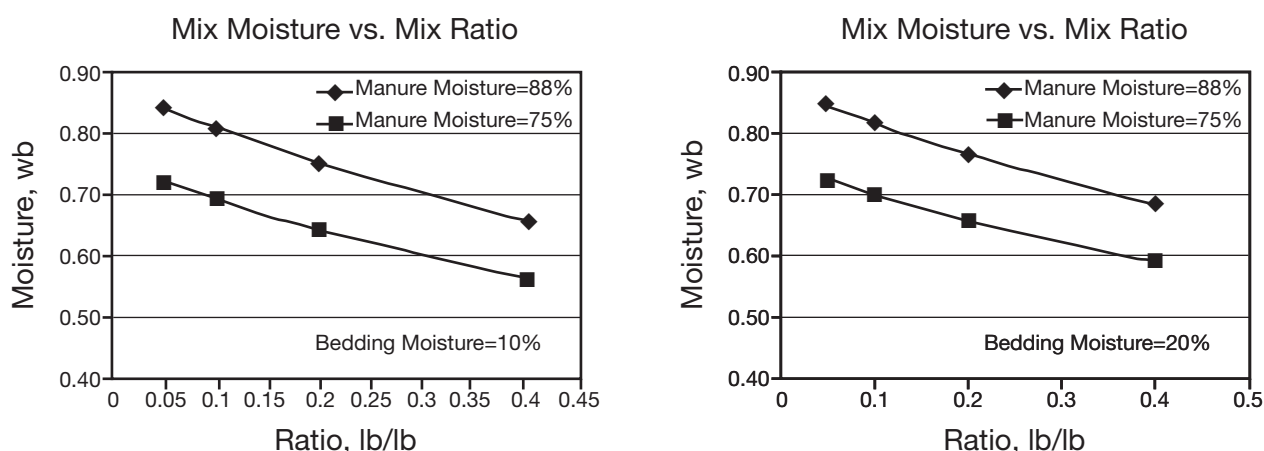


Figure 2. Expected manure moisture based on ratio of bedding added to fresh manure.

Sand Bedding

Sand-bedded dairy free-stall barns have become increasingly popular because of cow comfort and hygienic improvements over organic bedding and mats. Sand usage averaged about 53 lb per stall per day in Michigan State University studies (Michigan State University Extension Bulletin E-2561). The sand significantly increases the solids content of the manure and its volume. However, since sand does not readily absorb water, the manure will continue to behave as a slurry or semi-solid. For details on the amount of bedding required to thicken manure, refer to MidWest Plan Service (MWPS), *MWPS-18-S1, Manure Characteristics*, available from your local county office of Ohio State University Extension or online at the MidWest Plan Service, www.mwps.org/default.htm.

Other materials often get added to fresh manure. Feed waste and soil can add considerable nutrients, while water additions from washing equipment and buildings, leaking waterers inside buildings, rain from building roofs and outside lots, and rainfall into open storage structures can add considerable volume and weight. Conversely, manure in open lots or well-ventilated buildings will often lose water. Thus, the quantity and the properties of manure depend on:

- Quantity of added bedding, feed waste, soil, surface water, washwater, etc.
- Environment—wet or dry climate, housing ventilation, handling and storage losses.

Handling and Storage Losses

Nutrient losses occur in the handling, storage, and spreading of manure. The major nutrient lost is nitrogen through volatilization of ammonia and can range as high as 80% or more of the total nitrogen. Also, phosphorus can be lost due to its accumulation in the unrecovered sludge in the storage system. Because nutrient losses are highly variable, the information on fresh manures and bedding given in Tables 1, 2, and 3 should not be relied upon once manure is available for sampling and analysis. Sampling is also recommended because of uncontrolled water additions or losses (drying) that can occur. **Thus, to accurately predict manure properties, sampling and testing manure from storage is critical.**

Sampling, Testing, and Evaluating Manure Nutrients

Sampling

To make the most appropriate and environmentally responsible use of manure, it is necessary to test the manure to accurately determine its nutrient concentrations. Furthermore, for the test results to be meaningful, it is important to obtain an adequate number of samples that are representative of the bulk manure. The number of samples needed will depend on the variability of the manure. The more variable the manure, the more samples are required. Variability of liquid manures is usually less than for solid manures, especially if the liquid manure can be mixed prior to sampling.

Manure from different storage systems should be sampled differently. For solid manures, the sample can be taken while loading or during spreading. For poultry, the sample can come from within the house or from a stockpile of litter. Liquid manure can be sampled from storage or during the time of application. Liquid manure in storage should be agitated two to four hours before taking the sample. More details on recommended sampling procedures are given in Appendix A.

Testing: Select a reputable testing laboratory. In selecting a laboratory, determine if the laboratory is knowledgeable in testing manure and belongs to a manure proficiency testing program. Obtain the laboratory's appropriate sampling kit and read the corresponding instructions thoroughly. Manure samples should be identified regarding the farm, animal species, and date of sampling. The samples should be kept frozen until shipped to a laboratory. It is best to ship early in the week.

The laboratory analyses required on manure are moisture, total nitrogen (N), ammonia-N ($\text{NH}_3\text{-N}$), phosphorus (generally reported as phosphate [P_2O_5]), and potassium (generally reported as potash [K_2O]). Other useful analyses include pH, electrical conductivity, calcium (Ca), magnesium (Mg), and sulfur (S). The nutrients manganese (Mn), copper (Cu), and zinc (Zn) may also be important, especially if these nutrients are included in the animal diet.

Evaluation of Test

Most laboratories design their test reports to meet the needs of their customers. However, there may be differences from laboratory to laboratory in the reporting format, reporting units of the test values, conversion factors, and the estimate of the nutrient availability. The test report usually involves three types of information. The first type is the descriptive information about the sample and the customer, including sample identification, sample description, and date of analysis.

The second type of information is the actual analytical results. Careful attention should be paid to the units associated with the test values. Typically, the laboratory will report the test values in parts per million (ppm) or percentage (%), and then convert them to the units needed by the customer to calculate application rates. Examples are lb per

1,000 gal for liquid manure and lb per ton for solid manure. Laboratories may also report the analysis on an as-is basis and a dry-matter basis. The as-is basis is used to calculate the application rates. Most laboratories report the results only on an as-is basis. However, the dry-matter basis, if it is needed, can be calculated from the moisture determination. The dry-matter basis is used to compare the nutrient concentrations of one manure with those of another manure.

The third type of information is interpretive and includes estimates of nutrient availability and fertilizer value. Since the laboratory may be using estimates of nutrient availability from other sources, it is important to verify that the lab's nutrient availability factors are the same as reported in this bulletin for Ohio conditions. The fertilizer value is often assigned to the manure by taking into account the current local fertilizer prices for the nutrients in the manure. However, the fertilizer value may be less when not all nutrients are needed due to already high soil-test levels. Manure application costs vary between fields and can be more than the fertilizer value of the nutrients. Therefore, the value of manure may be different, depending on the field to which it is applied. More details for reporting manure test results can be found in Appendix B.

Record Keeping

The frequency of testing should be such that a good record of the nutrient concentrations in the manure can be established. It is important to get a feel for the variation in these concentrations over time. With good frequency of testing and record keeping, substantial changes in nutrient concentrations in manure, such as those due to changes in manure storage or animal feed, can be recognized.

Summary

The quantity and properties of manure depend on:

- Animal—species, age, productivity.
- Levels of nutrients fed and ration digestibility.
- Quantity of added bedding, feed wastage, soil, surface water, washwater, etc.
- Environment—wet or dry climate, housing ventilation, handling and storage losses.

Once a manure system is in place, sampling manure from storage is critical to estimate nutrient loading rates on farms and calculate the value of manure accurately.

References

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Chapter 2—Whole Farm Nutrient Budget/Planning

Introduction

Source: Adapted from the Livestock and Poultry Environmental Stewardship curriculum, MidWest Plan Service (MWPS). Used by permission.

Over application of manure is a major concern for water quality and soil health. Nitrogen and phosphorus are two nutrients that can hurt the quality of our groundwater and surface water. Nitrogen leaching out of the root zone may enter a tile and be transported to surface water, or it may leach to the groundwater. Phosphorous leachate or runoff entering the surface water contributes to excessive algae growth which causes low oxygen levels in surface water. This, in turn, impairs aquatic life. Proper management of manure is critical to protecting water quality and to sustaining the livestock and poultry industry.

The key to preventing manure nutrient overload is to balance manure nutrients with crop needs. However, as livestock and poultry operations get larger, the manure nutrients generated often exceed the nutrient needs of the crops on the farm. When more manure nutrients are applied to the crops than the crops can use, nutrient levels built up in soil, leading to a higher risk of nutrient runoff or leaching to surface and groundwater.

The purpose of this chapter is to provide an understanding of the flow of nutrients on the farm and to help the livestock producer determine if his or her farm:

1. Has a nutrient balance.
2. Has an excess of manure nutrients.
3. Has a shortage of nutrients.

In addition, strategies will be discussed to deal with excess nutrients.

Nutrient Imbalances

Nutrient imbalances can occur on a single field, an individual farm, or on a regional basis.

Single-field nutrient imbalances are common on any livestock farm. Easy access fields, fields close to the barn, loafing areas, and pasture fields often accumulate excess manure nutrients. Spreading manure based on convenience and not the crop's nutrient requirements may result in excessive nutrient concentrations and water-quality problems.

Individual farm nutrient imbalances. Livestock farms import significant quantities of nutrients as animal feeds. Livestock utilize only 10 to 30% of these nutrients, excreting the remainder as manure. This results in a concentration of nutrients on the livestock farm. This is a common challenge in the Corn Belt states where producers tend to concentrate either on grain production or livestock production.

Regional nutrient imbalances have developed in the past 30 years as livestock/poultry production and feed-grain production have concentrated in specific, but separate, regions of the state and the country. Nutrient excesses on a regional scale involve townships, counties, or multiple counties with high concentrations of livestock or poultry that produce more manure nutrients than the crop base in the geographical area can utilize. Several top livestock-producing areas have accumulated high concentrations of nutrients where more nutrients are available from the manure produced than can be utilized by the crops grown.

The primary question a livestock farmer must ask is: Am I building up nutrients (producing more nutrients than can be utilized on the farm)? To answer this question, the farmer needs to understand the flow of nutrients into the farm, the nutrient needs of the farm, and the flow of nutrients off the farm. The primary nutrients to track for the farm nutrient balance are nitrogen, phosphorus, and potash (N-P₂O₅-K₂O).

The main nutrient *inputs* on a livestock or poultry farm are commercial fertilizer, purchased feed, animals, irrigation water and rainfall, and legume nitrogen fixation. Figure 3 illustrates the flow of nutrients onto, and off, a farm.

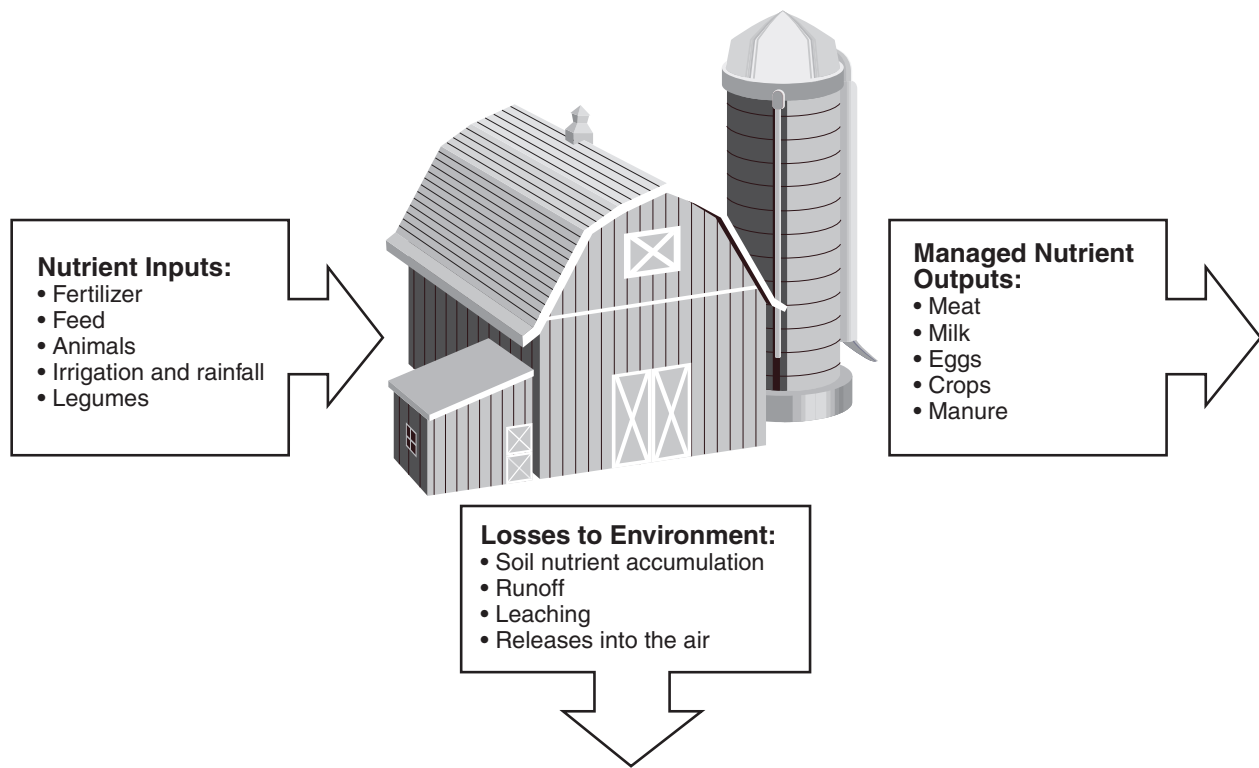


Figure 3. Typical livestock and poultry nutrient flows. Adapted from the Livestock and Poultry Environmental Stewardship curriculum, MidWest Plan Service (MWPS). Used by permission.

Within the boundaries of the farm, a recycling of nutrients occurs between the livestock and the crops. Manure nutrients are recycled, at least in part, for crop production. Feed crop nutrients are recycled as animal feed for livestock or poultry production.

Nutrients exit a livestock operation preferably as *managed outputs* including animals and crops sold and possibly other products moved off farm (e.g., milk, eggs, or manure sold or given to a neighboring crop producer). Some nutrients exit the farm as losses to the environment (nitrates in groundwater, ammonia volatilized into the atmosphere, and nitrogen and phosphorus into surface water). Nutrients (especially phosphorus) also accumulate in large quantities in the soil. Although not a direct loss to the environment, a growing accumulation of nutrients in the soil adds to the risk of future environmental losses.

The *loss to environment* is the difference between the inputs and the managed outputs. This imbalance accounts for both the direct environmental loss and the accumulation of nutrients in the soil. Livestock operations with a significant imbalance are concentrating nutrients, resulting in increased risk to water quality (Lanyon and Beegle, 1993, and Klausner, 1995) and are fundamentally unsustainable. In contrast, livestock farms that have achieved a balance represent a sustainable production system.

The goal of the livestock or poultry operation is to achieve a balance of inputs with managed nutrient outputs. On some farms, a farm nutrient balance can be managed on the farm itself; in other cases, manure needs to be moved to other farms to achieve a nutrient balance.

$$\text{Nutrient Inputs} - \text{Managed Nutrient Outputs} = \text{Losses to Environment}$$

Evaluating the Whole Farm Nutrient Balance for Livestock or Poultry Operations

There are two primary methods for estimating the *whole* nutrient balance on your farm.

1. Whole Farm Nutrient Balance review assesses nutrient *input* content of the feed purchased, the fertilizer purchased, the legume nitrogen produced on the farm, animals purchased, and an estimate of the nutrients added as a result of irrigation and/or rainfall. The second phase of this budget involves estimating the nutrient content of all the nutrients flowing out by way of crops, meat, milk, eggs, animals sold, and manure transported off the farm. This method is scientifically based, but time consuming, and requires extensive records to calculate.
2. A second method provides an easier, but factual, estimate of your whole farm nutrient balance. It involves measuring or estimating total manure nutrient production compared to whole farm crop nutrient utilization. An excess of manure nutrients for crop production suggests a likely whole farm nutrient imbalance. This is the method we will discuss in this chapter.

Estimating Manure Nutrient Content

One of the best ways to determine manure nutrient content is to obtain a manure analysis of the different types of manure produced on the farm. An annual manure analysis should be taken for each different manure storage on the farm. For specifics on sampling procedures and reading laboratory analyses, see Appendices A and B, respectively.

The manure analysis will provide information on the amount of nitrogen, phosphorus, and potash in the manure. For solid manures, the amounts are expressed as pounds of N (nitrogen), P_2O_5 (phosphate), and K_2O (potash) per ton. For liquid manure, the amounts are expressed in pounds of N, P_2O_5 , and K_2O per 1,000 gallons of manure.

In addition to knowing the concentration of nutrients, the quantity of the manure that coincides with the respective manure analysis must be determined. For example, a typical manure analysis may indicate 20 lbs of nitrogen (N), 14 lbs of P_2O_5 , and 17 lbs of K_2O per 1,000 gallons. If this represents 1 million gallons of manure, then the total nutrient content of the liquid manure is 20,000 lbs of nitrogen, 14,000 lbs of P_2O_5 , and 17,000 lbs of K_2O .

Note: Software programs are available at the local USDA, Natural Resources Conservation Service, and Soil and Water Conservation district offices to do Whole Farm Nutrient Budgets.

If manure analyses are not available, a second method to determine manure nutrient content involves using book values to determine volumes of manure and pounds of manure nutrients produced. Table 4 provides estimates of the nutrients and volumes of manure produced for various types of livestock and poultry.

Using Table 4, let's look at an example for a swine operation with 500 grower-finishers averaging 150 lbs. The manure is stored in an underground pit and handled as a liquid.

Table 4. Estimated Nutrient Content and Volumes of Manure Production (As Excreted).

Animal Type Group Size	Size Lbs	See Notes 1-3 Below.							
		Estimated Nutrient Content						Amount of Manure Produced	
		Lbs/Ton			Lbs/1,000 Gallons			Tons Per Year	1,000 Gal. Units Per Year
		N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O		
Col. 1*	Col. 2*	Col. 3*	Col. 4*	Col. 5*	Col. 6*	Col. 7*	Col. 8*	Col. 9*	Col. 10*
Dairy Cattle									
Heifer	150	5.8	1.5	6.2	21.8	5.8	23.3	2.4	0.6
Heifer	250	5.7	1.9	6.7	21.6	7.2	25.2	3.8	1.0
Heifer	750	5.3	2.2	6.8	20.1	8.1	25.6	11.9	3.1
Dairy Milk 40 lbs/day	NA	9.7	3.7	7.2	35.2	13.3	26.0	22.1	6.3
Dairy Milk 50 lbs/day	NA	9.8	3.9	7.2	35.2	14.0	26.0	23.3	6.5
Dairy Milk 60 lbs/day	NA	9.8	4.0	7.2	35.2	14.4	25.9	24.5	6.9
Dairy Milk 70 lbs/day	NA	9.8	4.2	7.2	35.1	14.8	25.9	25.7	7.2
Dairy Milk 80 lbs/day	NA	9.8	4.3	7.2	35.0	15.2	25.8	26.8	7.5
Dairy Milk 90 lbs/day	NA	9.9	4.4	7.2	35.3	15.7	26.1	28.0	7.8
Dry Cow	800	6.6	3.0	6.8	23.7	10.8	24.6	12.2	4.1
Dry Cow	1,000	6.6	3.0	6.8	23.6	10.8	24.7	15.0	4.7
Dry Cow	1,200	6.6	3.0	6.9	23.5	10.8	24.9	18.1	5.3
Dry Cow	1,400	6.5	3.0	7.0	23.5	10.8	25.1	21.0	5.8
Veal	250	6.7	6.7	13.3	24.0	24.0	48.1	1.6	0.5
Beef Cattle									
Calf	450	8.1	7.7	8.5	29.6	28.2	31.0	4.7	1.3
High Forage	750	9.9	4.5	8.1	36.3	16.5	29.5	11.3	3.1
High Forage	1,100	9.9	4.6	7.8	35.9	16.5	28.2	16.8	4.7
High Energy	750	10.6	5.2	8.1	38.0	18.7	29.4	9.9	2.7
High Energy	1,100	10.1	5.3	8.0	36.5	18.9	28.8	14.6	4.1
Cow	1,000	7.4	6.0	8.3	27.0	22.1	30.2	11.5	3.1
Swine									
Nursery	25	11.1	7.4	7.4	40.1	26.7	26.7	0.5	0.1
Grow-Finish	150	12.6	10.5	8.4	45.5	37.9	30.4	1.7	0.5
Gestating	275	10.0	10.7	10.7	36.0	38.4	38.4	1.4	0.4
Lactating	375	12.0	11.6	12.4	44.0	42.3	45.6	4.1	1.1
Boar	350	10.4	11.1	11.1	38.2	40.7	40.7	1.3	0.4
Sheep									
Sheep	100	15.0	10.0	20.0	54.9	36.6	73.3	0.7	0.2
Poultry									
Layer (per 1000)	4	20.2	20.8	12.3	76.3	78.5	46.5	47.5	12.6
Broiler (per 1000)	2	19.2	15.6	12.2	70.2	57.0	44.8	32.9	9.0
Turkey (per 1000)	20	21.0	24.0	12.0	76.9	87.9	44.0	164.3	44.8
Duck (per 100)	6	20.9	23.0	17.0	75.4	83.0	61.2	6.0	1.7
Horse									
Horse	1,100	7.4	4.5	4.4	27.1	16.5	16.0	10.2	2.8

Notes:

* Column Number (e.g., Col. 1) will help users find the correct values in the following example.

1. Values do not include bedding or additional water that may be added.
2. The actual values can vary + or - 30% (recommend actual manure analysis).
3. Estimated nitrogen assumes a 25% loss during storage and handling prior to land application.

Source:

1. Adapted from Table 6, MWPS-18-S1 (2000) for all except lactating dairy cows.
2. Lactating Dairy Cows: Equations for Nutrient Excretion from Dairy Cattle, Proposal for ASAE D384. February 1, 2002, and Ohio Agricultural Research and Development Center (OARDC) data for dairy.

Step 1: Estimate manure and nutrient production for each animal type.

Using the book values in Table 4, determine the total manure output:

500 grower/finishers x 0.5 thousand gallons/year (Col. 10) = 250 thousand gallon units/year

Then, calculate the total nutrient output for the manure produced:

250 x 36.0 lbs of N per 1,000 gal. (Col. 6) = 9,000 lbs N/year

250 x 38.4 lbs P_2O_5 per 1,000 gal. (Col. 7) = 9,600 lbs P_2O_5 /year

250 x 38.4 lbs K_2O per 1,000 gal. (Col. 8) = 9,600 lbs K_2O /year

Step 2: Add the nutrient amounts for each animal type.

Round the total nutrients calculated in Step 1 and complete the table shown here:

Animal Phase/Type	Nitrogen	P_2O_5	K_2O
Grower/Finishers	9,000	9,600	9,600
Totals	9,000	9,600	9,600

Now we have a good estimate of the manure nutrients available on the farming operation. The next step is to determine the farm's crop nutrient needs.

Estimating Crop Nutrient Needs

Step 3: Determine acres of each crop and average yield per acre.

Example:

100 acres of corn grain..... 140 bushels/acre

100 acres of soybeans.....40 bushels/acre

100 acres of wheat + straw..... 60 bushels/acre

Step 4: Determine crop nutrient needs.

Using Tables 5 and 6 to determine nutrient needs, complete the table shown here. (Note: P_2O_5 and K_2O amounts are for crop removal; results from soil tests may vary.)

Crop	Yield	Acres	Nutrient Needs = Yield x Acres x Crop Removal (Tables 5 and 6)		
			N	P_2O_5	K_2O
Corn Grain	140	100	16,800**	5,180	3,780
Soybeans	40	100	0*	3,200	5,600
Wheat+ Straw	60	100	6,600	4,320	7,680
Totals		300	23,400	12,700	17,060

* Up to 150 lbs per acre of manure nitrogen could be budgeted if this acreage is needed to help balance excess nitrogen that cannot be utilized for the non-legume crops.

** (e.g., N = 140 bu per acre x 1.2 lbs N per bu. x 100 Acres = 16,800 lbs)

Table 5. Recommended Nitrogen.

Crop	Yield Units	Recommended Nitrogen
Corn	Bu/Acre	1.2 lbs/bushel
Corn Silage	Tons/Acre	7.2 lbs/ton
Tobacco	Lbs/Acre	0.1 lbs/lb
Wheat	Bu/Acre	1.1 lbs/bushel
Oats	Bu/Acre	0.65 lbs/bushel
Grass Hay/Pastures	Tons/Acre	40 lbs/ton (max. 175 lbs/acre)

Source:

- Adapted from the *Tri-State Fertilizer Recommendations*, Ohio State University Extension Bulletin E-2567, July 1995. Recommended nitrogen was averaged over a range of yields to simplify calculations for farm budgeting.
- Ohio Agronomy Guide*, 13th Edition, Ohio State University Extension.

Table 6. Approximate Amounts of P_2O_5 and K_2O Removed by Harvested Crops.

Crop	Nutrients Removed for the Given Unit Yield	
	P_2O_5	K_2O
Alfalfa and Grass Forages	13.0 lb/ton	50 lb/ton
Corn, Grain	0.37 lb/bu	0.27 lb/bu
Corn, Silage	3.3 lb/ton	8.0 lb/ton
Oats, Grain	0.25 lb/bu	0.20 lb/bu
Oats, Grain + Straw	0.40 lb/bu	1.20 lb/bu
Sorghum, Grain	0.39 lb/100 lbs	0.39 lb/100 lbs
Soybeans	0.8 lb/bu	1.4 lb/bu
Sugar Beets	2.0 lb/ton	10.0 lb/ton
Tobacco, Burley	1.3 lb/100 lbs	8.3 lb/100 lbs
Wheat, Grain	0.63 lb/bu	0.37 lb/bu
Wheat, Grain + Straw	0.72 lb/bu	1.28 lb/bu

Source:

1. *Tri-State Fertilizer Recommendations*, Ohio State University Extension Bulletin E-2567, July 1995.
2. *Ohio Agronomy Guide*, 13th Edition, Ohio State University Extension.

Step 5. Compare Manure Nutrients and Crop Needs.

Comparison of Nutrients and Crop Needs.			
	N	P_2O_5	K_2O
Nutrient Available from Manure	9,000	9,600	9,600
Crop Nutrient Needs/Removal	23,000	13,000	17,000
Whole Farm Nutrient Balance (Available from Manure-Crop Needs)	-14,000	-4,400	-7,400
* The actual amount available to the crop will depend on the storage method, and the time and method of application. The actual amount available may range from 25% to 60%. Figures from Nutrient Needs rounded to nearest 1,000.			

Step 6: Whole Farm Budget Analysis.

With this particular example, the nutrients available from the manure are less than the recommended nitrogen needs and crop removal rates for P_2O_5 and K_2O (short 14,000 lbs of N, 4,400 lbs of P_2O_5 , and 7,400 lbs of K_2O). Even though a deficit is shown, the farm may not need additional P_2O_5 or K_2O if soil-test levels are above the critical levels for P and K. Also, if soil test levels for P and K are low, more nutrients may be needed than indicated in the Whole Farm Nutrient Budget.

What Is the Most Important Nutrient for the Whole Farm Nutrient Balance?

In general, it requires fewer acres to balance the available manure nutrients for the farm's nitrogen needs. However, applying manure nutrients at the nitrogen needs rate generally over applies P_2O_5 by two to four times the crop needs. This poses an environmental risk due to the high application of P_2O_5 at one time and the build up of phosphorus in the soil. As phosphorus soil-test levels approach 300 pounds or 150 ppm (Bray-Kurtz P1), the risk of phosphorus runoff in the dissolved and particulate form begins to increase substantially. Also, applying manure nutrients at a nitrogen needs level can very rapidly increase soil-test potassium levels, which can contribute to animal-health problems.

A farm can sustain itself for a short time by balancing for nitrogen, but this will rapidly increase soil-test phosphorus and potassium levels. The goal is to operate a livestock enterprise in a manner that can sustain the cycling of manure nutrients indefinitely while minimizing the risk of nitrogen and phosphorus leaching and runoff.

Table 7 provides a quick reference to determine the number of acres needed to utilize manure nutrients. When using Table 7, read the assumptions made in the notes area.

Table 7. Manure Production (As Excreted), Estimated Nutrient Content, and Acres to Utilize Nutrients.

Animal Type and Size	Size lbs	See Notes 1-3.					
		Annual Nutrients Available for Application in lbs/Animal			Acres Needed per Animal Type and Size to Utilize Nutrients		
		N	P ₂ O ₅	K ₂ O	@130 lbs/ac	@50 lbs/ac	@50 lbs/ac
					N	P ₂ O ₅	K ₂ O
Dairy Cattle							
Heifer	150	13.7	3.7	14.6	0.11	0.07	0.29
Heifer	250	21.9	7.3	25.6	0.17	0.15	0.51
Heifer	750	63.0	25.6	80.3	0.48	0.51	1.61
Dairy Milk 40 lbs/day	NA	217.0	82.1	159.9	1.67	1.64	3.20
Dairy Milk 50 lbs/day	NA	228.0	90.2	168.3	1.75	1.80	3.37
Dairy Milk 60 lbs/day	NA	240.0	98.2	176.7	1.85	1.96	3.53
Dairy Milk 70 lbs/day	NA	251.0	106.2	185.1	1.93	2.12	3.70
Dairy Milk 80 lbs/day	NA	263.0	114.2	193.5	2.02	2.28	3.87
Dairy Milk 90 lbs/day	NA	274.0	122.3	202.6	2.11	2.45	4.05
Dry Cow	800	89.0	32.0	91.0	0.68	0.64	1.82
Dry Cow	1,000	98.6	45.0	102.2	0.76	0.90	2.04
Dry Cow	1,200	118.0	54.0	124.0	0.91	1.08	2.48
Dry Cow	1,400	137.0	63.0	146.0	1.05	1.26	2.92
Veal	250	11.0	11.0	21.9	0.08	0.22	0.44
Beef Cattle							
Calf	450	38.3	36.5	40.2	0.29	0.73	0.80
High Forage	750	112.2	51.1	91.3	0.86	1.02	1.83
High Forage	1,100	167.0	76.7	131.4	1.28	1.53	2.63
High Energy	750	104.0	51.1	80.3	0.80	1.02	1.61
High Energy	1,100	147.8	76.7	116.8	1.14	1.53	2.34
Cow	1,000	84.9	69.4	94.9	0.65	1.39	1.90
Swine							
Nursery	25	5.5	3.7	3.7	0.04	0.07	0.07
Grow-Finish	150	21.9	18.3	14.6	0.17	0.37	0.29
Gestating	275	13.7	14.6	14.6	0.11	0.29	0.29
Lactating	375	49.3	47.5	51.1	0.38	0.95	1.02
Boar	350	13.7	14.6	14.6	0.11	0.29	0.29
Sheep							
Sheep	100	11.0	7.3	14.6	0.08	0.15	0.29
Poultry							
Layer (per 1000)	4	1,000.0	985.5	584.0	7.69	19.71	11.68
Broiler (per 1000)	2	629.6	511.0	410.5	4.84	10.22	8.21
Turkey (per 1000)	20	3,449.3	3,942.0	1,971.0	26.53	78.84	39.42
Duck (per 100)	6	1,259.3	1,387.0	1,022.0	9.69	27.74	20.44
Horse							
Horse	1,100	75.3	45.8	44.5	0.58	0.92	0.89

Notes:

1. Values do not include bedding or additional water that may be added.
2. The actual values can vary + or - 30% (recommend actual manure analysis).
3. Estimated available nitrogen assumes a 25% loss during storage and handling prior to land application.
4. Rotation—corn, soybeans, and wheat.

Source: Adapted from Table 6, MWPS-18-S1 (2000) for all except lactating dairy cows. MidWest Plan Service.

Source: Lactating Dairy Cows, Equations for Nutrient Excretion from Dairy Cattle, Proposal for ASAE D384. February 1, 2002, and Ohio Agricultural Research and Development Center (OARDC) data for dairy.

Strategies to Improve Nutrient Balance

Source: Adapted from Livestock and Poultry Environmental Stewardship Program, MidWest Plan Service (MWPS). Used by permission.

Evaluating a livestock system's nutrient balance from a whole farm perspective provides a more complete picture of the driving forces behind nutrient-related environmental issues. The original sources of these nutrient inputs are clearly identified, which in turn suggests management strategies for reducing excess nutrient accumulations. The management strategies presented here should help to reduce nutrient imbalances:

Strategy 1. Efficient use of manure nutrients in crop production.

By accurately crediting manure nutrients in a cropping program, the purchase of commercial fertilizer can be reduced or eliminated and the risk to the environment reduced. This practice is especially important to livestock operations with significant crop production and substantial commercial fertilizer nutrient inputs. It may offer greater benefit for nitrogen-related issues due to common use of commercial nitrogen fertilizers as insurance on manure-applied fields.

Strategy 2. Alternative livestock feeding programs.

Opportunities are available for reducing both nitrogen and phosphorus inputs by alternative livestock feeding programs.

Feeding certain rations can also increase the nutrient content of the manure produced. A Nebraska study observed a greater phosphorus imbalance when high phosphorus rations were used in feedlot feeding programs. Ethanol and corn processing by-products, attractive feed alternatives for some cattlemen, are typically high in phosphorus concentrations, resulting in finished cattle rations with excess phosphorus levels. Participating operations that used these by-products experienced substantially greater phosphorus imbalance as compared to those operations not utilizing these by-products. Both groups had similar nitrogen balance. Feeding program choices are likely to impact whole farm nutrient balance, especially for farms purchasing significant quantities of feed from off-farm sources.

In addition to changes in feed rations, some additional options that may reduce purchased feed nutrient inputs include:

- Alternative crops or crop rotations that result in a greater on-farm production of livestock protein and phosphorus requirements.
- Harvesting and storage practices that improve the quality of animal feed and reduce losses.

Strategy 3. Marketing of manure nutrients.

Marketing of manure creates an additional managed output similar to the sale of crops or livestock products. Several farms throughout Ohio and the United States are now marketing their manure to other farms and for other beneficial uses. Some farms sell their manure based on its nutrient content to other farms needing nutrients. Some livestock and poultry producers have manure-spreading agreements with neighboring farms to apply manure nutrients on their farms at no cost. Still others market their manure products to non-farm individual users as well as commercial firms, such as landscapers. (See Chapter 4, *Treatment and Utilization Options for Livestock Manure*.)

Strategy 4. Manure treatment.

In some situations, it may be necessary for animal production systems to consider manure-treatment technologies similar to municipal and industrial-waste treatment systems. Some manure-treatment systems focus on disposal of nutrients with modest environmental impact. For example, treatment systems commonly dispose of wastewater nitrogen as a gas (no environmental impact) or ammonia (some environmental impact). Other treatment systems enhance the value of manure (e.g., solids separation or composting) to allow alternative uses of the nutrients. Complementary manure-treatment and manure-marketing strategies can contribute to improved nutrient balance. For example, some producers are successfully combining composting (for odor control and volume reduction) with marketing of manure to crop farms and urban clients.

Strategy 5. Changing crop rotations.

Changing rotations should include crops that can utilize more nutrients such as wheat/straw removed and forage crops compared to corn and soybeans. Corn and soybeans generally use fewer pounds of

phosphate and potash per acre than do wheat with straw removed or hay crops.

Table 8 illustrates the additional amounts of phosphate and potash that can be utilized by adding more wheat or hay crops to the farming system. This strategy diversifies the cropping system on the farm and better utilizes nutrients from the manure produced on the farm.

Table 8. Nutrient Removal Rates for Specified Rotation and Yield.

Rotation/Yields	Average Phosphate (P ₂ O ₅) Removed/ Acre/Year	Average Potash (K ₂ O) Removed/ Acre/Year
Corn (140 bu/ac) Soybeans (40 bu/ac)	42	47
Corn (140 bu/ac) Soybeans (40 bu/ac) Wheat (60 bu/ac) with Straw Removed	47	57
Corn (140 bu/ac) Soybeans (40 bu/ac) Wheat (60 bu/ac) with Straw Removed plus three years of Alfalfa (4 tons/ac)	49	128

Source: USDA – Natural Resources Conservation Service (NRCS), Ohio, used by permission, with calculations from Tri-State Fertilizer Guide, Ohio State University Extension Bulletin E-2567, July 1995.

Summary—Whole Farm Nutrient Balance

Sustaining the livestock and poultry industry requires achieving a balance between environmental concerns and production goals. Manure nutrients must be balanced on the field scale, the farm scale, and the regional scale. Whole farm nutrient balancing requires management of:

- **Nutrient inputs**, including fertilizer, feed, animals, irrigation and rainfall, and legumes, with feed and fertilizer usually being the largest contributors.
- **Managed nutrient outputs**, including meat, milk, eggs, crops, and manure, with the goal of recycling as many manure nutrients through crops as possible.
- **Unmanaged nutrient outputs**, including soil nutrient accumulation, runoff, and leaching, all of which lead to environmental concerns that can negatively impact an individual operation and, potentially, the entire livestock and poultry industry.

A single strategy will not fit all situations. In many cases, farms will need to implement multiple strategies to achieve whole farm nutrient balance. For farms with sufficient cropland, utilizing manure nutrients on the crops is usually best. This strategy should focus on preventing manure nutrient losses and reducing commercial fertilizer inputs to achieve a nutrient balance and gain the greatest benefit from manure.

When the land base is insufficient, livestock dietary options for reducing manure nutrients may be an important strategy for attaining nutrient balance. If neighboring crop farms or other nutrient users are in the vicinity of livestock operations, manure treatment and marketing of manure nutrients to off-farm customers may be an important alternative.

Good agronomic use of manure nutrients will result in good environmental use of manure nutrients.

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Manure Handling and Storage

Chapter 3—Manure-Management Systems: Collection, Transfer, and Storage

Components of a manure-management system include collection, transfer, storage, possible treatment, hauling, and utilization (land application). Many factors should be considered when selecting a manure-management system for a specific operation. These include livestock type, age and size, feed rations, housing, bedding, labor requirements, land availability adjacent to the farmstead, cropping rotation, topography of farmstead and fields for planned manure application, proximity to waterways, proximity to neighbors, prevailing wind direction, and personal preference.

When on-farm manure-application areas are limited, the management plan must also include off-farm manure transport. Therefore, a manure-management system should fit the needs of each individual livestock operation. There is no single “best” system. Each has advantages and disadvantages. Proper implementation and management are the keys to a successfully operated manure-management system. A complete system should accomplish the following goals:

- Maintain good animal health through sanitary facilities.
- Minimize air and water pollution.
- Minimize impact on family and neighbor living areas.
- Reduce odors and dust.
- Control insects and pests.
- Be compatible with a sustainable nutrient management plan.
- Balance capital investment, cash flow requirements, labor, and nutrient use.

This chapter presents different options of equipment types and facilities for handling animal manures. System options for handling liquid, semi-solid, and solid manure for different livestock species are discussed.

Manure can be handled as a liquid, slurry, semi-solid, or solid. The amount of bedding or dilution water influences manure characteristics as discussed in Chapter 1, *Manure Characteristics*.

Manure characteristics influence the collection, transfer, storage, and selection of spreading equipment.

Solid manure is a combination of urine, bedding, and feces with no extra water added, such as that found in a loafing barn, bedded pack, calving pen, or open lot with good drainage.

Semi-solid manure has little bedding and no extra liquid added. Little drying of semi-solid manure occurs before handling. Solid and semi-solid manure can be handled with tractor scrapers, front-end loaders, or mechanical scrapers. Conventional box or flail spreaders are common for land application.

Slurry manure is a combination of feces and urine with little organic bedding or dilution. Manure slurry can be transferred directly into storage with a mechanical or tractor scraper, or scraped to a reception pit for gravity flow or pumping into storage. If the storage facility is covered, the manure can be loaded out of storage onto a V-tank spreader.

Liquid manure has water added to form a flowable mixture that can be handled by solids-handling pumps. Liquid manure is usually less than 8 to 10% solids. Very liquid manure is usually only 1 to 2% solids and is common with flushing and lagoon systems. Liquid and slurry manure are handled with scrapers, flushing gutter, gravity-flow gutters, or storage under slotted floors. Liquids are spread on fields with tank wagons or by irrigation.

In most facilities, manure storage is needed to provide handling and spreading flexibility. The primary purpose of a storage structure is to provide flexibility in scheduling field spreading to avoid wet ground, poor weather conditions, growing crops, and conditions conducive to causing pollution.

Collection and Transfer

Several collection and transfer methods are possible to manage manure. Selection considerations include facility type, labor requirements, investment, and overall manure management system.

Open-lot and confined systems livestock housing have different requirements and options.

An **open-lot** system requires two manure-handling methods. Lot scrapings and open-front shelter manure packs are solid or semi-solid, and lot runoff is liquid. Solid manure from the shelter or lot can be moved to storage with a tractor scraper and front-end loader. Lot runoff contains manure, soil, chemicals, and debris and must be stored or treated as a component of the manure-management system. Runoff from roofs, drives (not animal alleys), and grassed or cropped areas without animal traffic is relatively clean and should be diverted from the manure system. See Chapter 5, *Farmstead Runoff Control*, for more details.

A **confined** system can store manure in a tank under the building or in outdoor storage. For an under-the-building storage tank, manure is transferred through a slotted floor or drain plug and collected in the tank. With outdoor storage facilities, manure is removed from the building to storage with a mechanical or tractor scraper, front-end loader, flushing gutter, or gravity-flow gutters or channels.

Slotted, Woven-Wire, and Concrete Slat Floors

Slotted and expanded metal floors effectively transfer manure from the animal space to storage below a building. Expanded metal floors are also used in conjunction with below-building manure storage or gravity-flow channels. Concrete slats are the most durable, are suitable for animals of all ages, and are the most widely used flooring system for confined swine facilities.

Slightly crowned and tapered slats improve cleaning but may stress the livestock's feet and legs. Slip-resistant surfaces provide better footing and longer wear. Slats are typically 4 to 10 inches wide. Wider slats provide better footing, but animals are usually dirtier.

Scrapers and Front-End Loaders

Solid or semi-solid manure can be mechanically scraped. A mechanical scraper system has one or more scraping blades, a cable or chain to pull the

scraper, and a power unit with controls. Common scraper systems are gutter cleaners, below-slat scrapers, alley scrapers, and elevator stackers. Mechanical scrapers allow more frequent removal of manure from the building and can reduce daily labor requirements. However, maintenance requirements can be higher because of corrosion and deterioration.

A small tractor with a back- or front-mounted blade or skid-steer loader can be used to scrape manure. Skid-steer loaders can clean in cramped areas, greatly reducing hand labor. Most have a low height and a turning radius of their own length, so they can work easily in tight quarters; however, some have a relatively low load-lifting capacity.

Front-end loaders remove solid manure from open lot surfaces, building floors, and storage facilities. Tractor loaders have a relatively high load-lifting capacity and are available in 1,000- to 4,000-pound sizes. Their relatively large turning radius usually limits them to straight runs and areas with few turns.

Flushing Systems

In a flush system, a large volume of water flows from one end of a building to the other, down a sloped, shallow gutter. The water scours manure from the gutter or alley and removes it to a lagoon or storage pond (Figure 4). Three types are common:

- Wide-open gutter, used in dairy free-stall alleys, holding areas, and milking parlors.
- Narrow-open gutter (less than four feet wide), used primarily in hog finishing buildings. In open-gutter swine units, the flushing attracts hogs to the gutter, helping to toilet-train them. Residue buildup and disease transmission are potential challenges with an open-gutter system.
- Under-slat gutter, used in beef buildings and swine farrowing, nursery, gestation, and larger facilities where residue or disease transmission is a concern.

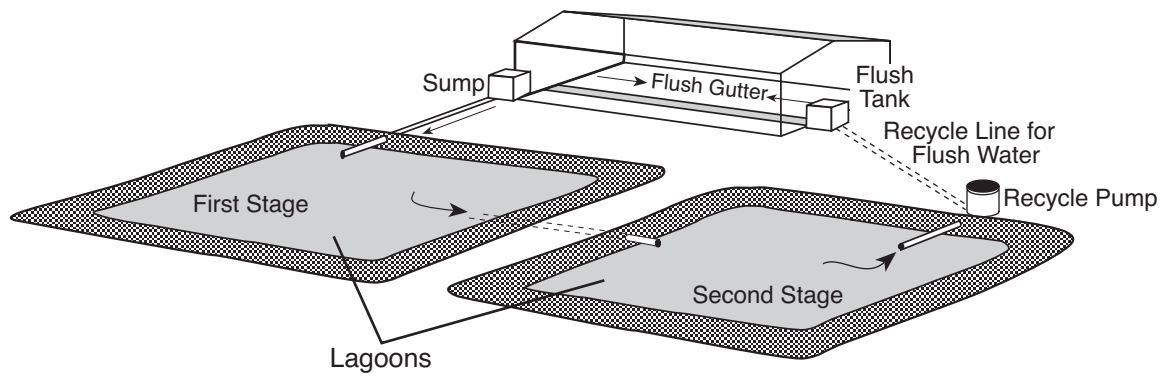


Figure 4. Flush system with two-stage lagoon. (Source: *Ohio State University Extension Bulletin 604, 1992 Edition, Figure 2.*)

Water may be recycled from a lagoon, holding pond, or earthen storage. If irrigating, producers may use fresh water for flushing rather than recycled water. In a flushing system, a pump transports either fresh or recycled water to a flush tank at the high end of the gutter. The flush tank periodically releases a large volume of water into the gutter. Flushing frequency is determined by animal type and size, gutter width, gutter slope, and flush-tank volume. Flush tanks can be automatic siphon tanks, manual flush tanks, tipping tanks, or gated flush tanks. Flush tanks should release the entire volume in 10 to 20 seconds.

Some systems use a large-capacity pump operated by a time clock to supply flush water instead of a flush tank. Pump flushing uses much more water than tank flushing.

Gutter slopes usually range from nearly flat to 5% to get the desired initial flush-water flow depth. Make the alley or gutter flat with no cross slope or only a slight crown, which will force the flow toward the curbs. Limit gutter length to 125 feet. If longer gutters are required, slope both ends of the gutter so they flush toward the middle of the building length. For more information about flushing system selection, design, and management, refer to MWPS 18, *Livestock Waste Facilities Handbook*, available from your local county Extension office.

Gravity-Drain Gutters

Gravity-drain gutters are commonly installed in swine buildings under raised farrowing stalls, raised nursery decks, and slotted floors. These gutters have Y, U, V, and rectangular shapes. Manure and wastewater is allowed to build up in gutters.

When gutters are full, usually in three days to two weeks, a drain plug is pulled and manure flows by gravity to some outdoor storage structure. Gravity-drain gutters use less water than flushing systems. Wastage from waterers usually provides the liquid necessary to make the manure flow out of the gutter. If gutters do not receive waterer wastage, additional water is required to provide enough liquid. To reduce the amount of fresh water needed, water from a lagoon can be pumped into the gutter to suspend solids and improve cleaning. However, recycled lagoon water may result in mineral and salt buildup in pipes and pumps.

A deep, narrow gutter gravity-flow system is nearly self-cleaning because manure flows rapidly when the plug is pulled. Deep, narrow gutters are located at the lower end of a solid feeding floor or solid floor under raised farrowing stalls or nursery decks (Figure 5). Some scraping of the solid floor section is required. For more information about the use and management of deep, narrow gutters, refer to MWPS 18, *Livestock Waste Facilities Handbook*, available from your local county Extension office.

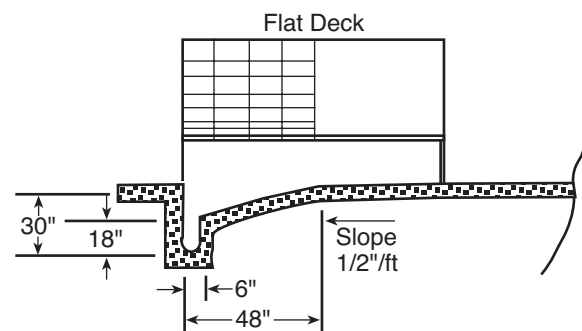


Figure 5. Deep, narrow gutter. (Source: *Ohio State University Extension Bulletin 604, 1992 Edition.*)

The Y-gutter is an adaptation of the deep, narrow gutter. The objective is to provide the cleaning action of the deep, narrow gutter with a sloped floor below slats or raised decks in swine buildings to promote a cleaner floor in the animal space. Side slopes of the upper channel are usually 1:1 or 0.75:1. Construction of Y-gutters is more complicated than for V- or rectangular-bottom gutters.

The V-gutter resulted from attempts to simplify construction of the Y-gutter (Figure 6). The bottom of the V-gutter can be a 6- to 8-inch PVC pipe cut in half or flat 6- to 8-inch concrete. The sides of the V-gutter appear to clean easier than the Y-gutter because manure solids have less time to dry on the upper slope. Cleaning action seems comparable to the deep, narrow channel and Y-gutter.

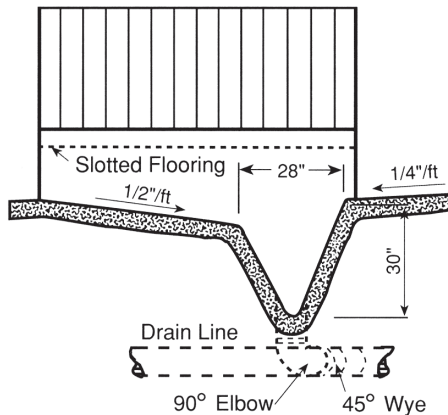


Figure 6. V-bottom gutter under a raised deck. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Rectangular gutters are easier to construct and provide more storage capacity than the Y- or V-gutter (Figure 7). Cleaning action of rectangular gutters depends on the location of the drain plugs. Earlier versions had only one drain plug at the end of a sloping gutter, and solids tended to build up at the high end of the gutter. Recent designs leave the bottom flat with a drain plug at each end of the gutter. By alternating the plug pulled, draining the gutter two different ways has helped reduce solids buildup. An alternative approach is to locate drain plugs uniformly down the length of the gutter. Pull a different plug each time to clean solids from the gutter. In wide, flat-bottom gutters, cleaning is improved by dividing the gutter in the direction of flow into narrow channels 18 to 24 inches wide. Use channel dividers for all but the first 20 feet of the gutter and near the drain plug.

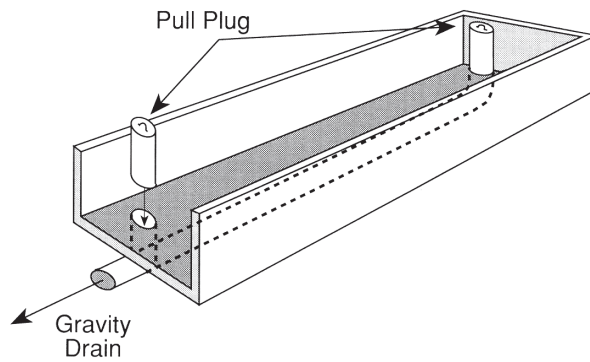


Figure 7. Flat-bottom gutter manure transfer. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

The reverse hairpin gravity gutter system, shown in Figure 8, is a modification of the original rectangular gravity-drain gutter. The primary difference is that the gutter is shaped like a horseshoe, and two drains are located at one end on opposite sides of a dividing wall. This approach simplifies drain line placement. A dividing wall is located down the center of the gutter, dividing it into two channels. The dividing wall extends to within 4 feet of the end farthest from the drains. In practice, two drain plugs are pulled in an alternating pattern every one to three weeks to reverse the flow of manure to the drain and reduce solids buildup. Gutter depth must be at least 18 inches although a gutter depth of 24 inches is preferred. Gutter length is limited to about 100 feet. Pumping 2 to 6 inches of recycled water back into the gutter will reduce ammonia odors, suspend solids, and improve cleaning. See AEX-114-96, Hairpin Gutters for Swine Facilities at: <http://ohioline.osu.edu/aex-fact/0114.html>.

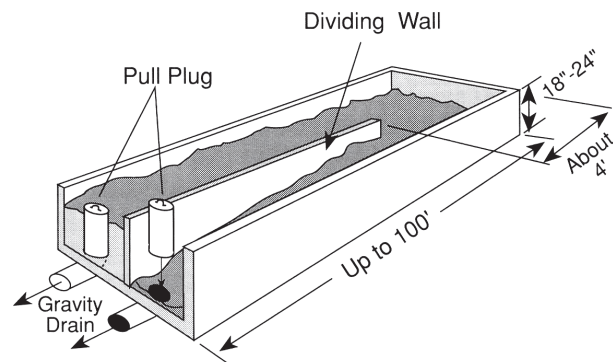


Figure 8. Reverse hairpin flat-bottom gutter. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Gravity-Flow Channels

Gravity-flow channels are rectangular-shaped channels with a flat bottom and a 6- to 8-inch-high dam at the discharge end. They have been used in tie-stall and free-stall dairy barns. The dam retains a lubricating layer under the manure, and the manure surface forms a 1 to 3% incline. Manure flows by gravity down the incline. Biological activity helps liquefy the manure and promote a constant flow. The manure flowing over the dam falls into a cross channel or discharge pipe. These systems can freeze in cold housing.

Channel width does not affect performance. However, limiting channel width to 36 inches can improve flow. Channel depth depends on channel length and manure-surface incline. For design, assume manure inclines 3%. Channel length is typically 40 to 80 feet and should not exceed 80 feet. If longer channels are required, increment the channel into steps. The overflow dam must be water-tight and can be concrete block, a steel plate, or pressure-preservative-treated wood. Removable dams allow for total clean-out but may be difficult to keep water-tight. Before putting animals in the barn, fill the gutter with 3 to 6 inches of water to form the lubricating layer. Limit the use of bedding.

Transfer to Storage

Manure can be transferred to storage by gravity, piston pump, pneumatic pump, or centrifugal pump. System selection depends on the waste

characteristics, bedding practices, available labor, and storage system.

Gravity-flow transfer uses the hydraulic head exerted by liquid waste to force the waste to flow (Figure 9). The transfer pipe size required depends on the manure characteristics. Very liquid wastes, such as swine manure and milking center wastewater, flow well through small-diameter (6- to 8-inch) pipes. Little or no bedding should be used. Larger-diameter (24- to 30-inch) pipes, discharging from a collection hopper, work well with dairy and beef manure with well-mixed sawdust or chopped straw bedding and a solids content of up to 8 to 12%. Pipe materials can be either SDR 35 PVC, smooth-wall polyethylene, concrete, or steel.

These systems work best when the pipe is installed on a uniform grade with a nearly flat slope (0 to 1%). Avoid horizontal bends in the pipe. Install the transfer pipe below the frost line to prevent freezing. To assure adequate hydraulic-head pressure for manure flow, the minimum head (elevation difference) between the scraped alley, or top of collection hopper, and the top of the maximum depth of the stored material should be 4 to 6 feet for transfer distances up to 125 feet. When manure from an outside lot is included, an additional small storage area for dry and frozen manure should be added, and the head requirement should be increased to 8 feet. For dairy facilities, the milkhouse washwater should be put in at the collection hopper to further liquefy the manure.

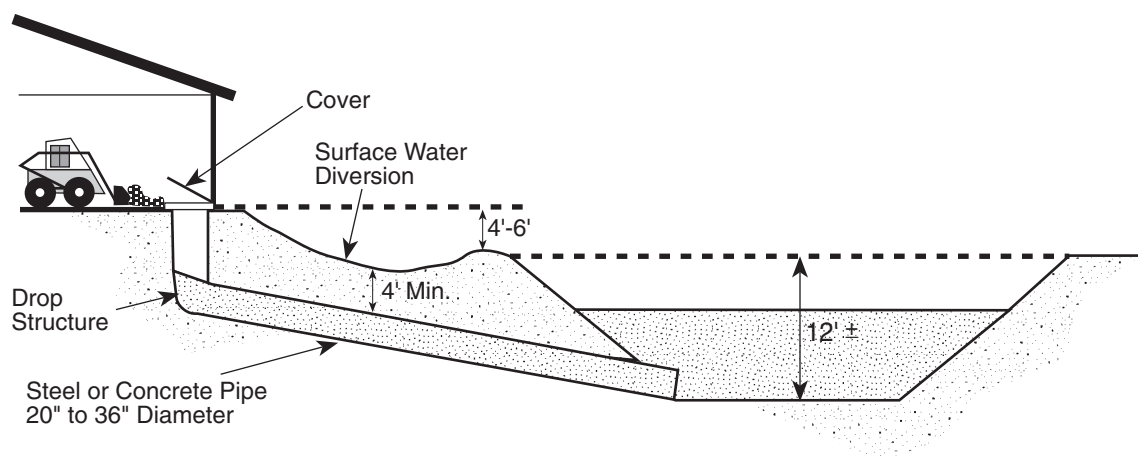


Figure 9. Gravity-flow manure transfer to storage. (Source: *Liquid Application Manure Systems Design Manual*, NRAES-89. Natural Resource, Agriculture, and Engineering Service, Ithaca, N.Y.) Used by permission.

Gravity flow transfer of sand-laden dairy manure includes additional design considerations. The slope of the transfer pipe should be approximately 2%, the required head should a minimum of 8 feet, and the collection hopper functions as a temporary storage structure that is “flushed” every two to four days. The milkhose washwater should **not** go into the collection hopper, because it may cause the sand to separate from the manure within the transfer system.

Bottom-load the storage facility because top-loading can result in cold-weather freezing problems. Keep the exit of the gravity-flow pipe at least 1 to 2 feet above the floor of the storage to reduce settled solids blocking the pipe. Be sure to cover the pipe end with at least 1 foot of liquid before winter freezing occurs. To reduce plugging, provide adequate clean-outs.

Manure Pumping

Another method of moving manure to storage is to collect the manure in a small concrete pit and then pump it to storage with a centrifugal chopper pump. Locate the pit for easy access. Size the pit for at least one-day storage, preferably several days. Select a pump that can handle manure with bedding and develop sufficient head pressure to pump manure from the bottom of the pit to the maximum level of the storage.

Pump selection depends on the solids content and required pumping pressure. Solids content varies with livestock species, housing type, and manure-collection system. If possible, settle out solids before pumping. Pressure requirements vary considerably, depending on the application. Irrigation of manure and wastewater may require high pressure to pump the material to the nozzle and spray it onto the land. Other typical applications may require only that manure be lifted 10 to 20 feet to storage or manure spreader.

Centrifugal pumps are not positive-displacement pumps because the impeller can slip in the liquid. Centrifugal pumps typically cannot handle manure with a solids content greater than 10 to 12%. Pump performance depends on impeller design. Closed impellers are more efficient with water and very liquid manure, but they cannot handle large solids percentages or large solid particle sizes. Open or semi-open impeller pumps can handle liquids

with a larger solids content. However, in applications where fibrous, stringy material (such as hay or silage in a dairy lagoon) is present, use a cutter or chopper pump. These pumps have a cutting or chopping device (located just outside the pump inlet) that rotates with the impeller and shreds fibrous material as it enters the pump.

Positive-displacement pumps include screw pumps and piston pumps. Screw pumps handle manure with high solids content, but the manure must be free from hard or abrasive solids. Screw pumps should not be operated dry. Always add a small stream of water directly into the pump casing during operation. Piston pumps are used to move high-solids-content manure to storage. They are commonly used to transfer lot-scraping or tie-stall and free-stall barn manure to storage. Piston pumps generate very high pressures if the discharge pipe is plugged. Large-diameter (10- to 15-inch) pipes are typical and seldom plug; therefore, release valves are seldom used for manure transfer.

Manure pump characteristics are shown in Appendix C.

Storage

A manure-storage structure is often needed to provide management flexibility for scheduling appropriate land application that avoids wet soil, growing crops, fields already high in nutrient concentrations, and other conditions conducive to potential pollution. The storage facility must be sized to provide for manure bedding, washwater, and dilution water for the period that livestock manure cannot be spread and utilized. Open manure storage systems also need to store or treat rainfall that contacts the manure during the planned storage period and have reserve capacity to prevent release of a 24-hour, 25-year frequency rainfall event. Design storage facilities to minimize the potential for odors and contaminated runoff. Although higher in cost, a covered manure structure may be practical due to improved handling conditions, less excess water, and potentially fewer odors.

When planning manure storage facilities, consider all farmstead operations, building locations, well locations, future building expansions, and prevailing winds. Locate, size, and construct storage facilities for convenient filling and emptying. Provide all-weather access. Evaluate site and soil

conditions carefully to avoid contaminating ground and surface water. Do not locate unlined storage facilities where leakage can cause ground water pollution, such as over shallow creviced bedrock, below the water table, or in pervious soils. For additional information or help in evaluating a site, contact your local Soil and Water Conservation District (SWCD) or the Natural Resources Conservation Service (NRCS).

Storage type depends on the manure characteristics. Manure can be handled as a liquid, slurry, semi-solid, or solid. The amount of dilution water or bedding influences the form and the choice of storage system.

Storage capacity depends on regulations, number and size of animals, amount of dilution by spilled and cleaning water, amount of stored runoff, and desired length of storage. Length of storage required may vary from farm to farm. Provide enough storage capacity and length of storage to allow spreading of manure when field conditions and weather permit. Plan for six to 12 months of storage capacity for liquid manure and at least three months storage for solid manure. Storage capacity of up to 12 months will provide more flexibility for scheduling field-spreading of manure. Table 9 provides a comparison of manure storage alternatives.

Table 9. Comparison of Manure Storage Alternatives.

Manure Storage Type	Advantages	Disadvantages
Solid manure, roofed or covered (steel, concrete, timber plank)	<ul style="list-style-type: none"> • High nutrient density. • Do not have to haul water. • Little or no seepage. • Low nutrient loss. • No runoff from stacked manure. 	<ul style="list-style-type: none"> • More expensive than open stacks. • Not applicable as sole storage for systems with lot runoff or high water use. • Bedding may be required.
Solid manure, not covered (steel, concrete, timber plank)	<ul style="list-style-type: none"> • Less expensive than roofed storage. • High nutrient density. • Do not have to haul water. • Low nutrient loss, but higher than a covered storage. • Most applicable in arid regions. 	<ul style="list-style-type: none"> • Rainfall/runoff contamination potential. • Runoff controls may be required. • Not applicable as sole storage for systems with lot runoff or high water use. • Bedding likely to be required. • Less applicable in humid regions.
Slurry pit, reception pit, or roofed tank (earthen, concrete)	<ul style="list-style-type: none"> • Relatively high nutrient density. • Low/moderate nutrient loss. • Manure may be injected or incorporated. • No rainfall effects. 	<ul style="list-style-type: none"> • More expensive than earthen storage. • May have more odor. • May require pit ventilation. • May not be compatible with system having significant lot runoff or high water use. • Relatively expensive application equipment.
Below building pit (concrete)	<ul style="list-style-type: none"> • Relatively high nutrient density. • Low/moderate nutrient loss. • Manure may be injected or incorporated. • No rainfall effects. 	<ul style="list-style-type: none"> • More expensive than earthen storage. • May have more odor. • Animal/worker health problems may result with prolonged exposure to manure gases. • May require pit ventilation. • Not appropriate for regions with shallow water table on high-risk soil conditions or geology. • May not be compatible with systems having significant lot runoff or high water use. • Relatively expensive application equipment. • Manure solids are more difficult to remove.
Slurry pit or tank, not roofed (concrete, steel)	<ul style="list-style-type: none"> • Moderately high nutrient density. • Low/moderate nutrient loss. • Manure may be injected or incorporated 	<ul style="list-style-type: none"> • More expensive than earthen storage. • May have more odor than covered storage. • Rainfall adds extra water. • May not be compatible with system having significant lot runoff or high water use. • Relatively expensive application equipment.

Table continued on next page

Table 9 (continued). Comparison of Manure Storage Alternatives.

Manure Storage Type	Advantages	Disadvantages
Earthen holding pond	<ul style="list-style-type: none"> • Relatively low nutrient density. • Low/moderate nutrient loss • Feasible for long-term storage • Manure may be injected or incorporated. • Less expensive than concrete or steel tanks. • Can be sized for lot runoff and minimal fresh water inputs. 	<ul style="list-style-type: none"> • May have highest odors because of greater surface area. • Rainfall adds extra water. • May be difficult to agitate properly. • Requires soils evaluation, proper soil material, and seal construction. • Relatively expensive application equipment. • Not appropriate for regions with shallow water table on high-risk geology.
Treatment Lagoon (earthen)	<ul style="list-style-type: none"> • Can be used to irrigate growing crops. • Feasible for long-term storage. • Can be sized for lot runoff and fresh water inputs. • Provides biological treatment of manure. • Can be managed with irrigation equipment. • Can be a source of flush water. 	<ul style="list-style-type: none"> • May have seasonally offensive odors, especially after extended frozen periods. • High loss of nitrogen due to volatilization. • High phosphorus levels in sludge if not agitated and removed regularly. • Agitation may be difficult due to size. • Requires soils evaluation, proper soil material, and seal construction. • Irrigation not suitable on steeper slopes. • Not appropriate for regions with shallow water table on high-risk geology. • Requires significant fresh water precharge prior to successful usage.
Runoff holding ponds (earthen, concrete)	<ul style="list-style-type: none"> • Most applicable for storm events in arid regions. • Primarily used for storage of lot runoff from storms. • Can be managed with irrigation equipment. 	<ul style="list-style-type: none"> • Should be preceded by solids separation. • Requires soils evaluation, proper soil material, and seal construction. • Not appropriate for regions with shallow water table on high-risk geology.

Source: Adapted from MWPS-18, Section 2, Table 1-2, with modification for Ohio conditions. Used by permission.

Liquid Manure

Liquid manure can be stored in below-ground tanks either under or separate from the building, earthen storage basins, or above-ground tanks. Plan for up to 12 months storage capacity and provide sufficient capacity for dilution water, rain, snow, and washwater. Dilution water results from live-stock waterer leakage and spillage, washwater, and rainwater entering an open storage facility during the storage period. The volume of dilution water is highly variable and can range from 10% to more than 100% of the manure volume.

Planning for a liquid storage facility should include metered water usage for existing operations and realistic estimates for new facilities. Wastewater volumes in swine facilities are dependent on the frequency of barn cleaning and type of waterers used. Manure volume estimates inclusive of dilution water for swine facilities can be found in MWPS-18-S1, Table 7. Building ventilation and amount of salt in the feed rations also impact swine facility wastewater generation. Estimates of the volume of dairy milkhouse and parlor wastewater can be found in MWPS-18-S2, Table 2-6.

Below-ground storage tanks can be limited by depth to bedrock, water-table elevation, and, possibly, effective lift of a pump. Tanks must be designed to withstand all anticipated earth, hydrostatic, and storage loads, plus uplift if a high water table exists. Fill a newly constructed storage tank with 6 to 12 inches of water before adding manure to submerge solids and counter-balance any uplifting forces. For assistance with concrete tank design, contact the Natural Resources Conservation Service and MidWest Plan Service publications (see Chapter 12, *Technical Services*, for contact information). Protect tank openings with grills, covers, or both, and enclose open-top tanks with a fence at least 5 feet high to prevent accidental entry.

Earthen holding ponds are earth-walled structures at or below grade that provide long-term storage at a low to moderate cost. Holding ponds are intended for manure storage, not treatment, and can be an odor source. However, holding ponds for dairy manure do have a tendency to form a floating crust that contains odors until agitation. Holding ponds are designed to prevent ground and surface-water contamination and may or may not be lined. Planning for an earthen storage pond should always include a geologic exploration to a depth at least

5 feet below the pond bottom. Your local Natural Resources Conservation Service office can provide help in evaluating site suitability and provide design and construction quality-control services.

In general, steeper bank slopes conserve space, reduce the amount of rainfall runoff entering the pond, and leave less manure on the sides when emptying. Inside bank slopes of 2:1 to 3:1 (run: rise) are common for most soils. Outside side-slopes should be no steeper than 3:1 for easier maintenance. Make the embankment at least 12 feet wide to provide access for agitation, loading, and mowing equipment. Enclose earthen holding ponds with a fence at least 5 feet high to prevent unintentional access. Provide at least 40 feet of clearance between the earth basin and fence where agitation and loading equipment are used (Figure 10). The agitation and loadout ramps should be paved with gravel or concrete to prevent bank erosion, and the pond bottom should be paved with concrete at the agitation points to prevent scour. A holding pond designed for sand-laden dairy manure must have accessibility to the pond bottom for a loader and manure spreader. This is normally accomplished by constructing an access ramp sloped no steeper than 10:1. The ramp and pond bottom are lined with concrete.

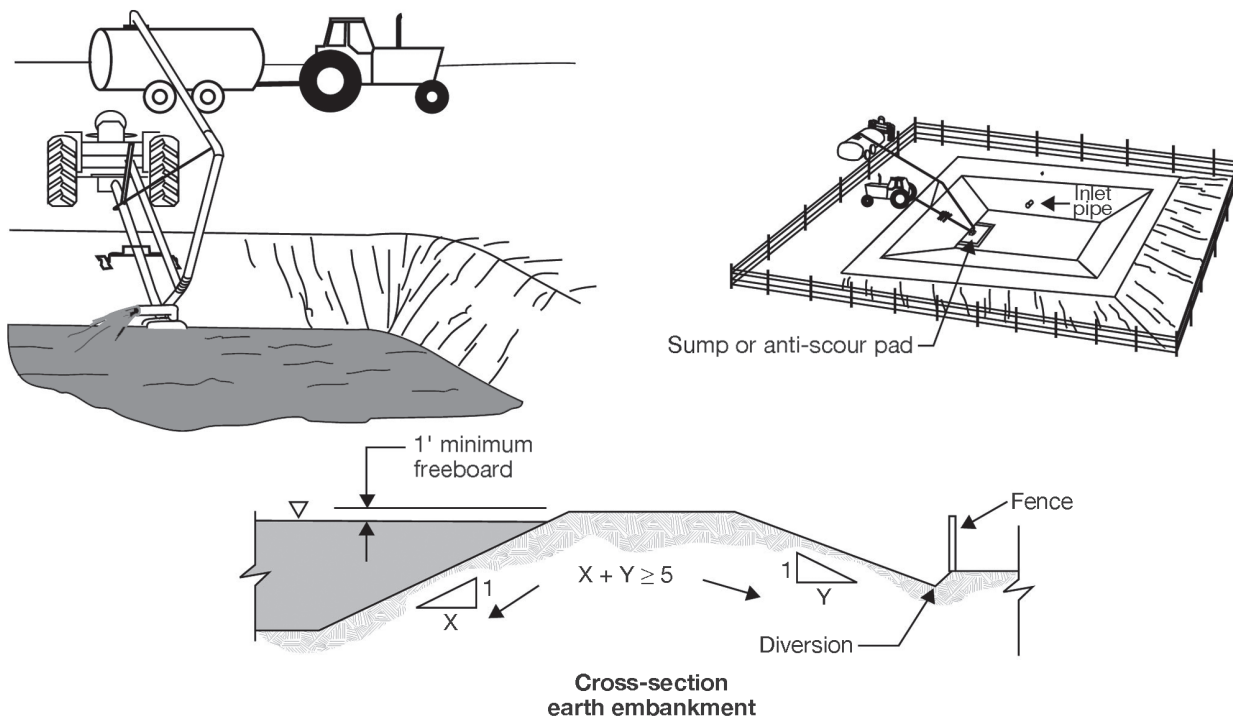


Figure 10. Liquid storage system. (Source: Natural Resources Conservation Service (NRCS) *Agricultural Waste Management Field Handbook*. Used by permission.)

Above-ground circular storage facilities are more expensive than earth storage basins and are usually not used to store runoff or dilute wastes. However, they are a good alternative where an earth basin or below-ground tank is limited by space, high ground water, shallow creviced bedrock, or where earth basins are not aesthetically acceptable. Above-ground storage facilities are usually 10 to 20 feet high and 30 to 120 feet in diameter. They are made of steel, reinforced concrete, and concrete stave. Locate or lock-out access ladders to reduce the risk of accidentally falling into the storage. Consider a ladder on the inside of an above-ground storage because the inside surface is usually very smooth and difficult to climb.

Liquid-Storage Sizing

Determine storage capacity requirements when planning a manure-storage facility. Determine the capacity based on a working capacity, which includes manure storage, precipitation, runoff water, washwater, water wastage, agitation clearance, and remaining manure level after emptying.

Plan to store precipitation from a 25-year, 24-hour-duration storm unless the storage has a roof. Provide at least 1 foot of additional freeboard in the storage and plan on a remaining manure depth, after emptying, of 12 to 24 inches when determining the storage depth (Figure 11).

Semi-Solid Manure

Manure can be stored and handled as a semi-solid or solid if ample bedding is added or additional water is excluded. Semi-solid manure has excess liquids drained off and some bedding added to increase solids content. Solid manure has a relatively large amount of bedding added to give it a stackable consistency. Semi-solid manure can be stored in either an above-ground roofed storage or an outside structure with a picket dam to drain off rainwater (Figures 12 and 13).

The emptying and hauling schedule from a solid or semi-solid storage is more flexible. Storage length and capacity can vary from a few days to several months. With semi-solid or solid manure storage, manure can be hauled whenever time allows without planning ahead to agitate the storage as is required with liquid storage facilities. Also, less total storage capacity is needed for a given storage length because less water is added. Plan for at least three months storage to allow flexibility for hauling manure when conditions are appropriate.

A drained storage facility allows semi-solid manure to be stored uncovered outside and maintain semi-solid handling characteristics by draining off rainwater. Divert all excess lot water away from the manure storage. A picket dam is often used to hold the manure solids and remove rainwater; it does not reduce the water content of the manure. Vertical picket-walls with vertical slots not exceeding 3/4-inch wide between planks allow continuous drainage of liquid from the manure. With proper drainage, the manure will not absorb rainwater and become more soupy. The drainage water from these storage facilities contains manure, chemicals, and debris and must be collected and contained, or treated. A concrete trough along the storage facility perimeter directs drainage water to a liquid storage facility or treatment area.

Where the site is not well suited for storage or treatment of the runoff, a roofed storage facility is better. This system provides an aesthetically pleasing structure that appears to be another building on the farmstead, rather than a manure-storage facility (Figure 14).

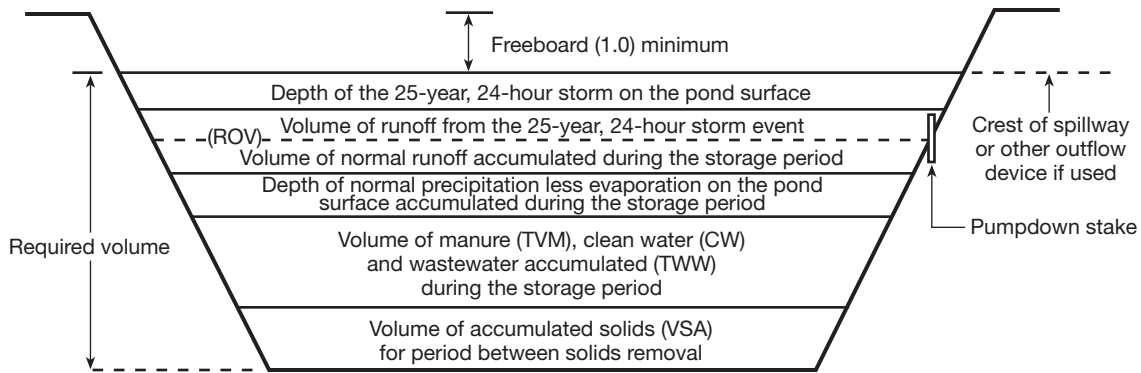


Figure 11. Liquid manure storage pond. (Source: Natural Resources Conservation Service (NRCS) Agricultural Waste Management Field Handbook. Used by permission.)

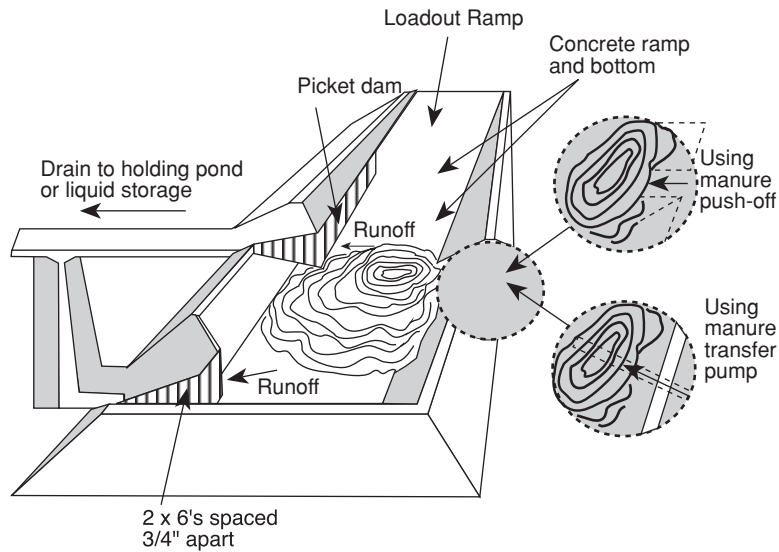


Figure 12. Manure storage structure with picket dam. (Source: Natural Resources Conservation Service (NRCS) Agricultural Waste Management Field Handbook. Used by permission.)

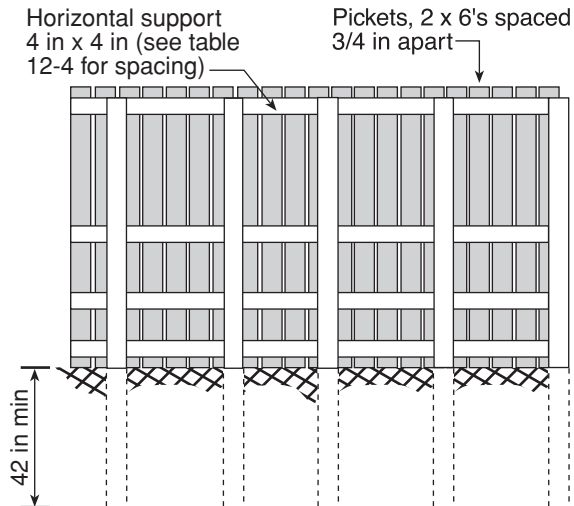


Figure 13. Picket dam details. (Source: Natural Resources Conservation Service (NRCS) Agricultural Waste Management Field Handbook. Used by permission.)

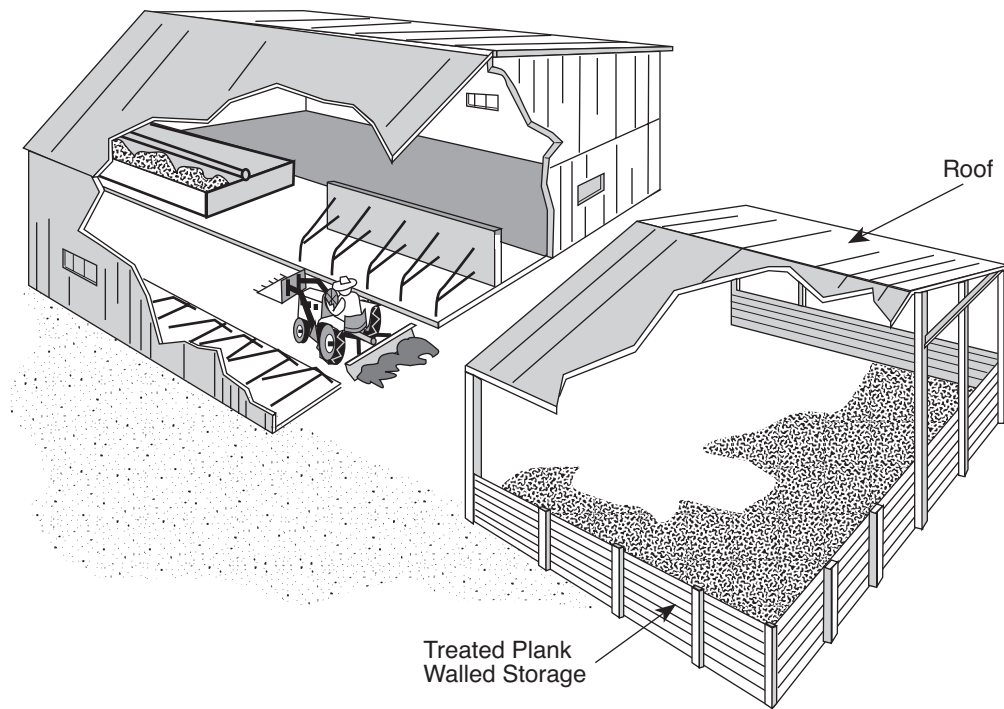


Figure 14. Roofed post-and-plank storage. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Solid Manure

Solid-manure storage is an option where adequate amounts of bedding are used to make the manure a stackable solid. Solid manure can be stored on an open or covered stacking slab with or without retaining walls. Retaining walls around the stacking

slab reduce the total area required for the storage (Figure 15). Provide at least one or two sturdy walls to buck against for unloading. Walls are usually post-and-plank, concrete, or masonry block.

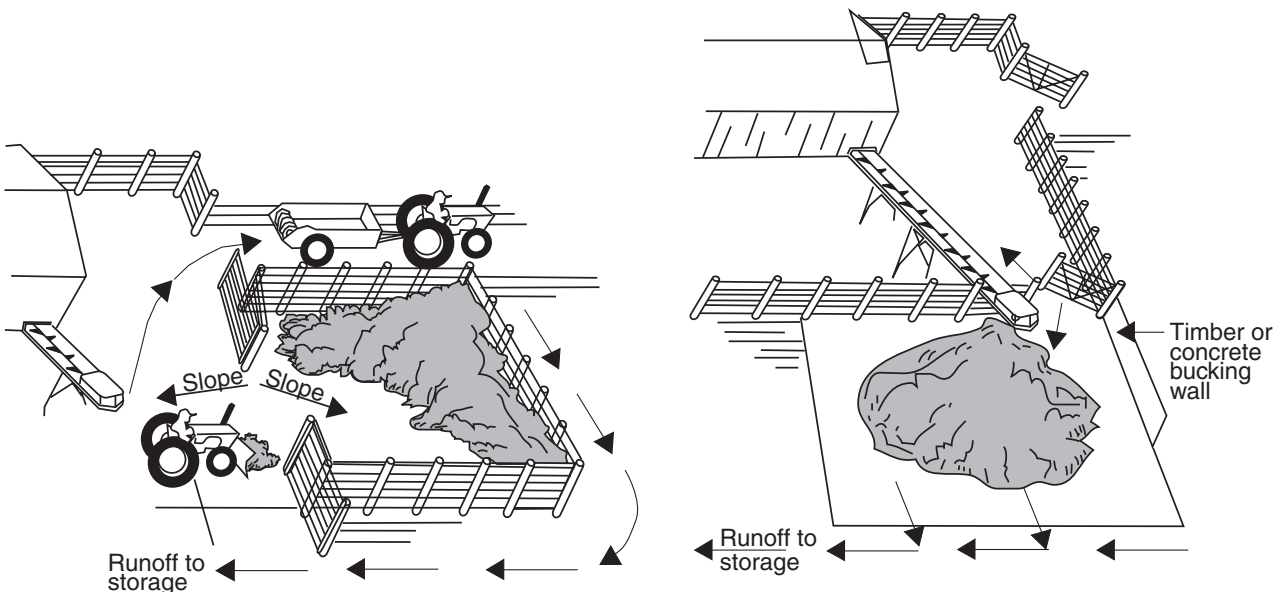


Figure 15. Solid manure stacking slab. (Source: Natural Resources Conservation Service (NRCS) Agricultural Waste Management Field Handbook. Used by permission.)

Prevent surface runoff water from entering the storage. Slope the entrance ramp upward to keep out surface water. Any rainwater that falls on the storage must be collected and contained or treated. If the slab is enclosed by walls, install picket dams to drain excess water. Collect and store drainage water in a storage tank, earth basin, or holding pond. Slope the slab about 1/8 inch per foot toward the picket dam or drain. Start stacking at the high end of the slope.

Provide for convenient filling with a tractor-mounted manure loader or scraper, elevator stacker, or piston pump. Unload with a tractor-mounted bucket. Locate the storage for year-round access so manure can be spread when field conditions and weather allow.

Solid and Semi-Solid Storage Sizing

Adequate storage provides convenience and flexibility to spread manure under appropriate weather and soil conditions. Provide a minimum storage capacity of three months. For better management and hauling flexibility, plan for six months or more of storage capacity. Determine the storage capacity based on animal manure production, amount of bedding used, any stored liquids (rain, snow, runoff), and availability of fields for manure application. Stored liquids should be only a small fraction of the storage capacity because successful solid and semi-solid storage facilities require excess liquids to be drained off. To estimate the required storage volume of manure and bedding, add the manure production volume to half of the bedding volume added in the barn. Bedding volume is usually halved because it compacts during use.

Drain excess liquids. If animals have access to an outdoor lot and manure from the lot is not added to the solid or semi-solid storage, assume half the daily manure production volume when estimating storage capacity. Additional capacity is needed for drainage water, lot runoff, and possibly lot scrapings.

Additional planning and design considerations for waste storage facilities are available in Ohio Natural Resources Conservation Service (NRCS) Conservation Practice Standard 313, Waste Storage Facility. NRCS conservation practice standards are

available at: http://www.oh.nrcs.usda.gov/technical/ohio_eFOTG.html.

Manure Handling Alternatives

Mechanical Separation of Manure Solids

Adapted from Natural Resources Conservation Service (NRCS) Animal Waste Management Field Handbook, Chapter 10, pages 62-64. Used by permission.

Animal manure contains material that can often be reclaimed. Much of the partly digested feed grain can be recovered from manure of poultry and livestock fed high grain rations. Solids in dairy manure from animals fed a high roughage diet can be removed and processed for use as good quality bedding. Some form of separation must be used to recover these solids. Typically, a mechanical separator is employed. Separators are also used to reduce solids content and required storage volumes.

Separators also facilitate handling of manure. For example, solid separation can allow the use of conventional irrigation equipment for land application of the liquids. Separation eliminates many of the problems associated with the introduction of solids into waste storage ponds and treatment lagoons. For example, it eliminates the accelerated filling of storage volumes with solids and also minimizes agitation requirements.

Several kinds of mechanical separators can be used to remove by-products from manure. One kind commonly used is a screen. Screens are statically inclined or in continuous motion to aid in separation. The most common type of continuous motion screen is a vibrating screen. The total solids (TS) concentration of manure to be processed by a screen should be reduced to less than 5%. Higher TS concentrations reduce the effectiveness of the separator.

A centrifuge separator uses centrifugal force to remove the solids, which are eliminated from the machine at a different point than the liquids. In addition, various types of presses can be used to force the liquid part of the waste from the solid part.

Several design factors should be considered when selecting a mechanical separator. One factor

is the amount of liquid waste that the machine can process in a given amount of time. This is referred to as the throughput of the unit. Some units have a relatively low throughput and must be operated for a long time. Another very important factor is the TS content required by the given machine. Centrifuges and presses can operate at a higher TS level than static screens.

Consideration should be given to handling the separated materials. Liquid can be collected in a reception pit and later pumped to storage or treatment. The separated solids will have a TS concentration of 15 to 40%. Typically, solids should be composted to kill pathogens and control disease before they are used for bedding. While a substantial amount of nutrients are removed with the solids, the majority of the nutrients and salt remain in the liquid fraction. In many cases, water drains freely from piles of separated solids. This liquid needs to be transferred to storage to reduce odors and fly breeding.

A planner/designer needs to know the performance characteristics of the separator being considered for the type of waste to be separated. The best data, if available, would be that provided by the separator manufacturer. If that data is not available, the manufacturer or supplier may agree to demonstrate the separator with waste material to be separated. This can also provide insight as to the effectiveness of the equipment.

Dairy

The housing system influences the amount of bedding or dilution water used, which influences manure characteristics. Manure characteristics influence selection of collection, transfer, storage, and spreading equipment. The components of solid and liquid manure systems for dairy are shown in Table 9 and Appendix D. Also consider rainwater runoff from barn lots. Procedures for handling runoff are discussed in Chapter 5, *Farmstead Runoff Control*. Alternative handling systems for dairy manure are shown in Appendix D.

Solid handling is used by many dairy operations with comfort-stall barns as well as free-stall barns with added bedding. Storage length varies from a few days with a daily haul system to three months or more. An alternative liquid-handling system is

required for milking-center waste. See Chapter 6, *Land Application of Manure*.

Solids storage can be a stacking slab or covered storage. Provide at least one or two walls to control leachate, ease load-out, and reduce required floor area. A roofed storage keeps out precipitation so manure can be handled as a solid or semi-solid. A picket dam structure for storing solid or semi-solid manure can be used to remove rainwater that falls on an uncovered storage, but does not reduce the manure's water content. Do not expect to put a slurry in and get a solid out. The vertical slots in the plank fence allow rainwater runoff to drain away. Transfer manure and load the storage with a tractor-mounted front-end loader, elevator stacker, and solid piston pump. Unload the storage with a front-end loader. Manure can be spread as a solid or semi-solid in a box or flail spreader.

Sand-laden manure scraped directly from the free-stall barn can be stored in a covered storage facility and loaded into a "V" box spreader with a tractor-mounted front-end loader. The storage facility must include an access ramp sloped not steeper than 10:1.

Liquid handling is used in many dairy facilities with free-stall housing. Free-stall manure is commonly collected and removed from the barn with a tractor-mounted scraper, mechanical alley scraper, flushing system, or slotted floor. Depending on site conditions, manure can be stored in earth basins, below-ground tanks, or above-ground tanks. Common methods for transferring liquid dairy manure to storage include gravity, large piston pump, pneumatic pump, and centrifugal chopper pump.

Free-stall manure with sawdust or chopped straw bedding can be transferred to storage by gravity. In general, four to six feet of elevation drop between the floor of the barn and full storage level is adequate for manure to flow over 100 feet. Terrain that slopes about 10% away from the barn for 250 to 300 feet can provide enough head pressure for both filling and emptying a liquid storage by gravity. A gravity pipe used to empty a storage pond must be equipped with two valves to prevent an accidental release. One valve should be located near the pipe inlet below the frost line, and the other located near the pipe outlet. Each valve needs to have an independent power source and be dual acting (able to apply pressure to flow in either direction).

A piston-type pump provides convenient transport of manure to a storage structure. A key factor in the design and operation of any liquid-storage structure is provision for agitating the waste prior to irrigating or loading the tank spreader. Without complete agitation, solids will accumulate in the structure, reducing storage capacity, and the nutrient concentrations of the manure will be non-uniform. Allow for solids accumulation that cannot be completely removed when determining the required storage capacity.

When placed in a storage structure, undiluted manure from cattle usually will develop a crust of floating solids. This crust helps control odors and should not be disturbed until the manure is agitated just prior to field spreading.

The principal advantage of the flush system for collecting manure is that it can be automated. To minimize the amount of water to be field spread, some means of recycling clarified wastewater for flushing may be desirable. Separation of solids from flush water can be used to reduce the solids in the recycled flush water. Separated solids can be hauled and land applied or reused as bedding if dried or composted to remove excess moisture and reduce volume.

Skim-and-Haul Systems for Sand-Laden Dairy Manure

In skim and haul systems, most if not all of a farm's manure and wastewater streams are put directly into an outdoor storage facility. The premise behind these systems is that given some dilution and time, gradations of material will develop in the storage facility that allow a portion of the contents to be readily removed as a liquid. The remaining material is removed using equipment designed to handle solid manure. Some producers opt for this type of system because, compared to the alternative systems, a skim-and-haul system usually:

- Provides the most storage capacity for a given level of initial investment.
- Appears to be the least complicated (just put all of the materials into the storage).

However, management of these systems at clean-out time is usually more demanding than for alternative systems. Successful operation and management of a skim-and-haul system requires

consideration of the entire manure-management system, including application.

Sand bedding can be separated from the manure prior to storage by mechanical separation or gravity settling of flush system manure. Gravity settling requires the manure to be diluted to less than 5% solids content, and mechanical separation requires a constant water flow of 1 to 5 gpm during operation. The decision to choose sand separation must consider the economic feasibility and additional water requirements.

Source: Michigan State University Extension Bulletin E-2561, *Storing and Handling Sand-Laden Dairy Manure*, by R. R. Stowell and W. G. Bickert, 1995. A much more complete discussion of skim-and-haul systems and sand separation can be found in this excellent Michigan State University Extension bulletin.

Beef

Handling alternatives for beef cattle manure can be divided into solid and liquid options. Alternative handling systems for beef manure are shown in Appendix D. In Ohio, the typical cow/calf beef operation provides housing and bedding during winter and early-spring months. Solid-manure handling systems are commonly used with cow/calf operations and confined feeder operations.

The common housing system for feeder beef cattle is an open-front shelter with an earthen or paved lot. Many feedlots are unpaved and require more total lot area for effective management. Paved lots are recommended to reduce the required lot area and ease manure collection and runoff control.

Open-lot systems require two manure-handling methods. Lot scrapings are either solid or semi-solid, and lot runoff is liquid. Move solid manure from the lot to storage with a tractor scraper and front-end loader. Lot runoff contains manure, soil, chemicals, and debris, and must be collected as part of the manure handling system. Divert clean runoff away from manure and animal areas to reduce the total volume of liquid to be handled. See *Farmstead Runoff Control* in Chapter 5.

Beef cattle can be fed in solid or slotted-floor confinement buildings. Liquid manure-handling

systems are common with confinement housing. Manure storage can be a concrete tank under the building or an outdoor earthen or concrete storage. Remove manure from the building with a tractor or mechanical scraper, or by gravity flow.

Swine

Swine manure can be handled as a solid, semi-solid, or liquid. Alternative handling systems for swine manure are shown in Appendix D. Additional bedding or drying is required to handle manure as a solid. Solid manure handling is common for shed and lot systems used for swine gestation and finishing. Where shed and open-lot systems are used, solid storage for lot scrapings and shed manure are required, along with facilities for controlling runoff (Figure 16).

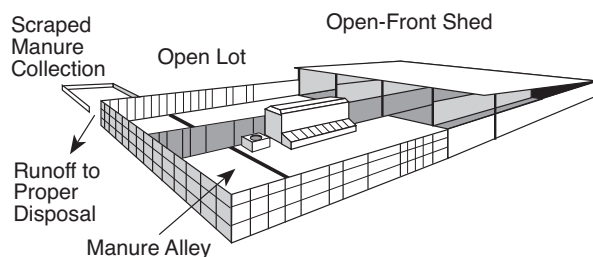


Figure 16. Open-lot manure handling system. (Source: *Ohio State University Extension Bulletin 604, 1992 Edition.*)

Liquid Manure Storage

Slurry and liquid manure handling are more common in larger swine-production facilities. Liquid handling requires less time and labor to collect, transfer, and store manure. Manure can be stored below the partial or full-slotted floor in deep pits, in an outdoor below-ground or above-ground storage facility, or treated in an anaerobic lagoon.

Deep Pit Storage

A primary objective in swine manure handling is to minimize the accumulation of noxious gases and odors. Pit ventilation can be used to reduce odors and gases within the building. The stored manure must be agitated before removal to facilitate removal of settled solids. Failure to sufficiently agitate will result in decreased storage capacity because of accumulated settled solids. The effects of agitation are limited to a radius of about 40 feet; therefore, access ports should be located so that all manure is

within 40 feet of a port. (From MWPS-18 Section 2, page 3 and figure 1-1.)

Outdoor Storage or Treatment

Removing manure from the building to outdoor storage can also reduce odor and gas accumulations within the building. However, uncovered swine manure storage facilities are odorous and should not be considered in sensitive locations. Where odor control is important, an anaerobic waste-treatment lagoon is often recommended.

Manure can be removed from the building with manual or mechanical scrapers, gravity-flow gutters, and flushing gutters. Mechanical scrapers are often used in shallow gutters below slotted floors.

In a flush system, a large volume of water flows from one end of a building to the other down a sloped, shallow gutter. The water scours manure from the gutter and removes it to a lagoon. There are two types:

- Open gutter, used primarily in finishing buildings.
- Under-slat gutter, used in farrowing, nursery, gestation, and facilities where residue or disease transmission is a concern.

A modification of the flush system is pit recharge. This system uses a single or two-stage lagoon for storage. A water depth of one to two feet is maintained in an under-floor storage or gutter after emptying. Use a flat-bottom gutter or slope less than 1%. The gutter is drained every three to four days and refilled with water from the top of the lagoon. Size the refill line to fill the gutter in four hours or less. A recharge sump pit can be placed on the outside of the lagoon.

Solid Manure System

Hoop Structures (Adapted from *MidWest Plan Service, Hoop Structures for Grow-Finish Swine, AED 41.*) Used by permission.

Hoop structures are a low-cost alternative pig housing system that is gaining attention in the upper Midwest. Hoop structures use treated wood posts and tongue-in-groove siding for 4- to 6-foot side walls. Steel tubes or trusses are fastened to the top of the side walls to form an arch. The arch is covered with a UV-resistant polypropylene tarp.

For a finishing operation, an earthen floor that is heavily bedded covers about 75% of the building area. The remaining 25% of the floor area is designated as the feeding and watering area and is covered with concrete.

Finishing pigs are placed in the structure at a stocking density of approximately 12 square feet per pig. Common bedding materials are shredded corn stalks, long straw, sawdust, and wood chips. Typical bedding usage (for wheat straw) is approximately 225 lb per pig for the finishing period. Summer bedding usage ranges from 140 to 170 lb per pig, and winter usage averages from 225 to 285 lb per pig. The building is cleaned and disinfected between finishing cycles.

Hoop structures can also be used for gestation barns. Further information for this application is found in MidWest Plan Service, *Hoop Structures for Gestating Swine*, AED 44.

Poultry

Poultry manure has a higher total solids content than most other manures. Dilution with water increases the potential for odor, so handling the manure as a solid is usually preferred. Handling alternatives for hen, broiler, and turkey manures are shown in Appendix D.

Most cage layers are housed in high-rise poultry facilities. A deep pit is used in the cage layer house to minimize odor and insect problems, eliminate water pollution potential, and maximize the potential value of the manure. The manure “cones” under the cages in a well-managed high-rise layer house and is typically stored from nine to 18 months. These management objectives can be achieved by keeping the manure as dry as possible. Note the following guidelines:

- Collect manure in water-tight areas that cannot be infiltrated by ground or surface water.
- Avoid flushing manure or adding water to manure in all but liquid manure-handling systems.
- Maintain drinking or cleaning systems to reduce water leakage. Nipple-type waterers are more efficient than cup-type waterers.
- Provide adequate ventilation system capacity to maximize water loss by evaporation from manure when environmental conditions

permit. Mechanical ventilation efficiency is significantly increased by regular cleaning of fans, and sealing the manure storage area in a high-rise building prevents ventilation short-circuiting.

- Provide adequate roof and wall insulation to conserve energy, maintain higher air temperatures during winter months, and increase ventilation air moisture-carrying capacity.
- Restrict salt and other mineral levels in drinking water and poultry rations to those required for maximum growth and/or egg-production.
- Practice effective disease-prevention methods to avoid gastrointestinal infections that lead to diarrhea and excessive water consumption.
- Hister beetles that destroy fly larva and darkling beetles that tunnel through the manure piles are used by some producers to control flies and keep the manure piles dry. However, uncontrolled beetle populations can cause structural damage to wood posts and beams and can cause disease transmission if they contact the flock.
- Remove manure from the poultry house when it can be utilized and whenever necessary to prevent odor and insect problems. Newer European battery cages with manure belts allow for daily clean-out of manure to a well-managed, appropriate storage or processing facility.

These guidelines should help keep manure moisture levels low enough to avoid significant odor and insect problems when used with other insect control methods. Dry poultry manure (25% moisture) is also more easily handled for transportation and field application.

The primary difference between cage layer manure and broiler and turkey manure is that the broiler and turkey manure is diluted with litter material. This usually results in a manure-containing mixture that is easier to handle, because it is drier and has fewer problems with odor and insects than manure without litter. Good ventilation in the poultry house and tilling of the litter between flocks will help control moisture levels. Avoid water spillage on the litter or runoff drainage into the building.

When using broiler and turkey manure as a fertilizer, consider the dilution of the manure with

the litter material. Analysis of the used litter for nitrogen, phosphorus, and potassium is essential to determine the amount of this manure to apply in a particular crop situation. In most cases, dilution of the manure with litter means that a higher application rate can be used than for cage layer manure.

Composting or ensiling of used poultry litter for feeding to ruminants may be an option where drugs used in broiler- and turkey-growing diets do not interfere with rumen function or result in tissue residues in the ruminant animal. Proper composting of used poultry litter can also yield a stable product for use as a fertilizer, soil amendment, and mulch in gardens, greenhouses, and production of specialty crops.

For more information, refer to Ohio State University Extension Bulletin 804, *Poultry Manure Management and Utilization*, available from your local county Extension office.

Horses

Horse manure is best handled as a solid. Plan horse housing and manure management carefully to avoid difficulties with neighbors and health officials. Review local zoning and health regulations if housing horses in a suburban area. Flies and odors are the most common complaints. See Chapter 9, *Insect and Pest Control*, and Chapter 8, *Odor and Dust Emission Control*.

Successful management requires daily clean-out and removal of wet or soiled bedding to a container or storage facility or for field spreading. Fresh bedding is added after removing manure and soiled bedding to ensure clean, dry conditions. Regular cleanup reduces odors and insect breeding. Because of individual horse stalls, manual cleaning with a fork or shovel and wheelbarrow, tractor loader, or trailer is common. Simply adding fresh bedding and allowing manure and soiled bedding to accumulate in the stall results in dirty animals, an excellent fly-breeding environment, and generally unhealthy conditions for horses.

Protect the manure storage from rainfall and surface runoff. The type and size of manure storage depend on the amount of manure to be stored. A horse produces about 0.75 cubic feet of manure per day per 1,000 pounds of body weight, plus bedding.

Storage facilities can be covered boxes, concrete or pressure-preservative-treated lumber sheds, covered piles, or covered trash receptacles. The required storage volume needs to be sufficient to store the manure between planned removal intervals.

Open manure piles are not recommended. However, if used, they need a minimum separation distance of 300 feet to neighboring residents, and the manure should not accumulate more than 30 days. These piles should be on a paved pad, with all-weather access, where runoff from the pad is filtered through a vegetative buffer. The pad needs to be located where it is protected from flooding and upstream runoff.

Note the following recommendations when planning a manure storage-and-handling system for horses:

- Remove manure daily if possible.
- Provide temporary manure storage with all-weather access if daily spreading is not possible. Each 1,000-lb horse produces approximately 2.5 cubic feet of manure with sawdust bedding daily. The volume requirement for temporary storage needs to be adequate to contain the manure between cleanout events. Storage facilities can range in size from trash dumpsters to roofed fabricated concrete or timber structures.
- Locate the storage in an area for convenient loading and unloading. Make certain that storage and access areas are of adequate size for any power equipment used.
- Locate the storage facility away from water sources and natural drainage ways, and divert any surface water away from the storage structure.

Land application of manure is the most practical method of utilization; however, since both sawdust and wood-shaving bedding are very high in carbon, the soil can become depleted of nitrogen which stunts crops. Ammonium nitrate (34-0-0) or ammonium sulfate (21-0-0) added to the manure at a rate of 1/2 cup per 1,000-lb horse per day can be used to balance the carbon/nitrogen ratio of the land-applied manure. See Ohio State University Extension Fact Sheet AGF-212-03, *Horse Manure Management — The Nitrogen Enhancement System* at <http://ohioline.osu.edu/agf-fact/0212.html>.

Disposal or utilization of horse manure can be a challenge for horse owners with no available cropland. Producers with limited land resources are encouraged to seek off-site partners for manure utilization.

Horse manure-bedding mixture can be used as an amendment for composting raw dairy or swine manure. Composted manure can be used in specialty markets such as greenhouses, gardens, and nurseries. See Chapter 4, *Treatment and Utilization Options for Livestock Manure*, for more information on composting.

Horses on pasture generally spread their manure over the pasture, where it is recycled naturally. The pasture must be managed to maintain vegetation and control soil erosion and surface water runoff. Access to streams should be limited. The animal density should not be greater than one-half acre per horse. Exercise lots and corrals need to be surfaced to prevent erosion and contaminated runoff.

Proper manure management is as important for the horse owner with only a few horses as for large horse farms and boarding stables. Seek competent help when planning a workable, environmentally safe manure-handling system.

Horse facilities are generally exempt from township zoning regulations, but they may not be exempt from municipal zoning or subdivision regulations when the facility is on less than five acres. Horse owners should always check with all applicable local regulations before locating a facility in a non-agricultural land-use area.

Sheep

Sheep are most commonly housed in bedded pens with a manure pack. They can also be raised on slotted floors or expanded-metal floors that allow manure to pass through to a pit. Sheep manure is about 75% water and is usually handled as a solid. It is difficult to dilute or mix the manure with water because solids from mature sheep float to the surface. Liquid handling is practical only for early-weaned lambs on a liquid diet. Typical sheep manure management systems are shown in Appendix D.

Sheep manure can collect on the barn floor, on the lot, or in a pit. Sheep housing should be constructed for easy clean-out with a tractor scraper and loader. Manure collected in a pit can be removed with a cable scraper or front-end loader. Sheep manure is often stored in the building or below-floor pits until field spread.

If separate manure storage is needed, plan for about one-half cubic foot per day per 1,000 pounds live weight for raw manure. Add half the volume of bedding for bedded-pack housing. Cover the storage to keep out excess water. A conventional box spreader is used for land application of sheep manure. Feedlot runoff from open-lot production can be controlled with settling basins, holding ponds, and infiltration areas. For more information, see Chapter 5, *Farmstead Runoff Control*.

Flooding of Facilities

Livestock waste-management facilities should not be located in a floodplain unless adequately protected from inundation or damage. They should never be located in a regulatory floodway designated on a Flood Insurance Rate Map provided by the Federal Emergency Management Agency (FEMA).

Information on floodplains, flood frequencies, flood inundation maps, and floodplain management is available from the County Floodplain Management Coordinator, the Ohio Department of Natural Resources Division of Water, the local SWCD/NRCS office, and Flood Insurance Rate Maps (FIRM) provided by FEMA.

Animal manure should not be surface applied to land subject to flooding, except at those times of the year when flood risk is nearly zero. Follow the guidelines discussed in Chapter 6, *Land Application of Manure*. See also Chapter 7, *Safety and Manure Handling*.

Chapter 4—Treatment and Utilization Options for Livestock Manure

Direct land application of livestock manure is often the preferred method of utilization, but it is not always feasible. If the land to be used for application is distant or the location is sensitive to odor, some type of manure treatment may be desirable. Unfortunately, treatment will not necessarily reduce the land area needed for application and may result in increased loss of ammonia nitrogen from manure.

Livestock manure is treated for several reasons:

- To reduce its volume and weight.
- To reduce its odor.
- To kill pathogens and weed seeds.

Treatment processes fall into three categories—physical, chemical, and biological. Physical treatment systems involve such simple processes as settling, filtering, and drying to change the characteristics of the manure. Chemical treatments add something to help condition it. Biological treatments take advantage of naturally occurring microorganisms in the manure to change its properties.

Physical Treatment

It is sometimes desirable to separate the solid and liquid portions of livestock manure. This can be accomplished through physical treatment for the following purposes:

- To reuse manure solids for bedding.
- To improve the treatment efficiency of vegetative infiltration areas and leach fields.
- To use the liquids for flushing.
- To reduce the volume of waste to be hauled.

Settling takes advantage of gravity to separate the solids from the liquids. Livestock manure is placed in a stilling basin to allow solids to settle to the bottom. A detention time as short as 30 minutes can be used to settle out solids from dilute wastewater such as open-lot runoff. Septic tanks installed ahead of leach fields and settling basins used with vegetative infiltration areas are examples of settling systems. Refer to Chapter 5, *Farmstead Runoff Control*, for more information on settling basins. Solids must be removed regularly to maintain treatment efficiency of settling systems and to recoup the storage capacity.

Centrifuge separators function similarly to a centrifuge to dewater manure and rely on the differences of density between solid and liquid material. Since solid material is denser, it will settle out in an applied sedimentation field. Centrifuge separators are in general more efficient in dewatering manure than other mechanical separators.

Filtering and screening systems use a medium to hold solids as the liquid moves through. Gravity, vacuum, or pressure can be used to move the liquids through the media. Liquid-solid separators that use stationary and vibrating screens remove solids from flushing water. Sand drying beds are a simple application of filtering where gravity carries the liquid down through the sand and the solids form a cake on top. Vacuum filters often use cloth or a wire screen to hold the solids as the liquid is drawn through. Presses also use cloth or wire screens to hold the solids as the liquid is pushed through.

Drying is used primarily for volume reduction by encouraging the water to evaporate, concentrating the solids. In Ohio, drying systems must be covered to protect them from rainfall, and supplemental heat or forced air is needed to encourage rapid evaporation.

Chemical Treatment

Coagulating agents such as ferric chloride, lime, alum, and organic polymers can greatly improve the dewatering characteristics of livestock manure. These chemicals bring the solids in manure together so they settle more rapidly. Bringing the smaller particles together also improves solids removal by filtration. Care must be taken when handling coagulants. Some are corrosive and others are very slippery if accidentally spilled.

Raising the pH of livestock manure to pH 12 for 30 minutes kills many of the microorganisms that live in manure. The result is to eliminate odor production and limit the spread of disease. Quick lime (CaO) or hydrated lime (CaOH) is usually used to raise the pH level of livestock waste. One limitation to this treatment is the immediate loss of ammonia from the manure. Both quick lime and hydrated lime are highly reactive and need to be handled

with extreme care. Consult manufacturer guidelines for proper safety procedures.

Various manure-storage pit additives are marketed to reduce manure odor. The additives are made of chemicals, microbes, bacteria, enzymes, or plant derivatives used individually or in combination. The effectiveness of additives varies, depending upon the manure characteristics and storage configuration. The National Pork Producers Council Odor Solutions Initiative Committee published the booklet *Odor Solutions Initiative Testing Results, Manure Pit Additives* in 2001. The booklet summarizes the testing of 35 pit additive products. Most additives tested did little to control ammonia or odor emissions.

Biological Treatment

Anaerobic Lagoons

Anaerobic lagoons stabilize livestock manure by taking advantage of natural processes. In the absence of oxygen, high-strength organic wastes, such as livestock manure, is digested by anaerobic bacteria. Anaerobic lagoons are commonly used in Ohio for treatment of swine manure from pull plug gutter systems and treatment of washwater from egg packaging facilities.

Anaerobic lagoons for livestock manure have several advantages:

- Odors are reduced in treated manure for application.
- Flush system precharge water can be supplied from the lagoon supernatant.

Anaerobic lagoons for livestock manure also have several limitations:

- Improperly designed and operated lagoons create odors.
- Ammonia nitrogen is lost to the atmosphere.
- Large size in comparison to a facility constructed for manure storage only.
- Significant fresh water precharge is necessary for proper startup.
- Accumulated sludge must be periodically removed for the lagoon to function properly.

In an anaerobic lagoon, bacteria break down the manure in a two-step process (Figure 17). One group of bacteria converts the manure to organic acids. The second group converts the organic acids to methane gas and carbon dioxide.

The management requirements of an anaerobic lagoon are primarily concerned with creating the right environment for the methane-forming bacteria. These bacteria are upset by sudden changes in temperature, a drop in pH, “slug loads” of organic waste, or toxic substances.

Anaerobic lagoons are usually constructed as deep as allowable by soil conditions or pumping equipment limitations. A cross section of an anaerobic lagoon is shown in Figure 18. Anaerobic lagoons can be constructed as single- or two-stage lagoons. Single-stage lagoons are more typical in Ohio; however, two-staged lagoons are used where high-quality water is desired for pit recharge.

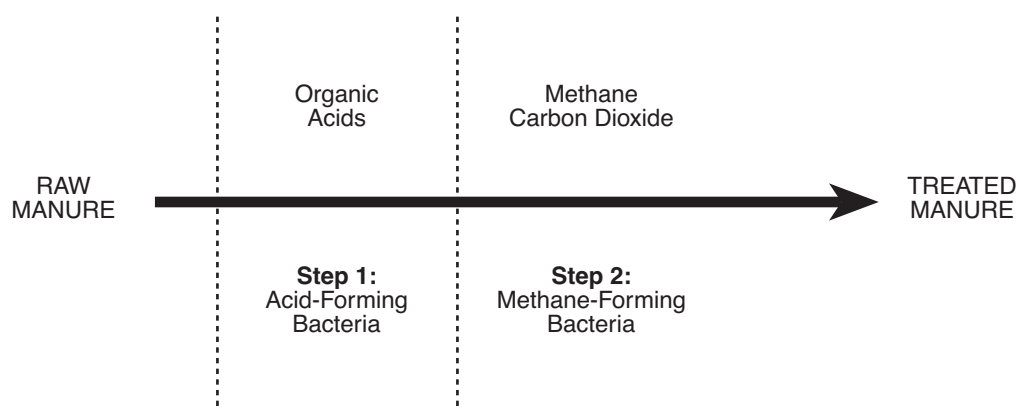


Figure 17. Anaerobic digestion process. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Anaerobic lagoons work best in warm weather. Even in warm weather, several months are required to fully stabilize manure in an anaerobic lagoon. As the temperature drops, more time is needed. In areas like Ohio, where winter water temperatures can drop near or below freezing, lagoons can experience “turnover” in the spring and fall. Turnover occurs as the lagoon is heating up in the spring or cooling down in the fall. During turnover, water from the bottom (which is high in odor) comes to the top and water from the top moves to the bottom. Agitating the lagoon can help shorten the turnover period.

A well-functioning lagoon will have a neutral pH (7.0 to 8.0). If the first group of bacteria, the organic-acid formers, grows and multiplies faster than the methane formers, the pH of the lagoon can drop. If the lagoon is left untreated, it will go “sour,” methane production then ceases, and strong odors are released. If the lagoon pH drops below 6.7, it is important to add hydrated lime or caustic soda—use extreme caution as these are highly reactive chemicals; consult the manufacturer’s guidelines for safety procedures—daily at a rate of 1 pound per 1,000 cubic feet of lagoon volume until the pH is raised above 7.

A well-functioning anaerobic lagoon requires continuous loading of manure and wastewaters. When starting up a lagoon, fill it one-third to one-half full with clean water to dilute the manure and reduce shock on the system. Failure to do so will result in high odor production. Constant amounts of manure should be added each day. Slug loads of manure can cause an increase in organic-acid production, a drop in pH, and strong odors. Slug loading is especially discouraged in the winter,

when biological activity is lowest. Store the excess manure until it can be slowly added to the lagoon.

Certain compounds are toxic to the organisms in an anaerobic lagoon. Keep chemicals such as arsenic, copper, and antibiotics out of the lagoon.

An alternative design to a single- or two-stage lagoon is the anaerobic lagoon/settling basin. The anaerobic lagoon/settling basin is designed to hold the majority of total and volatile solids in the settling basin which significantly reduces the lagoon loading and resulting size. The system will typically be desired by a producer who wants to utilize the nutrient value of the manure and have recycled water available for flushing. This system should not be considered when odors are an issue because the settling basin behaves like a holding pond.

Additional information on the planning and design of anaerobic lagoons can be found in Ohio Natural Resources Conservation Service (NRCS) Conservation Practice Standard 359, Anaerobic Waste Treatment Lagoon, at: http://www.oh.nrcs.usda.gov/technical/ohio_eFOTG.html and Chapter 10 of the NRCS AWMFH available at: <http://www.wcc.nrcs.usda.gov/awm/awmfh.html>.

Aerobic Lagoons

Aerobic lagoons stabilize livestock manure through the addition of oxygen. By adding large amounts of oxygen to the manure, naturally occurring bacteria will begin to break down the manure and reduce its odor in one to six months. Aerobic digestion is a one-step process. Bacteria use oxygen to convert manure to carbon dioxide and water. Aerobic lagoons can be either naturally or mechanically aerated.

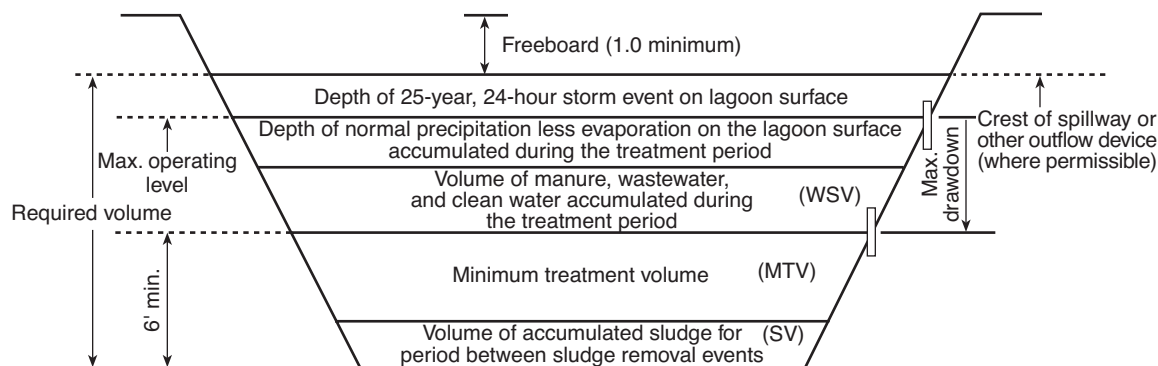


Figure 18. Anaerobic lagoon cross section. (From Natural Resources Conservation Service (NRCS), *Animal Waste Management Field Handbook*, Figure 10-21.) Used by permission.

Naturally aerated lagoons operate within a depth range of two to five feet to allow oxygen entrainment necessary for the aerobic bacteria to digest the manure. They are designed for an allowable loading, ranging from 27 to 37 pounds (depending upon location in Ohio) of BOD₅ (biological oxygen demand) per acre per day. These lagoons will have a large surface area in comparison to an anaerobic lagoon or mechanically aerated aerobic lagoon. A cross section of a naturally aerated lagoon is shown in Figure 19.

Mechanically aerated lagoons use mechanical aeration to supply the oxygen needed to treat manure and minimize odors. Two kinds of mechanical aerators are used—the surface pump and the diffused-air system. The **surface pump** floats on the surface of the lagoon, lifting water into the air, thus assuring an air-water mixture. The **diffused-air system** pumps air through water, but is generally less economical to operate than the surface pump.

Aerators are designed primarily on their ability to transfer oxygen (O₂) to the lagoon liquid. Of secondary importance is the ability of the aerator to mix or disperse the O₂ throughout the lagoon. Poor mixing or shutting off the aerator will result in strong odors.

Aerobic bacteria need oxygen, so the lagoon must be managed carefully to make sure that adequate oxygen is always present. Dilution water is needed from the start-up of the lagoon, and a steady daily supply of manure is required. Slug loads will quickly use up the oxygen and result in a strong odor.

Aerobic lagoons used for livestock manure have several advantages:

- Limited or no odor from lagoon or treated manure.
- Mechanically aerated lagoons are smaller than anaerobic lagoons.

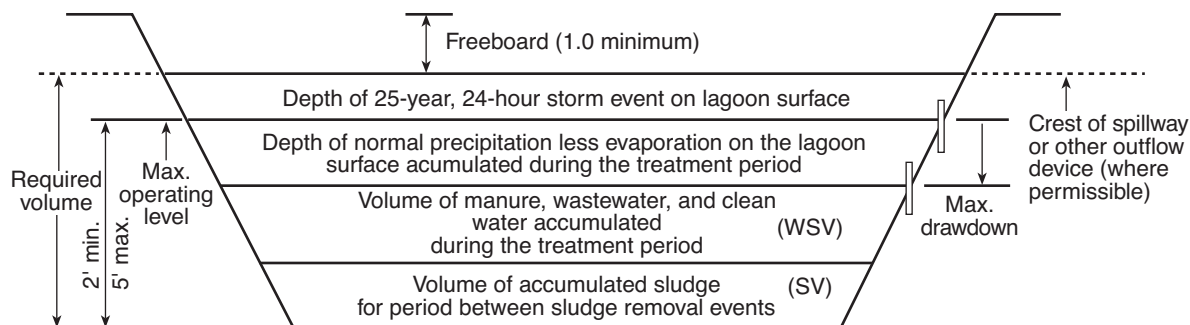
Aerobic lagoons also have limitations:

- Large land area needed for naturally aerated lagoon.
- High energy requirement for mechanically aerated lagoon.
- Aerator requires regular maintenance.

Anaerobic Digesters

Anaerobic digesters are used to more fully control the anaerobic processes taking place in an anaerobic lagoon. Digesters are covered, heated, and stirred to shorten the time needed to stabilize the manure, to control odors, and to capture the methane produced. Due to the shortened treatment time, the treatment volume required for anaerobic digesters is almost 100 times smaller than the treatment volume required for anaerobic lagoons; however, the total system volume must also include storage of treated manure between periods of land application (Figure 20).

Anaerobic digesters work under the same two-step biological process as anaerobic lagoons. One group of bacteria converts manure to organic acids, and another group converts the organic acids to methane and carbon dioxide. The same factors that upset an anaerobic lagoon will upset a digester, such as sudden temperature changes, a drop in pH, slug loading of manure, and toxic substances.



Note: An aerobic waste treatment lagoon has a required minimum surface area based on BOD₅

Figure 19. Cross section of naturally aerated lagoon. (From Natural Resources Conservation Service (NRCS), Animal Waste Management Field Handbook, Figure 10-24.) Used by permission.

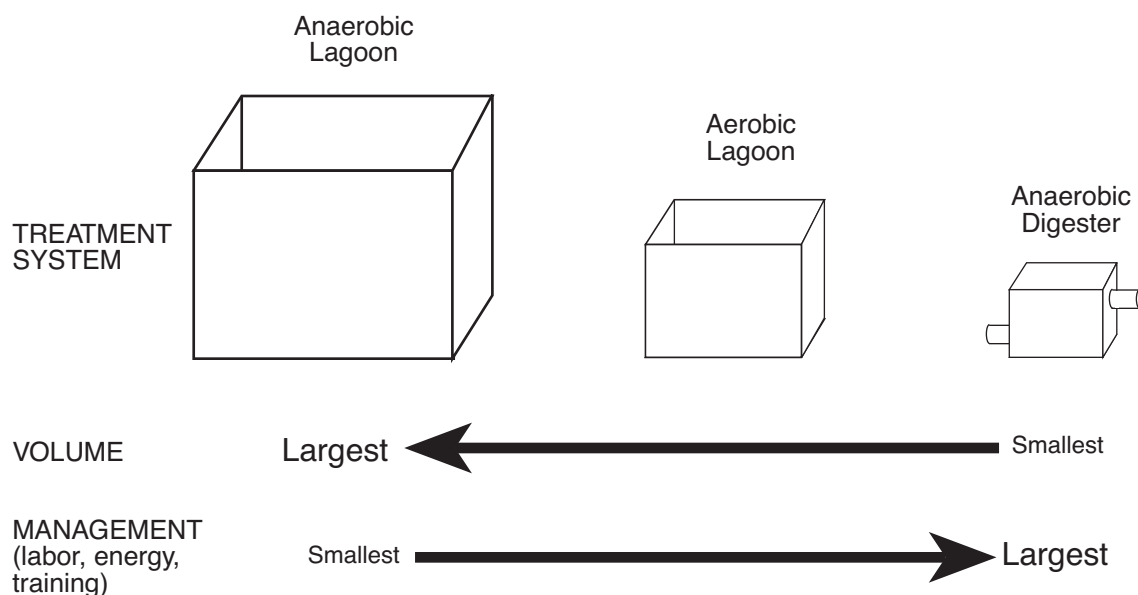


Figure 20. Total treatment volume and level of management for three treatment systems. The same volume of raw manure is treated in each system. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Anaerobic digesters are operated at relatively high temperatures to stabilize manure as quickly as possible. They are heated to maintain a temperature of 70°F to 140°F, with 100°F being optimum. Maintaining the right temperature is the single most important management factor in operating an anaerobic digester.

Mixing within the digester helps keep the bacteria in contact with the manure and keeps solids from settling out in the digester. Several mixing systems can be used, such as mechanical mixers, pumps, or bubbling with digester gas. To eliminate the need for mixing, plug-flow digesters have been developed to slowly move the manure through a tube-shaped vessel. In plug-flow digesters, the manure added today will leave the other end of the digester in about a month (Figure 21).

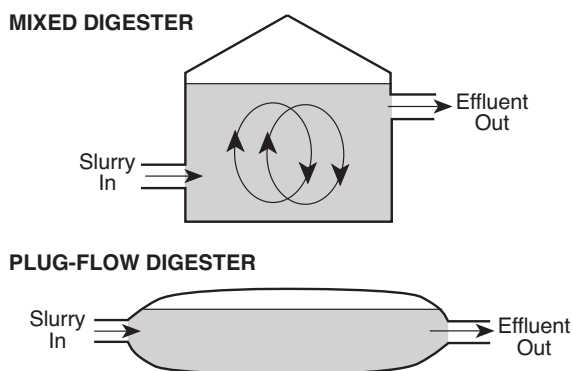


Figure 21. Basic digester types. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Mixed digesters are usually used with liquid manure, and plug-flow digesters are best loaded with semi-solid manure (about 13% solids). Large amounts of bedding and soil should not be added to a digester. A carefully controlled mixed digester can stabilize manure in 20 to 30 days. As with an anaerobic lagoon, the digester should be loaded with steady amounts of manure daily. Slug loads will upset the digester. The first sign of upset is a drop in pH. If the pH drops below 6.7, first check the temperature and then check and possibly reduce the feed rate. Adjust the pH if needed.

The biogas produced by anaerobic digesters is about 50 to 60% methane (natural gas), 40 to 50% carbon dioxide, and less than 1% other gases such as hydrogen sulfide. The digester gas is often burned to heat the digester. Although digester gas can be burned to generate heat and electricity, the trace gases and water vapor in digester gas are corrosive to equipment and must either be removed before burning or equipment must be more extensively maintained.

For every 100 pounds of raw manure added to a digester, four pounds are converted to biogas. The remaining 96 pounds still contain all the potassium and phosphorus present in the manure. Some of the organic nitrogen in the manure is converted to ammonia during digestion, increasing the possibility of nitrogen loss during land application.

Daily attention is required to measure the anaerobic digester's temperature and pH and check the manure-loading and gas-collection systems. Daily management takes about 15 to 30 minutes. The digester should be emptied every one to two years to remove solids from the floor, clean heating pipes, and make necessary repairs. Major repairs and preventive maintenance will also be needed.

Safety considerations are important with anaerobic digesters. The methane produced is flammable, and the greatest threat for explosion is in a confined space. Because methane is lighter than air, a continuous ridge vent in the building housing the digester equipment is necessary. The hydrogen sulfide in biogas is also hazardous. Hydrogen sulfide levels become life-threatening in 30 minutes at 300 ppm. Because hydrogen sulfide is heavier than air, sensors in buildings housing digester equipment should be placed near the floor.

Anaerobic digesters used for livestock manure have several advantages:

- Small size.
- Limited or no odor from digester or treated manure.
- Digester gas can be used as an energy source.

Anaerobic digesters also have limitations:

- Require daily attention.
- Digester gas is explosive and must be handled with care.

Manure Composting

Composting is a natural biological process requiring air, moisture, and the right proportion of carbon to nitrogen to stabilize organic material. It is predominantly an aerobic process and is used to stabilize all types of organic wastes. The process consumes oxygen and releases heat, water, and carbon dioxide (CO₂). The microorganisms use the most readily biodegradable substances as their food source. The compost that remains resembles humus and can be used as a soil conditioner, organic fertilizer, or as a food base for organisms that suppress plant diseases. Composting reduces the volume and mass of the parent materials by 40 to 80% and destroys pathogens if the process is controlled properly.

In conventional composting, ingredients are brought together, mixed, then put into a pile to compost. Rynk (1992) describes materials used as being primary (material of interest to be composted), amendment (material added to adjust C/N or water content), and bulking agent (material added to "open" up the compost mix, giving it porosity so air can move through the pile to provide oxygen and cooling). Generally, the mix is turned every three or four days, but sometimes every day or only weekly or monthly.

In some systems air is forced through the compost to control temperature and keep the pile supplied with oxygen. When little or no heat output is observed, the material is removed, remixed, and put into a curing pile for several months. The rate of composting can be controlled by adjusting the air, moisture, and carbon and nitrogen contents. Manure mixes typically take several months to a year to compost and cure.

While composting occurs naturally, the process requires proper conditions to occur rapidly, minimize odor generation, and prevent nuisance problems. More than 20 controllable factors affect composting (Keener *et al.*, 1993). Of these factors, nutrient balance, water content, porosity, and temperature will be discussed.

Nutrient Balance (C/N)

The ratio of carbon to nitrogen (C/N ratio) is critical to the composting process. The recommended range is 25:1 to 40:1, with the ideal ratio about 30 parts carbon to 1 part nitrogen. This C/N ratio in the compost meets the needs of microorganisms for high rates of decomposition while minimizing the loss of nitrogen as ammonia. Many manures have a C/N ratio that is too low to compost efficiently, so amendments that contain a high C/N ratio must be added. Plant materials such as wood chips, sawdust, chopped corn stover, or straw are ideal amendments. Phosphorus and other principal and trace elements are generally available in satisfactory amounts for microorganisms when manures are blended with amendments to achieve a proper C/N ratio.

Water Content and Porosity

Composting is a biological process requiring air (oxygen). If the material to be composted is too wet, as with most manures, the limited amount of air available in the pile will hinder the process.

Adding a bulking agent to manure, such as wood chips, corn stover, or leaves, allows air to get into the pile. Turning the pile over is another way to ensure that air gets into the composting material. Fans can also be used to draw air through the compost pile to ensure proper aeration (Figure 22).

Moisture is also an important factor for micro-organisms to function during composting. The ideal moisture content is about 60% moisture with an acceptable range of 50 to 70%. It is important to avoid excess water because of the potential for odor and leaching conditions. If the mixture feels moist, but no water drips from it when a handful is squeezed, the mixture probably has adequate water content. Moisture is lost from the pile throughout the composting process. It is important to add water if the compost gets too dry and to stir or add more bulking agent if it gets too wet. Composting in the open air is affected by rainfall, and in some regions, rainfall saturates compost piles, causing leachate and odor problems.

Temperature

The optimum temperature range for composting is 110 to 145°F. Temperatures above 131°F kill most animal pathogens, plant pathogens, and weed seeds if sustained for three days or longer. At temperatures above 145°F, microbial activity declines, with activity approaching low values as compost temperatures exceed 160°F.

Optimum composting temperatures are achieved by regulating airflow and/or pile size and allowing heat generated through microbial activity to leave the pile. A compost mass stored in piles more than five-feet high by 10 feet across usually allows the temperature to reach 140°F in less than two days. Maximum practical depth ranges from 5 to 11 feet, depending on the material to be composted. Deep piles (depths >15 feet) sometimes lead to spontaneous combustion.

Composting Systems

Composting systems can be classified as static piles, aerated static piles, turned windrows, and aerated turned windrows. The terms windrow and pile can be used interchangeably in these descriptions. The terms in-vessel and tunnel indicate that the pile or windrow is contained within a structure. Which system represents the best technology depends on the material to be composted and takes into account not only environmental issues (health, safety, public nuisance, etc.) but also the economics. A brief description of various systems follows.

Static Pile

Composting material is placed in a pile (or windrow) and left to compost with minimal turning and without using forced ventilation. This approach is generally used with materials unlikely to generate offensive odors if anaerobic, materials such as leaves and ground yardwaste which have high C/N ratios (>50). However, dead animal composting also uses the static pile approach to composting.

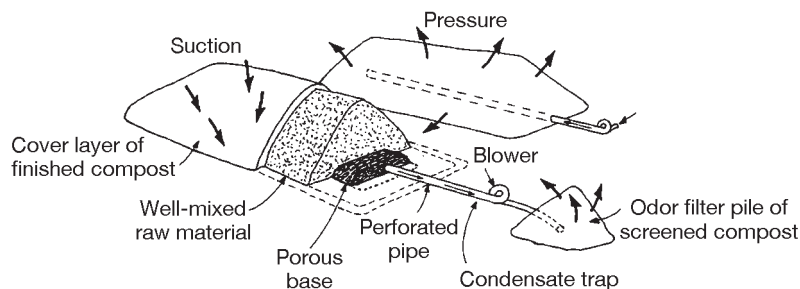


Figure 22. Aerated static pile. (Source: *On-Farm Composting Handbook*, NRAES-54, 1992. Natural Resource, Agriculture, and Engineering Service, Ithaca, N.Y.) Used by permission.

When escaping odors may be a problem, the pile is capped with a biofilter type material to trap and destroy the odors. These systems are usually turned using a front end loader once at the end of the first phase (high rate) of composting and once between a secondary phase (stabilizing phase) and a curing stage.

Aerated Static Pile

Composting material is placed in piles (or windrows) with ventilation ducting underneath the piles. Past studies on aerated pile systems show they work best using forced ventilation as opposed to suction because of higher pressure drops and accumulation of water in the piping under suction. Even so, many systems ventilate by negative-pressure on the compost and exhaust the resulting gases through a biofilter system.

The rate of aeration required to prevent anaerobic metabolism varies with the product being composted. Pile height is generally limited to 8 feet and less than 100 feet in length to balance airflow required to control temperature, static pressure drops, and fan power requirements. Spacing of ducts is usually controlled by pile height since duct spacing is approximately equal to the height of the pile. A block approach, as opposed to windrows with aisles, is often used to maximize use of space. Pipe sizing, both header and aeration duct, and hole placement in the aeration duct are critical for successful operation of this system.

Turned Windrow

Composting material is placed in a windrow (pile) and is turned at regular intervals. Pile heights are generally limited to five to eight feet because of the ability of equipment to handle material and porosity considerations. Equipment ranges from tractors with buckets to payloaders and from pull type turners handling 5 feet (height) x 8 feet (width) windrows to straddle turners handling 8 feet x 10 feet windrows (or larger). Length of the windrow depends on site location.

Porosity of compost is important to prevent anaerobic conditions in windrows, as with the static piles, since both depend on natural convection (chimney effects) to ventilate the pile. Turning the pile does incorporate oxygen, but if the pile lacks porosity, the center of the windrow becomes anaerobic within minutes. Many turners designed

today can introduce water back into the windrow to maintain conditions favorable for a high rate of composting.

Windrow systems often generate some odors early in the process with highly putrescent material. One method to minimize odor is to cap the piles with biofilter type material to trap escaping odors and delay turning the windrows until the temperature of the high-rate phase of composting has declined to <135°F and oxygen levels have recovered in most regions of the compost pile.

In-Vessel

In-vessel composting is used to more fully control the composting process that takes place in a compost pile. In the reactor vessel, the optimum mix of organic waste, moisture, and bulking agent is mixed and aerated. With careful control, composting can be completed in a few weeks. Composting vessels are usually housed in a building to control moisture and reduce odors.

An enclosed reactor version of in-vessel is the tunnel system, which completely controls the path of exhaust air leaving the system. In-vessel systems can be used for all types of **prepared** (particle size is critical) materials and have the capabilities of controlling emissions. They have high fixed and operating costs and should be selected based on materials to be composted and site requirements.

Composting used for livestock manure has several advantages:

- Low odor and minimal flies are associated with the finished compost.
- Pathogens and weed seeds are destroyed.
- A 40 to 80% reduction in volume and mass compared to liquid systems.
- End product can be spread uniformly on many different cropping systems.
- End product can be marketed to nonfarmers.

Composting also has limitations:

- Land area for compost piles and equipment for operation is required.
- Ammonia is lost during composting.
- Odor is released during composting process.
- Management is needed to control process, prevent odors, etc.

For more information on composting, refer to Ohio State University Extension Bulletin 792, *Modern Composting*, and Natural Resource, Agriculture, and Engineering Service NRAES-54, *On-Farm Composting Handbook*, available through your local county Extension office.

References

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Rynk, R., Editor. *On-Farm Composting Handbook*. NRAES-54. 1992. Natural Resource, Agriculture, and Engineering Service (NRAES), P. O. Box 4557, Ithaca, NY 14852-4557, **www.nraes.org**.

Chapter 5—Farmstead Runoff Control

Livestock facilities are typically located to use natural surface-drainage. However, runoff—from open areas, such as feedlots, aprons adjacent to livestock confinement barns, and manure load out areas—transports pollutants including manure, waste feed, soil, chemicals, and dust from confinement buildings. These conditions require facilities for pollution control and drainage to intercept and store or treat surface runoff so contaminated waters do not enter surface or ground waters. A typical open-lot runoff control system is shown in Figure 23.

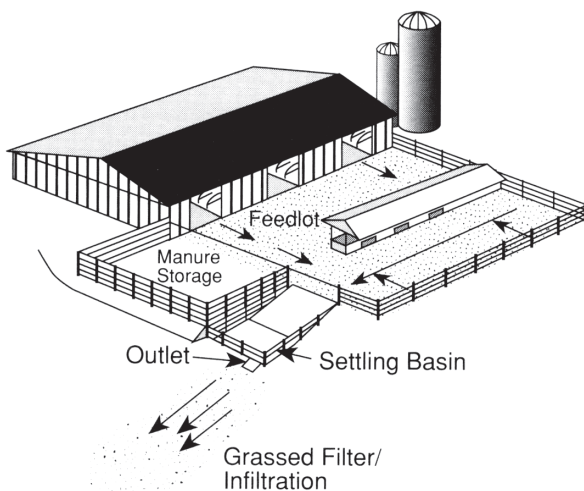


Figure 23. Runoff control system. (Source: *Ohio State University Extension Bulletin 604, 1992 Edition.*)

Proper assessment of the pollution potential depends on the size and other physical characteristics of the lot and on rainfall intensity, duration, and frequency. An open lot may be any outdoor animal area, such as a beef feedlot, outdoor dairy feeding and resting area, or sow feeding pens, and may include an unpaved dirt lot, completely paved, or partially paved areas around feed bunks and waterers.

Where livestock spend only part of their time outdoors, a proportion of total manure production exposed to lot runoff is estimated. With a manure pack bedded area and lot feeding, the proportion of manure on the lot is typically about 50 to 70% for cattle. If sows are fed outdoors at least daily, a large proportion of the manure, up to 90%, is exposed to lot runoff.

Figure 24 illustrates the major components of a runoff control system.

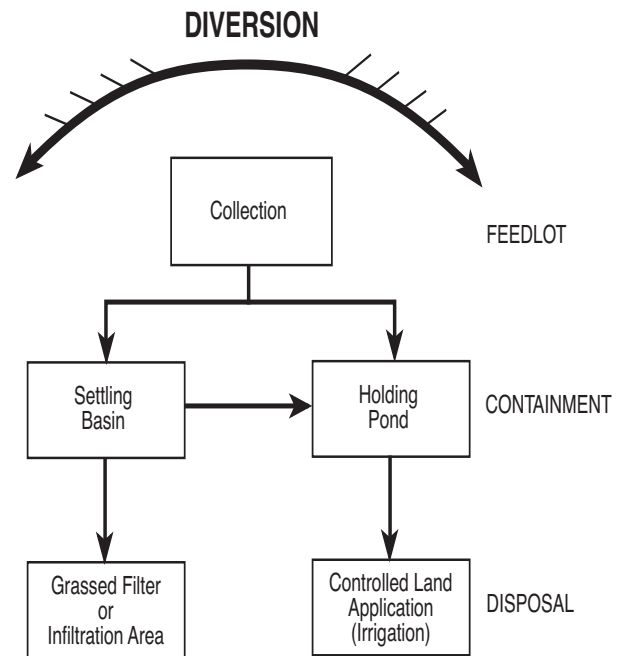


Figure 24. Components of a runoff control system. (Source: *Ohio State University Extension Bulletin 604, 1992 Edition.*)

Clean Water Diversion

All clean roof and surface water should be diverted away from the feedlot to a clean-water drainage system independent of the waste-handling system. This reduces the amount of waste to be handled, reduces the amount of solids eroded from the lot, and maintains the settling facility's efficiency. All roofs that would contribute to runoff from the feedlot should have gutters, downspouts, and outlets that discharge water away from the feedlot. A 25-year, 24-hour storm should be used when designing the diversion system.

Collection

Lot runoff, whether from rainfall or snowmelt, may contain manure, soil, chemicals, and debris, and must be handled as part of the manure management system. Runoff can be collected and transferred to a settling basin or holding pond by diversions, curbs, gutters, lot paving, and, in some cases, by pumping.

Containment: Settling Basin

A settling basin retains runoff and reduces the flow rate to allow settling out and recovery of solids. The liquids are drained off to a holding pond, constructed wetland, or vegetative treatment area, and the solids remain in the basin for drying and later removal and spreading.

The settling basin slows the runoff flow to allow solids to settle. Typically, runoff solids that will settle out will do so in about 30 minutes. To settle most solids, the basin should provide a large, shallow settling area (<3 feet deep) and retain runoff for at least 30 minutes. Although the most conservative approach would allow for a 25-year, 24-hour rainfall, experience shows that rainfall during a 10-year, one-hour storm can be used to size the settling basin, provided larger flows can bypass the settling basin without carrying manure solids, and be routed through a vegetative treatment area.

The required surface area for settling should be equal to at least 5% of the open-lot area plus any other areas that contribute runoff. To prevent scouring of the settled solids from the settling basin, the liquid cross-sectional area should be about 5% of the ponded surface area. The settling basin should be concrete or at least have a concrete bottom for solids removal and should provide at least one vertical wall to buck against for solids removal (Figure 25).

Several types of basin outlets are available to drain liquids from the full depth of the basin and dewater the solids. The perforated pipe, slotted pipe, and porous-plank dam are common examples. The outlet design should take into account manure and other debris that can plug outlet holes. For perforated or slotted pipe outlets, an additional screen, such as an expanded-metal screen (3/4 inch, No. 9) around the outlet, will increase the screening area and protect the drain from larger debris. For a porous dam outlet, a material that can be easily cleaned by scraping the surface should be selected. Spaced boards, welded-wire fabric, or expanded-metal mesh can be cleaned easily.

Frequent maintenance and clean-out increases the efficiency of the settling basin. Cleaning the basin after every major runoff event will improve its treatment efficiency, reduce odors, and restore the basin capacity. A properly managed open lot and settling basin can retain up to 85% of the solids from the lot. If solids are not cleaned out after each runoff event, additional storage capacity must be included in the settling basin volume.

The solids storage volume required depends on the solids removal rate from the lot, lot size, and time between clean-outs. Rainfall runoff from an unpaved lot has up to about 1.5% solids, which is about 6 cubic feet of solids per 1,000 cubic feet of runoff. Longer and steeper slopes may result in more solids accumulating in the basin.

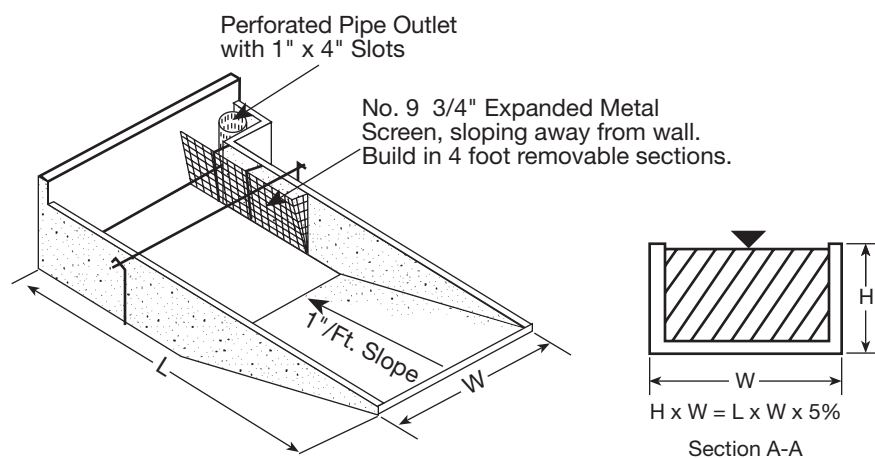


Figure 25. Concrete settling basin with screened perforated pipe. (Source: Ohio Natural Resources Conservation Service (NRCS) Design Staff. Used by permission.)

For a paved lot, the maximum amount of manure likely to be washed off between scrapings is 1 inch of solids over the lot area which would require 20 inches of storage depth assuming the settling area is 5% of the lot area. For dirt lots, a maximum of one-half inch of solids erode from the lot, requiring a minimum of 10 inches of depth for solids in the settling basin.

To ease scraping of the basin, liquid and solid depths can be reduced by proportionately increasing the surface area above the 5% basis. It is often practical to provide the settling basin as part of the feedlot by providing a curb along the low part of the lot to control lot runoff and trap solids, which can be removed after draining the water. It is important that the settling basin or channel is shaped and located so that it can be easily managed and maintained.

Holding Pond

A holding pond, basin, or tank temporarily stores runoff water from a lot until it can be applied to the land. If manure solids are to be recovered, lot runoff must pass through a settling facility before going to the holding pond. The holding pond is not intended to receive roof water, cropland drainage, or other unpolluted waters and does not treat manure as in a lagoon.

Holding ponds must be sealed to prevent seepage into ground water. Although holding-pond bottoms tend to seal naturally, if the pond is located in sandy or gravelly soils or near fractured bedrock, the pond must be sealed with a synthetic liner or compacted clay. The Natural Resources Conservation Service, a geologist, or a professional engineer should be consulted during project planning for assistance to determine site feasibility.

The required storage volume should consider desired length of storage, source of liquids and runoff water, rainfall duration and frequency, and the balance between rainfall and evaporation. The holding pond should provide capacity for a 25-year, 24-hour rainfall with 25% added storage to the design volume for emergency situations. If a settling basin is not included or becomes short-circuited, capacity for manure solids must also be included in the storage volume.

To ensure maximum capacity, the holding pond should be emptied regularly, by pumping and land application using some type of irrigation. Because of the dilute nature of runoff, it may be feasible for direct irrigation onto growing crops. However, accumulated manure solids can affect the ability to irrigate unless they are separated. The pond should be emptied before it is full as specified in a nutrient-management plan.

Constructed Wetlands

A constructed wetland provides an opportunity to store and treat contaminated runoff by reducing nutrients, especially nitrogen and phosphorus. Before entering the constructed wetlands, solids must be removed in a settling basin. The wetlands should be designed in accordance with Natural Resources Conservation Service standards, which take into consideration nutrient and hydraulic loading rates. In addition to average runoff, constructed wetlands should provide storage for a 25-year, 24-hour rainfall.

A series of three or more wetland cells allow optimum treatment. Adjustable risers between the cells permit flexibility in controlling water depth, which should be uniform across each cell. Wetlands are not designed to discharge directly into waters of the state unless specifically permitted. Overflows from wetlands should outlet into vegetative infiltration areas or can be irrigated onto cropland.

The constructed wetland consists of an impervious subbase covered with a minimum six-inch layer of hydric soil, which will usually contain wetland plant seeds. If a hydric soil is not available, topsoil may be used. Plantings in each cell should be limited to two species that may include cattails, softstem bulrush, river bulrush, arrowhead, and pickerel weed. Following planting, the soil should be saturated to permit germination, then raised to the design depth at a rate that does not flood the plant but allows for optimum plant growth. Polluted runoff should not enter the constructed wetland until plants are well established. Livestock should not be permitted in the wetland, and muskrats must be controlled to prevent damage to earthen dikes.

Irrigation

Generally, runoff from open lots is applied to agricultural land for utilization of the manure nutrients. For **holding ponds**, it is usually economical to use irrigation equipment to transport the liquid to the application site. If the manure is handled as a liquid, it may be feasible to use the same disposal equipment for the contained runoff. The emptying schedule specified in the system's waste management plan should be followed.

Vegetative Treatment

A **vegetative treatment area** is an alternative to holding ponds for runoff detention. Runoff flows through a settling facility to settle out most of the solids, then to a vegetated area where it is treated. **It is essential that solids be settled out before runoff enters the treatment area.** To be effective, a vegetative treatment area must be designed, constructed, vegetated, and adequately maintained.

The vegetative treatment area is designed either for **overland flow** or **slow-rate infiltration**. The vegetated area may be designed either as a long, grassed, gently sloping channel or a broad, flat area sloped away from the inlet. Divert all outside surface water so that only lot runoff and direct precipitation enter the infiltration area.

Overland flow treatment refers to a specific microbial remediation technique that has minimal infiltration of wastewater. Treatment by overland flow consists of the application of wastewater along the upper portion of a uniformly sloped strip of herbaceous-vegetation, allowing it to flow over the vegetated surface for aerobic treatment. Overland flow design consists of dosing the flow every two to four days over the treatment area. The size of the filter is based upon a loading rate for the soil and a minimum flow contact time.

The slow-rate infiltration process refers to a specific remediation technique involving the application of wastewater to a vegetated surface for treatment as it flows down through the plant-soil matrix.

The design hydraulic loading is based on the more restrictive of two limiting conditions—the capacity of the soil profile to transmit water (soil permeability) or the nitrogen concentration in the

water percolating below the root zone. The anticipated nutrient loading should not exceed the vegetation's agronomic nutrient requirement. To maintain soil infiltration, the treatment area should not be constructed or later traveled when the soil is wet. Other surface water should be diverted from the filter area. Livestock need to be excluded from the vegetative treatment area.

The success of the treatment depends largely on the establishment and maintenance of a good stand of vegetation. In planning the facility, provisions must be made to have an established stand of vegetation before allowing lot runoff on the filter. Fescue and reed canary grass have proven acceptable. Although the natural habitat for reed canary grass is a poorly drained, wet area, it is also one of the more drought-tolerant grasses and can utilize high fertility. The vegetation should be harvested and removed when conditions allow.

Water ponding and the buildup of solids at the beginning of the filter may be minimized by using a slope of 2% or more for the first 50 feet. Slopes can be decreased to 0.5% for the remainder of the filter area and the channel can be straight or can take on a switchback shape, depending on the area where the filter is located. On steep topography, the filter area should be a graded terrace with a slope that will not allow erosion.

The required infiltration area depends on the soil-infiltration capacity, soil water-holding capacity, and runoff volume and should be designed to control a 25-year, 24-hour rainfall event. Typically, the channel has a minimum bottom width of eight feet and can be up to about 24-feet wide. If wider channels are needed, meandering and channeling can be controlled with low dividing ridges. The length of the channel can be reduced by decreasing the lot area, diverting lot and roof water, decreasing the amount of manure exposed to rain, or by increasing the width of the grass filter. The bottom of the channel should be flat in cross-section.

The final design of the grass filter should take into consideration the topography and area available, number and size of animals, lot size, and lot management practices. The success of a vegetative filter is dependent upon a shallow flow depth uniformly spread over the entire filter width being in contact with dense vegetation.

Table 10. Typical Silage Leachate Constituents.

Constituents	Silage Seepage (typical)	Dairy Manure Liquid (typical)
Dry Matter	5% (2-10%)	5%
Total Nitrogen	1,500-4,400 mg/liter	2,600 mg/liter
Phosphorus	300-600 mg/liter	1,100 mg/liter
Potassium	3,400-5,200 mg/liter	2,500 mg/liter
pH	4.0 (3.6-5.5)	7.4
Biochemical Oxygen Demand (BOD ₅)	12,000-90,000 mg/liter	5,000-10,000 mg/liter

Source: American Society of Agricultural Engineers, Paper No. 94-25 60 by P. E. Wright and P. L. Vanderstappen, 1994, and Ontario Ministry of Agriculture Food and Rural Affairs, Agdex No. 723.

Several management considerations need to be evaluated in the planning, design, and operation of a vegetative treatment area.

- The vegetative treatment area is not to be designed or constructed with an outlet to a stream. The outlet should consist of a spreader that acts to direct sheet flow to cropland or pasture.
- The vegetative treatment area must be well established with a lush vegetative stand prior to runoff loading.
- Milkhouse washwater should be routed through a septic tank to remove solids and milk fats prior to entering the vegetative treatment area. Milkhouse washwater is best managed by temporary storage and dosing of the treatment area every two to three days. Dosing allows the soil to recover, minimizing the chance of saturation at the inlet.
- Manure solids and saturated soil conditions at the head of the vegetative treatment area will cause the vegetation to die out, thus reducing the effective treatment length. Over time, flow in the treatment area will channelize and pass through without treatment. The settling basin needs to effectively trap the solids. Careful cleaning of the settling basin and frequent scraping of the feedlot is necessary.
- Dual vegetative treatment areas should be considered, particularly when milkhouse washwater enters the treatment area, because the soil needs additional recovery time during wet periods of the year. Each treatment area can be rested or maintained while continuing treatment in the other treatment area.

Silage Drainage

Silage drainage into streams can kill fish and other aquatic life. The sugars, proteins, and acids in the leachate have a high oxygen demand and are highly polluting to streams. Their loss also significantly reduces feed value. Typical silage leachate constituents are shown in Table 10.

Place forage in upright and horizontal bunker silos at the proper moisture content so as to avoid drainage from the silo. The amount of silage effluent varies throughout the year. Ideally, when a bunk silo is loaded, effluent flow starts. It peaks from five to 10 days later and then dwindles to a minimum by three months. Silage leachate production increases as the silage moisture content increases. Leachate production estimates are shown in Table 11.

Table 11. Leachate Production Estimates.

Dry Matter %	Leachate gal/ton
<15	100 to 50
15 to 20	50 to 30
20 to 25	30 to 5
>25	<5

Source: American Society of Agricultural Engineers, Paper No. 94-25 60 by P. E. Wright and P. L. Vanderstappen, 1994.

Collect and divert the leachate so it does not enter field tile, drainage ditches, or streams. Collect the drainage in a holding tank or add to a liquid manure storage facility, and land-apply when conditions are appropriate.

As a rule of thumb one cubic foot of leachate storage should be provided for each ton of silage. (*Animal Waste Management Field Handbook*. Page 4-23, Natural Resources Conservation Service (NRCS), AWMFH).

Milking-Facility Wastewater

Both the daily volume and the strength of milking-center wastewater must be considered when designing milking facilities. Table 12 provides estimated daily quantities of wastewater. As herd sizes increase, less water is used per cow because the milking equipment washwater does not increase proportionately. The values given are for facilities with parlors. It is assumed that holding areas are scraped and not washed down. Milking in stanchions produces less wastewater per day, and the quantity of wastewater from milk rooms will be one-third to one-half of the values given in Table 12.

Table 12. Estimated Quantities of Wastewater Discharged from Milking Centers.

Cows Milked	Quantity
Up to 50	7 to 10 gal/cow/day
50 to 150	4 to 6 gal/cow/day
More than 150	2 to 4 gal/cow/day

Source: Ohio State University Extension Bulletin 604, 1992 Edition.

The design of the wastewater collection system in the milking center is very important. Poor drain locations, improper floor slopes, or inadequate piping can lead to continual frustration for the operator. Floor slopes should be a minimum of 2% (1/4 inch per foot). Drains should be recessed below floor level so that water and solids will easily enter the drain without ponding. Drains should be located in corners or at ends of gutters so that solids can be easily washed (hosed) into them. A water-seal trap must be located in the drainpipe between the water-disposal unit and the milking center to prevent gases from entering.

The use of the conventional septic tank and leach bed for modern milking-center wastewaters is not satisfactory, for three reasons:

1. Larger herds generate more wastewater.
2. Sanitizers used for cleaning milking equipment may kill bacteria.
3. Manure solids washed from parlor floors will clog the leach bed.

Failure of a leach bed can result in discharge of untreated wastewater into waters of the state.

Alternative Milkhouse Washwater Handling Methods

A very acceptable and easy method of handling milking-center wastewater is to put it into a liquid-manure system. Dairy manure requires addition of some water to ease agitation and pumping. Including milking-center wastewater in liquid manure storage structures will provide the necessary dilution and solve the wastewater disposal challenge. When designing liquid-manure-storage structures, extra volume must be provided for the wastewater.

When a dairy facility utilizes dry manure storage, milkhouse washwater must be handled independently of the manure. Alternatives include:

- A separate holding pond or anaerobic lagoon (when odor control is necessary). The effluent can be irrigated onto cropland.
- An adaptation of the septic tank system also works well. Rather than using a leach bed, the effluent is discharged to a constructed treatment wetland, or periodically (every two to five days) pumped to a designated vegetative treatment area. The septic tank is used to trap solids and milk fats in order for either system function properly. Cattle need to be excluded from constructed wetlands and vegetative treatment areas.
- Discharge the wastewater into a constructed treatment wetland following settling.

Whatever the disposal method used, proper management is needed to prevent pollution and nuisances.

Human-Waste Handling

Sanitary facilities from livestock enterprises are not to be directly mixed with livestock manure and need to be permitted by the District Office of the Ohio EPA. A septic tank/leach bed system is normally used.

Research on Food Processing Wastewater

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The Department of Food, Agricultural, and Biological Engineering at The Ohio State University has an ongoing research program on the treatment of food processing wastewater. Wastewaters from meat and milk processing plants, restaurants, and even dairy farm milking facilities are significantly different from domestic and municipal sewage. Food processing wastewater has four to 10 times higher COD and BOD₅ levels because of the presence of fats, oils, and grease.

These wastewaters are difficult to treat using conventional wastewater-treatment systems or soil-absorption systems.

The Ohio State University research program is studying the treatment of cheese- and turkey-processing wastewaters through gravel/sand bioreactors. Properly designed and intermittently loaded, these laboratory-scale bioreactors remove over 99% of the COD, BOD₅, suspended solids and fats, producing effluent suitable for permitted stream discharge.

Some of the initial research findings include:

- Gravel/sand bioreactors are fail-safe, which means that if overloaded or neglected, they back up, rather than discharge poorly treated wastewater. In this way, the negligent operator is penalized, while protecting Ohio's environment.
- The media in the bioreactors are colonized by naturally occurring microbes from the wastewater and the soil. Over the first two

weeks of bioreactor operation, the microbial inoculum develops a biofilm on surfaces of gravel and sand particles to achieve subsequent peak performance.

- Media selection is an important design criterion. Layers of clean, graded fine sand, coarse sand, and pea gravel have shown the best performance.
- The loading rate is another important design criterion. For wastewater containing slowly biodegradable waste products such as fat, the COD loading rate must be carefully tested to ensure high treatment levels without clogging.
- Dosing is the third necessary design criterion. Dosing of up to three times per hour is beneficial in preventing overloading and clogging. Frequent dosing can be combined with increasing loading rates.
- Gravel/sand bioreactors are tolerant of:
 - Fluctuations of wastewater flow and BOD₅ and fat concentration.
 - Transient fluxes of cleaning agents used to sanitize food-processing equipment.
 - Periodic shut-downs of the facility—in fact, periodic resting for a few weeks will restore the treatment capacity of a clogged bioreactor.

Although this research has not yet examined on-farm milkhouse wastewater treatment, the current research results are promising for future on-farm design application.

References

ASAE Paper No. 94-25 60, American Society of Agricultural Engineers. Peter E. Wright, Senior Extension Associate, Cornell University, Ithaca, NY 14853, and Peter L Vanderstappen, Civil Engineer, Natural Resources Conservation Service, Lebanon, PA 17042. <http://wmc.ar.nrcs.usda.gov/partnerships/AWMIT/baseflow.html>

USDA Natural Resources Conservation Service, Agricultural Waste Management Field Handbook. <http://www.wcc.nrcs.usda.gov/awm/awmfh.html>

Manure Application

Chapter 6—Land Application of Manure

Manure is a valuable resource that needs to be managed effectively and efficiently. Land application of manure should not be considered simply a disposal system. Manure provides nutrients for crops and helps build and maintain soil fertility. Manure can also improve soil tilth, increase water-holding capacity, lessen wind and water erosion, improve aeration, and promote beneficial organisms. There are three principal objectives in applying animal manure to land:

- Ensure maximum utilization of the nutrients in the manure by crops.
- Minimize environmental hazards.
- Minimize neighborhood complaints and concerns.

Available land for manure application is an important consideration for all livestock operations. When planning a new operation or expanding an existing operation, adequate land area for manure application must be included in the plan. A conservative approach in determining the amount of land required is to consider the removal of the nutrient by the harvested crop. This will ensure that enough land area is available in future years to prevent nutrient buildup in the soil beyond recommended agronomic and environmental levels.

The whole farm nutrient management procedures described in Chapter 2, *Whole Farm Nutrient Budget/Planning*, provide guidelines for balancing nutrient inputs and outputs on the farm. In addition to balancing nutrients, best management practices (BMPs) for applying manure to crops must be used. To maximize manure nutrients while minimizing potential environmental impacts and neighbor's concerns, manure application must consider nutrient losses during handling and storage, runoff and preferential flow, and timing and rate of application.

Nutrient Losses During Handling and Storage

Nitrogen (N) is the nutrient most likely to be lost during handling and storage of manure. Table 13 provides a comparison of N losses due to storage and handling. The systems are described in Chapter 3, *Manure-Management Systems*. Nitrogen lost to the atmosphere through volatilization can be reduced by applying manure when soil and air temperatures are less than 50°F and by incorporating manure into the soil within 24 hours of application. The amount of N available from the manure also depends on the method of application. Injecting, chiseling, or knifing liquid manure into the soil minimizes odors and nutrient losses to the air or as surface runoff.

Table 13. Estimated Nitrogen Losses During Storage and Handling.

System	Percent Nitrogen Lost
Solid Systems	
Daily Scrape and Haul	25–35%
Manure Pack	20–40%
Open Lot	40–55%
Deep Pit (poultry)	25–50%
Litter	25–50%
Liquid Systems	
Pit under Floor*	15–30%
Above-Ground Tank*	10–30%
Holding Pond	20–40%
Lagoon	70–85%

*Indicates losses due to agitation

Source: MWPS-18, Section 2, Table 1-1. MidWest Plan Service. Used by permission.

Table 14 gives approximate manure nutrient values for land-applied manure, taking into account handling and storage losses.

Table 14. Approximate Manure Nutrient Values at the Time of Application.

Animal Type and Storage Type	Estimated Nutrient Content ¹					
	Lbs/Ton			Lbs/1000 Gallons		
	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
Dairy Heifer						
Manure Pack	4.2	1.7	5.6			
Open Lot	3.0	1.7	5.6			
Holding Pond				12.1	5.0	16.1
Pit				22.7	8.2	26.6
Dairy Lactating Cow						
Manure Pack	6.9	5.1	5.2			
Open Lot	4.9	5.1	5.2			
Holding Pond				18.9	13.9	14.4
Pit				28.6	18.5	19.1
Dairy Dry Cow						
Manure Pack	5.4	2.4	6.0			
Open Lot	3.9	2.4	6.0			
Holding Pond				14.7	6.4	16.4
Pit				22.1	8.4	21.5
Veal						
Pit	6.2	5.8	11.6			
Manure Pack				3.9	4.1	8.3
Beef Cattle						
Manure Pack	7.9	4.4	6.6			
Open Lot	5.6	4.4	6.6			
Holding Pond	20.0	11.1	17.0			
Pit				29.1	14.1	21.5
Swine						
Manure Pack	6.6	5.9	4.8			
Open Lot	4.7	5.9	4.8			
Holding Pond				18.0	16.0	13.1
Pit	31.8	24.8	20.3			
Lagoon ²				1.4	3.6	2.9
Sheep						
Manure Pack	6.3	4.5	9.0			
Poultry³						
Manure Pack	52	72	38			
Horse						
Manure Pack	6.6	3.7	7.7			

¹ Values vary with bedding, water content, feed programs, and specific livestock.² Values are for the supernatant (unagitated liquid on the top of the lagoon).³ Poultry—based on typical analysis from poultry barns from Ohio NRCS records.

Source: Manure Characteristics, MWPS-18, Section 1, 2000, and Purdue MMP version 1.9.4. Used by permission.

Irrigation of Liquid Manure and Wastewater

Additional issues need to be considered when applying liquid manure and wastewater. To minimize the risk of runoff or preferential flow (see following section), site inspection and preparation are important. In addition, hourly application rates must be controlled as discussed later in this chapter. Appendix E, *Liquid Manure Application*, provides management guidelines and information on equipment needs.

The use of manure or wastewater for “true” irrigation is seldom accomplished because of the relatively small volumes applied and annual application-rate restrictions. Those who desire to irrigate in addition to spreading manure must be certain of an adequate supply of water available for irrigating. Liquid manure from below-ground storage, earth basins, or above-ground storage should not be used to irrigate growing crops as the manure is usually high in ammonia and solids, which can coat and/or burn vegetation. However, wastewater in the second stage of a two-stage lagoon may be dilute enough for irrigation on growing crops.

Advantages of Irrigating with Liquid Manure

- Large amounts of effluent can be spread in a relatively short time.
- Waste effluent can be used to supplement irrigation water and to supply plant nutrients where regular crop irrigation is practical.
- Irrigation may cost less than other land-application methods to install, usually is cheaper to operate, and requires less labor for equivalent volumes of application.
- A high degree of automation is possible with some types of irrigation equipment.
- Manure guns (nozzles) can handle slurry directly from confinement and wash-down operations.
- Disposal can often be accomplished when moist soil conditions prohibit conventional hauling. However, do not irrigate on saturated soil, as runoff will occur. (See Appendix F, *Available Water Capacity*, for more information.)
- Less soil compaction occurs with irrigation than with tank wagons.

Disadvantages of Irrigating with Liquid Manure

- An adequate application area may not be within economical pumping distance of the waste source.
- Odors and spray drift (aerosols) are possible, depending on location and management.
- Additional water supply and/or large storage basins may be required for dilution, flushing the equipment, and safe efficient use of wastewater.
- Runoff is a potential pollution hazard. (See Appendix F, *Available Water Capacity*, for more information.)
- Without good management, annual application of nutrients may be excessive and cause nitrate pollution in ground water. Operator error or mismanagement is often a cause of liquid manure flowing through subsurface drains to surface waters of the state.
- Over-application or a too-high application rate may result in irrigated wastewaters entering the drainage tile and surface water supplies. See section on Preferential Flow in this chapter for best management practices to prevent liquid manure in subsurface drains.

Runoff and Preferential Flow

Excess nutrients in soil may impact the environment when they are dissolved or eroded and transported to surface or ground water supplies. Excess phosphorus (P) in surface waters can result in eutrophication and a decrease in oxygen levels in the water that leads to loss of animal life. Nitrogen compounds may harm human health and are toxic to fish. In addition, erosion of manure may contaminate water supplies with pathogens such as *E. coli* or *Cryptosporidium*. Minimizing these environmental risks requires using best management practices when applying manure to cropland.

While most transport of P occurs with the erosion of soil sediment, it can also leach if soil P levels are too high. Phosphorus accumulates in soils if applied in quantities greater than those removed by crops. Accumulation of P in the soil can be measured by soil-testing.

To minimize potential N runoff, manure applications should not provide more available N than what is needed by the succeeding crop. For

corn, the determination of total available N should include credits for any contributions of the present or preceding crop, any N fertilizer added, and available N provided by previous manure applications. The Tri-State Fertilizer Recommendations (contact Ohio State University Extension or see <http://ohioline.osu.edu/e2567>) provide recommendations for corn, soybeans, wheat, and alfalfa for N-P-K fertilizer.

Minimizing Runoff

Runoff potential is affected by numerous factors, some of which are fixed by the nature and location of the field, while other factors can be altered through management. Runoff potential must be determined on a site-by-site basis by evaluating:

1. **Location of receiving stream.** Runoff to streams is more likely when the field selected for manure application is bordered by a stream or other surface water rather than separated from surface water by a field, pasture, wooded area, or other suitable buffer strip.
 2. **Slope steepness and complexity.** Runoff is more likely from fields sloping steeply and evenly toward a stream than fields with a gentle or no slope. Priority areas for land application of manure should be on gentle slopes located as far as possible from waterways. When manure is applied on more steeply sloping land or land adjacent to waterways, other conservation practices should be installed to reduce runoff potential.
 3. **Soil and weather conditions.** Runoff is more likely when applied on frozen, saturated, or compacted soils.
 4. **Soil type.** Soils with low infiltration rates and/or soils with limited water-holding capacity are more likely to promote runoff than soil types that absorb and retain large quantities of water.
- Management factors that can alter the potential for manure runoff into a stream include:
1. **Buffer strips.** Properly designed buffer strips along stream banks adjacent to sites with high-runoff potential can absorb the runoff, reducing the amount of manure entering a stream.
 2. **Soil surface condition.** A rough or covered soil surface reduces runoff compared with soil surfaces that are smooth or have very little residue cover.
 3. **Manure characteristics, application rate, and application method.** Liquid manure applied at rates greater than the soil infiltration rate or water-holding capacity can promote runoff. Injection or incorporation of applied manure reduces chances of runoff. (See Chapter 5, *Farmstead Runoff Control*.)
 4. **Pre-existing nutrient status of the soil.** Greater quantities of nutrients are likely to move off fields when soils have a high soil test level rather than lower soil test levels.
 5. **Surface and subsurface drainage.** Proper installation and routine maintenance of surface and subsurface drainage systems can reduce the potential for runoff or direct discharge of manure from land application.
 6. **Setback distances.** To protect the environment and minimize neighbor complaint, manure should not be applied adjacent to sensitive areas. Table 15 specifies these minimum setback distances. Consider additional application setback distances from neighbors and environmentally sensitive areas such as sinkholes, wells, gullies, ditches, surface inlets, or rapidly permeable soil areas. Setback distances may need to be increased due to local conditions such as a pond or lake used for a water supply or recreational area or a stream that is already impaired by excess nutrients.

Table 15. Minimum Recommended Setback Distances from Sensitive Areas.

Minimum Setback Distances for the Application of Manure and Other Organic By-Products.			
Type of Sensitive-Setback Area	Setbacks Based on Methods of Manure Application		
	Surface Application	Winter Application Frozen or Snow-Covered Soils⁵	Surface Incorporation Within 24 Hours OR Direct Injection
Residences/Private Wells down slope from the application area.	100 ft.	200 ft.	100 ft.
—Sinkholes	300 ft.		100 ft.
—Pond or Lake	35-ft. Vegetative Barrier ¹ , with the remaining 100-ft. setback in non-vegetative setback ²	35-ft. Vegetative Barrier ¹ , with the remaining 200-ft. setback in non-vegetative setback ²	35-ft. Vegetative Barrier ¹
—Streams —Ditches —Surface Inlets	35-ft. Vegetative Barrier ¹ , OR 100-ft. setback in non-vegetative setback, OR 35 ft. in non-vegetative setback ³	200 ft.	None
Grassed Waterway	35 ft.	200 ft.	None
Field Surface Drains	35 ft. ⁴	200 ft.	None
Public Wells	300 ft.	300 ft.	100 ft.
Developed Springs	300 ft. upslope	300 ft. upslope	300 ft. upslope
Public Surface Drinking-Water Intake	300 ft.	300 ft.	300 ft.

Source: Ohio Natural Resources Conservation Service (NRCS) *Field Office Technical Guide*, Section IV, Standard 633. Used by permission.

Footnotes:

¹ Permanent vegetation consisting of grass, grass/legume mix, trees/shrubs, or trees/shrubs and grass/legumes. Measured from top of bank.

² Includes 100-ft. total setback. The setback must include a minimum of 35 ft. of vegetative cover from top of bank with the remainder of the 100 feet with no vegetative requirement. The setback is measured from the top of bank.

³ Applies if the manure application area has at least 50% vegetation/residue cover at the time of application.

⁴ No setback required for field surface drains if the manure is incorporated.

⁵ A more detailed estimate can be obtained by using the Purdue Manure Management computer program available through the Natural Resources Conservation Service.

Comments:

- CAFO's must follow the setbacks defined in the Ohio Department of Agriculture (ODA) rules regarding manure application (Rule 901:10-1-14: Land Application Restrictions and Setbacks).
- Excludes sludge that is regulated by the Ohio Environmental Protection Agency (OEPA) and septage regulated by the Ohio Department of Health.
- See "Application of wastes to frozen and snow-covered soil" in this chapter for additional criteria to minimize runoff from frozen and snow-covered soils.

Minimizing Preferential Flow

From USDA–Natural Resources Conservation Service (NRCS), Ohio Field Office Technical Guide, Section IV, Standard 633. Used by permission.

Liquid manure applied to fields that are tile drained presents a risk of the liquid manure following preferential flow paths, such as worm holes, cracks, old root channels, directly to subsurface (tile) drains. Some of these channels connect directly to subsurface drains and are a direct route to surface water. Anything that promotes good drainage will increase the risk of preferential flow of liquid manure to subsurface drains. The greatest area of concern is two to three feet horizontally from the tile line.

Most problems occur with liquid manure having a low solids content. As the percentage of solids in the manure decreases (high water content), viscosity (stickiness) decreases, and the manure flows more easily to tile lines. Typically, liquid swine manure from a lagoon is 95% water, 5% solids, and liquid dairy manure is 97 to 98% water and only 2 to 3% solids. Milkhouse wastes and egg wash are highly diluted and have even less solids. However, gray water from all these systems may have very high BOD (biological oxygen demand), ammonia, and soluble phosphorus levels that can be deadly to fish and aquatic organisms if it reaches surface water without treatment.

Injection of the liquid manure can actually make the situation worse, especially if sweep-type shovels are used on the injection equipment. Ideally, the liquid manure should be applied at low rates, under low pressure, evenly across the soil, and either at or slightly below the soil surface to allow the liquid manure to infiltrate the soil, be absorbed by the soil, and be treated. Strategies to minimize the movement of liquid manure to subsurface drains include:

1. Avoid applying manure before or after a heavy rain. Monitor manure storage capacity to prevent applying when conditions are not acceptable. Applicators have a limited number of days to apply manure when environmental conditions (soil, wind, rain, moisture) are optimal, so it is advisable to contact custom applicators up to a year in advance of the anticipated manure application. Use crop rotations that will allow timely manure applications throughout the growing season.
2. Reduce liquid manure application rates. No more than 13,000 gallons or 0.5 inch of liquid manure per acre should be applied in one application. Multiple smaller applications of 7,000 gallons or 0.25 inch of liquid manure per acre allow for more effective absorption by the soil than one large single application. Reduce manure application rates if wet soil conditions exist. Do not apply a greater volume (gallons per acre) than the upper eight inches of soil can hold. See Appendix F, *Available Water Capacity*.
3. Maintain subsurface drainage lines and drainage outlets. Do not apply liquid manure if subsurface (tile) lines are flowing with water. In areas with springs, subsurface lines flow continually, and soil moisture conditions should determine application. (See Appendix F, *Available Water Capacity*.) Monitor drainage outlets before, during, and after manure applications for signs of discharge. If manure is in the tile flow, plug the outlets or capture the flow immediately. Provisions for tile plugging or the capture of tile flow must be planned and available prior to application. Follow emergency manure spill procedures if a spill occurs.
4. Minimize preferential flow by tilling the soil at least three to five inches when large macropores like cracks, earthworm burrows, or root channels exist. If manure is injected, use straight points spaced closely to reduce the volume of liquid manure coming out of each knife point. For soils with “cracks” more than six- to eight-inches deep at the time of application, till before application or do not apply until adequate moisture seals the cracks.
5. Calibrate manure application equipment before application. Over application of liquid manure is a major cause of liquid manure in surface water.
6. Maintain minimum setback distances from surface water. See Table 15, Minimum Recommended Setback Distances from Sensitive Areas. Minimum suggested setback distances vary depending on weather, soil conditions, and time of year. For winter manure application, setback distances are doubled.
7. Install in-line tile flow controls that can plug tile flow or have inflatable tile plugs

available during application. Control structures allow for easy monitoring and cleanup of manure in tile lines but need to be installed properly to prevent leaching around the control structure. Allow enough time for the liquid manure and surface water to absorb into the surrounding soil before removing the plug.

Record keeping is important in preventing manure in subsurface (tile) lines. Document application rates, set-back distances, weather and soil conditions, subsurface drain lines and outlets, broken tile, sink holes, and other potential problems to help prevent environmental problems in the future. Have emergency equipment (backhoe, bales of straw, pumps, etc.) available if a liquid manure spill occurs. See Chapter 7, *Safety and Manure Handling*.

Rate and Timing of Application

Source: USDA-Natural Resources Conservation Service (NRCS), Ohio Field Office Technical Guide, Section IV, Standard 633. Used by permission.

Using best management practices to determine the rate and timing of manure application will optimize crop production, reduce environmental risks, and minimize neighbors' concerns. The factors that most often limit the amount of manure that should

be applied to cropland are existing soil-fertility levels, manure nutrient content and concentration, crop nutrient needs, runoff potential, slope, leaching potential, and site limitations. Hauling distances, distance to surface water, distance to neighbors, distance to water wells, the potential for manure leaching to tile lines, and other factors can also limit how and when manure is applied.

Assessing Nutrient Needs

Manure application rates must balance manure nutrients with crop nutrient requirements as discussed in Chapter 2, *Whole Farm Nutrient Budget/Planning*. In general, only about one-third of the organic nitrogen in animal manure is available to crops during the year it is applied, and the remaining two-thirds, residual organic nitrogen, becomes part of the soil organic matter over time (Table 16). Phosphorus and potassium from manure application are considered as available as commercial fertilizer during the first growing season. The limiting nutrient, usually nitrogen (N), phosphorus (P), or potassium (K), will determine the amount of manure applied. The limits on the amount of phosphorus that can be applied are those that most often limit any further manure applications. Since it is difficult to balance manure nutrients, additional fertilizer applications may be needed to balance the crop's nutrient needs.

Table 16. Estimated N Availability of Manure Based on Time and Application Method.

Available Nitrogen Percent		Time of Application	Days Until Incorporated
NH ₄	Organic N	Date	Days
50%	33%	Nov-Feb	< 5
25%	33%	Nov-Feb	> 5
50%	33%	Mar-April	< 3
25%	33%	Mar-April	> 3
75%	33%	April-June	< 1
25%	33%	April-June	> 1
75%*	15%	July-Aug	< 1
25%	15%	July-Aug	> 1
25%	33%	Sept-Oct	< 1
15%	33%	Sept-Oct	> 1

Notes:

- The calculations are for all animal manures. It is assumed that 50% of the organic N in poultry manure is converted to NH₄ rapidly and is therefore included in the NH₄ column for calculating available N.
- Incorporation is the mixing of manure and soil in the tillage layer. Disking is usually enough tillage for conserving nitrogen availability.

*c. The 75% available nitrogen (NH₄) is based on the nitrogen being used in the year it is applied. If the nitrogen is carried over to the following year, then 25% available nitrogen should be used.

Source: Ohio State University Extension Bulletin 604, 1992 Edition.

Evaluation of nutrients is needed to determine accurate manure application rates. Plant tissue analysis should be done on a regular basis to monitor the nutrient balance of the crop. Soils receiving manure should be tested for plant-available nutrients before manure application. Also, the manure should be tested. Application rates of manure are determined by using the results of these tests.

Soil should be tested at least every five years. If the grower has applied P and K over the years, soil-test levels may be in the adequate to high range. It is important to note that manure contains more K than magnesium (Mg) and after many years of continued manure application, the ratio of K to Mg may be too high for optimum crop growth. To adjust the ratio, additional Mg may have to be added as dolomitic limestone, if the soil pH indicates an acid soil. Adding high levels of manure may also increase soluble salts in the soil and reduce plant stands.

Application Rates

Accurate application rates for manure should consider soil moisture to reduce the risk of runoff (Appendix F, *Available Water Capacity*), and equipment should be calibrated to obtain the desired application rate (Appendix H, *Nutrient Application Equipment Calibration* and Appendix I, *Manure Spreader Volume Conversions*). In addition, understanding the effects of manure application practices on nutrient levels in the soil and methods to minimize nutrient buildup is essential to minimizing environmental impacts.

The manure utilization and cropping systems used on a particular field should maintain Bray-Kurtz P1 soil-test P levels at no greater than 80 pounds per acre or 40 ppm of P in the top eight

inches of soil. Special precautions should be taken if manure is applied where Bray-Kurtz P1 levels already exceed this level. If manure must be applied to fields with levels greater than 80 pounds per acre or 40 ppm P, the following recommendations should be considered:

- No additional phosphorus fertilizer should be used on such fields.
- Crops should be monitored for nutrient deficiencies and nutrient imbalances using plant-tissue analysis.
- Manure should be applied in quantities such that the long-term P level at the soil surface does not increase appreciably. If the manure is surface-applied or incorporated to a shallow depth (within the tillage depth), ensure that applications supply no more N than will be removed by the crop in the following year and no more P than will be removed in the next one to three years.
- Adequate soil and water conservation should be practiced to control soil erosion and minimize runoff.
- Manure application is not recommended for crop production where the Bray-Kurtz P1 level in the top eight inches of soil exceeds 300 pounds per acre or 150 ppm P.
- If more than 250 pounds of P_2O_5 are applied at one time from manure, the manure should be incorporated within 24 hours to a minimum depth of 4 inches.

One approach to planning manure application rates is to apply two or three years of P or K in one year. See Table 17 as an example. Often the goal with manure applications is to meet the nitrogen needs of the crop first. However, with this goal, phosphorus and potassium needs are often exceeded.

Table 17. Multiple-Year Manure Nutrient Applications**Applying 2-3 Years P_2O_5 or K_2O Crop Requirements with “one” application of manure.**

Due to the nutrient composition of most livestock manure, one can usually apply two or three years worth of P_2O_5 and K_2O while not over applying nitrogen for the succeeding crop. Applying manure on a two- to three-year cycle also reduces the risk of soil compaction and reduces the acres needed in any one year. The following example demonstrates how one can apply enough manure in one application to meet the P_2O_5 and K_2O crop needs while not over applying nitrogen for the succeeding crop:

EXAMPLE:

- Corn–Soybean Rotation. Manure injected in soybean stubble in November prior to Corn.
- Crop Fertility Needs: Nitrogen Corn 1 year (145 lbs/ac); 3 years P_2O_5 (152 lbs/ac); 3 years K_2O (152 lbs/ac).
- Swine Pit Manure Analysis: N = 34.7 lbs/1,000 gal; P_2O_5 = 33 lbs/1,000 gal; K_2O = 27 lbs/1,000 gallons.

Apply enough manure to meet P_2O_5 needs for three years:

- Applying 5,000 gallons per acre will provide: Nitrogen @ 130 lbs/acre (application losses deducted); P_2O_5 @ 165 lbs/acre, and K_2O @ 135 lbs/acre.

RESULTS:

- Additional nitrogen will need (15-20 lbs/ac) to be applied to meet the corn yield goal; no additional P_2O_5 will be needed for three years; and 15-20 lbs/ac of K_2O will be needed during the three-year period.

Source: USDA-Natural Resources Conservation Service (NRCS), *Ohio Field Office Technical Guide*, Section IV, Standard 590. Used by permission.

Multiple year applications of P_2O_5 may be applied at a rate equal to the recommended P_2O_5 application rate or estimated P_2O_5 removal in harvested plant biomass in a single application. When such applications are made, the application rate should:

1. Not exceed the recommended nitrogen application rate for the succeeding crop, or:
2. Not exceed the estimated nitrogen removal in harvested plant biomass (for legumes) during the year of application when there is no recommended nitrogen application, or:
3. Not exceed a phosphate (P_2O_5) application rate of 250 lbs/ac per year, or:
4. Not exceed the potash (K_2O) application rate of 500 lbs/ac per year.

Applications of P_2O_5 above 250 lbs per acre are not recommended. However, if P_2O_5 concentrations in the liquid manure exceed 60 lbs P_2O_5 per 1,000 gallons or 80 lbs P_2O_5 per ton for solid manure or other bio-solids rates higher than 250 lbs per acre may need to be applied due to limitations of the application equipment. P_2O_5 applications should not exceed 500 lbs per acre of P_2O_5 during one year from manure or other bio-solids. **When P_2O_5 applications exceed 250 lbs per acre, the following are recommended:**

1. Do not apply to fields with a soil test exceeding 100 ppm P, Bray-Kurtz P1 test or equivalent.
2. Immediately inject or incorporate manure three to five inches deep.
3. Do not apply on either frozen or snow-covered soil.
4. Do not apply additional P_2O_5 for a minimum of three years on land below 40 ppm P, Bray-Kurtz P1 test or equivalent, and for a minimum of five years above 40 ppm P, Bray-Kurtz P1 test or equivalent.
5. Apply P_2O_5 at rates that meet application rate criteria for both nitrogen and potash.

Other limitations to manure application include volume limitations relating to how much manure can physically be applied to the soil at one time. With low nutrient concentrations in liquid manure, large volumes of liquids may be applied and yet the crop nutrient needs may not be met simply because the liquid is mostly water and has low concentrations of nutrients. Application of liquid manure above the available water capacity of the soil can create a runoff risk and leaching to tile or underground water (See Appendix F, *Available Water Capacity*.) Manure application equipment on wet soils can cause significant soil compaction.

Application Rate Considerations for Liquid Manure and Wastewater

To prevent runoff or preferential flow, hourly application rate should be matched to the infiltration rate and permeability of the soil. The design application rate should be conservative and usually lower than the maximum allowable rate in the Ohio Irrigation Guide, because the soil intake rate may be reduced over time by the solids and salt content in some wastes. When recommended application rates vary with soil depth, use the value at eight inches of depth, which is less than that at the surface.

Limit the one-time application volume to an amount that will bring the soil to field moisture capacity. (See Appendix F, *Available Water Capacity*.) Limit application rates to the water-holding capacity of the top eight inches of the soil profile. The amount applied must not exceed the holding capacity of the soil at the time of application. Inspect fields for broken tiles and other possible short-circuit routes that could result in a direct discharge of manure to drainage tile and surface-drainage ditches. If rapid infiltration to subsurface drainage tile is a problem, consider light disking, shallow chisel plowing, or other tillage operations before irrigating manure and wastewater to improve the soil's infiltration and holding capacity. Lower application rates and multiple passes with irrigation equipment may also be necessary.

Timing of Application

Source: USDA-Natural Resources Conservation Service (NRCS), Ohio Field Office Technical Guide, Section IV, Standard 633. Used by permission.

Crop rotation and seasonal variations affect when manure should be applied. In a corn-soybean rotation, the fall, after the crops are harvested, is the best time to apply manure. Generally, the fall has drier weather so compaction problems can be minimized. Fieldwork can also be accomplished in the fall to incorporate the manure. Sometimes manure can be applied in the spring if weather conditions and time permit. Usually, manure cannot be applied during the growing season, although some liquid systems may permit side-dress applications of manure to corn.

If wheat or oats are in the rotation, the manure can be applied in the late summer months. For wheat or oats, winter and spring applications of manure to the growing crop are not recommended. Forage crops (grasses and legumes) are capable of using more nutrients than row crops (corn, soybeans, and wheat).

A planned grazing system can substantially reduce the manure that must be handled and applied and can reduce costs and environmental hazards. Manure can be applied to hay or pasture land but smaller applications are needed to preserve forage quality and to limit crop damage. It is preferable to apply manure on pastures and hayland soon after cutting or grazing before re-growth has occurred. Also, limit the application rate to avoid salt damage and/or coverage to the pasture and hayland. Table 18 provides general guidelines for timing manure application.

Table 18. General Field/Crops Availability for Manure Application.

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Corn												
Soybeans												
Wheat/Stubble												
Oats												
Hay												
Pasture												

Legend:

Winter Application Not Recommended. If applications are necessary, apply with 90% ground cover, < 10 tons or 5,000 gal, and use wider setbacks.

Apply with care to minimize compaction.

Growing cropland not available for manure application.

Generally lowest risk of runoff and lowest compaction risk.

Apply with care to avoid crop damage and forage quality.

Source: USDA-Natural Resources Conservation Service (NRCS), *Ohio Field Office Technical Guide*, Section IV, Standard 633. Used by permission.

Application of Manure on Frozen Soil

Source: USDA-Natural Resources Conservation Service (NRCS), *Ohio Field Office Technical Guide*, Section IV, Standard 633. Used by permission.

Application on frozen and snow-covered soil is not recommended. However, if manure application becomes necessary on frozen or snow-covered soils, only limited quantities of manure should be applied. Frozen soil means that the soil surface is frozen so that manure cannot be injected into the soil profile. If winter application becomes necessary, applications should be applied only if ALL the following criteria are met:

- Application rate is limited to 10 wet tons per acre for solid manure with more than 50% moisture and five wet tons for manure with less than 50% moisture. For liquid manure, the application rate is limited to 5,000 gallons per acre.
- Applications are to be made on land with at least 90% surface residue (*e.g.*, good quality [grass] hay or pasture field, all corn grain residue remaining after harvest, all wheat residue cover remaining after harvest).

- Manure should not be applied on more than 20 contiguous acres. Contiguous areas for application are to be separated by a break of at least 200 feet. Utilize areas for winter manure application that are the farthest from streams, ditches, waterways, and surface water and use areas that present the least runoff potential.
- Increase the application setback distance to 200 feet minimum from all grassed waterways, surface drainage ditches, streams, surface inlets, and water bodies. Minimum suggested setback distances are doubled for winter application of manure to frozen or snow-covered soils. See Table 15, Minimum Recommended Setback Distances from Sensitive Areas. This distance may need to be further increased due to local conditions.
- Additional winter application criteria for fields with significant slopes of more than 6%.** Manure should be applied in alternating strips 60 to 200 feet wide generally on the contour, or in the case of contour strips on the alternating strips.

Application of Manure on Steep Slopes

Source: USDA-Natural Resources Conservation Service (NRCS), Ohio Field Office Technical Guide, Section IV, Standard 633. Used by permission.

Manure should not to be applied to cropland with slopes of more than 15% or to pastures/hayland with slopes of more than 20% unless *one* of the following precautions is taken:

- a. Immediate incorporation or injection with operations done on the contour, UNLESS the field has 80% ground cover (residue and/or canopy).
- b. Applications are timed during periods of lower runoff and/or rainfall (late May to mid-October).
- c. Lower rates can be applied by using split applications (separated by rainfall events). Apply no more than 10 wet tons/acre for solid manure, or 5,000 gallons/acre for liquid manure.
- d. The field is established and managed in contour strips with alternate strips in grass or legume.

Timing of manure application should also consider the potential impact on neighbors. To develop and maintain good neighbor relations, give adequate notice of the intent to land-apply manure and do not haul and spread on weekends, holidays, or important events. Good communication is key to minimizing neighbor's complaints.

Manure Application Record Keeping

Keep good field records of soil and manure test results, yields achieved, and nutrients applied (time, form, rate, and method of application). Records should be kept for a period of five years or longer (metals analyses and associated application rates and locations should be maintained permanently):

- Quantity of manure produced and its appropriate analysis.
- The last three soil-test results.
- Dates, analysis, and amounts of manure that are land-applied.
- The dates and amounts of manure removed from the system due to feeding, energy production, or export from the operation.
- Manure application methods.
- Crops grown and yields (both yield goals and measured yield).
- Other tests, such as determining the nutrient content of the harvested product.
- Calibration of application equipment. See Appendix H.
- Soil moisture and weather conditions (temperature and wind direction) at the time of application.
- Consider annual reviews to determine if changes in the nutrient budget are desirable (or needed) for the next planned crop.

Chapter 7—Safety and Manure Handling

Liquid-manure-handling systems can reduce labor requirements in confinement facilities but can introduce hazards due to the toxic effects of manure gases, manure runoff into streams, and offensive odors. Outdoor and open-top manure storages can also be potential drowning sites.

Under certain conditions, manure gases may be fatal to both humans and livestock. Poor ventilation or ventilation failure in a tightly constructed building can threaten the health and life of animals. To protect humans, manure storage areas should first be ventilated or, where necessary, self-contained breathing equipment should be used when entering manure storage areas. Increased gas levels above manure pits in buildings can also slow the daily gain of animals.

Dangerous Situations

Dangerous situations resulting from **manure gases** are associated with four main gases that are produced as manure decomposes. These are listed in Table 19 along with some of their characteristics. All of the gases listed in Table 19 are **colorless**.

Ammonia (NH_3) is released from fresh manure/urine and during decomposition. Ammonia levels tend to be high in buildings with litter, solid floors, or scrapers because manure spread over the floor increases ammonia release. Heated floors also increase ammonia release. Ammonia is very soluble in water, so liquid-manure systems release less ammonia. High pH levels cause more ammonia to be released into the air.

Concentrations in ventilated hog buildings have been measured as high as 35 ppm (slightly irritating to eyes and nose) and in unventilated buildings at 176 ppm, which produces extreme discomfort. At 100 to 200 ppm, ammonia causes sneezing, salivation, and loss of appetite for hogs. Prolonged exposure may lead to respiratory diseases in people and animals.

Carbon dioxide (CO_2) is released through livestock respiration and manure decomposition, and by unvented heaters. Most of the gas in bubbles coming from stored manure or lagoons is CO_2 . Death of animals in closed confinement buildings following a ventilation-equipment failure (such as that caused by a power failure) is due in part to excessive CO_2 . Vigorous agitation of stored manure can release a “slug” of CO_2 .

Hydrogen sulfide (H_2S) is the most toxic gas from liquid manure storage. Dangerous concentrations can be released by agitation of stored liquid manure. Concentrations reaching 200 to 300 ppm have been reported in a building a few minutes after starting to pump out a storage pit and have been as high as 800 ppm during vigorous agitation. Exposure to 200 ppm for 60 minutes will cause headaches and dizziness; 500 ppm for 30 minutes will cause severe headache, nausea, excitement, or insomnia. High concentrations of 800 to 1,000 ppm cause immediate unconsciousness and death through respiratory paralysis unless the victim is moved to fresh air, and artificial respiration is immediately applied. Even the characteristic rotten-egg smell of H_2S does not give adequate warning because the sense of smell is rapidly fatigued by H_2S , and high concentrations do not give proportionately higher odor intensity.

Methane (CH_4) is generated in the decomposition of manure under strict anaerobic (no air) conditions. It is insoluble in water and lighter than air and will accumulate in stagnant air corners in the top of enclosed pits or rooms. CH_4 is not toxic, but high concentrations can produce an asphyxiating atmosphere. Concentration in confinement housing is normally well below the lower end of the 5% to 15% explosive range (Table 19). Explosions attributed to methane have occurred around manure storage pits.

Table 19. Characteristics and Effects of Gases Produced in Decomposing Manure.

Gas	Odor	Density	Exposure Limits	Effects
Ammonia (NH ₃)	Pungent	Lighter than air	10 ppm	Irritation to eyes and nose. Asphyxiating at high levels.
Carbon Dioxide (CO ₂)	None	Heavier than air	5,000 ppm	Drowsiness, headache. Can be asphyxiating.
Hydrogen Sulfide (H ₂ S)	Rotten-egg smell	Heavier than air	10 ppm	Toxic: Causes headache, dizziness, nausea, unconsciousness, death.
Methane (CH ₄)	None	Lighter than air	1,000 ppm	Headache, asphyxiant, explosive in 5% to 15% mixture of methane with air.

Source: Ohio State University Extension Bulletin 604, 1992 Edition.

Fatalities

Fatalities may occur when people enter manure-storage structures, including covered manure pits, and are probably due to CO₂ and H₂S because these gases are heavier than air. Caution should also be taken when agitating manure as the asphyxiating effect of NH₃, CO₂, and CH₄ combined with the toxic effect of H₂S could be fatal.

Another potential risk, especially for children, is drowning in a pit, storage tank, and earthen storage basin or lagoon. Failure and breakage of slats or covers on pits and lack of protective barriers or railings around pit openings during agitation can lead to accidents. Push-off platforms or ramps (piers) can be a site for the tractor scraper and driver to tumble into an open storage structure or lagoon. Crusts on earthen storage basins can be a problem, especially for children, as they may appear capable of supporting one's weight, but they are not.

Precautions

When designing manure structures and systems, think safety. When operating or managing manure equipment, think safety. Consider the following major safety points when designing and operating manure equipment, structures, or systems:

- Do not enter a manure pit unless absolutely necessary and then only if:
 - The pit is ventilated beforehand
 - You have supplied air to a mask or a self-contained breathing apparatus.
- You are wearing a safety harness and attached rope with at least **two** people standing by who are capable of pulling you out.
- When agitating a manure storage, always have at least one additional person available who can go for help if you are overcome by gases.
- Properly designed and operated ventilation systems can reduce the concentration of gases within the animal zone, improving animal performance. Poorly designed or improperly adjusted ventilation air inlets may actually increase gas concentrations at the animal level.
- When possible, construct lids for manure pits or tanks and keep access covers in place. If an open ground-level pit or tank is necessary, build a fence around it and post with "Keep Out" and "Danger — Manure Storage" signs.
- Get help before attempting to rescue livestock or people that have fallen into a manure-storage structure.
- Build railings alongside all walkways or piers of open manure storage structures.
- Permanent ladders on the outside of above-ground tanks should have entry guards locked in place, or the ladder should be terminated above the reach of individuals.
- Never leave a ladder standing against an above-ground tank.

9. Construct permanent ladders on the **inside** wall of all pits and tanks, even if covered. Use of noncorrosive material is important.
10. Fence in earthen storage basins and lagoons and erect signs: “Caution – Manure Storage (or Lagoon).” The fence is also needed to keep livestock away from these structures. Additional precautions include a minimum of one lifesaving station equipped with a reaching pole and a ring buoy on a line.
11. All push-off platforms or piers need a barrier strong enough to stop a slow-moving tractor. It should be low enough so that livestock cannot slide underneath.
12. If possible, move animals before agitating manure stored in a pit underneath a building. Otherwise, if the building is mechanically ventilated, turn fans on full capacity when beginning to agitate, even in the winter, or if the building is naturally ventilated, do not agitate unless there is a brisk breeze. Watch animals closely during agitation, and turn off the pump at the first sign of trouble. The critical area of the building is where the pumped manure breaks the liquid surface in the pit.
13. If manure storage is outside the livestock building, provide a water trap or other anti-back flow device to prevent storage gases from entering, especially during agitation.
14. If an animal drops over, do **not** try to rescue it. You might become a victim of toxic gases. Turn off the pump, and do not enter the building until gases have had a chance to escape.
15. Due to the possibility of explosion and fire, don’t smoke, weld, or use an open flame in confined, poorly ventilated areas where methane can accumulate. Electric motors, fixtures, and wiring near manure-storage structures should be kept in good condition.
16. Keep all guards and safety shields in place on pumps, around pump hoppers, on manure spreaders, tank wagons, power units, etc.

Take time now to review your total manure management system from a safety viewpoint. Think through each step of the collection system, storage or treatment units, and the land application phase.

Are there dangerous areas in construction or operation? If so, make them safe. It could save your life or the life of a loved one or employee.

Emergency Action Plan

Every livestock farm should have an Emergency Action Plan in place. What is an Emergency Action Plan and why have one? It is a well-thought-out, simple, basic, common-sense plan that will help those involved with an emergency to make the right decisions. A plan is needed:

- To meet the requirements of many states for a plan.
- To keep humans and livestock safe.
- To rectify an emergency situation.
- To protect the environment.
- To teach family members and employees.
- To record for future situations (prevention, law suits, etc.).
- To ensure notification of proper authorities.

Safety Equipment

Locate first-aid or rescue equipment near the manure-storage area. Clearly mark a wall closet or box and store the equipment inside it. Make occasional checks to ensure the equipment is in good order and has not been removed. Post the phone number of the local fire department/rescue squad on the wall beside the box and also near the telephone.

Personal protective equipment that includes air packs and face masks, nylon lines with snap buckles, and a parachute-type body harness with “D” rings for attaching lines can be obtained from supply sources of industrial safety and hygiene equipment. Look in the yellow pages under *safety*, *safety equipment*, *industrial safety and hygiene*, or *safety supplies*. These supply sources can also provide information on monitoring or measuring devices used to test hazardous atmospheres. Be sure to specify the gases you are dealing with when asking for or purchasing equipment.

Familiarize yourself, your workers, and your family with the proper operation of all safety equipment. Local medical (rescue) teams can assist in this education.

Immediate First-Aid Procedures

Victims of Manure-Gas Asphyxiation

1. Do not attempt to rescue a victim from a hazardous gas situation unless you are protected with a supplied air-breathing apparatus.
2. Have someone telephone for an emergency medical (rescue) squad, informing them there is a “victim of toxic (manure) gas asphyxiation.”
3. If the victim is free from the immediate area of danger and there is no personal threat to your life, take the following steps:
 - With the victim on his or her back, check for breathing, then give four quick mouth-to-mouth breaths and check for a pulse.
 - **If there is a pulse**, continue mouth-to-mouth breathing every five seconds (12 per minute).
 - **If there is no pulse**, start CPR (cardiopulmonary resuscitation) immediately. When the emergency squad arrives, the victim should receive a high concentration of oxygen at the scene and in transport.

If members of your family have not taken CPR and first-aid training, enroll them in a course at your earliest opportunity. Periodic refresher courses in CPR are recommended.

Victims of Drowning

1. Rescue the person from the drowning situation using standard water-rescue technique.
2. If the victim is unconscious or not breathing, use standard CPR procedures. (See No. 3 under *Victims of Manure-Gas Asphyxiation*.)
3. Have someone telephone for an emergency medical (rescue) squad, informing them there is a victim of drowning.

Manure Issues

Chapter 8—Odor and Dust Emission Control

Some livestock operations are becoming larger. As a result, odor and dust from livestock operations have become an increasing concern for farmers and their neighbors. Control of odors and dust is becoming a necessity for farmers to maintain the sustainability and profitability of their livestock operations.

Odor and dust control are affected by factors such as biological characteristics of the farm animals, animal density and scale of operation, management practices, topography, distance from neighbors, weather conditions, people's perception and tolerance to odor and dust, and governmental regulations.

Although it is difficult to eliminate odor and dust emissions from livestock operations, there are many ways to reduce the emissions. This chapter provides information on odor and airborne dust and the means to reduce odor and dust emissions. Appendix J describes methods of measuring odor.

Characteristics of Odor and Dust

What Is Odor?

Odor is an unpleasant smell caused by emissions of odorous compounds. Anaerobic decomposition/transformation of livestock and poultry manure by microorganisms generates the odorous compounds. Metabolic processes within the gastrointestinal tract of livestock also generate some of the odorous compounds. More than 160 volatile compounds have been identified as contributors to odor from confinement facilities. These compounds include ammonia, hydrogen sulfide, mercaptans, fatty acids, and amines, to name a few. Because of the vast number of compounds contributing odor, their individual contribution under various conditions is not yet clear.

What Is Dust?

Dust is the airborne particulate emission from livestock operation and typically consists of manure solids, dander, feathers, hair, and feed. Dust particles are carriers of odor, toxic gases, endotoxins, and pathogens. Dust is measured as mass

concentration in air (mg/m^3) by gravimetric filter method, or numbers of particle per volume of air ($\text{particles}/\text{m}^3$) by electronic particle counters.

Factors That Affect Odors

Air temperature, relative humidity, manure accumulation time, ventilation of the production buildings, weather conditions, and dust level affect odor generation, transportation, and human perception. High temperatures speed biological processes and can increase odor emissions. High humidity and moisture levels promote anaerobic decomposition of organic compounds and in turn generate more odors. Manure accumulation time affects total odor generation. Weather conditions affect the spread of odors. Ventilation systems in production buildings reduce odor levels within the structure. Dust is known as a major odor carrier. Dust levels correlate well with odor levels.

Sources of Odor and Dust at Livestock Facilities

Livestock facilities have three major sources of odor and dust:

- Animal-production facilities.
- Manure-storage and handling systems.
- Manure land-application processes.

Of these sources, odors are likely from all three sources while most dust emits from the animal-production buildings. There are many other minor odor sources on a farm, such as the animal's breath, flatulence, dirty coats, milking center, feed room, etc.

Means for Odor and Dust Control in Animal Production Facilities

Basic concepts for odor control at an animal production facility are:

- Remove manure frequently from buildings.
- Keep odor-emitting surfaces clean (as practical).

- Manage nutritional and feeding plan to minimize odor excretion.
- Treat the air in the building and/or at the exhaust outlets of the building.
- Direct the exhaust air stream to reduce odors that reach neighbors.

Farmstead Planning and Landscaping

Considerations to minimize odor and dust when building new or expanding facilities include:

- Distance from neighbors.
- Prevailing wind directions.
- Air drainage.
- Locations of other facilities on the farm.

There is no absolute standard separation distance, but location of buildings should be considered. Odor sources should be located downwind of other buildings to maintain a better living environment for farmer and animals.

Because odor is often visualized (perception), good landscaping around the farm, especially around odor sources, can reduce complaints about odor. In addition, the landscaping can help change the odor and dust dispersion patterns and dilute the polluted airstreams.

Good Management and Housecleaning Practices

Manure, wet feed, and dust generate odor and should be removed regularly. Keeping the floor surface, wall, and animals dry and clean will reduce odor. Manure temporarily stored in the facility should be removed at least once a week as manure stored longer than five to seven days generates more offensive gases. For swine, if a pull-plug system is used, recharge the manure pit with clean or treated water to reduce the odor generation rate.

Bedded Systems

Solid manure systems usually generate less odors compared to liquid manure systems. Using some type of bedding can reduce odor generation in buildings. Odor control effectiveness is one of the reasons that hoop structures are currently become popular among swine and dairy producers. High-rise buildings for swine production and the litter system for broilers and turkeys effectively manage odor problems.

Diet Manipulation

Diet manipulation to minimize odor is becoming an accepted concept. Research has shown that manipulation of feed additives, level of protein, and other nutrients in an animal's diet may affect the potential odor and gas emissions from animal manure. However, the quantitative effects of diet manipulation on odor and gas reduction and animal performance are still being determined along with its effects on the quality of egg, meat, and milk products.

Ventilation

Proper ventilation supplies fresh air into the buildings and prevents anaerobic decomposition of organic materials and in turn reduces odor generation. Fresh air also dilutes odorous air in buildings. In addition, proper ventilation is also critical to the animals' health and productivity.

Vegetable Oil Sprinkling

Airborne dust is known as a carrier of odor and toxic gases. Research has shown that sprinkling vegetable oil is one way to reduce dust concentration in animal buildings. Under some conditions, daily sprinkling reduced the dust level by 80%; hydrogen sulfide concentration, 20%; and ammonia concentrations, 30%. However, sprinkling can lead to other management issues, such as the coating of equipment and building surfaces. For detailed information on how to sprinkle vegetable oils in hog barns, please refer to MWPS publication AED-42.

Ozonation

Ozone is a powerful oxidizer and an effective natural germicide. Ozone has been used to treat drinking water on a municipal scale. Research at Michigan State University has shown that applying ozone at concentrations of 1 to 3 mg/l to fresh or stored swine manure reduced odor emission significantly. More studies are needed to evaluate ozone effectiveness and economics.

Wet Scrubber/Deduster

Wet scrubber technologies are widely used in the chemical and mining industry and are recognized for being able to not only reduce dust emission but also to reduce water-soluble gases. The technology has been applied to the animal production industry. Evaporate cooling pads in tunnel ventilation systems can serve as a wet-wall to scrub 60% dust at low ventilation rates and 20% dust at high ventilation rates. The wet pad had minor odor re-

duction— 50% ammonia reduction at low ventilation rates and 33% ammonia reduction rate at high ventilation rates (Bottcher, *et al.*, 1999).

A wet scrubber developed for swine exhaust air has 84% dust collection efficiency and 90% water recovery (Zhao, *et al.*, 2001). Because the current odor intensity measurement method does not take into account odors carried by dust particles, the odor reduction efficiency of the wet scrubber mentioned earlier is not significant using the current odor measurement method. However, the wet scrubber is believed to have great potential to reduce dust, gases, and odor. Further development of low-cost and efficient wet scrubbers for agricultural buildings is being conducted.

A deduster is a device to clean dust in animal buildings. The particle separation efficiency of the deduster reaches 90% for particles larger than 10 μm and 77% for particles larger than 7 μm . In terms of mass concentration measured using mass samplers, the particle separation efficiency reached 85% (Zhang, *et al.*, 2001). The deduster could be an effective method for air cleaning of dusty air-spaces, such as livestock and poultry buildings.

Biofilter

Biofiltration uses microorganisms to break down gas contaminants to non-odorous products using a biofilter media. The filter media can be ground yard trimmings, compost, corncobs, chopped cornstalks, and other organic materials. Air to be treated is slowly passed (minimum resident time of 10 seconds) through a biologically active bed of material, generally 1.5- to 3-feet deep. The odor reduction rate can reach 80% to 90% for odorous organic compounds in properly maintained systems. Hydrogen sulfide and ammonia have also been reduced as much as 50% or more. Recent studies indicate that the construction and operating cost of a biofiltration system is about \$0.22 per pig produced per year. In addition, there is a \$400 cost associated with extra energy requirement and rodent control (Nicolai and Janni, 1998 b, c).

Windbreaks

Windbreaks redirect the exhaust air from animal buildings upward to prevent the direct movement of odors and dust onto neighboring properties. They could be artificial walls or natural trees and vegetation. Typically, windbreaks are placed 10 to 20 feet downwind of the exhaust fans of tunnel-

ventilated barns. For naturally ventilated buildings, windbreaks should be placed at least 100 feet, or 10 times the windbreak height, from the buildings to prevent blockage of cooling breezes and air exchange.

Research shows some effect of windbreaks on odor reduction, but the exact effectiveness has not been assessed yet. Snow deposition concerns should be evaluated during the windbreak planning to ensure snow drift will not be deposited next to or on the barn.

During Manure Storage and Handling

Manure storage facilities are significant sources of odor on a farm. There are several ways to reduce the odor emission from a manure storage and handling site.

Covers

A logical method to reduce odor emission from open manure storage is to cover the manure storage space. There are many different kinds of covers to reduce odor emission—concrete and wood impermeable covers, plastic impermeable covers, and floating permeable covers. Rigid covers are more expensive and are expected to last 10 to 15 years. Depending on the materials used, the cost of rigid covers varies considerably. Plastic covers can be inflatable over the lagoon or floating over the manure surface. The cost is about \$100 per liner foot of diameter. The lifetime is about 10 years. Research shows that floating plastic covers are easier to maintain than the inflatable ones.

Floating permeable covers can be formed naturally or artificially. Natural covers usually are formed by the fibrous material in the manure. Artificial covers can be formed by organic materials such as barley straw, wheat straw, chopped cornstalks, sawdust, wood shavings, and rice hulls. Man-made materials, such as Polystyrene foam, plastic mats, air-filled clay balls, and geotextiles, also can be used as floating permeable covers.

Research by the University of Minnesota indicated that permeable covers are more suitable for odor reduction than impermeable covers. Layers of straw in four-inch, eight-inch, and 12-inch-deep layers can reduce odor 60%, 80%, and 85%, respectively. The odor and gas emission reduction efficiencies of

permanent roofs of wood, concrete, and plastic covers can be as high as 80% for odor and 80% to 95% for ammonia (Hoff, *et al.*).

In summary, covers can significantly reduce odors from the manure-storage facilities. When selecting a cover, consider the size and type of manure-storage system, the type of manure-treatment system, the frequency of pumping, the cost and lifetime of the cover, the maintenance required, and the ease to operate.

Aerobic Treatment

Aerobic treatments aerate manure to prevent anaerobic decomposition by adding oxygen. Complete aerobic treatments can eliminate manure odors. The treatment can be an aerobic reactor or aerated lagoon. The drawbacks of aerobic treatment are high energy cost, high bio-solids production, and the potential for release of ammonia and other gases if the aeration is not controlled well. The high operating cost prevents aerobic treatment from being widely used by producers.

Anaerobic Treatment

Anaerobic treatment of manure treats manure without oxygen. The typical anaerobic treatment is an anaerobic lagoon, either one-stage or two-stage lagoon system. When an anaerobic lagoon is properly sized and managed, odor emission can be reduced significantly. However, nitrogen gases are natural byproducts of anaerobic decomposition.

Anaerobic digesters are another anaerobic treatment alternative. Compared with the anaerobic lagoon, the decomposition processes can be well controlled in an anaerobic digester and thus are more efficient. One of the most common anaerobic digesters is the plug-flow reactor. Others include complete-mix, contact, and up-flow anaerobic sludge blanket digesters. Very little odor is produced from a properly managed anaerobic digester.

Odor reduction from land-spreading treated manure can be 70% to 80% compared to spreading untreated manure slurry. However, proper design, construction, and operation of an anaerobic digester are critical to the success and wide application of the system. See Chapter 4, *Treatment and Utilization Options for Livestock Manure*, for more information on anaerobic lagoons. For more detailed design of anaerobic lagoons, please refer to MWPS-18, *Livestock Waste Facilities Handbook*.

Composting

Composting is a biological process in which microorganisms convert organic materials, such as manure, sludge, and leaves, into a soil-like material called compost. Composting treatment is applicable to solid or semi-solid manure. Composting can reduce manure volume, stabilize manure nutrients, kill pathogens and weed seeds, and produce a homogeneous non-odorous product.

If operating conditions are managed properly, carbon dioxide and water vapor will be the primary gases emitted during the composting process. In addition, compost is a value-added material. For detailed information about the composting process, please refer to NRAES 54, *On Farm Composting Handbook*.

Manure Additives

Many biological and chemical additives for manure are on the market. The performance of various manure additive products is still not reliable. Currently, it is still difficult to justify the balance between the odor reduction effect and the cost associated with the additive products.

Landscaping

Odor perception is a human subjective response and is affected by visualization. If proper landscaping is designed and maintained, odor conflicts with neighbors can be reduced. Landscaping physically changes the odor dispersion pattern, provides a large filtration surface for odorous compounds and dust, and forces more dilution to the odorous air stream.

During Manure Land Application

Land application of manure returns nutrients and organic matter to the soil. It also is the most frequent source of odor complaints from the public. Therefore, how, where, and when to apply manure all affect odor dispersion and odor complaints. Alternatives to reduce the odor emission during land application of manure include:

Injection and Incorporation

Odor emissions are affected by the surface area of the manure that contacts the air. Applying manure beneath the soil surface by injection or by covering it immediately after surface application,

called incorporation, eliminates most of the odor. Injection is the most effective way to reduce odor during the land application of untreated manure. In addition, manure injection and incorporation can also reduce manure nitrogen losses by reducing ammonia volatilization. Field research shows a 90% odor and ammonia reduction by shallow or deep manure injection compared with surface application. Incorporation after spreading also reduces the odor level and nitrogen losses, but not as efficiently as injection.

The common injectors on the market are narrow tines, sweeps, disk injectors and covers, and conventional chisel plows. When selecting an injector, system power consumption is another important factor to consider. Generally, newer injectors, such as disks and sweeps, use less power and distribute the nutrients better.

Drop Holes

Surface application using drop holes, which apply manure liquid on the surface through a series of drop holes close to the surface, has proved to be an effective odor control practice in Europe. Placing the manure on the surface but beneath the crop canopy also helps to control odor emission.

Irrigation/Mobile Spreaders

Applying liquid manure by spray or surface irrigation systems remains a popular method to distribute manure. This method produces considerable odor if the manure is not treated. Means to reduce odor are:

- Using nozzles and pressure to create large droplet sizes.
- Installing drop nozzles on center pivot systems.
- Adding dilution water to the liquid manure before application.
- Treating manure before the application, if possible.

Time and Location Constraints

When applying manure, always consider time, weather conditions, and location constraints. Try to avoid applying manure while the wind is blowing towards your neighbors. Build good communications and relationships with your neighbors to minimize misunderstandings and complaints. Make an effort not to apply the manure during weekends, holidays, and any other special event days.

Summary

Odor and dust emissions can become limiting factors for the sustainability of animal production. Understanding sources of odor, perception of odor, and current technologies to reduce odor are the first steps to control odor. Producers should use professional help to develop a comprehensive odor and dust-control plan, considering all aspects of the production and combination of odor-control efforts. Odor and dust control is a complex issue. It is difficult to eliminate odor and dust emissions completely from livestock operations. However, many technologies are available to reduce the emissions to an acceptable level, and new technologies are being developed to help producers control odor and dust efficiently.

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Chapter 9—Insect and Pest Control

Diseases can be spread on a farm by insects, rodents, and birds, but the most common issues relate to nuisances.

Controlling Insects

Many insects can reproduce in livestock manure. These insects may be a nuisance, or they may be of economic concern due to transmission of disease, reduction in growth or production by animals, and contamination of food products. Flies, mosquitoes, and rattailed maggots are frequently of major concern.

Control of Flies In and Around Livestock Facilities

Good sanitation is the basis for all fly-control programs. Nevertheless, it is often necessary to supplement sanitation practices with pesticides.

Managing manure properly with good sanitation is the best way to control flies on livestock farms. The fly life-cycle takes about two weeks, one for the larvae to develop and one for the larvae to pupate prior to emerging as an adult fly. Manure is a favorite place for flies to lay their eggs, but wet feed and seepage from silos also are prime areas for fly breeding. Preventing water leaks and seepage from outside sources into the animal housing, feed distribution, and feed storage areas can help to minimize fly breeding. Barnyards should be well drained, and vegetative growth around the facilities should be kept low to minimize areas where flies might breed.

Manure should be removed from animal quarters frequently and stored in facilities that will minimize fly breeding. Many dairy farms use free-stall housing and avoid bedded manure packs, thus less manure remains in the animal housing area for infestation by flies. Also, many dairy farms have changed to inorganic bedding (*e.g.*, sand) in free stalls, which is less desirable for fly breeding than organic bedding. Most swine and poultry operations are enclosed, and manure does not build up in the housing area for swine.

The use of lagoons and pits for manure storage prevents flies from laying eggs in the manure, because there is an inadequate amount or type of biomass to provide ova position stimulant (stimulant that must be present for flies to lay eggs). For stacked manure, moisture should be less than 30% to discourage fly breeding. Coverage of this storage area will limit moisture from precipitation, reducing the risk of run-off and fly infestation.

Fly larvae can still develop in manure spread on the field, but this can be minimized by spreading the manure when conditions are not wet and by thinly spreading the manure to reduce drying time. For totally enclosed animal housing and handling facilities, the structure must be designed to limit entry of flies either by providing airtight facilities or screen doors and windows where appropriate.

An Integrated Pest Management (IPM) program needs to be implemented on every farm. The IPM can consist of a wide array of practices to monitor and control pests. The use of biological and chemical controls needs to be considered in the IPM program. Products are available to control flies on the animals, and pesticides are available for use in the areas of the facility not occupied by the animals. (For more information, refer to OSU Extension Bulletin 473, *Livestock and Livestock Building Pest Management*, <http://ohioline.osu.edu/b473/index.html>, or OSU Extension Bulletin 853, *Poultry Pest Management*, <http://ohioline.osu.edu/b853/index.html>).

Economic Injury Level

The threshold density for determining when to control flies depends on the area where the control measures will be taken. In general, the threshold at homes is very low, and control actions are taken with few flies. The threshold density of the house fly at waste-management sites may be 150 flies per fly paper per 30 minutes.

House flies can be monitored with baited traps, sticky ribbons, or spot cards on livestock facilities. Spot cards are three-inch by five-inch white index cards attached to a fly resting surface. A minimum of five cards should be placed in each animal facility and left in place for seven days. A count of 100 or more fecal or vomit spots per card per week indicates a high level of fly activity.

Pesticide Program

For successful fly control, organize a control program that best fits your farm. A single pesticidal product rarely gives the most effective and economical control. It is normally best to use a combination of pesticide applications, such as residual wall sprays, space or aerosol sprays, baits, and larvicides, during the fly season.

Because fly resistance is always a possibility, it is best to rotate different chemical-family insecticides, especially when one group begins to lose effectiveness. Consider alternating synthetic pyrethroids with organophosphates. Do not wait for heavy fly populations. It is much easier and less expensive to prevent heavy fly buildup than to control heavy fly populations after buildup. As fly populations begin to build up, take time to treat and treat regularly.

For detailed information on pesticides refer to OSU Extension Bulletin 473, Livestock and Livestock Building Pest Management, <http://ohioline.osu.edu/b473/index.html>, or contact your local county office of Ohio State University Extension.

Feed Additives

Oral larvicides or insecticides given through the feed prevent the development of flies in manure. Certain states do not recommend the use of oral larvicides or insecticides given through the feed. Oral larvicides are usually fed from May through September. Animals must consume the recommended dosage for the feed additive to be effective. They are not effective against adult flies. Oral larvicides should be used in conjunction with good manure sanitation. A supplemental fly-control program is needed where flies breed in manure from untreated animals or other organic sources.

Feed additives often are not the answer to fly control unless used extensively. All feces must be treated within an area to effectively reduce fly populations. The required treatment area must be several miles across because flies can move readily from herd to herd over an area of several miles within one or two days. This treatment is usually more effective in controlling horn flies and is not very effective against face flies. Feed additives do not control housefly and stable-fly larvae that develop in sites other than fresh manure. Follow label directions and precautions when using oral larvicides and insecticides in the feed.

Manure Treatments

Manure treatment (larviciding), applied directly to the manure surface to control fly maggots, is discouraged because beneficial arthropods associated with manure can be killed. Also, adding extra moisture to the manure can result in additional fly breeding with increased fly resistance to insecticides. Effort should be made to keep all manure as dry as possible, less than 30% moisture, to greatly reduce or halt fly breeding. However, if manure cannot be kept dry or removed on a weekly basis, it is possible to use manure sprays.

Use a hoe or a trowel to sample the larvae present in manure before treatment. "Hot spots" with high larvae and egg counts can be spot-treated. Apply treatment sprays to wet the manure surface but do not soak. Repeat applications as necessary but not more often than once every seven days. Avoid widespread use of manure sprays, but treating the edges of a covered manure stack may be helpful. Do not apply where animals or birds can come in contact with treated manure. Follow mixing and application directions before use. Do not apply treated manure to crops not approved on the insecticide label.

Biological Control

Biological control is the reduction or mitigation of pests and pest effects through the use of natural enemies. Naturally occurring parasites (wasps) and predators (beetles and mites) in dry manure accumulations undisturbed over long periods of time attack and kill fly larvae and pupa stages. To encourage the establishment of natural enemies, farm operators should avoid excessive use of residual insecticides, especially synthetic pyrethroids.

Fly parasites are tiny wasps that kill fly pupae. They attack only fly pupae in manure and are so small (similar in size to gnats) that they go unnoticed by humans and livestock. Farmers can make frequent releases of small numbers of these beneficial wasps to augment their existing populations of beneficial insects. The wasp females seek out fly pupae, kill them, and then lay eggs within the dead pupae. These eggs hatch and mature into a new generation of beneficial parasitic wasps.

Fly parasites are useful for the control of house flies, stable flies, blowflies, and many other fly species. They cannot sting or bite humans or animals.

Advantages of fly parasites are ease of application and reduced need for chemical pesticides. Using fly parasites also prevents buildup of resistance to chemical pesticides, prevents immature flies from maturing to adult flies, and is cost-effective. With application, there is no equipment, no mixing, and no feed additives. Simply sprinkle them out of the bag onto the manure or staple the opened bag to posts or rafters near areas where fly breeding is a problem.

Although fly parasites are an integral part of a good Integrated Pest Management (IPM) program, insecticides will still play a role in your control program. Insecticide use should be restrained. If biological control agents are to significantly contribute to fly-control programs, they must be integrated with chemical control, manure management, and moisture control to best enhance the beneficial populations. If you have a serious adult fly problem now, it is recommended that you use natural pyrethrins to get the adult population under control before introducing fly parasites. Permethrin is highly toxic to parasites and should be used with caution.

Larvicide use should also be limited, because most larvicides will kill beneficial insects as well. However, if you have a “hot spot” of heavy fly larvae, larvicides can be used without inflicting much damage on the overall beneficial insect population. Insect Growth Regulator (IGR), such as cyromazine (Larvadex) approved for poultry operations, does not affect beneficial insects. It only kills the fly larvae. This is the only larvicide that does not

harm beneficial insects and can safely be applied to the breeding site without fear of destroying the beneficial insect populations. Sticky paper, tapes, or ribbons and bait traps will help reduce the adult fly population without hurting the natural enemies.

Weekly removal and spreading of manure disrupts the fly life-cycle and prevents new adults from emerging in and around the barn. Removing the manure also helps the parasitic wasps, which find fly pupae more easily if the depth of the manure is relatively shallow. Leaving some surface manure behind when you clean out will keep the new generation of wasps in the barn.

Flies have the ability to produce more eggs, produce a new generation in a much shorter period of time, and travel much greater distances than fly parasites. Consequently, it is best to release small amounts of fly parasites throughout the fly season rather than just one large release. Make weekly releases of 250 wasps per animal from mid to late May to August or September. Some farmers practice the release of 200 parasites per milking cow or 1,000 parasites per calf. Commercial farms that generate large quantities of manure should import fresh parasites weekly. For small farms, choose a biweekly, triweekly, or monthly schedule.

Many companies who sell parasites advertise their products in farm magazines but not all of them sell the right species adapted for the Ohio climate. Dairy farmers should purchase *Muscidifurax raptor* and avoid *Nasonia vitripennis*. Existing data indicates that in the Midwest the recommended species are as follows:

Fly Parasite Species**Flies Attacked*****Muscidifurax zaraptor*****House fly pupae preferred. Also attacks stable flies.**

Comments: *Muscidifurax zaraptor* stays nearer the surface where house fly pupae are more commonly found. Populations peak in summer, often July and August when the fly population peaks. This species is often the dominant parasitoid species in Midwest feedlots. Considered best against house fly pupae. Early season spring releases show promise. *M. zaraptor* moves out evenly from release sites, killing off concentrated house fly populations within 50 feet of release sites.

Muscidifurax raptor**House and stable fly pupae**

Comments: An outdoor species that also works indoors. *M. raptor* prefers dry, dark habitats and is active almost year-round, preferring cool temperatures and readily reproducing on late-season freeze-killed fly pupae. It has the potential to parasitize 20 fly pupae per day for one to four weeks. Early-season inundative releases have been helpful against house flies. *M. raptor* populations increase in late September and October when temperatures drop.

Spalangia nigroaenea**Stable fly pupae preferred. Also attacks house fly, horn fly, little house fly, dump fly, false stable fly, etc.**

Comments: Works well against both stable flies and house flies. *S. nigroaenea* digs deep into manure where stable fly pupae are found.

Parasite release costs are usually offset by reduction in insecticide treatments. In research trials, dairy farmers using fly parasites have made as much as 80% fewer insecticide treatments with 50% lower fly populations than with conventional insecticide control. There is still much to learn on using fly parasites most effectively in fly management programs.

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Mosquito Control

Water management that prevents mosquito breeding is essential for effective control. Eggs do not hatch unless they are in water. Locate standing water on premises and eliminate it if possible. Drain or fill stagnant water pools, puddles, ditches, or swampy areas around the facility. Tires, in particular, require special mention because they are ideal breeding places for vector mosquitoes. Stagnant ponds, which are highly septic, and waste lagoons also can be breeding areas for a large number of mosquitoes. Mosquito larvae live around the edges of ponds and waste lagoons. A waste lagoon with a heavy crust will shelter fewer mosquitoes than a waste lagoon with floating scum and floating debris. Excessive amounts of emergent aquatic vegetation will also shelter mosquitoes.

Follow these steps to reduce mosquito breeding areas:

- Remove tin cans, old tires, buckets, glass jars, and other water-holding containers.
- Clean out roof gutters so that water does not accumulate. Examine flat roofs after rains to

make certain that no water remains more than one week.

- Drain or fill stagnant water pools, puddles, and ditches or swampy areas around the farm.
- Place tight covers over cisterns, cesspools, septic tanks, fire barrels, rain barrels, and tubs where water is stored. Drain tarps and silage covers where water may collect.
- Drain tree holes and fill with Treekote and mortar.
- Keep the grass mowed around ponds and lagoons and other bodies of water, taking care to keep clippings out of the water. Maintain farm ponds and waste lagoons according to good management practices.
- Stock ponds and reservoirs with mosquito-eating fish, such as green sunfish, bluegills, guppies, or any surface-feeding minnow.
- Keep drainage ditches on property clean and flowing.

For more information on mosquito species and control procedures, including chemicals, refer to

Ohio State University Extension Bulletin 641, *Mosquito Pest Management*, <http://ohioline.osu.edu/b641/index.html>, or contact your local county Extension office.

Control of Rattailed Maggots (Syrphid fly larvae)

Frequently during the warm summer months, rattailed maggots are reported as a nuisance. These creatures are not a problem as long as they remain in the liquid manure pit; however, they are known to move out of the pit or lagoon in large numbers, contaminating livestock feed, accumulating in electrical boxes and causing short circuits, and congregating in stacks of egg cartons and other unwanted places. The maggots migrate to a drier place for pupation.

Rattailed maggots, known as the larval or immature stage of syrphid flies, are about 1-1/4 inches long. The body portion is about three-fourths of an inch long, and the tail portion (breathing tube) one-half inch long. These maggots are white-colored with the body portion an elongated, oval, cylindrical shape, which is wrinkled and semitransparent, protruding into a long breathing tube (tail).

These larvae of the Syrphid fly live in highly polluted water, such as livestock lagoons, abandoned fish pools, foul pools, and streams associated with barnyards, etc. Maggots are able to live in the water, if sufficient solids are present as food. The adult flies resemble honey bees in appearance and are often seen “hovering” near the ground in the barnyard. These flies do not bite or sting humans and are considered beneficial because they kill aphids.

Control Measures of Rattailed Maggots

Non-chemical treatment. Since this maggot breeds and feeds in highly polluted waters, efforts must be made to keep the lagoon in the optimum condition, promoting a more nearly ideal anaerobic condition. Never allow accumulations of manure above the water line, either floating or sticking to the sides, because these conditions enhance fly development. Keep the banks steep and weeds under control.

Use loose soil and construct a soil barrier between the milk house and the rattailed maggot source. As maggots migrate to the soil barrier, they

will dig into it to pupate rather than move into the milk house. Try to agitate the pit contents frequently during the spring and summer by pumping the pits routinely (at least once a week) to disrupt maggot development. Always maintain a waterline above the manure solids and clean out the pit contents on a routine basis.

Chemical treatment. Unfortunately, there are no good pesticide control measures. There has been some success by layering either Ravap or Larvadex larvicide on the liquid and manure surface. Read the label for application instructions and safety guidelines. For best results, do not agitate the pit contents after application. The pesticides are typically mixed with fuel oil, which clogs the long breathing tube of the rattailed maggot, similar to oils applied to the surface of stagnant, non-moving water to kill mosquito larvae.

Control of Rodents

Control of rodents around livestock structures is best accomplished by minimizing their access to a food supply. Farmers control rodents by proper storage of feed, proper disposal of spoiled feed, and limiting areas attractive as living quarters for rodents. The presence of rodents in enclosed livestock facilities can be minimized by proper design of structures and use of proper methods to eliminate rodents that do enter the facilities. Farmers must control rodents to minimize costs caused by feed loss, damage to livestock and feed structures, and spread of disease carried by rodents. Rats can get through a 1/2-inch hole, and mice only need 1/4 inch. Rats drink water three times a day and feed nocturnally twice a day.

Construction and Design

Rodent-proofing must include protective devices on pipes, electrical cables and conduits, drains, and other equipment where rodents travel. In addition to preventing access to buildings along these routes, attention must be given to reducing shelter and food and water sources that rats and mice use. Both rats and mice use drainage pipes or sewage systems as routes to enter buildings. Equip floor drains with metal grates fastened securely in place. Use grate openings that are 1/4 inch across or less.

Manure management systems in livestock facilities may be of a type where manure water is periodically drained from the building to a lagoon

or other storage area. Extend discharge pipes far enough over the bank or into the lagoon to prevent rodents from jumping or crawling into the open end. Install rodent shields or use a downward-turned elbow to prevent rodents from gaining access.

A “floating” metal cover at the open end of the discharge pipe, with a hinge at its upper edge, can also be effective. The hinge must operate easily so water or manure will open the cover, but the cover must fall back into the closed position when the flow stops. These covers sometimes freeze shut, so they must be checked regularly. Always cap pump-out ports for manure storage pits when they are not in use. When left open, they allow easy entry to rodents.

References

Bait Stations for Controlling Rats and Mice, (G94-1215-A), NebGuide, University of Nebraska. <http://ianrpubs.unl.edu/wildlife/g1215.htm>

Controlling House Mice, (G92-1105-A), NebGuide, University of Nebraska. <http://ianrpubs.unl.edu/wildlife/g1105.htm>

Controlling Rats, (G92-1106-A), NebGuide, University of Nebraska. <http://ianrpubs.unl.edu/wildlife/g1106.htm>

Rodent-Proof Construction, (G94-1217-A), NebGuide, University of Nebraska. <http://ianrpubs.unl.edu/wildlife/g1217.htm>

Chapter 10—Pathogens and Pharmaceuticals

Disease pathogens associated with livestock may be present in manure, and these pathogens may affect humans coming in contact with the animals or by the manure contaminating the human water supply. Some of the chemicals and drugs used for promoting animal health and performance may become mixed with animal manure. It is important to understand the potential areas of risk and then to minimize the potential for disease transmission or contamination of the water supply.

Pathogens

Controlling the presence of pathogens on a livestock farm is very important for the health and performance of the animals, profitability, and in minimizing the risk to human health. Four approaches to controlling pathogens on animal operations are:

- Minimize the risk of importing pathogens onto the farm (external biosecurity).
- Break the cycle of infection once the presence of a pathogen has been identified (internal biosecurity).
- Collect, handle, and treat manure and wastes appropriately to minimize the spread of the pathogen.
- Control the pathogen from being exported off the farm.

Many of the aspects relating to waste treatment and pathogen control have been discussed in detail in other chapters, especially as they relate to collection, storage, and land application of manure. Pathogenic bacteria require an adequate food source, appropriate temperature, and adequate moisture to survive. The survival of pathogenic bacteria that are found in manure can be lessened by providing a clean, dry environment in animal facilities.

Potential risk has been identified for the transfer of pathogens in the airborne dust particles from livestock farms, with most of the focus being on swine and poultry operations. Limited data are available to date on the concentration of bacteria in particulate matter from livestock farms and its relative risk to human health. See Chapter 8, *Odor and Dust Emission Control*, for more information on dust-control measures.

Animal Contact

Although a number of diseases are shared by both man and animals, many of them require specific conditions, such as a mosquito or tick bite, for their transmission. Examples of these include Lacrosse encephalitis, West Nile fever, and Lyme disease. Fortunately, the number of diseases that are transmitted from animals to man, either directly or by contact with animal manure, is rather small. These diseases are all infections caused by organisms classified as bacteria, viruses, fungi, or protozoa. The more important of these diseases are discussed here.

Bacteria

Brucellosis is also known as “undulant fever” in humans and is spread mainly by contact with aborted fetuses and milk. Although it was once a serious problem, brucellosis has been essentially eradicated in the United States through an active testing and monitoring program (<http://www.aphis.usda.gov/vs/ceah/ncahs/nsu/surveillance/bru.htm>). If brucellosis should occur in a herd, the infected herd is quarantined until all known infected animals are removed.

Bovine Tuberculosis is spread by aerosols and by contamination of food and the environment. Tuberculosis is also nearly eradicated from the United States. Human and bovine tuberculosis are caused by different bacterial strains. Whereas humans are susceptible (mainly through drinking water) to bovine tuberculosis, cattle are relatively resistant to the human form. Pasteurization of milk and meat inspection procedures have virtually eliminated the exposure of people to both brucellosis and bovine tuberculosis.

Salmonella, Campylobacter, and Escherichia coli are bacteria that inhabit the intestines of many animals and human beings. People usually get exposed to these bacteria by contamination of their food through unsanitary food processing or handling practices, contaminated water supplies, or by drinking unpasteurized milk. These bacteria are commonly involved in cases of food poisoning, and the source of the bacteria may be both infected animals and other humans. Pasteurization of milk, thorough cooking of foods, and routine water chlorination usually kills these bacteria, and it is often

post-treatment, or post-cooking, contamination that leads to illness in people.

Direct transmission of these pathogens to humans following contact with farm animals or farm environments can and does occur. This is of primary concern for high-risk groups, such as young children (less than five years of age), the elderly, and immuno-compromised individuals. Much of this risk can be mitigated with proper hygienic practices, such as hand washing.

Listeria is a bacterium that lives in the intestines of many types of animals and occasionally humans. It may be found in the milk of infected cows. Often it causes no harm, but the environment may become contaminated, thus leading to exposure of other animals and people. The bacteria can live in the environment for a long time, including the environment inside food-processing plants. Some outbreaks in people have been associated with contamination of food products in the processing plant where *Listeria* survived on inadequately sanitized equipment or in air-handling systems. Other outbreaks have been traced to improperly pasteurized milk or uncooked, or improperly cooked, foods.

Leptospirosis is caused by several species of the *Leptospira* genus of bacteria. These bacteria live in the urinary tracts of many species of animals, including rats, mice, dogs, raccoons, deer, and muskrats as well as cattle. Most people get exposed by direct contact with the urine of infected animals or by swimming or wading in ponds or other contaminated water sources.

Viruses

Rabies is the only virus of importance to mention here. It is transmitted by a bite or other direct contact with saliva from an infected animal, and all warm-blooded animals are susceptible. The reservoir for the virus in the United States is predominantly wild animals. Raccoons, skunks, foxes, and bats are the principal species involved. In the past decade, all human cases developing from exposures in the United States have been traced to bats. Livestock species are infected primarily through bites of wild animals, and humans are only at risk when they have close, direct contact with them. (See OSU Extension fact sheet VME-1-97, *Rabies Prevention in Livestock*, at <http://ohioline.osu.edu/vme-fact/0001.html>.)

Fungi

Ringworm is the common name for skin infections caused by a number of fungi. Athlete's foot is an example of a fungal infection unique to humans. Ringworm is most common in cattle and occasionally seen in horses and sheep. Transmission to humans occurs, but it is not common. The fungi that cause ringworm are spread by direct contact with the infected animal and by contamination of clothing and other objects, such as grooming equipment, with fungal spores. Although people occasionally become infected by contact with livestock, the general public is more at risk by contact with pet animals that may also carry various types of fungi.

Protozoa

Cryptosporidia and **Giardia** are found in the intestinal tracts of many species of livestock and other domestic animals, as well as human beings and some wild animals. People usually become exposed through contaminated food or water. It was once thought that these organisms were rather freely transmitted between animals and people. Newer scientific techniques have shown us that this may not be the case.

Although people can become infected by the strains of *cryptosporidia* that infect cattle, we now know that some people may harbor a strain transmissible only to other people. Since some of these newer scientific tools have become available, it has been suggested that most cases of cryptosporidiosis in people, where there are outbreaks, have come from other human sources.

Giardia can be found in some surface water supplies. Although chlorination of drinking water does not destroy these organisms, other water treatment processes, such as sand filtration required for municipal water systems, make the water safe. Properly sealed and maintained water wells should not be contaminated with these organisms.

Water Contamination

Most rural residents have private wells, but many rural and most urban residents obtain water from public wells, lakes, or streams. Organisms of primary concern for contamination of water supplies include *Salmonella*, *Campylobacter*, *E. coli*, *Leptospirosis*, *Cryptosporidia*, and *Giardia* (see previous section for discussion about each organism).

Well contamination is usually caused by surface water running into the top of the well or problems in the well casing that permit entry of contaminated water. If the well is properly constructed and is of adequate depth (*i.e.*, to bedrock), it should be safe. Local health departments can check wells for bacterial contamination.

Pathogens in manure tend to be retained at or near the soil surface. As a result, surface runoff is the primary cause of pathogen transport. Soil may retard and filter bacteria by their absorption to organic matter; thus soil may entrap bacteria during leaching events. Higher soil organic matter would promote more entrapment, and therefore, the organic matter content of the manure applied may impact movement of the bacteria. Finer textured soils are more likely to entrap bacteria. Also, grass buffer strips are quite effective at filtering out pathogens.

The Environmental Protection Agency (EPA) requires municipal water systems to have filtration systems in-place, which, when functioning properly, will remove cryptosporidia oöcysts. While chlorination will not kill *cryptosporidia*, it is very effective in killing bacteria, such as *E. coli* and *Salmonella* spp.

Pharmaceuticals

Antibiotics

Antibiotics are primarily administered to animals either by addition to feed or by injection. Antibiotics in the feed that are not absorbed will be excreted in the manure. Absorbed antibiotics or injected antibiotics are generally metabolized and the resulting metabolites excreted in urine (these metabolites do not function as antibiotics). Therefore, antibiotics can enter the manure storage facility from discarded feed with antibiotics, manure from animals receiving antibiotics, dumped milk from treated dairy cows, and footbaths (see the section on footbaths). Antibiotics in the manure are in very low concentration and likely will be denatured in vegetative buffer strips and in soil. The highest risk for antibiotics getting in the water supply is caused by runoff directly into a water source. Judicial use of all medications for animals is expected, and antibiotic usage will continue to be under close scrutiny.

Milk from dairy cows treated with antibiotics, most commonly for an udder infection known

as mastitis, must be discarded for the number of milkings described on the product's label. Although only a single quarter may be infected and treated on a cow, the milk from all four quarters must be discarded for the specified withholding time period. Antibiotic testing kits are available to farmers to test questionable milk. Generally speaking, antibiotics are not used extensively or indiscriminately on dairy farms; thus, dairy farms are unlikely to be a source of water contamination by antibiotics.

Footbaths

Footbaths are commonly used for cattle, especially dairy, and sheep to control foot rot and other infectious foot diseases. The most common product used in the footbath is copper sulfate (usually mixed to provide a 5% solution), but antibiotics and formalin may sometimes be included in the solution. The frequency of usage is variable, but the animals may be required to pass through the shallow bath several times per week during selective times of the year. The bath becomes contaminated with manure, and a new solution is mixed periodically. Another footbath with just water or mild detergent solution prior to the medicated one will help to extend the life of the solution and increase the effectiveness of the medicated footbath.

The contents of the footbath are usually emptied into the manure-storage facility. A footbath 6 ft x 34 in x 6 in (3.4 cu ft) at 75% capacity (2.5 cu ft) will contain about 18.5 gallons of solution. Although this amount of solution mixed into a manure-storage facility will usually result in negligible increases in the concentration of copper and the other compounds in the manure, awareness of this risk is important.

Milking Parlor Wastes

Detergents and acidic chemicals are used in milking parlors to wash and sanitize equipment. Also, chemical solutions for disinfecting teats to prevent the spread of mastitis are used at each milking, with most farms dipping teats before and after milking. The primary active ingredients used in the products include chlorhexidine, iodine, linear dodecyl benzene sulfonic acid, and sodium hypochlorite, among others (<http://www.nmconline.org/docs/Teatbibl.pdf>). For more information about the disposal and handling of milking parlor wastes, see Chapter 3, *Manure-Management Systems*.

References

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Other Manure Considerations

Chapter 11—Economic Considerations of Manure Handling

When properly managed, manure nutrients can be a valuable resource for the farm; however, failure to manage these nutrients wisely may hurt farm income, land, water, and air resources. Presented here is an overview of the market and non-market costs and benefits that producers should address before investing in a manure-handling system. Estimates of the market costs and benefits are provided for representative operations.

Often, manure storage is necessary to efficiently utilize available nutrients for growing crops and to minimize adverse environmental impacts. Yet, storage is only one component of a manure-handling system. Considered here are the costs of owning and operating a manure-handling system. A manure-handling system is defined as the structures, equipment and labor required to handle and/or store manure for an extended period of time (Table 20).

The benefits of a manure-handling system are realized when manure nutrients are used as a replacement for commercial fertilizers. Manure, depending upon the animal, contains 70 to 80% of the nitrogen, 60 to 85% of the phosphorus, and 80 to 90% of the potassium fed (Klausner, 1989). Recycling these nutrients through growing crops can benefit the farm operation and the environment.

Off-Site Impacts

Properly managed feedlots, manure stacks, and manure spreading can minimize run-off and the magnitude of other off-site impacts. Nutrient rich waters promote excessive algae and aquatic plant growth which can reduce wildlife habitat, recreational activities, and can increase downstream water-treatment costs. In addition, bacteria and other pathogens may enter surface waters with run-off, causing health concerns for end users. The cost for water treatment alone can be staggering. For example, a water filtration plant capable of minimizing the potential contamination of *Giardia* cysts and viruses in the source waters for New York City was estimated to cost between \$3 and \$8 billion to build and an additional \$300 million to operate each year (Platt, 2000).

Over application of manure nutrients is costly for animal producers. Excess nutrients beyond the crops' need provides no additional yield response, and increases the risk these nutrients will move off-site (Chapter 3, *OSU Agronomy Guide, Tri-State Fertility Guide*). Manure nutrients should be applied where they can be fully utilized by growing crops, increasing yields and reducing potential risks to the environment. The value of manure, as a nutrient resource, is only realized when manure is substituted for fertilizer. To do so, can increase farm profit.

Manure handling systems are unique to each operation and the individual management style. There are many factors to consider before selecting a system. Is there enough equipment and labor available to operate the system at critical times of the year? How well does the system control odors (Chapter 8, *Odor and Dust Emission Control*)? Can this operation best handle manure in liquid or solid form (Chapter 3, *Manure-Management Systems*)? What is the initial capital requirement? How will changes to the current manure-handling practice impact the demand for labor and equipment, and ultimately farm profits?

Characteristics of a Manure-Handling System

Four general characteristics define a manure-handling system. These are structural, equipment, nutrient, and labor (Table 20). Three of these characteristics—structural, equipment, and labor—define the costs of owning and operating the system. Nutrient characteristics define the benefit of manure when utilized as a substitute for purchased fertilizer.

Table 20. Characteristics of a Manure-Handling System.

Characteristic	Attribute
Structural	Type of structure.
	Design size (volume).
	Cost of construction.
	Cost of secondary structures.
	Useful life.
	Interest rate.
	Insurance.
Equipment	Type of equipment.
	Size of equipment.
	Cost of equipment.
	Hours of use.
	Cost to own and operate.
	Hauling distance.
	Safety.
	Custom applicators.
Labor	Hours required.
	Cost per hour.
	Peak demand.
	Availability.
Nutrient	Concentration.
	Crop rotation.
	Land available and soil nutrient levels.
Other considerations	Odor management.
	Hauling distance.
	Cost of current system.
	Management requirements.
	Future needs.
	Manure contracts.
	Type of bedding used.
	Good neighbor issues.

Structural Characteristics

Each system begins by sizing the manure storage structure (Chapter 3). Not only do the number and type of animals determine the volume requirements, but also the total desired or needed storage period, the inclusion or exclusion of feedlot run-off,

milking center wastewater, silage leachate, rainfall, availability of land, as well as other factors.

Your local Natural Resource Conservation Service can provide guidelines to accurately size a manure storage structure to meet current needs as well as planning for the future. In some cases, push-off ramps, reception pits, liners, and other secondary structures must be built to make the system operational. These additional structures add to the initial cost of the manure storage structure and impact the total cost of owning and operating the system.

Equipment Characteristics

The storage structure is only one aspect of the manure-handling and storage system. Each system requires equipment to move manure into and out of the holding structure. It is necessary to include the cost of owning and operating this equipment as a cost of the manure-handling system. Ownership and operating costs for the equipment include depreciation, interest, insurance, housing, and taxes as well as maintenance, repair, fuel, oil, and labor. The sum of these costs, on an annual basis, is the annual cost of owning and operating the manure-handling system.

Each system requires equipment to transport manure from the storage structure to the field for application and nutrient utilization. Some systems require a substantial investment in specialized equipment while others may more fully utilize existing equipment. An important question to ask—Is there sufficient equipment available to handle manure in a timely manner? For example, to move 1.4 million gallons of manure from a holding pond with a 3,000-gallon tanker will require more than 450 loads. Can your operation meet this kind of demand on labor and equipment when demand on labor and equipment is already high? For example, manure hauling prior to planting and/or during harvest to fully utilize available nutrients.

Alternatively, custom applicators specializing in manure application are available for hire. However, several important questions must be addressed. First, can a quality applicator be hired when the farm needs to apply manure nutrients? Will manure nutrients be applied when and where they are needed and in an environmentally responsible manner? Is it cost effective?

Labor Characteristics

Labor requirements must be understood prior to investing in a system. Storing manure for extended periods can provide many advantages, but it also presents many challenges. For many operations, manure is frequently collected, and transferred into storage. This routine continues for months until the storage structure becomes full, at which point, dedication of labor and equipment is required to empty the holding structure.

Expanding upon the previous example, hauling two loads of manure per hour will require over 230 hours per year to haul 1.4 million gallons of manure. That is more than four weeks of continuous hauling each year. Furthermore, these labor requirements may coincide with spring planting, summer forage production, fall harvest, and fit within a narrow window of suitable soil moisture. Can your operation function under these constraints? Will additional labor be required and if so, is it available?

Nutrient Characteristics

Contained within the manure holding structure is a “reserve” of nutrients that can reduce the need for purchased fertilizer. A laboratory analysis may be used to determine the nutrient content of manure in the holding structure. Local Extension offices have guidelines for collecting and shipping manure samples for nutrient analysis. Alternatively, guidelines for average manure nutrients can be obtained from this publication (Chapter 1, *Manure Characteristics*). Using this information, the total quantity and value of each nutrient can be determined for the volume of manure produced.

To maximize the value of manure, it should be applied at rates that meet the nutrient requirements of growing crops, assuming other factors such as a limiting nutrient, slope, leaching, and run-off potential are not more restrictive (Chapter 6, *Land Application of Manure*). Generally, the limiting nutrient is phosphorus, but it may be nitrogen or potassium in some situations. Nutrient utilization plans should be developed and followed to maximize the benefits of manure and minimize the potential for environmental damage.

Other Considerations

Odors

Manure, especially odors associated with manure, readily move off-site, and in some situations become a nuisance to those downwind. These impacts are real and can negatively impact the farm’s long-term viability. This impact can be measured as a change in perceptions of how well the farm is managed (goodwill), quantified as legal fees accumulate defending civil action suits, or as a change in the value of neighboring properties. Regardless, the producers may pay awards from a civil action suit and incur the costs associated with implementing odor-reduction technology. Odor-reduction technology can be costly, depending upon the extent of odor control desired. Generally, it becomes more costly to remove increasingly more and more odor. An overview of odor control technologies is provided in Chapter 8, *Odor and Dust Emission Control*.

Hauling Distance

Hauling distance is influenced by factors such as land availability, crop rotation and nutrient need, current soil nutrient levels, slope, and the potential for manure entering water resources. In addition, distance from neighbors and public-use facilities should be considered. These factors should be assessed to determine which fields are used for manure application, which will determine the distance manure is hauled.

Hauling distance may be a significant factor influencing the manure-handling system decision. As animal density per acre of land increases, manure must be moved greater distances if soil nutrient levels are to remain in balance. Generally, liquid manure can be handled efficiently when moved relatively short distances. However, solid manure has a higher nutrient density and can be hauled greater distances more economically than dilute liquids.

Manure-Handling Systems

Outlined here is a daily hauling system that handles manure as a semi-solid. This system is followed by three alternative manure-handling systems, which differ by the volume of manure and wastewater stored and the method used for ma-

nure application. Two of the liquid systems use an earthen holding pond to store animal manure and all wastewater sources. These two systems differ primarily by the total capacity of the storage structure desired. The fourth system handles manure as a semi-solid and diverts wastewater from other sources into a settling basin with a vegetative filter area for treatment. *This analysis includes the cost of the secondary structures needed to make each system work and is sized for 100 lactating dairy cows weighing 1,400 lb each, on average.*

Daily Haul

Often, a daily haul system will have little or no manure storage capacity beyond what accumulates in the barn and/or in the spreader. Handling manure from this type of confinement system requires a tractor, box spreader, and loader. Manure is scraped directly into the box spreader and transported to the field for spreading daily or very frequently. The total cost of owning and operating this type of system for 100 lactating dairy cows is about \$18,000 per year (Table 21) which includes a vegetative filter area to treat feedlot run-off, silage leachate, and milking center wastewater (Chapter 5, *Farmstead Runoff Control*).

One hundred lactating dairy cows generate about 2,700 tons of manure (including bedding) each year. The nutrient value of this manure is estimated to be about \$12,100 when valued at commercial fertilizer rates. In 2001 Ohio farmers paid \$0.29/lb of nitrogen, \$0.25/lb of phosphorus, and \$0.14/lb of potassium (Ohio Department of Agriculture, 2001). The net cost (cost of owning and operating equipment plus the cost of owning and operating settling basin less the value of the manure nutrients) for this type of manure handling is expected to be about \$6,000 per year (\$59 per cow per year).

Often dairy operations of this size will keep cows on pasture for six months of the year. This practice reduces the annual cost of manure handling. For these operations, about 1,350 tons of manure would be hauled during periods when animals are confined (six months). During the time animals are on pasture, it is assumed that all manure generated during this period is distributed on the pasture, and the nutrients are utilized by the growing crop. Any supplemental fertilization of

the pasture accounts for the addition of the manure nutrients. This system is expected to have an annual cost of owning and operating of about \$3,700 per year (\$37 per cow per year).

Table 21. Estimated Cost for Two Daily Haul Systems.

	Daily Haul (365 day)	Daily Haul (180 days)
Tons of manure hauled	2,700	1,350
Total cost	\$18,000	\$15,800
Nutrient value	\$12,100	\$12,100
Net cost	\$5,900	\$3,700
Cost per cow per year	\$59	\$37

Manure and Wastewater Storage

Alternatively, animal manure can be stored for an extended period of time and applied when growing crops can more fully utilize available nutrients. Three systems are presented that utilize varying manure storage strategies (Table 22).

Two liquid manure-handling systems store all sources of manure and wastewater in an earthen holding structure. These two systems differ by the number of days animals are confined which affects the total number of days of storage needed during the year. One liquid system is designed for a total confinement facility desiring 365 days of storage for all animal manure and sources of wastewater (feedlot run-off, silage leachate, and milking center wastewater). The second liquid-manure system is designed for a pasture-based dairy which confines animals for about 90 days of the year.

The final system handles manure as a solid, semi-solid, and excludes all sources of water. The covered holding structure excludes rainwater. Feedlot run-off, milking center wastewater, and silage leachate are diverted into a holding pond which is periodically land applied (90 days). The cost of these secondary structures are included in this analysis.

Nutrient Benefits

Recycling excreted nutrients is one benefit of manure that is easily quantified. A simple manure analysis or estimate of available nutrients can be used to value manure using current market prices of the nutrients it will replace. Shown in Table 23 are the expected quantities of each nutrient—nitrogen, phosphorus, and potassium—contained in each manure storage structure (one-time capacity). The total value of these nutrients are based upon the average price paid by Ohio farmers for commercial fertilizer: \$0.29, \$0.25, and \$0.14 per pound of nitrogen, phosphorus, and potassium, respectively (Ohio Department of Agriculture, 2001). Animal manure nutrients can vary considerably and are dependent upon the animal and the feeding program. Laboratory testing of animal manure is recommended to better quantify available nutrients.

The nutrient benefits of manure nutrients are only realized when they are used as a substitute for purchased fertilizer. In many situations, excess nutrients have accumulated in the soil from years of over application. Nutrients beyond what are required for the growing crop will provide no additional yield. These excess nutrients should be considered an additional cost of production. That is, these nutrients could be better utilized where a crop response would be achieved by replacing additional purchased nutrients. Here it is assumed that manure nutrients are fully utilized, and the value of this nutrient resource reduces the cost of owning and operating the manure-handling system (Table 23). If manure nutrients are applied on soils already saturated with nutrients, the nutrient benefit will not be realized. Thus, the cost of owning and operating the manure-handling system increases.

Table 22. Manure Handling and Storage System Overview.

365-Day Liquid-Manure System (1,400,000 gal)	180-Day Liquid-Manure System (700,000 gal)	90-Day Solid-Manure System (675 ton)	365-Day Daily Haul (2,700 ton)
Designed for: <ul style="list-style-type: none"> • Animal manure • Milking center wastewater • Feedlot runoff • Silage leachate • Rainwater 	Designed for: <ul style="list-style-type: none"> • Animal manure • Milking center wastewater • Feedlot runoff • Silage leachate • Rainwater 	Designed for: <ul style="list-style-type: none"> • Animal manure Holding pond: <ul style="list-style-type: none"> • Feedlot runoff • Milking center wastewater • Silage leachate • Rainwater 	No storage beyond barn accumulation and spreader capacity. Settling basin + filter area: <ul style="list-style-type: none"> • Milking center wastewater • Silage leachate • Feedlot runoff

Table 23. Summary of Nutrient Benefits by System.*

Nutrient	365-Day Liquid System	180-Day Liquid System	90-Day Solid System	365-Day Daily Haul
Total Nitrogen (lb)**	30,300	15,150	7,575	30,300
Total P ₂ O ₅ (lb)	15,200	7,600	3,800	15,200
Total K ₂ O (lb)	17,200	8,600	4,300	17,200
Total value	\$12,100	\$6,050	\$3,025	\$12,100

* Assumes a one-time capacity or annual value for daily haul.

** Assumes 50% of total nitrogen is organic, and one-third of organic nitrogen is available in the year it is applied.

Equipment Characteristics

Manure nutrient utilization requires that manure be land applied at critical times of the year. Ideally, this is when a growing crop is available to utilize available nutrients. This, in turn, requires that equipment be available for spreading (Table 24). Generally, manure is transported to the field by tractor-drawn spreaders, but manure can be pumped directly by means of irrigation equipment to a drag-line system. Tractor-drawn transport generally takes less equipment than does the drag-line. As more equipment is required, the annual cost of owning and operating the equipment also increases.

Comparison of Manure Handling Systems

The bottom line for most decisions is what it will cost. Table 25 summarizes the costs and benefits of each system outlined, using different storage capacities and land-application practices for a 100-cow dairy. Outlined are the annual costs associated with owning and operating the manure-holding structure, any secondary structures necessary to make the system operational, and equipment necessary for land application.

A range of values is given for those systems that are designed for less than one year storage; these values are based on the one-time capacity and annual use of the system. In other words, some operations may only store manure to satisfy the one-time capacity each year while others may use the system for year round confinement. For example, a solid manure system sized for 90-day storage is expected to cost about \$19,000 per year, while this same system used for 365 days is expected to cost about \$22,500 per year. Basically, this reflects the cost of equipment and labor needed to move the manure out of storage three additional times each year.

For each system, equipment has been identified (Table 24), and the cost of owning and operating this complement has been estimated. Again, a range of values is presented and represents the estimated cost of owning and operating the equipment for the design capacity and for 365 days of storage. For example, the yearly cost of the equipment necessary to make the 180-day liquid-manure storage systems operational is expected to be between \$20,500, if the system is filled only once per year, and \$25,500, if it is filled and emptied twice per year.

Each manure-storage structure contains some quantity of manure nutrients. The value of these nutrients is shown and is calculated based on estimated nutrient content for the one-time volume of manure in storage. Manure nutrients were valued as commercial fertilizer and reduce the cost of owning and operating each system (system maintenance + annual cost of structure + application cost - nutrient value / 100 cows = per-cow cost of owning and operating the system).

Shown is a range of nutrient values (Table 25) reflecting the one-time storage capacity of the structure through full utilization, *i.e.*, store manure 365 days a year. The value of manure nutrients assumes these nutrients are fully utilized by the growing crop. If manure nutrients are applied in excess of the crop needs and there is no benefit to storing these nutrients in the soil profile, the value of these nutrients is greatly reduced. In some situations, manure applied where soil nutrients are in excess will increase the potential that these nutrients will leach, move off-site, and become an environmental hazard.

The liquid-manure system stores all sources of wastewater, run-off, silage leachate, and rainfall in an earthen holding pond. One system has storage

Table 24. Equipment Requirements and Land Application Options.

Liquid Manure (broadcast)	Semi-Solid Manure (broadcast)	Liquid Manure (injection)
		Drag-line
Liquid tanker	Box spreader	Tractor 1
Tractor 1	Tractor 1	Tractor 2
Tractor 2	Skid loader	Utility tractor
Utility tractor		Chopper pump
Chopper pump		Toolbar
		Irrigation equipment

capacity for 365 days and is expected to cost upwards of \$200 per cow per year, depending on the land application option used (Table 25). Conversely, the liquid system that has 180 days of storage is expected to cost upwards of \$166 per cow per year.

The semi-solid manure-handling system excludes all additional sources of water, including rainwater. However, this system has a high capital-

investment requirement because of the building materials used, increased water exclusion requirement (roof), the need for a secondary wastewater treatment structure, and associated handling equipment. This system stores manure for 90 days and has an expected cost of about \$125 per cow per year, depending on land-application options and the extent the structure is utilized.

Table 25. System Summary.

	365-Day Liquid System	180-Day Liquid System	90-Day Solid Manure	365-Day Daily Haul
One-Time Capacity ¹	1.4 M gal	700K gal	675 ton	2,700 ton
System Maintenance ²	\$500	\$275	\$817	\$100
Annual Cost of Structure ³	\$3,200	\$1,900	\$6,300	\$1,150
Application Costs/Storage Capacity				
Tanker/spreader ⁴	\$27,000	\$20,500-\$25,500	\$11,900-\$15,400	\$16,700
Drag-line ⁵	\$28,000	\$22,400-\$24,618	NA	NA
Custom applicator ⁶	\$8,400	\$4,200-\$8,400	\$1,300-\$5,200	NA
Nutrient Value/Storage Capacity				
All nutrients (N,P,K) ⁷	\$12,100	\$6,050-\$12,100	\$3,025-\$12,100	\$12,100
Cost to Own and Operate Storage and Handling System per Cow/Storage Period				
Tanker/spreader ⁸	\$186	\$156-\$166	\$104-\$125	\$59
Drag-line ⁹	\$196	\$125	NA	NA
Custom applicator ¹⁰	\$0	(\$15) - \$3	\$2-\$54	NA

¹ Maximum one-time design capacity of storage structure.

² Annual estimated cost to maintain structure (2% of total cost).

³ Annual ownership cost includes interest, depreciation, and insurance. Includes settling basin and vegetative filter area required for milking center wastewater, feedlot run-off, and silage leachate; system includes liquid holding pond for milking center wastewater, feedlot run-off, and silage leachate (46,000 gal/90 day).

⁴ Assumes a 5,000 gallon tanker is used; equipment compliment identified in Table 24. Each load requires 30 min. to load, travel to field, unload, and return to storage structure.

⁵ Drag-line uses irrigation equipment and continues application of manure.

⁶ Custom applicator is available and provides all equipment necessary for land application (see note 10 for cost assumptions).

⁷ Manure nutrients are valued equal to commercial fertilizer and valued at \$0.29, \$0.25 and \$0.14 per pound of nitrogen, phosphorus, and potassium, respectively (Ohio Department of Agriculture, 2001). Value for animal manure nutrients based upon one-time capacity and 365-day storage.

⁸ Estimated cost of using tractor-drawn 5,000-gallon liquid tanker or 12-ton box spreader.

⁹ Estimated cost of using a drag-line system to apply liquid manure.

¹⁰ Based upon \$6/1,000 gal or \$1.50/ton of manure applied in an environmental sound manner.

Selected References

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Chapter 12—Technical Services

Ohio State University Extension (OSU Extension)

The Ohio State University and Ohio State University Extension (OSU Extension) provide a wide range of research-based educational programs. Information used in many of the education programs and publications come from Ohio State University, the Ohio Agricultural Research and Development Center (OARDC), the U.S. Department of Agriculture, and affiliated agencies and organizations. Information from these resources is available through professional Extension educators in each county and through state specialists.

Efforts of OSU Extension in livestock waste management involve assembling facts and research from various sources. This information provides farmers, industry, organizations, government agencies, and concerned citizens with a wealth of information that can be supported with sound science and research. The primary objective of OSU Extension is to provide Ohio's citizens with objective research-based information (visit <http://www.extension.osu.edu> for more information). Access to OSU Extension fact sheets and bulletins can be found at <http://ohioline.osu.edu>.

Ohio Department of Natural Resources, Division of Soil and Water Conservation (ODNR-DSWC)

The Ohio Department of Natural Resources, Division of Soil and Water Conservation coordinates the activities of local Soil and Water Conservation Districts. The Ohio Department of Natural Resources, Division of Soil and Water Conservation encourages livestock owners and operators to follow the required levels of operation and management for pollution abatement.

Chapter 1511 of the Ohio Revised Code gives the Ohio Department of Natural Resources, Division of Soil and Water Conservation regulatory authority and responsibility for controlling water pollution from concentrated animal feeding operations. ODNR-DSWC may be contacted at 4383 Fountain Square Drive, Bldg. B-3, Columbus, OH

43324 or at the web site: <http://www.dnr.state.oh.us/soilandwater>.

ODNR-DSWC also implements several pollution abatement cost-share programs available to Ohio's animal operations. A listing of cost-share programs available to Ohio's agricultural producers can be obtained through local Ohio State University Extension offices or Soil and Water Conservation and Natural Resources Conservation Service offices. OSU Extension fact sheet AE-1-97, *Incentive Programs for Improving Environmental Quality*, is available at <http://ohioline.osu.edu/ae-fact/0001.html>.

Soil and Water Conservation Districts (SWCD)

Each Soil and Water Conservation District, through its agreements with Ohio State University Extension, the USDA-Natural Resources Conservation Service, the ODNR-DSWC, and other pertinent agencies, provides information, technical assistance, and cost-share assistance to owners and or operators of animal-feeding operations regarding animal waste pollution abatement. SWCD offices are located in each county.

It is recommended that animal producers consult with their local SWCD office regarding environmental management issues. These would include such areas as soil and water conservation, animal manure management, wildlife and woodland management. Additional information can be found at the ODNR-SWCD web page: <http://www.dnr.state.oh.us/soilandwater>.

United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS)

The Natural Resources Conservation Service, an agency of the U.S. Department of Agriculture, provides technical assistance to land users for planning, design, and construction of various environmental management systems. The agency also provides cost-share assistance through USDA Farm Bill programs.

The systems are designed to contain solid and liquid manure and wastewater and manage storm-water runoff from areas with heavy concentrations of animals. Storage and disposition of the manure is managed so as not to degrade resources such as air, soil, and water.

The Natural Resources Conservation Service also assists landowners by providing plans and other data needed to obtain approval for such projects and systems.

Information regarding agricultural waste-management systems and technical assistance is available from local Soil and Water Conservation District offices upon request. Additional information can be found at Ohio's NRCS web page at: <http://www.oh.nrcs.usda.gov>.

Ohio Department of Agriculture (ODA)

The Ohio Department of Agriculture, under legislation passed in December of 2000 (ORC 903) and rules promulgated in June of 2002 (OAC 901:10), assumed authority for issuing permits to install and permits to operate for livestock facilities of greater than 1,000 animal units. ODA's Livestock Environmental Permitting Program may be contacted at 8995 East Main Street, Reynoldsburg, Ohio 43068. Additional information is available on the web site at <http://www.ohioagriculture.gov/lepp>.

Private Consultants

The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) and local Soil and Water Conservation District offices provide conservation planning and technical assistance to agricultural producers and others who make natural resource management decisions. Private consultants are qualified individuals who also offer this type of assistance. Producers are not required

to use private consultants, but they have this option for help with their conservation plans.

Conservation assistance includes both planning and technical assistance. Planning involves combining a variety of natural resource issues into a conservation plan. Technical assistance helps agricultural producers address natural resource problems and concerns on their land. Examples of technical assistance include design, layout, design modification, installation, inspection, and maintenance of conservation practices and systems dealing with natural resource management. Planning must be completed before technical assistance is provided.

For more information, contact your local USDA-NRCS, Soil and Water Conservation District, or Ohio State University Extension office.

Other Resources

Livestock Environmental Assurance Program (LEAP)

Available online at <http://www.ohleap.org> or by phone at 614-246-8288.

Ohio Livestock Coalition (OLC)

Available online at <http://www.ohiolivestock.org> or by phone at 614-246-8288.

MidWest Plan Service (MWPS) publications

Available online at <http://www.mwpshq.org> or by phone at 800-562-3618.

Natural Resource, Agriculture, and Engineering Services (NRAES) publications

Available online at <http://www.nraes.org> or by phone at 607-255-7654.

Chapter 13—Rules and Regulations

In Ohio animal-waste pollution-abatement programs are administered by the Ohio Department of Agriculture (ODA) and the Ohio Department of Natural Resources, Division of Soil and Water Conservation (ODNR-DSWC).

Legislative action in Ohio, effective Jan. 12, 1979, and revised in 1991, created the Agricultural Pollution Abatement Program and gave authority to the ODNR-DSWC to develop standards for livestock waste management, respond to complaints, and issue orders to control pollution from animal waste. It also created a state-funded agricultural pollution abatement cost-share program. This legislation is found in 1501:15-5-01 through 18 of the Ohio Administrative Code.

The Chief of the ODNR-DSWC, as required by law, adopted rules establishing state standards and procedures for the abatement of water pollution by animal manure. These standards are presented in the ODNR-DSWC Agricultural Pollution Abatement Rules available from the DSWC and local Soil and Water Conservation Districts (SWCD). The standards reference practices that are discussed in this bulletin and in the USDA-Natural Resources Conservation Service (NRCS) *Field Office Technical Guide*. They are used to determine if water pollution problems exist. They can also be used to plan acceptable abatement practices and develop an appropriate management program to prevent or eliminate a water pollution problem.

The adoption of approved operation and management plans with proper documentation of implementation can offer an affirmative defense against nuisance suits for the livestock producer using Best Management Practices. The Agricultural Pollution Abatement Rules do not apply to air pollution (odors and dust) from animal-feeding operations.

The DSWC, in cooperation with local SWCDs, offers assistance in determining whether a situation is considered a pollution problem, based on the use of or failure to use appropriate management practices to abate the degradation of waters of the state. Technical and financial assistance is available to help owners and operators develop and evaluate alternatives for solving pollution problems and to help implement appropriate practices and develop

related management plans to operate facilities without polluting waters of the state.

The DSWC may cost share with private owners and or operators to solve water pollution problems from animal waste. State funds may be used on eligible projects to pay up to 75% of the cost of eligible pollution abatement practices, up to a maximum of \$15,000 to solve a water pollution problem. In addition, federal funds are available through the USDA-Natural Resources Conservation Service Environmental Quality Incentives Program (EQIP). Producers can access these funds by contacting their local SWCD.

Enforcement authority for controlling violations of the state standards for animal waste pollution abatement also rests with the Chief of ODNR-DSWC. When local information, education, technical assistance, and applicable financial assistance provided by the local SWCD fail to bring a solution to an animal waste pollution problem, the Chief may issue a Chief's Order.

In instances where a violation of a standard established under division (E) of section 1511.02 of the Revised Code causes pollution of the waters of the state, the Chief may apply to the court of common pleas in the county where the violation exists for an order to compel the violator to cease the violation and to remove the agricultural pollutant or to comply with the rules.

If the Chief should determine that an emergency exists because of an unauthorized release, spill, or discharge of animal waste, or a violation of a rule adopted under division (E) of section 1511.02 of the Revised Code that causes pollution of the waters of the state, the Chief may, without notice or hearing, issue an order requiring that immediate action be taken to meet the emergency. Any person responsible for causing or allowing an unauthorized release, spill, or discharge is liable to the Chief for any costs incurred by the Division and SWCDs in investigating, mitigating, minimizing, removing, or abating the release, spill, or discharge.

Livestock mortality composting became legal in Ohio, in August of 1994, with the passage of Senate Bill 73, the Dead Animal Composting Bill. The ODNR-DSWC regulates livestock mortality

composting through Ohio Administrative Code (OAC) Chapter Rules 1501:15-5 adopted under ORC Section 1511.022. Rule 1501:15-5-18 of the OAC spells out what is required to be in compliance with the law. This rule is intended to prevent water pollution by livestock mortality composting. It does not address “nuisance issues” such as odors, dust, noise, or flies. It is enforced by the DSWC working through county SWCDs on a complaint basis, as are all of the Agricultural Pollution Abatement Rules. Producers wishing to compost livestock mortalities are required to receive certification training through OSU Extension.

SB 141 created the Livestock Environmental Permitting Program in the Ohio Department of Agriculture and provided for rules, funding, and staffing to require both Permits to Install, Permits to Operate, and eventually the delegation of the issuance of Federal NPDES permits to be issued by ODA. This statute transferred permitting authority from OEPA to ODA for livestock facilities.

For the purposes of determining the need for a Permit to Install or Permit to Operate, all large Concentrated Animal Feeding Operations (CAFOs) must have a state permit. (Previously, the U.S. Environmental Protection Agency used the term animal unit to determine the number of animals required for permitting, but in February 2003, the term animal unit was dropped.) A large CAFO is defined as 700 mature dairy cows, 1,000 beef cattle or heifers, 2,500 swine each 55 pounds or more, 10,000 swine each less than 55 pounds, 125,000 chickens except laying hens, 82,000 laying hens, 1,000 veal calves, 30,000 ducks, 5,000 ducks with a liquid manure-handling system, 30,000 chickens with a liquid manure handling system, 500 horses, 10,000 sheep or lambs, and 55,000 turkeys.

If a facility meets the definition of a large CAFO, it is also considered a Confined Animal Feeding Facility (CAFF), and a facility with more than 10 times the number of animals as a large CAFO is a Major Confined Feeding Facility (MCAFF) by definition in ORC 903. If the facility has more than the number of animals to be a large CAFO the owner must apply to and receive from ODA a Permit to Install and a Permit to Operate.

Regardless of the number of animal units involved, if the animal facility involves a waste-

management system having a controlled discharge to waters of the state or a permitted CAFF designed to operate with no discharge has a discharge to waters of the state, then a NPDES (National Pollution Discharge Elimination System) permit is required by the Clean Water Act and by state law. Storage or treatment facilities must be constructed and operated so that no overflow will occur, except from precipitation in excess of a 25-year, 24-hour storm. Currently the NPDES permits are issued by Ohio EPA until delegation of this federal permit is transferred to ODA. This is anticipated to happen sometime in 2005.

Ohio Revised Code Chapter 903 prohibits discharge of waste material directly into waters of the state and is regulated by ODA. This law applies to any discharge of wastewater to waters of the state from livestock operations of any size. ODA conducts routine inspections of all permitted facilities and will conduct complaint investigations involving manure run-off or discharge, insect complaints, and odor complaints for permitted farms only. Anyone found to be discharging pollutants to the state’s water without a valid permit might be liable for civil penalties of up to \$10,000 for each day of violation (Ohio Revised Code 903.16 and Ohio Administrative Code 901:10-5-04).

The Ohio Department of Natural Resources, Division of Wildlife, is mandated by sections 1531.02 and 1531.04 of the Ohio Revised Code to protect wild animals of the state. Anyone found to be discharging pollutants such as manure, including process wastewater, to the state’s waters can be found in violation of the Stream Litter Act, which carries penalties of a third-degree misdemeanor for a first offense. Violators can be fined up to \$500, or sentenced to 60 days in jail, or both, for a first offense. Corporations can be fined up to \$3,000 for a first offense and \$5,000 for subsequent offenses. Violations of the Stream Litter Act are heard in criminal court, and fines are levied by a judge. Wildlife kills do not have to occur for individuals or corporations to be charged.

Kills of wild animals are investigated by wildlife officers to determine the cause. If wildlife are killed as the result of a pollutant and the source can be firmly established, the party responsible is charged for damages. The value of the wildlife killed, environmental damages, and costs of inves-

tigation are included in the damage claim. Current market prices are used to establish the value of the animals.

Anyone planning to construct or expand animal-feeding operations should become familiar with the animal waste pollution abatement standards and, if necessary, seek assistance to clearly understand them. Questions about Ohio's animal waste pollution abatement program, including available techni-

cal and cost-sharing assistance, should be directed to the local Soil and Water Conservation District, county Extension office, or ODA.

For additional information regarding Ohio's animal waste pollution abatement program, contact ODNR-DSWC at their web site: **<http://www.dnr.state.oh.us/soilandwater>** or ODA at **<http://www.ohioagriculture.gov/lepp.stm>**.

Appendix A

Sampling Livestock Waste for Analysis

Solid Manure—Dairy, Beef, Swine, Poultry

Collect a composite sample by following one of the procedures listed here. A method for mixing a composite sample is to pile the manure and then shovel from the outside to the inside of the pile until well mixed. Fill a one-gallon plastic heavy-duty zip-lock bag approximately one-half full with the composite sample, squeeze out excess air, close, and seal. Store sample in freezer if not delivered to the laboratory immediately.

Procedure 1. Sampling while loading.

Recommended method for sampling from a stack or bedded pack. Take at least 10 samples while loading several spreader loads and combine to form one composite sample. Thoroughly mix the composite sample and take an approximately one pound sub-sample using a one-gallon plastic bag. Sampling directly from a stack or bedded pack is not recommended.

Procedure 2. Sampling during spreading.

Spread a tarp in the field and catch the manure from one pass. Sample from several locations and create a composite sample. Thoroughly mix the composite sample together and take a one-pound sub-sample using a one-gallon plastic bag.

Procedure 3. Sampling daily haul.

Place a five-gallon bucket under the barn cleaner four to five times while loading a spreader. Thoroughly mix the composite sample together and take a one-pound sub-sample using a one-gallon plastic bag. Repeat sampling two to three times over a period of time and test separately to determine variability.

Procedure 4. Sampling poultry in-house.

Collect eight to 10 samples from throughout the house to the depth the litter will be removed. Samples near feeders and waterers may not be indicative of the entire house and sub-samples taken near here should be proportionate to their space occupied in the whole house. Mix the samples well in a five-gallon pail and take a one-pound sub-sample, place it in a one-gallon zip lock bag.

Procedure 5. Sampling stockpiled litter.

Take 10 sub-samples from different locations around the pile at least 18 inches below the surface. Mix in a five-gallon pail and place a one-pound composite sample in a gallon zip lock bag.

Liquid Manure—Dairy, Beef, Swine

Obtain a composite following one of the procedures listed here and thoroughly mix. Using a plunger, an up-and-down action works well for mixing liquid manure in a five-gallon bucket. Fill a one-quart plastic bottle not more than three-quarters full with the composite sample. Store sample in freezer if not delivered to the lab immediately.

Procedure 1. Sampling from storage.

Agitate storage facility thoroughly before sampling. Collect at least five samples from the storage facility or during loading using a five-gallon bucket. Place a sub-sample of the composite sample in a one-quart plastic container. Sampling a liquid manure storage facility without proper agitation (two to four hours minimum) is not recommended due to nutrient stratification, which occurs in liquid systems. If manure is sampled from a lagoon that was not properly agitated, typically the nitrogen and potassium will be more concentrated in the top liquid, while the phosphorus will be more concentrated in the bottom solids.

Procedure 2. Sampling during application.

Place buckets around the field to catch manure from spreader or irrigation equipment. Combine and mix samples into one composite sub-sample in a one-quart plastic container.

Sample Identification and Delivery

Identify the sample container with information regarding the farm, animal species, and date. This information should also be included on the sample information sheet along with application method, which is important in determining first-year availability of nitrogen.

Keep all manure samples frozen until shipped or delivered to a laboratory. Ship early in the week (Monday-Wednesday) and avoid holidays and weekends.

References

Peters, J., S. Combs, B. Hoskins, J. Jarman, J. Kovar, M. Watson, A. Wolf, N. Wolf. 2003. Recommended methods of manure analysis. [Online]. Available at <http://uwlabs.soils.wisc.edu/pubs/A3769.pdf> (Posted 4 March 2003; verified 6 March 2003).

Appendix B

Reporting Manure Analysis Results

Guidelines for Reporting Manure Analysis Results

Manure analysis reports should provide information that is easy to use and interpret and should help fulfill the record-keeping needs of the customer. Ideally, livestock producers should be able to look at analysis reports from several different laboratories and be able to come to similar conclusions regarding application rates and nutrient credits for their manure. This may not be realistic, due to different approaches to estimating nutrient availability. The guidelines presented here are suggested in order to encourage dialogue within the testing industry that will result in some level of standardization of reporting, with simplicity and ease of interpretation being the primary goals. Two example laboratory reports are given to illustrate the guidelines suggested. Any number of formats can work equally as well, as long as the information presented and the purpose for presenting it is clear to the customer.

Descriptive Information

Descriptive information should include the following:

- Laboratory name, mailing address, telephone number, e-mail address.
- Customer name, mailing address, telephone number, e-mail address (farmer name also, if different than customer).
- Sample identification (laboratory number and customer-provided identification).
- Sample description (at a minimum, include livestock species, liquid or solid, manure application method; may also include storage and handling system, application timing, days until incorporation).
- Date of analysis and date of reporting.

Sample submission sheets should have spaces for customers to record the needed information. The more information the customer can supply about the sample, the more assistance the laboratory can provide for interpreting the results. Having this information on the analysis report also simplifies record keeping for the customer.

Analysis Results

Units and Reporting Basis

Report dry matter as percent solids, to at least the nearest 0.1%. Samples should always be analyzed for total solids content, and the results reported (rather than moisture content), even if the customer does not request it specifically. Dry matter determination is often necessary to convert the results of analyses performed on dried samples to an as-is basis. Also, most laboratories include solids in the fee charged for routine manure analysis. Reporting of dry matter or solids content also makes it easier to compare results between different samples.

Report total nitrogen (N), ammonium-nitrogen ($\text{NH}_4^+\text{-N}$), calculated organic N, total phosphorus as phosphate (P_2O_5), total potassium as potash (K_2O), and other minerals in units of lbs/1,000 gal for manures applied as liquids, and lbs/T for manures applied as solids. A strong effort should be made to obtain the desired reporting units from the client. The type of spreader being used will dictate how the results should be reported, not the dry-matter content. If a particular dry-matter level is used to generate reporting units, there should be an option in the computer program to over-ride this default if the sample dry matter falls outside the normal dry-matter ranges for liquid and solid manures.

Report N, $\text{NH}_4^+\text{-N}$, P_2O_5 , and K_2O to at least the nearest 0.1 lb/1,000 gal or lb/T to provide consistency for samples with low concentrations of particular nutrients. Do not report beyond the number of significant digits that are appropriate for the analysis methods and calculations you are using. Report phosphorus and potassium as P_2O_5 and K_2O . This is necessary to be consistent with standardized reporting of soil fertility recommendations and nutrient content of fertilizers.

Results may also be reported in units of percent or ppm, but these should be reported separately from the results reported as lbs/T or lbs/1,000 gal and should be clearly labeled in order to prevent confusion. It should then be indicated on the report which values should be used to calculate application rates and nutrient credits.

Results reported in units of percent or ppm should be reported on an as-is basis. Results reported on a dry-matter basis can be useful for comparing results between different manures, or for generating more accurate table values for different regions. Most producers, however, will have little use for dry-matter basis results. If they are reported, they should be clearly labeled, and the relationship between different units should be indicated. Dry-matter content should always be reported, to allow conversion of results to dry-matter basis results, if desired.

Conversion Factors

Most conversion factors are simply mathematical standards used by all laboratories. These include multiplying percentage by 20 to get lbs/T, multiplying ppm by 10^{-4} to get percent, multiplying P by 2.29 to get P_2O_5 , multiplying K by 1.2 to get K_2O , and multiplying dry-matter basis results by the dry-matter fraction to get as-is basis results.

For liquid manures, the factor used to convert percentage to lbs/1,000 gal is based on the density of the sample, and different laboratories use different factors. Some laboratories use the density of water (8.33 lbs/gal) and others use measured or estimated density values. This is done to account for the presence of solids in liquid manures and thereby improve the accuracy of the reported value. This practice is probably not justified, however.

In order to assess the affects of solids content and manure density on conversion factors and reported analysis values, 262 liquid dairy and swine manures from a variety of storage and handling systems were analyzed for density, solids content, specific gravity and total nitrogen (N) content (Jarman, 1999). The samples ranged in solids content from 0.3 to 16%. Nitrogen content in lbs/1,000 gal was calculated using the density of water, measured sample density, or measured specific gravity, or an estimated density of 9 lbs/gal.

Calculated N content in lbs/1,000 gal was similar when based on specific gravity, measured density or the density of water. Significantly larger N content values were obtained when a density value of 9.0 lbs/gal was used. Therefore, in order to standardize results between laboratories, it is recommended that the density of water (8.33 lbs/gal) be used, and percentage (as-is basis) would then be multiplied by 83.3 to obtain lbs/1,000 gal.

If standardized conversion factors are used, it is not necessary to report these factors. If they are reported, caution should be used in their placement on the report. In order to streamline the report and avoid confusion, conversion factors and calculations could be placed on the back of pre-printed reporting forms.

Accuracy of Reported Results

All results should be examined for transcription and other errors. The results should fall within the expected range of values for that manure type, unless unusual conditions are present. Computerized calculations should be checked for accuracy, and assumptions used in computer generation of numbers should be updated periodically. Every number on every report should be checked and verified before it leaves the laboratory.

Interpretive Information

Nutrient Availability Estimates

Differences in factors that affect manure nutrient availability do exist between regions and states and even within states. The use of consistent values across large regions would be inappropriate.

The simplest solution for dealing with differences in nutrient availability is to report only the actual analysis values and refer customers to their State Extension Service for assistance in determining nutrient availability, application rates, and nutrient credits. However, many laboratories want to provide these services to their customers. Information about nutrient availability and how to calculate nutrient credits and application rates does help producers interpret their results, as long as the information is correct for that producer. Providing availability factors (percentage of total nutrients available) rather than calculating the amounts of nutrients available, solves the problem of incorrect calculations in situations where insufficient information is provided by the customer to accurately determine the correct availability factors to use. However, providing amounts of available nutrients instead of availability factors can make it easier for the producer to interpret the results.

Regardless of the availability values provided, the actual analysis results should always be reported first, and the source of the availability values should always be stated prominently on the report, especially for the benefit of out-of-state custom-

ers. Availability values should not be considered as transferable between states. Laboratories should also check each report to ensure that the values provided (and the factors on which they are based) apply to that customer's particular sample. Due to development of new storage, handling, and application methods and the availability of their own large databases of manure nutrient content, laboratories could also help gather information to assist Extension in developing or modifying availability factors for their region.

Manure Nutrient Value

The economic value of manure nutrients is only equal to the cost of the fertilizer that is being saved on the particular fields to which the manure is applied and must account for application costs. Unless a laboratory has access to information about fertility levels, crops being grown, manure and fertilizer rates applied, and application costs for each of a customer's fields, then estimates of manure nutrient value are usually inaccurate and misleading. These estimates may provide some value to a producer as long as he or she understands what is being estimated.

References

Jarman, J. K. 1999. Fact sheet on use of liquid manure density values in reporting manure nutrient analysis results. Laboratory Certification Programs, Minnesota Department of Agriculture, St. Paul, Minn.

Peters, J., S. Combs, B. Hoskins, J. Jarman, J. Kovar, M. Watson, A. Wolf, N. Wolf. 2003. Recommended methods of manure analysis. [Online]. Available at <http://uwlax.edu/soils/wisc.edu/pubs/A3769.pdf> (Posted March 4, 2003; verified March 6, 2003).

Example Laboratory Report 1 (analysis results only, no interpretive information)

Laboratory Name _____

Laboratory Address _____

Tel. No. Fax No. _____

E-mail Address _____

Manure Analysis Report for: Producer/Farm name

Submitted by: Customer name

Customer address

Customer tel. no.

Customer e-mail address

Date received: Mo/Day/Yr

Date reported: Mo/Day/Yr

Lab No.

M1934

Sample ID

Finish

Manure Type

Liquid swine

Storage Type

Outdoor Lagoon

Application method

Knife injected

Incorporation

Immediate

Total solids

5.5 %

ANALYSIS

Lab No.

M1934

Units

lbs/1,000 gal

Total nitrogen (N)

39.2

Ammonium nitrogen (NH₄-N)

17.5

Total Phosphorus expressed as P₂O₅

30.0

Total Potassium expressed as K₂O

21.6

Manure analysis values must be multiplied by an availability factor to obtain pounds of available nutrients per 1,000 gallons of manure.

Availability factors depend on animal species and management, manure storage and handling system, application method and timing, days until manure incorporation, and other factors.

The amount of available nutrients is then multiplied by the application rate to obtain pounds of available nutrients applied per acre.

Contact your county Extension office for further information on manure nutrient availability and manure nutrient management.

Example Laboratory Report 2 (analysis results plus interpretive information)

Laboratory Name _____

Laboratory Address _____

Tel. No. Fax No. _____

E-mail Address _____

Manure Analysis Report for: Producer/Farm name

Submitted by: Customer name

Customer address

Customer tel. no.

Customer e-mail address

Date received: Mo/Day/Yr Date reported: Mo/Day/Yr

Lab No. M1934

Sample ID Finish

Manure Type Liquid swine

Storage Type Outdoor Lagoon

Application method Knife injected

Incorporation Immediate

Total solids 5.5 %

	Analysis	1 st Year Availability Factor	1 st Year Available Nutrients	2 nd Year Availability Factor	2 nd Year Available Nutrients
	lbs/1000 gal	%	lbs/1000 gal	%	lbs/1000 gal
Lab No. M1934					
Total nitrogen (N)	39.2	70	27	15	6
Ammonium nitrogen (NH ₄ -N)	17.5 (included in total N availability)				
Total Phosphorus expressed as P ₂ O ₅	30.0	80	24		
Total Potassium expressed as K ₂ O	21.6	90	19		

Nutrient availability factors are those provided by the State/University Extension Service.

Nitrogen availability is based on livestock species, manure type, storage, application method, and time until incorporation.

Availability of P₂O₅ and K₂O is the same for all manure types and application methods and is only for the first year following application.

Contact your county Extension office for further information on manure nutrient availability and manure nutrient management.

Appendix C

Waste Pump Characteristics

Table 26. Waste Pump Characteristics.

Pump Type	Max. Solids (%)	Agitate Distance (ft)	Pump Rate (gpm)	Pump Head (ft)	Power Required (hp)
High-pressure centrifugal	<10	40-60	1,000	200-300	80+
Chopper-agitator	10–12	50–75	<4,000	25–75	65+
Impeller-agitator	10–12	75–100	<5,000	30–35	60+
Submersible	10–12	25–50	<1,000	10–30	<15
Helical screw	4–6	30–40	<300	200+	40+
Hollow piston	18–20	N/A	<150	30–40	<15
Solid piston	18–20	N/A	<150	30–50	<10
Pneumatic	12–15	N/A	<150	30–40	<10
Vacuum	8–10	20–25	<300	N/A	50+
Diaphragm	10–12	N/A	<300	100+	25+

Source: Adapted from Table 12-9 of Natural Resources Conservation Service (NRCS) Agricultural Waste Management Field Handbook. Used by permission.

Appendix D

Manure Handling Alternatives:

Dairy, Beef, Swine, Poultry, and Sheep Manure

Handling Alternatives for Dairy Manure:

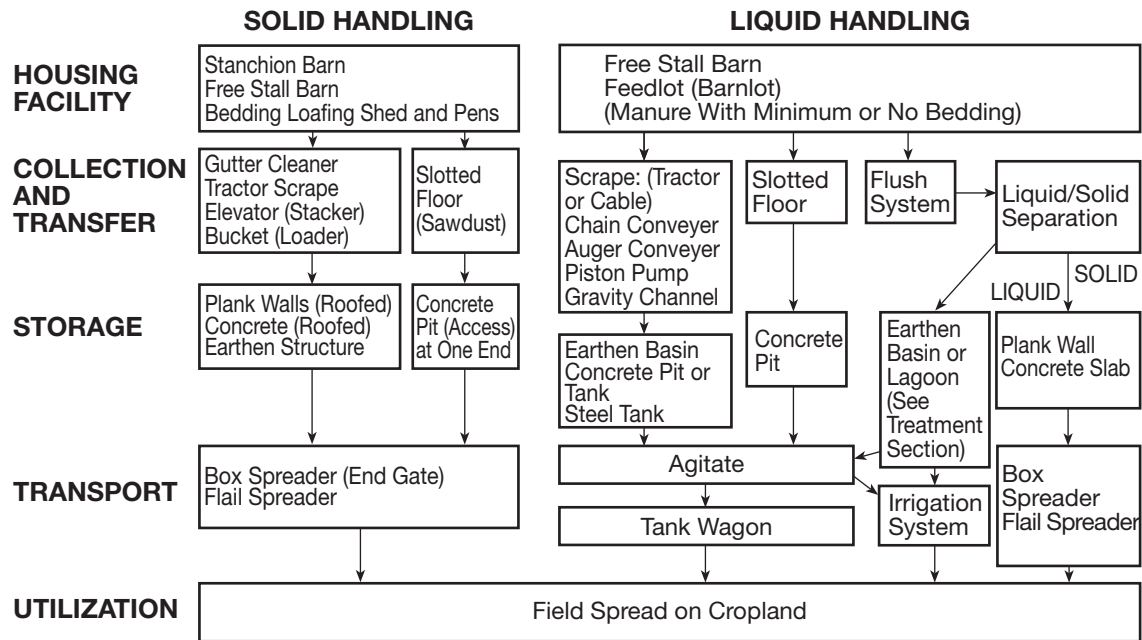


Figure 26. Handling alternatives for dairy manure. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Handling Alternatives for Beef Manure:

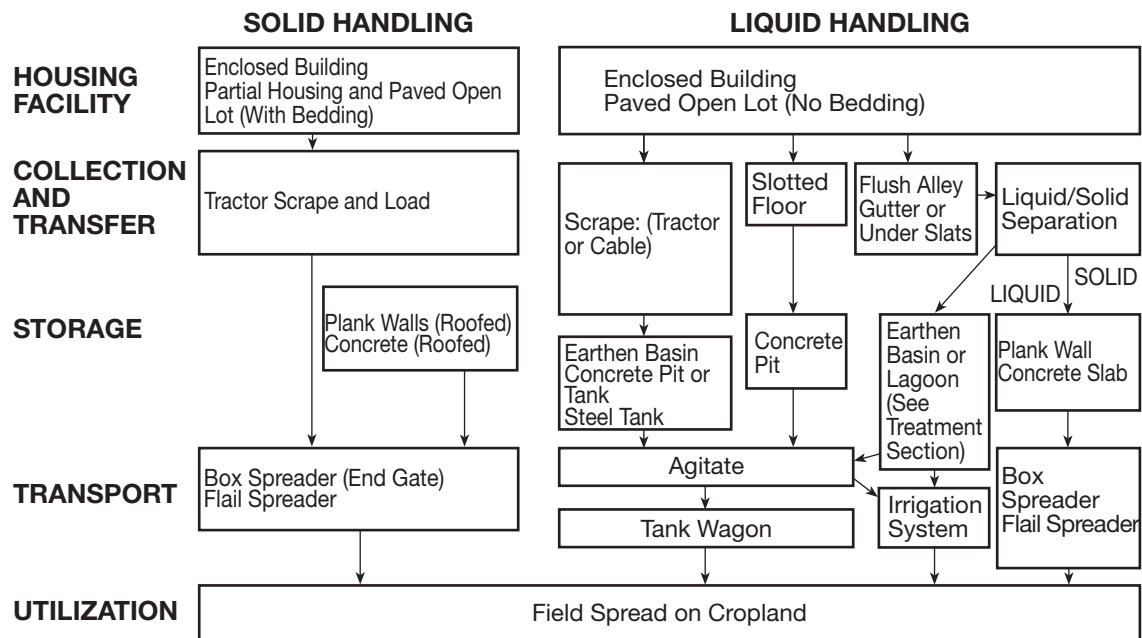


Figure 27. Handling alternatives for beef manure. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Handling Alternatives for Swine Manure:

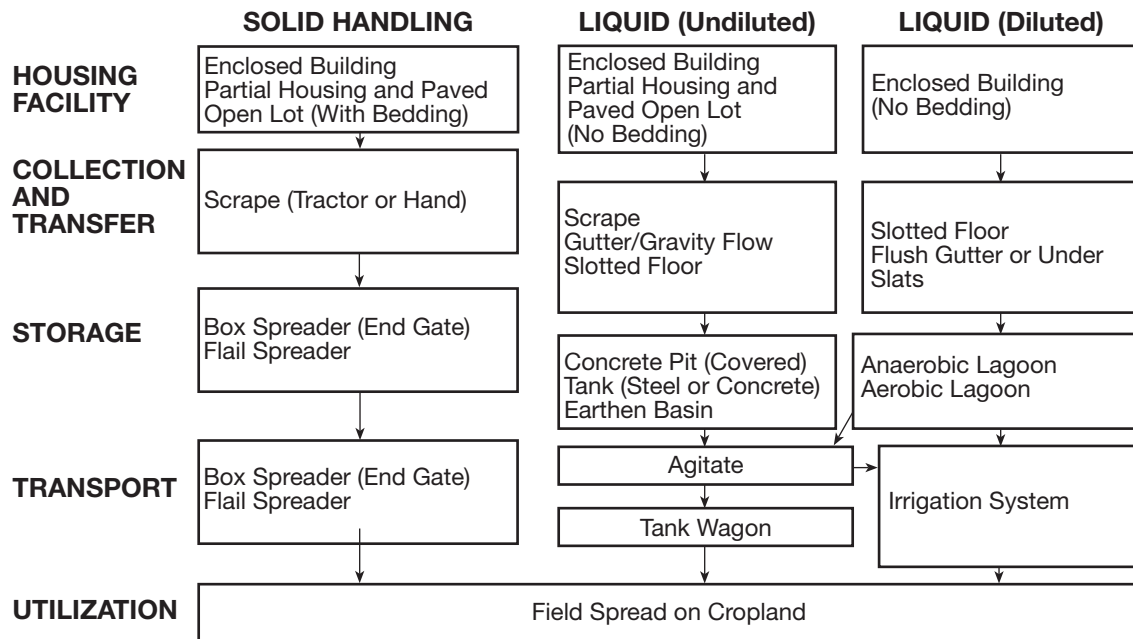


Figure 28. Handling alternatives for swine manure. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Handling Alternatives for Poultry Manure:

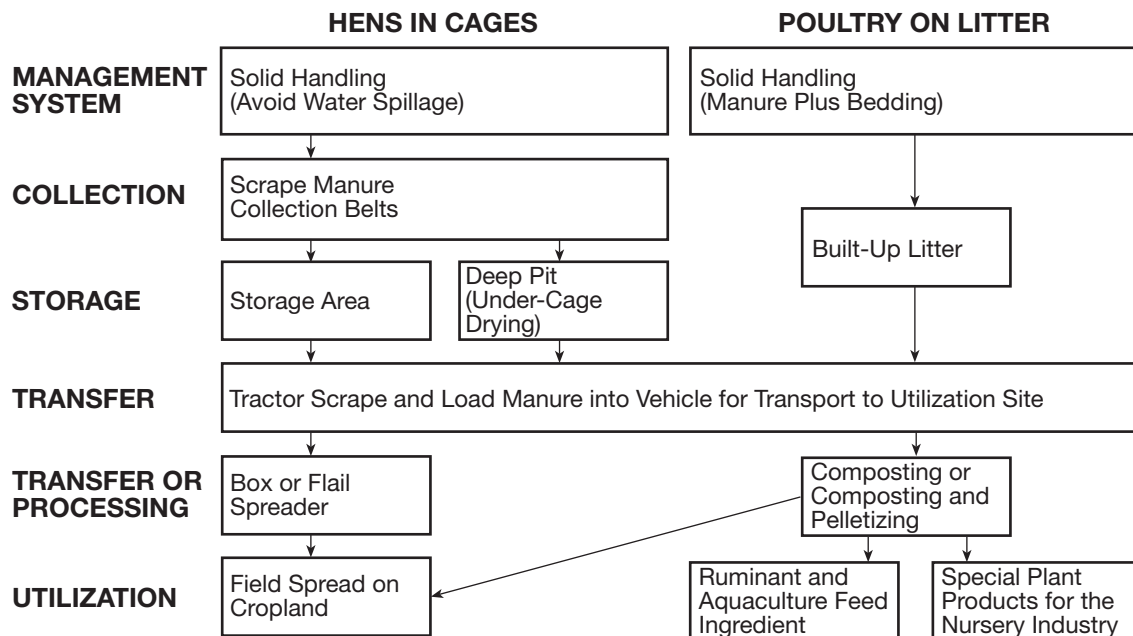


Figure 29. Handling alternatives for poultry manure. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Handling Alternatives for Sheep Manure:

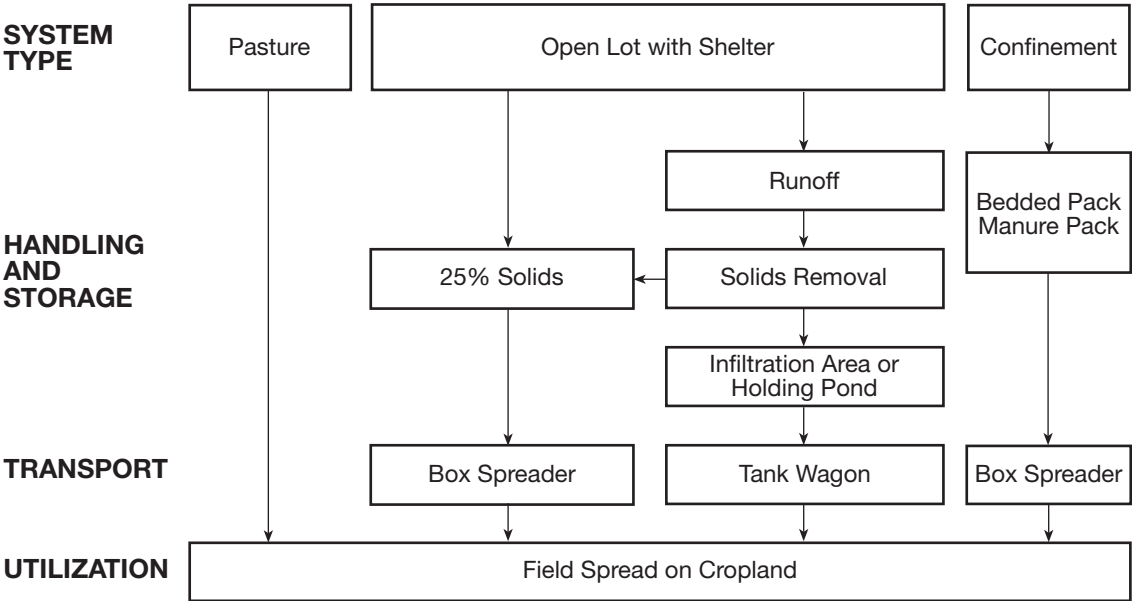


Figure 30. Handling alternatives for sheep manure. (Source: Ohio State University Extension Bulletin 604, 1992 Edition.)

Appendix E

Liquid Manure Application: Equipment Needs and Management Guidelines

Source: USDA—Natural Resources Conservation Service, Ohio. Used by permission.

Equipment and Systems

The following basic irrigation equipment is needed:

- High-pressure irrigation pump
- Suction line
- Pipe (portable) to application area
- Nozzle and stand
- Pump for agitating storage waste

Four main types of irrigation systems are used for wastewater disposal:

- Hand moved (portable pipe)—up to 1.5 acre per set
- Traveler with hose drag—up to 7 acres per set
- Traveler with hose reel—up to 12 acres per set
- Mobile center pivot (one tower)—10 acres per turn

Manure slurries should be less than 10% total solids when using irrigation equipment. Most manure in storage meets this requirement, and water can be added for dilution. Pressure should be 80 to 110 PSI at the nozzle for “big-gun” nozzles. Small irrigation pumps can deliver 200 to 400 gallons per minute. Large irrigation pumps deliver 400 to 1,000 gallons per minute.

Pipelines used in waste management systems can be of the same type and general design of those used in normal irrigation systems. Because of the corrosiveness of the wastewater, underground pipelines should be constructed of plastic or other non-corrosive materials. Flushing pipelines and other waste-disposal equipment with clear water is recommended after each use and definitely before storage. Operators should use caution in flushing and decoupling pipelines to prevent excess ponding and spillage of liquid manure and subsequently, manure runoff problems.

Operation and Maintenance

The nature of manure disposal contributes to the tendency of many operators to wait until holding facilities are full or overflowing before emptying them. Poor management of waste disposal by irrigation has resulted in pollution and dissatisfaction with the system.

Note the following management guidelines:

- Irrigate wastes according to schedule and recommended application rates in the waste management plan.
- Do not irrigate during rain or on saturated soils. Do not irrigate if subsurface drains (tile) are flowing.
- Locate and inspect subsurface drainage outlets regularly to prevent manure discharge to surface waters.
- Maintain and repair broken subsurface drains (tile) to prevent manure discharge to surface waters.
- Maintain proper setback distances from ditch banks and grass waterways to prevent manure discharge to surface waters.
- Be alert to potential odor problems. Select site and time of irrigation to minimize odor nuisance.
- Keep debris out of manure and wastewater.
- Follow the equipment manufacturer’s recommended maintenance program to prevent equipment failure.
- Have an Emergency Management Plan in case of a manure accident or spill. See Chapter 7, *Safety and Manure Handling*.
- If possible, flush pumps and other irrigation equipment with clear water after each use to help prolong their life.
- Fill underground pipelines with clear water before using them to help eliminate dead spots of solids.

Appendix F

Available Water Capacity (AWC)

Practical Soil Moisture Interpretations for Various Soils Textures and Conditions to Determine Liquid Waste Volume Applications not to exceed AWC.

Table 27 should be used to determine the AWC at the time of application and the liquid volume in acre-inches that can be applied not to exceed the AWC. To determine the AWC in the upper eight inches, use a soil probe or similar device to evaluate the soil to a depth of eight inches.

Table 27. Available Water Capacity.

Available Moisture in the Soil	Sands and Loamy Sands	Sandy Loam and Fine Sandy Loam	Very Fine Sandy Loam, Loam, Silt Loam, Silty Clay Loam	Sandy Clay, Silty Clay, Clay, Fine and Very Fine Textured Soils
<25 % Soil Moisture	Dry, loose and single-grained; flows through fingers.	Dry and loose; flows through fingers.	Powdery dry; in some places slightly crusted but breaks down easily into powder.	Hard, baked and cracked; has loose crumbs on surface in some places.
Amount to Reach AWC	20,000 gallons per acre	20,000 gallons per acre	40,000 gallons per acre	27,000 gallons per acre
25-50% Soil Moisture	Appears to be dry; does not form a ball under pressure.	Appears to be dry; does not form a ball under pressure.	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls under pressure.
Amount to Reach AWC	15,000 gallons per acre	20,000 gallons per acre	30,000 gallons per acre	20,000 gallons per acre
50 to 75% Soil Moisture	Appears to be dry; does not form a ball under pressure.	Balls under pressure but seldom holds together.	Forms a ball under pressure; somewhat plastic; sticks slightly under pressure.	Forms a ball; ribbons out between thumb and forefinger.
Amount to Reach AWC	10,000 gallons per acre	13,000 gallons per acre	20,000 gallons per acre	13,000 gallons per acre
75% to Field Capacity	Sticks together slightly; may form a weak ball under pressure.	Forms a weak ball that breaks easily, does not stick.	Forms ball; very pliable; sticks readily if relatively high in clay.	Ribbons out between fingers easily; has a slick feeling.
Amount to Reach AWC	5,000 gallons per acre	7,000 gallons per acre	11,000 gallons per acre	7,000 gallons per acre
100% Field Capacity	On squeezing, no free water appears on soil, but wet outline of ball on hand.	On squeezing, no free water appears on soil, but wet outline of ball on hand.	On squeezing, no free water appears on soil, but wet outline of ball on hand.	On squeezing, no free water appears on soil, but wet outline of ball on hand.
Above Field Capacity	Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles: free water forms on surface.

Source: USDA-Natural Resources Conservation Service (NRCS), *Ohio Field Office Technical Guide*. Used by permission.

Appendix G

Phosphorus Soil-Test Risk-Assessment Procedure

Table 28. Ohio NRCS Phosphorus Soil-Test Risk-Assessment Procedure

Criteria Applicable to All Soil-Test Levels:

1. All applications are based on current soil-test results (not more than three to five years old).
2. No manufactured P_2O_5 applied above 40 ppm (Bray-Kurtz P1 soil test) or equivalent soil test, unless recommended by appropriate industry standards or the land-grant university for specialty crops, vegetable crops, etc.

"P" Soil-Test Level	Application Criteria
Bray-Kurtz $P_1 < 40$ ppm (< 80 Lbs/Acre) OR Other Equivalents (e.g., Mehlich 3) LOW POTENTIAL	Recommended N or P_2O_5. Manure or other organic by-products can be applied to meet the succeeding crop's recommended NITROGEN requirements for non-legume crops or the NITROGEN removal for legume crops; OR the recommended P_2O_5 but not to exceed the NITROGEN needs of the succeeding crop.
Bray-Kurtz P_1 40-100 ppm (80 - 200 Lbs/Acre) OR Other Equivalents (e.g., Mehlich 3) MODERATE POTENTIAL	Recommended N or P_2O_5 Removal, whichever is less. The field shall have $> 30\%$ ground cover at the time of application or the manure or other organic by-products shall be incorporated within one week. The manure or other organic by-products can be applied to meet the succeeding crop's recommended NITROGEN requirements for non-legume crops or the NITROGEN removal for legume crops; OR P_2O_5 removal (annual or multiple year applications) whichever is less.
Bray-Kurtz P_1 100-150 ppm (200-300 Lbs/Ac) OR Other Equivalents (e.g., Mehlich 3) HIGH POTENTIAL	Recommended N or P_2O_5 Removal, whichever is less PLUS additional distance criteria from drainage way/water source or other sensitive area, OR filter strips. Manure or other organic by-products can be applied to meet the succeeding crop's recommended NITROGEN requirements for non-legume crops or the NITROGEN removal for legume crops; OR P_2O_5 removal (annual or multiple year applications) whichever is less IF: 1. The field has $> 50\%$ ground cover at the time of application or the material is incorporated within seven days on areas with $< 50\%$ cover. AND 2. Unless the manure or other organic by-products are incorporated within 24 hours, no manure or other organic by-products are to be applied within 100 feet of a drainage way, water source, or other sensitive area; OR, the width of a vegetative filter strip (minimum width 33 feet) maintained adjacent to the drainage way, water source, or sensitive area.
Bray-Kurtz $P_1 > 150$ ppm (> 300 Lbs/Ac) OR Other Equivalents (e.g., Mehlich 3) VERY HIGH POTENTIAL	No additional P_2O_5—Use P_2O_5 draw-down strategies.

Source: Ohio Natural Resources Conservation Service (NRCS) *Field Office Technical Guide*, Section 1, FOTG, page 9. Used by permission.

Appendix H

Nutrient Application Equipment Calibration

Source: USDA-Natural Resources Conservation Service (NRCS) Ohio. Used by permission.

Commercial Fertilizer Application Equipment Calibration

To calibrate commercial fertilizer applicators and planters, one should first set the equipment according to the manufacturer's recommendations then fill the applicator or planter with a known amount of fertilizer. The equipment is then checked over a known acreage. Adjustments are made to achieve the planned rates.

Manure Spreader Calibration

There are several methods that can be used to calibrate the application rate of a manure spreader. The two best methods are the load-area method and the plastic-sheet method. It is desirable to repeat the calibration procedure two to three times and average the results to establish the most accurate calibration.

Before calibrating a manure spreader, the spreader settings such as splash plates should be adjusted so that the spread pattern is uniform. Most spreaders tend to deposit more manure near the spreader than at the edge of the spread pattern. Overlapping can make the overall application more uniform. Calibrating the application rates when overlapping requires measuring the width of two spreads and dividing by two to get the effective spread width.

Calibration should take place annually or whenever manure is being applied from a different source or the consistency is different.

Load-Area Method

The load-area method is the most accurate and can be used for most types of manure handling. This method consists of determining the amount (volume or weight) of manure in a spreader and the total area over which it is applied. The most accurate method to determine the amount of manure in a spreader is to weigh the spreader when it is full

of manure and again when it is empty (portable pad scales work well for this). The difference is the quantity of manure applied over the area covered. Spreader capacities listed by the manufacturers can be used to determine the amount of manure in the spreader. However, care must be taken when using manufacturer's spreader capacities. Heaped loads, loading methods, and manure type may vary considerably from what is listed by manufacturers of box- and side-delivery manure spreaders. Spreader capacities for liquid tankers are accurate, provided the tanker is filled to the manufacturer's recommended levels, and no foam is present in the tank.

The area of spread is determined by measuring the length and width of the spread pattern. Measuring can be done with a measuring wheel, measuring tape, or by pacing.

The application rate is calculated using the following formula:

$$\frac{\text{Spreader capacity (tons or gallons)} \times 43,560 \text{ sq. ft per acre}}{\text{Distance traveled (ft)} \times \text{Spreading width (ft)}} = \text{Application Rate (tons or gallons/acre)}$$

Plastic Sheet Method

The plastic sheet method can only be used with solid or semi-solid manure. This method of calibrating spreader application rates involves:

- Cutting a plastic sheet to the specified dimensions (56 inches x 56 inches).
- Weighing the clean plastic sheet.
- Laying out the plastic sheet on the ground and driving the manure spreader (applying manure at a recorded speed and spreader setting) over the sheet.
- Weighing the plastic sheet with the manure on it.
- Determining the net weight of the manure on the sheet (weight of manure and sheet-weight of the clean sheet).

- Calculating: The net pounds of manure equals tons per acre applied.

When calibrating manure spreaders, all details regarding tractor speed and manure spreader settings and date(s) of each calibration should be recorded with manure application information, and directly on the equipment. Mark equipment to ensure a known application rate is applied each time the referenced tractor speed and spreader settings are used. Manure spreader settings can include such things as: fast and slow settings on some box spreaders, gate position on side-delivery spreaders, and splash-plate position and fill levels on liquid tankers.

Irrigation System Calibration

Place three to five buckets throughout the irrigation spray pattern and collect samples while operating the pump at a given rpm and pressure (for a traveling gun record the ground speed also). At the end of the planned sample period, measure the amount of liquid collected in inches (average the samples). Table 29 shows how many gallons per acre applied per inch applied.

Table 29. Gallons Applied Per Inch of Liquid Manure Applied.

Inches of Liquid Manure Applied by Irrigation	Gallons per Acre
0.20	5,430
0.30	8,146
0.40	10,860
0.50	13,577
0.75	20,365
1.0	27,154
1.25	33,942
1.5	40,731

Soft Hose Injection System with Irrigation Hose

Alternative 1. Use a flow meter mounted on the injector system and calculate the distance and width to determine the amount applied over a measured area. Example: the flow meter measures 1,000 gallons over a distance of 600 feet and an area 10-feet wide.

Formula:

$$\frac{\text{Gallons Applied (1,000 gal)} \times 43,560 \text{ sq. ft/acre}}{\text{Distance traveled (600 ft)} \times \text{Application width (10 ft)}} = \text{Application Rate (7,260 gallons/acre)}$$

Alternative 2. (Requires a 10- to 20-gallon graduated measuring container.)

- Step 1.** Measure the flow—in the field—out of one injector for five seconds into the graduated measuring container and record the number of gallons; repeat three times and average the results.
- Step 2.** Multiply the average amount collected from one injector by the number of injectors (equals amount applied for the whole system for five seconds).
- Step 3.** Multiply the results of Step 2 times 12 to get gallons per minute.
- Step 4.** Place the injector in the soil at the planned depth and operating speed and record the distance traveled in one minute (average three different measurements).
- Step 5.** Determine the effective application width (number of injectors x injector spacing in feet).
- Step 6.** Multiply the effective width times the distance traveled in one minute (this gives the square feet covered in one minute).
- Step 7.** Divide the result of Step 6 by 43,560; this gives the acres covered in one minute).
- Step 8.** Divide the results of Step 3 (gallons per minute) by the results of Step 7 (acres covered in one minute). This gives the gallons applied per acre.

Example:

- Step 1.** Collect an average of 6 gallons from one injector for five seconds.
- Step 2.** Multiply the amount by the number of injectors. The applicator has 8 injectors (8 injectors x 6 gallons per injector = 48 gallons for 5 seconds).
- Step 3.** 48 gallons in 5 seconds x 12 = 576 gallons/minute applied

Step 4. Average distance covered in 1 minute was 250 feet.

Step 5. Average width of the applicator is 12 feet.

Step 6. 12 feet wide x 250 feet long = 3,000 square feet

Step 7. 3,000 square feet divided by 43,560 square feet/acre = 0.0688 acres covered in one minute.

Step 8. 576 gallons/minute divided by 0.0688 acres/minute = 8,372 gallons/acre.

Appendix I

Manure Spreader Volume Conversions

Source: Manure Spreader Capacity and Common Conversions for Manure Spreader Volumes; Nebraska Guide G95-1276 A, University of Nebraska, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, November 1995. Used by permission.

Table 30. Common Conversions for Manure Spreader Volumes.

To Convert From:	To:	Multiply By:
Bushels	Cubic Feet	1.24
Gallons	Cubic Feet	0.134
Gallons	Pounds	8.3 (L)
Gallons	Tons	0.0041 (L)
Cubic Feet	Gallons	7.48
Cubic Feet	Pounds	62 (L) or 55 (S)
Cubic Feet	Tons	0.031 (L) or 0.0275 (S)

L = Liquid manure; S = solid manure.

Appendix J

Methods for Quantifying Odor

Odor perception is subjective and is affected by the individual's experience and physical and emotional sense of odor. To quantify odor levels, two kinds of measurement have been used: (1) measurement of concentration of single or group gases, and (2) human reaction to the comprehensive contribution of odorous gases. Because of the complexity of the odor composition, using concentration of single or group of gases to represent odor level has not been proved to fully estimate the presence or level of odors. Currently, olfactometry is considered as the most accurate method to assess odor level.

Odor can be qualitatively described by its characteristics, such as mint smell, rotting smell, etc. The **olfactometry** method uses a panel of humans to quantify odor as to its concentration or intensity, persistence, and hedonic tone. **Odor concentration** is defined as Odor Unit per cubic meter air volume (OU/m³). **Odor Unit** is ratio of the volume of clean air to the volume of odorous air sampled. The clean air is used to dilute the odorous air to either detection or recognition threshold levels at which 50% of the panelists can detect or recognize the odor.

Odor intensity describes the strength of an odor sample and is measured at concentrations above the detection threshold. **Persistence** is a calculated value to measure how easily the full-strength odorous air can be diluted to the detection threshold level. **Hedonic tone** describes the unpleasantness or pleasantness of an odor. It is typically rated using a scale that ranges from -10 to 10, representing from most unpleasant to most pleasant.

Besides the olfactometry method, the **scentometer** is a simple, hand-held device to measure ambient odor level in the field. A trained individual can use it to measure odor concentration or intensity in the field. The scentometer is simple to use, but is not high in accuracy.

A **field sniffer** is another way to measure ambient odor intensity. Trained sniffers calibrate their noses in a lab to establish consistent intensity detection levels. The sniffers sniff the air to determine the odor intensity. They wear charcoal filter masks to breath non-odorous air between measurements.



