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Chapter 11 Waste Utilization

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651.1100 Introduction

Waste utilization is the recycling of the organic by-products of animal agriculture. The by-products are mostly manures, but may also include bedding, contaminated runoff, and animal remains. The by-products to be addressed may also include the by-products of supporting activities like wash water from a milking house or broken eggs from a layer operation. These by-products contain nutrients that can cause algae blooms in water bodies, organics that can have an excessive oxygen demand on aquatic ecosystems, and pathogens that can result in health problems for other farm animals or humans. However, they also have recoverable value as nutrients for plant growth, carbon for soil health, fiber for bedding or composites, and hydrogen for energy production. At a minimum, waste utilization returns these by-products to the environment in a manner that does not cause harm, but preferably, the utilization activity should also result in the recovery of their residual values. It is unfortunate that these by-products are often called wastes because the by-products are not really wastes unless they are wasted.

Most of the manures of agricultural animals are applied to the land. Properly done, the residual nutrients in the manure are recycled through agricultural plants. This method of manure utilization is almost as old as agriculture itself and mimics the recycling of wild animal feces in nature. The use of manure for crop production is the focus of this chapter, but there are other alternatives that will be briefly described. This chapter does not address the recycling of synthetic agricultural chemicals, containers, or other nonorganic by-products. Also, agricultural land is often the recipient of many other wastes such as municipal wastewater and sludge, food processing waste, and waste classified as hazardous under the Resource Construction and Recovery Act. These other wastes have widely varying characteristics requiring special design considerations that are not addressed in this handbook.

Fresh poultry manure has relatively low moisture content, but freshly excreted manure from other livestock is 85 to 90 percent water. More water is often added from drinking water supplies and misters in an animal operation, wash water used in the transport and management of the manure, and rainfall and runoff that passes through the animal production area. Depending on the level of dilution, this manure water may be used directly for land application and irrigation. Suspended solids limit the use of livestock manure water, but left untreated, it can be used to replace water evaporating from a compost operation. Simple solids settling may be sufficient treatment for recycled flush water used to remove the manure from housing facilities. Additional separation of fine solids may be necessary for this water to pass through some irrigation spray nozzles and filtering if it is to be used in drip irrigation. In addition to suspended solids, the use of livestock manure water may be limited by nutrients, pathogens, salts, or odors. Manure water can be treated and purified for use as drinking water for livestock and even for humans, and this has been done in demonstrations, but the cost of such treatment is usually prohibitive for commercial agricultural operations.

Use of manure water in constructed wetlands falls peripherally under the utilization topic in that a constructed wetlands provides a water and nutrient source for aquatic vegetation associated with the wetland. The primary function of wetlands used in waste management systems is treatment. Influent quality of wastewater being supplied to the wetlands should be checked to assure that nutrient strength is not excessive for the aquatic vegetation involved. Effluent water from constructed wetlands is often of high quality and may be recycled for other uses, such as irrigation or even supplemental livestock water, but the direct discharge of this effluent usually requires a State-issued discharge permit.

Separated solids may be used directly as bedding as long as the solids are being recycled back into the operation from which they originated, and this is a common practice for dairies. Passing these solids through an anaerobic digester or a composting operation will help suppress pathogens in solids recycled as bedding, which may be required if this bedding material is to be used on a neighboring farm. Solids from an anaerobic digesters work well for bedding if they are used immediately after separation or if they are fully composted. Partially composted solids do not make good bedding due to the unstable and slick nature of the solids, and partial composting may actually increase pathogen counts. Separated solids can be treated and stabilized for use as a soil amendment or as a substitute for peat in a greenhouse. The solids can be used in the production of degradable pots for plants or fiberboard for permanent construction. Manure solids can be pelletized to enhance their value as a nutrient source for plants, an amendment for the soil, or a supplemental fuel for energy production. Fibrous organic solids separated from the waste stream may be used directly as a bulking agent and substrate for micro-organisms in a composting operation, and the sale of composted materials as nursery rooting materials or on the retail market makes composting a viable waste utilization component. Separated solids have been processed to produce supplemental feed for livestock, and while this has worked well when the feed is supplied to a species other than that from which the solids have originated, due to biosecurity concerns, this practice is usually discouraged or prohibited without significant treatment.

There is a long history of using manure as a fuel and energy resource. Dried manure has long been used in small open fires for cooking and heating, and this practice continues today in cultures where wood and other fuel for fire is not readily available. The energy value of manure can be recovered through various thermochemical processes. Pelletized and dried manure may be mixed with coal and used in co-fire plants that generate electricity. Poultry litter is directly used as a fuel in some power plants. On smaller scales, poultry litter can be used in specially designed manure burners to generate heat for chicken houses. The concern over emissions from aerobic combustion of poultry litter must be addressed through management of the burn and proper design of the burner. This often involves the use of a secondary burner to completely consume the particulates and gasses in the emissions and traps to catch emission ash particulates. A system that includes a manure burner must consider the management of the ash that results from the burn.

Other thermochemical processes include gasification, pyrolysis, and torrefaction. These processes apply heat to manure under conditions where the temperature and levels of oxygen are controlled. The heat releases volatile chemicals from the organic material in the manure. Restriction oxygen prevents consumption of the volatile gasses and oils so they can be captured as fuel for later use. These synthetic gasses are called syngas. The oils are heavy tar-like oils that can be further refined for use as a fuel, or otherwise used as a replacement or supplement for oils used in the manufacture of asphalt or other products. Under these controlled conditions, the burn can be stopped before all the carbon is consumed. The remaining manure solids are left as a charcoal dust called biochar, which has potential as a soil amendment. Manure nitrogen is usually not recoverable in thermochemical processes, but phosphorus and potassium are captured and concentrated in the biochar and ash. The biochar and ash may be transported great distances and applied to the land for use by plants. The heat leaves the ash pathogen free, so the phosphorus in the ash may be safely recycled as a feed supplement.

Anaerobic digesters produce a biogas that contains about 60 percent methane. Three common types of anaerobic digesters are covered lagoon, plug-flow, and complete mix. Covered lagoon digesters are not usually heated, and the amount of biogas they produce varies as the ambient temperatures vary through the year, producing less gas when cool and most gas when warm. This is can be problematic when the gas is used for heating. Plug-flow and complete mix digesters are typically designed to be mesophilic, meaning that the temperatures are maintained around 100 degrees Fahrenheit. Digesters can be thermophilic, with temperatures around 130 degrees Fahrenheit, but these are less common in agriculture. Manure is a low energy but reliable and stabilizing substrate for a digester. A manure digester is a good base for high-energy and more unstable organic waste like food waste. The biogas produced by the digesters can be purified and used like natural gas, or it can be used to run an engine-generator set that produces electricity. Manure nutrients are conserved in the digestion process so that the nutrient content of the influent is much the same as the nutrient content of the effluent. An anaerobic digester is a way to capture energy from manure and retain the nutrients, too. It is a common practice to pass the effluent from an anaerobic digester through a solids separator to facilitate the management and handling of the effluent.

There is much innovation in the technologies for capturing and recycling the value of manure. The energy capturing processes are constantly being refined and improved. For example, one innovative farmer captured the heat from composting to heat the floors of his calf barn. Another is working on a process to use the nutrient-rich wastewater to grow algae for feed and energy use. Processes that add value to the manure products improve their marketability. Small farms can still compost the manure and sell the compost as a soil amendment. Processes that concentrate manure nutrients and stabilize it for transport are growing in importance in watersheds with high concentrations of agricultural animals. Still, with all the innovations and alternatives, the most common use of manure is land application for plant nutrients, and that is the focus of this chapter.

651.1101 Waste consistency

Wastes are classified in four categories according to their consistency—solid, semisolid, slurry, and liquid. Ruminants tend to produce manure that is of semisolid consistency when excreted; swine excrete manure as slurry; and poultry excrete manure that is a more solid manure. This clearly points out the need to be knowledgeable of waste consistency in terms of total solids (TS) to properly select waste management system components. Chapter 9 of this handbook presents information about how the consistency of the waste controls how the waste is handled and how the TS content in the waste controls consistency. The consistency of manure when it is applied to the land affects the type of equipment used and the amount applied. Chapter 4 of this handbook gives the moisture content of manure (feces and urine) as excreted; however, changes in consistency as moisture is added or removed must be taken into account in planning a waste management system.

(a) Solid

Waste with high percent TS, called solid waste, is produced by a wide variety of agricultural, municipal, and industrial operations. Animal-feeding operations, particularly feedlots, yield large quantities of solid manure that can be applied to land. Various animal species produce solid particles in manure that vary in size, shape, and sorption characteristics. As a result, the manure from various species takes on the nature of solid, slurry, or liquid at different moisture levels (fig. 11–1); however, in general, manure with a solids content of 20 percent by volume or greater can usually be handled as a solid. A low-moisture mix of manure, bedding (straw or wood chips), and waste feed is generally managed as a solid waste stream and transported by box/open spreaders or dump trucks to the land for application.

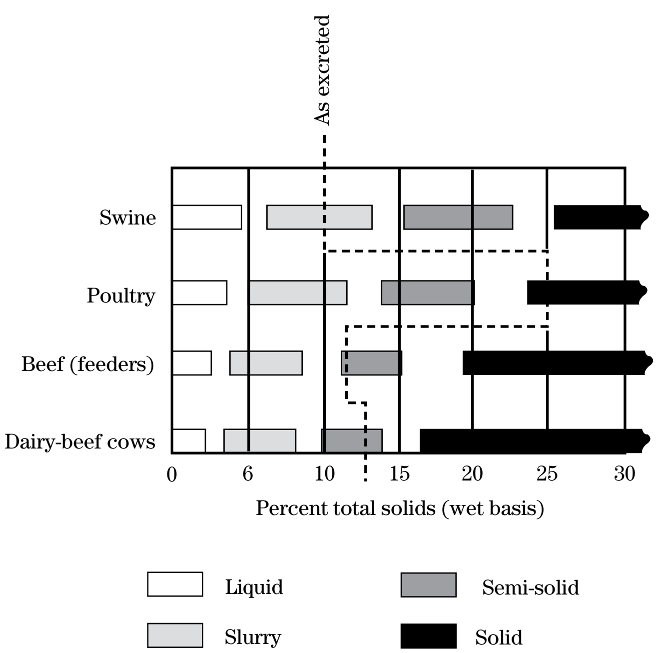
(b) Semisolid

Semisolid waste has a less firm consistency than solid waste, and it exhibits some flowable characteristics. With reference to figure 11–1, TS content of semisolid animal manure can range from 10 to about 22 percent, depending on the animal species. Semisolid manure generally can be transported and spread using the same box/open spreaders and dump trucks used for solid manure.

(c) Slurry

Slurry generally is associated with confined feeding operations for cattle and swine. The feces and urine are mixed and behave as a slurry rather than as a solid or a liquid. The solids content of slurry ranges from about 5 to 15 percent except as noted. In this range, manure has fluid-handling characteristics, but requires special pumping equipment. It can be transported by either tank wagon or pump and pipeline. Pump and pipeline are more economical for transporting large volumes of slurry because of the time and labor requirements for tank wagons. Slurry can be applied to the land by sprinklers that have large nozzles, by broadcasting from slurry tanks, or by injection under the ground surface. Because of the propensity to cause odors and pollute water, it is often recommended that slurry be incorporated immediately into the soil profile.

Figure 11–1 Relative handling characteristics of different types of manure and percent TS (ASAE 1990)



If slurry material from confined livestock facilities is properly agitated, it generally flows readily to a pump inlet. The more viscous materials are pumped into tank wagons by high-capacity, low-head pumps or are drawn in by vacuum pumps. On occasion, additional water is required for easier agitation and pumping.

Swine and poultry manure with about 12 percent solids and cattle manure with about 7 percent solids can be handled by certain types of large bore irrigation equipment. Large gun-type sprinklers must be powered by relatively low-capacity, high-head pumps that have chopping blades. Swine or poultry manure diluted to less than 7 percent solids and cattle manure diluted to less than 4 percent solids can be applied by most irrigation equipment if the manure is free of fibrous material. Standard centrifugal pumps, regular sprinkler nozzles, or gated pipes can be used. If the material is distributed in graded furrows, all irrigation tail water should be recovered to prevent the runoff from polluting the surface water.

Figure 11–2 can be used to determine the amount of water needed to dilute manure for a specific pumping consistency. For example, assume that the manure that is 20 percent solids must be diluted for use with a standard irrigation sprinkler. The desired solids content is 4 percent. According to information in figure 11–2, roughly 30 gallons of water are needed per cubic foot of manure.

Figure 11–2 is based on the equation:

$$G = \frac{7.48\left(P_o - P_d\right)}{P_d} \qquad \text{eq. 11–1}$$

where:

G = gallons of water required to be added to mixture per cubic foot of manure

P_o = original percent of solids in the mixture

P_d = desired percent of solids in the mixture

Important characteristics of different manure during storage in slurry form include:

- Poultry manure is heavy and dense and generally stratifies with a liquid layer forming on top.

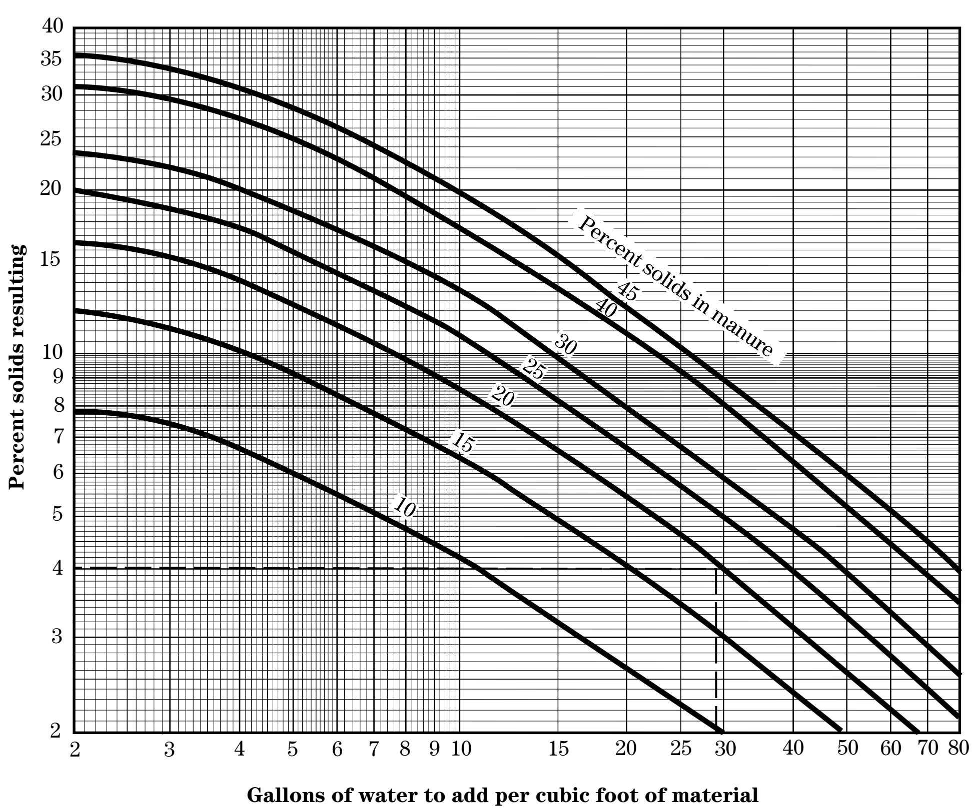
- Swine manure tends to remain in suspension; solids separation using short-term settling is often not effective.
- Some of the solids in cattle manure settle to the bottom, but some of the more fibrous solids rise to the top and form a crust. This is particularly true if long hay or silage is fed to the cattle or if bedding is collected with the manure.

(d) Liquid

Liquid manure has solids content of 5 percent or less. This consistency generally is produced where manure is diluted by wash water, flushing water, rainfall or runoff, or snowmelt. A common example is the liquid in a waste storage pond used to store runoff from a feedlot or outside dairy housing. Liquids also result from many food processing operations and municipal wastewater treatment.

Liquid manure application can be handled by any type of sprinkler or injection system (as long as large fibrous material is macerated or removed) or by flood irrigation methods such as furrows or borders. Wastewater application systems can often be combined with surface irrigation. Manure solids distribution, hence nutrients, may be uneven if flood irrigation methods are used because solids tend to settle out near the turnout. If adequate water is available for irrigation, the system can be designed to maximize the use of the manure for crop nutrients while meeting the consumptive use requirements. A screen or filter must be installed in the system for removal of long fibers, hair, and other debris before irrigation begins.

Figure 11–2 Gallons of water required per cubic foot of material for dilution to pumping consistency



651.1102 Land application

This section describes how manure can be applied to land to use nutrients for crop production while minimizing negative water quality impacts.

(a) Conservation plan

Land application of agricultural waste for crop production requires careful planning. Conservation plans developed for animal-feeding operations should include a plan for agricultural manure management and must address the overall nutrient management requirements for the farm or ranch operation. The nutrients in the manure to be land applied must be accounted for in the nutrient management plan for the farming operation. Realistic crop yield goals that recognize soil limitations must be established. The conservation plan must provide a fertility program that balances the nutrient application among all sources—manure, crop residue, soil minerals, commercial fertilizer, irrigation water, and nitrogen fixing plants. The plan should also include the land treatment necessary to control erosion on lands where manure is to be applied. Chapter 2 of this handbook gives details of the planning considerations. The goal of the manure management portion of the conservation plan should be to recycle nutrients in the manure as fertilizer in amounts that can be used by the crop without degrading the environment.

(b) Benefits of recycling

The most obvious benefit of recycling manure to the land is the fertilizer value. The return of the nutrients to agricultural land saves money that would otherwise be spent for commercial fertilizer. It also saves the energy required to produce and transport chemical fertilizers. It takes about 40,000 cubic feet of natural gas to produce a ton of commercial nitrogen fertilizer. Using manure as a replacement for commercial fertilizer could be considered an energy conservation practice. Manure application for nutrient also saves the raw materials mined to produce chemical fertilizers. Other on-farm benefits result from land application of manure. Manure can be used to add organic matter to the soil, which improves soil structure, infiltration, and tilth. This is enhanced by the use of conservation cover crops following manure applications. Soil erosion is controlled, and the moisture holding capacity is increased. Many farmers report that the fields on which manure has been applied always seem more loose and moist. Another benefit is that phosphorus and the organic part of the nitrogen are released slowly from the manure by the action of micro-organisms, making them available to crops throughout the growing season. A disadvantage common to other plant nutrient sources is that the nutrient release rate generally cannot be controlled.

Off-farm benefits also accrue. Properly applying manure reduces the potential of overenrichment of lakes and streams and also decreases the possibility of groundwater contamination.

(c) Application methods

The land application method should be based on the type and consistency of manure available, management of the confined animal operation (including manure management system), physical features of the farm, operator preferences and capabilities, and availability of labor. Generally, several management alternatives are available. Manure application methods can be broadly categorized into two groups—pumped and hauled. The travel distances and application rates achievable with the application equipment must be addressed in preparing nutrient management plans and planning waste management systems.

Incorporating manure into the soil as soon as possible will reduce the level of odors, slow the loss of nitrogen through volatilization, and remove the phosphorus from the surface where it may have been easily eroded. Without care, however, incorporation may cause more problems than it solves. Incorporation disturbs the soil surface, degrades soil structure, and reduces the biological activity in the soil ecosystem. A disturbed soil is more prone to erosion, and soil particles that are removed from the field take the nutrients attached to them. As soil structure is destroyed, the infiltration rate decreases, making it more difficult for nutrients on the surface to move into the soil profile. An active, viable functioning biological community in the soil has the ability to buffer and retain nutrients, holding them in place until they are used by the plant, increasing nutrient use efficiency. Earthworms, dung beetles, and other soil organisms, along with infiltration of rainfall into structured soils and through macropores can incorporate manure naturally. Manure is often valued as a soil builder, but the damage to the soils resulting from excessive incorporation can easily outweigh the benefits to the soil through the manure application. Incorporating manure to reduce the immediate potential for nutrient loss through volatilization and runoff may be short sighted if this benefit comes with a degradation of long-term soil health. Alternatives to incorporation or incorporation methods that minimize soil disturbance should be considered where possible. Chapter 3, section 651.0304 of this handbook provides guidance on management to minimize problems where wastes are applied on pasture.

(1) Pumped application methods

Pumped application methods require a liquid or slurry, a delivery system of pump and conveyance, and suitable application equipment such as large gun-type sprinklers, manure guns, gated pipe, or injection systems. Gravity-fed conveyance systems can be substituted for pumps where the specific operation provides the elevation differential required for operation.

Because wastewater that is pumped through an irrigation system applies the wastewater at a much faster rate than hauling, special consideration must be given to soil characteristics as follows (Horsfield 1973):

- Liquid manure application on soils that have very low internal drainage and a very slow intake rate results in runoff and ponding, which means a greater chance for unequal infiltration and potential stream pollution. Surface irrigation with wastewater should have a tail water recovery pond to prevent this water from leaving the field as a non-point source pollution discharge.
- A sloping terrain at the application site makes it increasingly important that waste application rates are less than soil intake rates to ensure no runoff to watercourses.
- A high water table means that nutrients from the manure have to move only short distances to contaminate the groundwater. Shallow or sandy soils that have little filtering capacity increase the potential for a problem.
- Excessively drained, low yield-potential soils are a problem because crops remove less of the applied nutrients and irrigation water moves through the soil too rapidly for adequate assimilation.

The design of a pumped application system is site specific. When using irrigation methods, a local irrigation specialist and irrigation guides should be consulted, where available. If the pumped system is to be used for both application and the irrigation water supply, special care should be taken to size the system to meet the water consumption requirements of the crop.

(i) Sprinkler systems—Sprinkler systems are widely used to apply liquid manure and agricultural wastewater. The type of irrigation system depends upon the consistency of the manure and wastewater. Particle size of the solids contained in the manure and wastewater also affects the applicability of the particular type of irrigation system.

Liquid consistency of the manure and wastewater can be assured by the addition of dilution water (fig. 11–2), removal of solids, or both. With proper screening and the appropriate liquid consistency, wastewater can be applied with any type sprinkler system. Pump intake screens should be sized with openings no larger than the smallest sprinkler orifice.

Slurry can be applied using special pumping equipment and sprinklers that have large nozzles, or manure guns that have flexible nozzles. Trash, abrasives, bedding, or stringy material in the manure are not suitable for most sprinklers unless preconditioned by chopping or grinding.

(ii) Pipelines—Pipe friction losses for water that contains solids are higher than those for clean water. The velocity in pipes should be less than 6 feet per second (ft/s), with a minimum of 3 feet per second to prevent sedimentation. Table 11–1 gives the relative increase in friction loss for slurries as compared to clean water for asphalt-dipped circular iron pipe that is 6 to 10 inches in diameter. Although friction ratios will be slightly higher for smoother pipe materials at high velocities, the ratios below are satisfactory for most design conditions using smooth pipe. The design should consider that the percent solids of slurries commonly vary during the pumping activity. Head losses in valves and fittings because of the turbulence should be approximately equal to those for clean water.

Table 11–1 Friction loss ratio, slurries versus clean water (asphalt-dipped circular iron pipe, 6- to 10-in diameter)

Velocity ft/s	- - - - - Percent solids - - - - -					
	4	5	6	7	8	10
1.0	1.1	1.5	2.1	2.9	3.4	5.3
1.5	1.0	1.2	1.5	2.1	2.5	4.0
2.0	1.0	1.0	1.0	1.6	1.9	3.3
2.5	1.0	1.0	1.0	1.3	1.6	2.9
3.0	1.0	1.0	1.0	1.2	1.5	2.7
3.5	1.0	1.0	1.0	1.1	1.3	2.5
4.0	1.0	1.0	1.0	1.0	1.0	2.4
4.5	1.0	1.0	1.0	1.0	1.0	2.3
5.0	1.0	1.0	1.0	1.0	1.0	2.2
5.5	1.0	1.0	1.0	1.0	1.0	2.1
6.0	1.0	1.0	1.0	1.0	1.0	2.0
6.5	1.0	1.0	1.0	1.0	1.0	2.0
7.0	1.0	1.0	1.0	1.0	1.0	2.0

Source: Adapted from Colt Industries Hydraulic Handbook, figure 44, Fairbanks Morse Pump Div., 11th Ed.

Example 11–1:

A smooth-sided, 8-inch pipeline is to deliver 550 gallons per minute (gal/min) of slurry containing 10 percent solids. The friction loss for clean water is 0.19 pounds per square inch (lb/in^2) per 100 feet, and the velocity is 3.42 feet per second. From table 11–1, the factor (ratio) for slurry versus clean water is 2.5 at 3.5 feet per second with 10 percent solids. The friction loss for the slurry would be calculated as:

$$\frac{0.19 \text{ lb/in}^2}{100 \text{ ft}} \times 2.5 = \frac{0.48 \text{ lb/in}^2}{100 \text{ ft}}$$

Although pipe friction losses might be higher for wastewater than for clean water, friction losses generally are a small percentage of the total power requirement in a sprinkler system. When the same pump is used for pumping both slurries and clean water, the pump might operate at different points on the pump curve for the two liquids. The effects when pumping slurries can include one of the following:

- a marked increase in brake horsepower requirements, a reduction in head produced, or
- a significant reduction in capacity, with some increase in head at the pump

The increased horsepower requirement is caused by the higher fluid viscosity and is necessary to overcome the velocity head loss and the pipe friction losses. To account for the differences associated with presence of solids and higher viscosity, it is satisfactory to increase the power unit rating by 10 percent as a rule of thumb for situations where friction loss ratio exceeds 1.0.

(iii) Application rates and amounts—For TS content of 0.5 percent or less, maximum application rates should be consistent with the local irrigation guide recommendations, with no adjustment. If no local irrigation guide data are available, application rates in table 11–2 (based on soil texture) can be used for design and management of the land application system to help avoid ponding and runoff. The actual application rate should be adjusted as needed to ensure that the target nutrient application amount is not exceeded.

For TS content in the wastewater of 0.5 percent or greater, application rates from the irrigation guide or table 11–2 should be reduced according to the information in table 11–3. The reduction coefficients in table 11–3 are based solely on decreases in hydraulic conductivity because of a layer of manure that forms on the soil surface during irrigation and has a lower hydraulic conductivity than the soil. Further reductions may be necessary in some situations such as applications of wastewater with salt concentrations sufficient to disperse clay aggregates. Salt content of the wastewater should be determined to assess its effect of the intake rates of the soil where it will be applied.

Table 11–2 Maximum application rate (in/h)

Soil texture	- - - - - - Application amount in inches - - - - - -						
	0.25	**0.5**	**0.75**	**1.0**	**1.25**	**1.50**	**2.0**
Sand	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Loamy sand	6.00	6.00	4.83	4.22	3.86	3.62	3.32
Sandy loam	4.91	2.97	2.32	1.99	1.80	1.67	1.51
Loam	3.11	1.69	1.21	0.98	0.84	0.74	0.62
Silt loam	2.70	1.45	1.03	0.82	0.70	0.61	0.51
Sandy clay loam	1.74	0.96	0.69	0.56	0.48	0.43	0.37
Clay loam	1.27	0.68	0.48	0.39	0.33	0.29	0.24
Silty clay loam	1.09	0.57	0.40	0.32	0.26	0.23	0.19
Sandy clay	0.61	0.33	0.23	0.19	0.16	0.14	0.12
Silty clay	0.84	0.44	0.30	0.24	0.20	0.17	0.14
Clay	0.39	0.21	0.14	0.11	0.09	0.08	0.07

Note: This table is for infiltration rate for full cover conditions and initial moisture content at 50 percent of the available water capacity. Field capacity of sand through sandy loam is assumed to be at 1/10 bar. The table is useful for prevention of ponding and runoff; it does not account for the nutrient content of the manure water.

Table 11–3 Reduction coefficients by percent solids

Soil texture	- - - - - - - Percent solids (by wt) - - - - - - - - - - -						
	0.5	**1.0**	**2.0**	**3.0**	**5.0**	**7.0**	**10.0**
Sand	0.88	0.55	0.31	0.22	0.13	0.10	0.07
Loamy sand	0.70	0.54	0.37	0.28	0.19	0.14	0.10
Sandy loam	0.87	0.77	0.63	0.53	0.40	0.32	0.25
Loam	0.97	0.93	0.88	0.83	0.74	0.67	0.59
Silt loam	0.98	0.95	0.91	0.87	0.81	0.75	0.68
Sandy clay loam	0.99	0.97	0.95	0.92	0.87	0.83	0.78
Clay loam	0.99	0.99	0.98	0.97	0.94	0.92	0.89
Silty clay loam	1.00	1.00	0.99	0.99	0.98	0.97	0.96
Sandy clay	1.00	1.00	1.00	1.00	0.99	0.99	0.99
Silty clay	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Clay	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Example 11–2:

The land user wants to apply 1 inch of wastewater with 5 percent solids content on a loam soil. What is the allowable maximum application rate in inches per hour?

Maximum application rate from table 11–2 is 0.98 inch per hour. The reduction coefficient from table 11–3 is 0.74. The allowable maximum application rate is:

$$0.98 \times 0.74 = 0.73 \text{ in/h}$$

Example 11–3:

A land user wants to apply wastewater with 5 percent solids content on a silt loam soil that has dense vegetation. The estimated surface storage is 0.2 inch, before any runoff would occur. The land user would like to apply 1.2 inches at a set. What is the allowable maximum application rate?

Because 0.2 inch can be applied before surface runoff starts, the minimum amount that must infiltrate into the soil is 1.2 less 0.2, or 1.0 inch. However, from table 11–2, the maximum application rate is 0.82 inch per hour, so the land user should not apply the full desired amount at a set. To determine the application rate for 5 percent solids, the maximum application rate for clean water is multiplied by the reduction coefficient for 5 percent solids. The factor is 0.81 from table 11–3. Therefore, the maximum application rate for 5 percent solids is:

$$0.82 \text{ in/h} \times 0.81 = 0.66 \text{ in/h}$$

The amount of application must be based upon either the nutrient requirements of the crop or consumptive use requirements of the crop, whichever factor is limiting. For example, to achieve a desired nutrient loading, the irrigation requirement might be exceeded. In this case, irrigation requirements would govern because meeting the nutrient needs necessitate an excess water application, leading to excessive deep percolation and leaching of nutrients below the root zone. If meeting the irrigation requirement is not a management objective, water requirements must still be considered so that excess leaching or runoff can be avoided.

(iv) Management considerations—Waste must be applied in a manner that:

- prevents runoff or excessive deep percolation of the wastewater
- applies nutrients in amounts that do not exceed the needs of the crop
- minimizes odors from the waste being applied

Other management considerations include flushing systems with clean water to clear manure solids from pipelines, washing waste materials from leaves of the crop, and maintenance of equipment.

(2) Hauled application methods

Hauling manure requires a means of transferring the material from a collection or storage area to a container, transporting the container and manure to the application area, and spreading the manure on the land. All consistencies of manure and wastewater are suitable for hauling.

Manure hauling equipment provides a mechanism for evenly applying or spreading manure to the application area. Manure spreaders or box spreaders are used primarily for solid and semisolid manure, and tank wagons (sometimes called honey wagons) and tank trucks are used for slurry and liquid manure. Injection equipment can be added to liquid and slurry spreaders for subsurface injection where odors are a problem or where maximum nutrient conservation is desired. Large volume tanker type equipment can transport the manure to the general area of application, where the manure is transferred to the application equipment. The separation of hauling equipment from the application equipment allows the economical transport of manure over considerable distances.

When transporting manure to a field, special consideration should be given to soil and climate characteristics that limit the opportunity for manure application. As described in a later section, soil texture and drainage characteristics can limit trafficability at application sites. Excess traffic on the sites during certain periods of the year can lead to soil compaction and eventually to excessive surface runoff.

Pumping of manure is generally more economical than hauling. The most important factors in making the economical determination are the volume of manure to be applied, time requirements, capital investment, and labor and fuel costs. The availability of existing equipment must also be considered. Figures 11–3 and 11–4 provide a method of comparing time needed to empty a manure storage facility by pumping or by hauling with a tank wagon.

Example 11–4:
A dairy operation has a 34,000-cubic foot, aboveground storage structure that needs to be emptied and a pump and pipe system that can deliver 275 gallons per minute to the field. A 1,000-gallon tank wagon is available to haul manure. It takes 17 minutes to fill the tank and make a round trip to the field. The operator estimates 1 hour of labor for pipe moving for each acre inch of waste applied, at a cost of $7 per hour.

Questions:

1. How much actual pumping time is required to empty the storage structure using the pump-pipeline system? Using the tank wagon?
2. What is the labor cost for pumping the manure to the field as compared to that for using a tank wagon and hauling?

Pump-pipeline—

$$\text{Storage} = \frac{\left(34{,}000\ \text{ft}^3 \times 12\ \text{in}\right)}{43{,}560\ \text{ft}^2/\text{acre} \times 1\ \text{ft}}$$

$$= \frac{\left(34{,}000 \times 12\ \text{in}\right)}{43{,}500}$$

$$= 9.4\ \text{acre-in}$$

Enter figure 11–3 at 9.4 acre-inches pumped and proceed vertically to the curves for 250 gallons per minute and 300 gallons per minute; 275 gallons per minute will be halfway between the curves. Go horizontally and read 15.5 hours pumped.

Tank wagon—Enter figure 11–4 at 34,000 cubic feet storage. Move up vertically to the curve for a 1,000-gallon tank wagon. Move horizontally through the number of loads line (255 trips) to the cycle time (17 minutes), which is between the 15 and 20 minutes per cycle lines. Then move down vertically to the removal time in hours (about 70 hours).

Actual time to remove 34,000 cubic feet is 72.3 hours:

$$\frac{34{,}000\ \text{ft}^3 \times 7.5\ \text{gal/ft}^3}{1{,}000\ \text{gal tank/cycle}} \times \left(17\ \text{min/cycle} \times \frac{1\ \text{h}}{60\ \text{min}}\right)$$

Pumping would require about 15 hours as compared to 70 hours to haul the waste to the field.

Labor requirement—From given information, 1 hour of labor is required for each acre-inch of wastewater applied; therefore, for 9.4 acre-inches, 9.4 hours of labor are required.

$$\text{Labor cost} = 94\ \text{h} \times \$7/\text{h}$$
$$= \$65.80$$

Tank wagon—Labor costs for hauling can be calculated by multiplying the emptying time by the hourly labor rate.

$$0.82 \times 0.81 = 0.66\ \text{in/h}$$

Labor costs for hauling manure to the field are seven times the labor costs for pumping.

The actual cost of pumping as compared to hauling involves much more than just an analysis of labor cost, even though labor may be the largest component in many cases. Other factors include fuel costs, capital investment, maintenance, and availability of power. Even though a worker may not be physically observing a pump system during the entire pumping period, some attention is required. Therefore, the total labor cost for pumping could be underestimated. Dilution of the manure in the storage structure to make it pumpable and agitation requirements for both the pumping and hauling processes must be evaluated.

Figure 11–3 Acre inches pumped in given time at various pumping rate

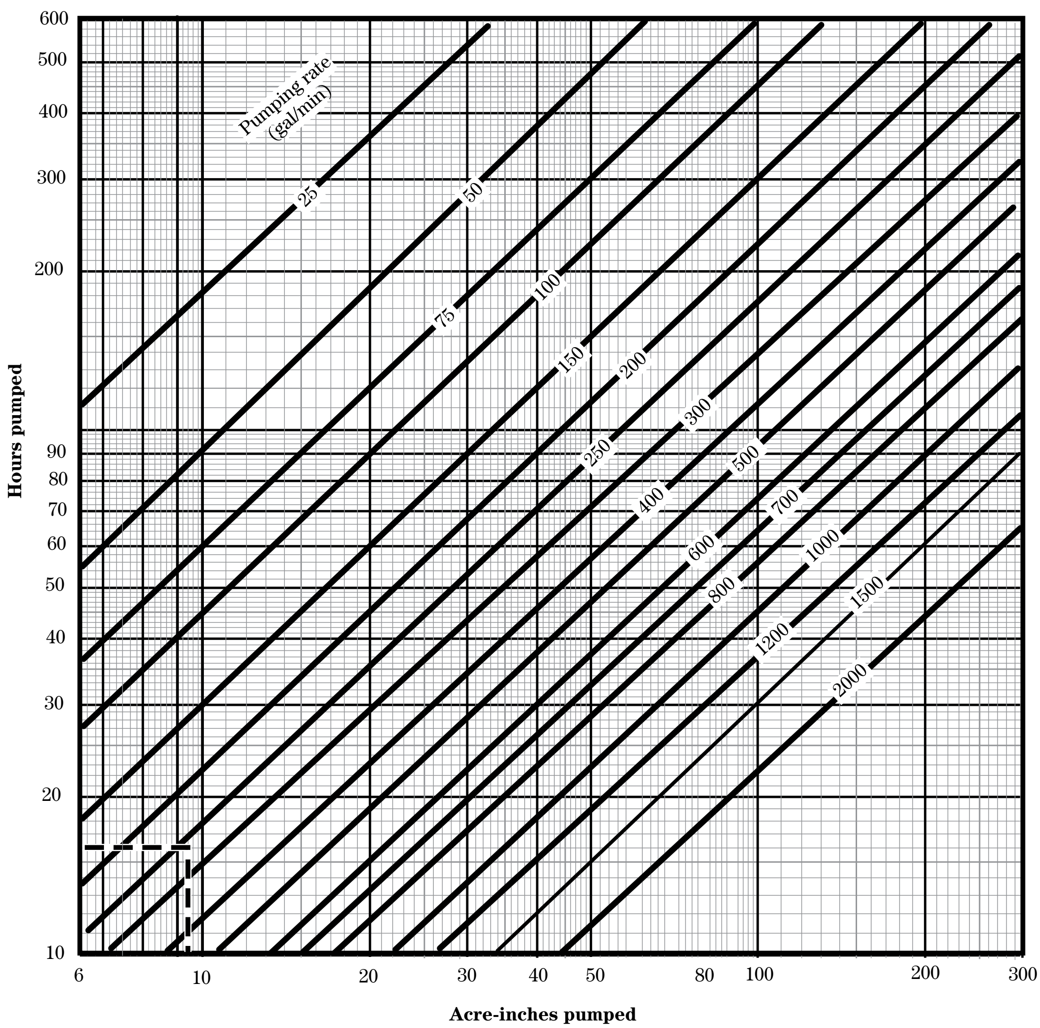
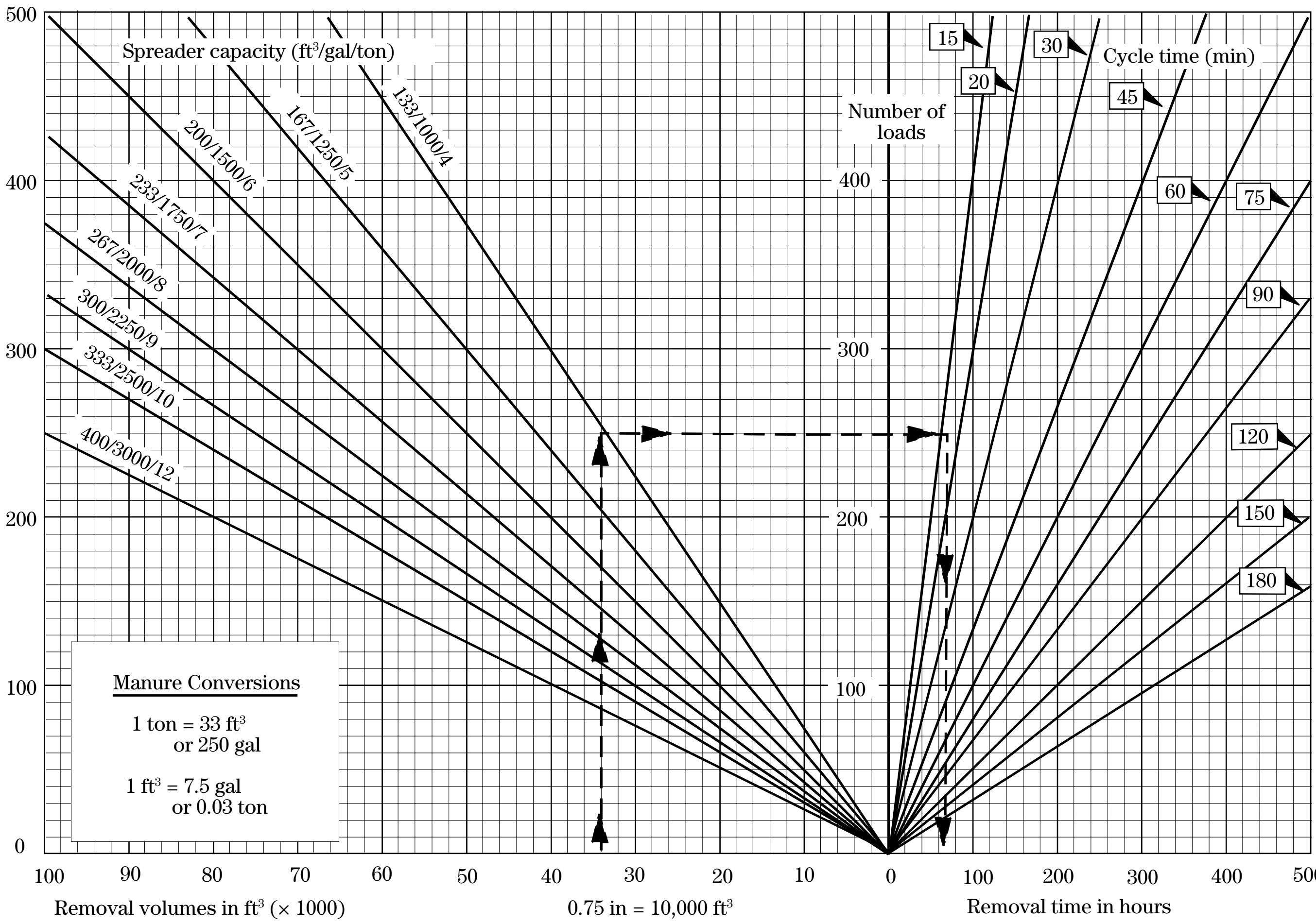


Figure 11–4 Removal time for various cycle times and spreader capacities



(d) Application management

Successful land application of manure starts with good planning. The key features of a manure utilization plan include details about objectives, rates, quantities, and timing. Success should be measured in terms of sound economics and environmental protection. Consequently, plans must take into account with the physical, management, and economic limitations of the farming operation. See chapter 2 of this handbook for guidance.

(1) Objectives

Where the application of manure is on cropland, the objective of a utilization program is to use the nutrients for crop production while minimizing negative water quality impacts. Where application is on pasture, the objective is to use nutrients to grow forage while minimizing water quality impacts and while timing the application to avoid rejection of the forage by livestock. A long-term objective is improvement of the soil health through increased organic matter. While manure is largely organic carbon, it would be difficult to build organic matter in the soil through manure application alone. Using manure nutrients to feed winter cover crops, minimizing soil disturbance, and including soil building crops in crop rotations are practices that should accompany manure application to achieve the long-term goal of soil health.

(2) Rates and quantities

Liquid manure must be applied at a rate that is compatible with the infiltration characteristics of the soil. For example, if a soil has a slow rate of intake, apply liquid manure at a slow rate. Total quantities of nutrients must not exceed the amount that can be used by the crop being grown or that can be safely stored in the root zone for carryover to the next crop. Rates and quantities must be carefully controlled on sites that have a high water table.

(3) Timing

Manure should be applied:

- With mineralization rates considered so that the manure nutrients will be available as close to the time of crop nutrient needs as possible. Crop growth stage curves should be consulted.
- When the ground is not frozen or snow covered.
- During periods that will result in minimal leaching and runoff of the manure nutrients.
- When the soil moisture content is not conducive to soil compaction from application equipment.
- On days when winds are relatively calm so that aerosols and odors are prevented from drifting onto neighboring areas, thus reducing odor complaints.
- Early in the day when the ground and air are warming and the air is rising, as opposed to late in the day when the temperature is dropping and the air is settling.

It is a common practice to apply manure in the fall after crop harvest. Among the benefits of fall applications are that it completes the application process before the busy spring planting season, it allows application when the fields are dry and not subject to severe compaction, and it empties the manure storage facilities before the winter season to allow for maximum storage over the winter months when manure application is more problematic due to snow covered ground and frozen soil. The problems with fall application are that it can leave the manure on the soil surface, which makes it subject to erosion during the winter months, and the nitrogen can be lost through volatilization and leaching. When a winter cover crop follows fall manure applications, the erosion is diminished and much of the nitrogen is captured in the soil profile due to the soil ecosystem that forms in presence of a live root. In addition, the winter cover crop will add much more organic matter to the soil than the manure can provide alone.

651.1103 Salinity

Salinity (saline or sodic soils) is not usually a problem in areas that receive high rainfall amounts and have soils that are naturally leached. However, poor seed germination and seedling growth have been experienced in humid areas where large amounts of broiler litter or manure have been applied just before planting time. This situation lasts only until rainfall can dilute the salts accumulated in the seed germination zone. Another cause of poor germination and seedling growth is the high levels of ammonia associated with poultry manure.

Excess soluble salt more typically causes problems on land in low-rainfall areas. Germination suffers and yields are reduced if the soils in these areas are not managed to minimize salt accumulation. Excess soluble salts reduce the amount of soil water available to plants and can cause nutrient imbalance or deficiencies that restrict plant growth (see chapter 6, section 651.0604(b) of this handbook). Many saline or sodic soils can be farmed successfully if an abundance of irrigation water is available to leach excess salts below the root zone. Because all irrigation water contains some level of soluble salts, the application of manure to irrigated land adds an additional source of salt. Irrigation of soils to leach salts should be timed to minimize the leaching of nitrates. Irrigation to leach salts can be done prior to manure application while the nitrogen content of the soil is low.

The soluble salt content of liquid and slurry wastes in storage vary from one storage facility to another. It also varies during the year in any one storage facility. The soluble salt content can be estimated by measuring the electrical conductivity of the liquid effluent. Electrical conductivity is reported in units of millimhos per centimeter (mmhos/cm) or micromhos per centimeter (µmhos/cm). One millimho per centimeter is equal to 1,000 micromhos per centimeter. The relationship between salt content and electrical conductivity varies from one storage facility to another, but is generally consistent in the same facility. Sweeten (1976) found that 1 millimhos per centimeter in a pond was equivalent to 1,900 pounds of soluble salt per acre-foot of water; others have referenced as much as 4,200 pounds of salt per acre-foot as equivalent to 1 millimhos per centimeter. Table 11–4 presents typical total salts and electrical conductivity for wastes that may be applied to agricultural land.

Where natural leaching does not occur, the salt content of waste storage ponds must be considered. If sufficient salts are present in the pond to cause problems, the pond contents can be diluted with good quality water or application volumes should be limited.

Figures 11–5 through 11–7 can be used to determine appropriate dilution factors and application rates. The dilution factors are based on an annual application rate of waste plus 24 inches of irrigation water. If application rates are less, annual soils tests are recommended. Where no opportunity for dilution exists and undiluted wastewater is applied as recommended in figure 11–8, annual soils tests are a must. Dilution needs related to soil texture generally can be ignored where adequate leaching water can be applied by irrigation.

Table 11–4 Total salts and electrical conductivity for various waste material (Stewart 1975)

Source of waste	Total salts	Electrical conductivity
	(mg/L)	(mmhos/cm)
Beef cattle waste	44–544	0.3–3.9
Feedlot runoff	1,810	13.0
Food process waste	44–653	0.3–4.7
Municipal wastewater	165–436	1.2–3.1
Municipal sludge	544–871	3.9–6.1

Figure 11–5 Waste storage pond dilution factors for resulting low salinity on coarse-textured soils

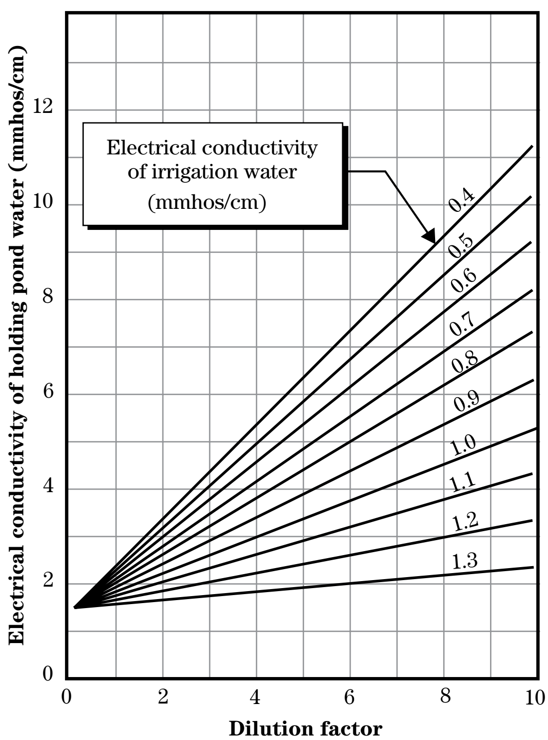


Figure 11–7 Waste storage pond dilution factors for resulting low salinity on fine-textured soils

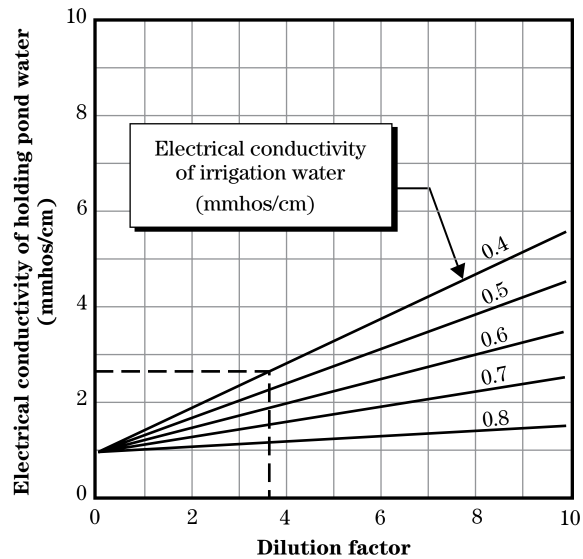


Figure 11–6 Waste storage pond dilution factors for resulting low salinity on medium-textured soils

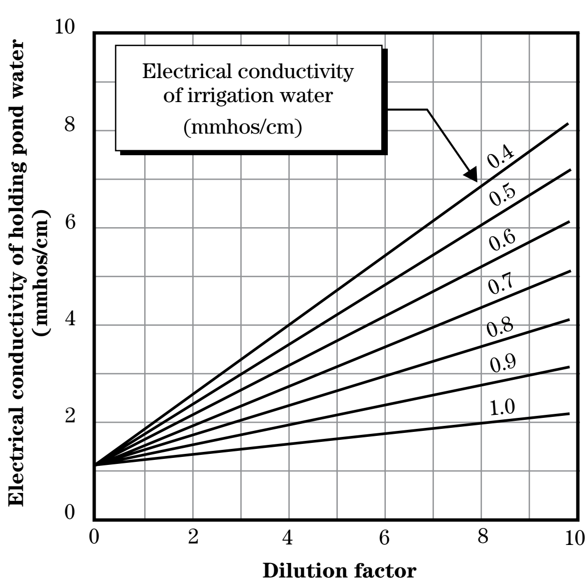
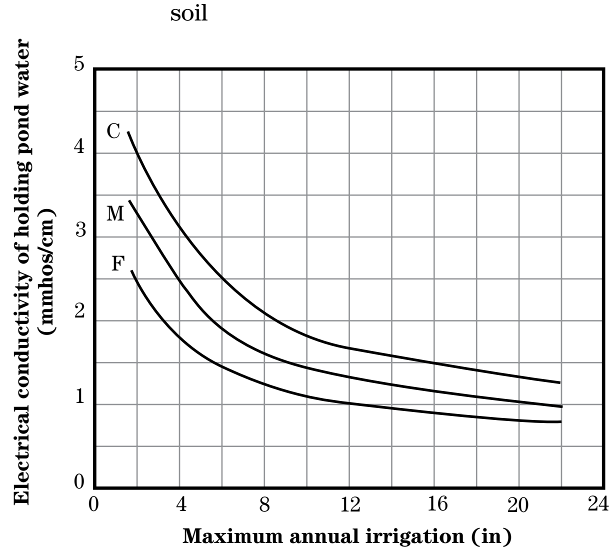


Figure 11–8 Maximum annual amount of undiluted waste storage pond water that can be added to a coarse (C), medium (M), or fine-textured (F) soil



Example 11–5:
Liquid waste from a 5 acre-feet dairy waste storage pond is to be applied to irrigated cropland. The annual irrigation application will be 28 inches per acre, and natural leaching is limited. The wastewater has an electrical conductivity of 2,700 micromhos per centimeter. The irrigation supply has an electrical conductivity of 400 micromhos per centimeter. The soil is clay.

Questions:

1. What dilution factor should be used to maintain a low salinity hazard in the irrigated cropland? What is the maximum waste application rate in inches per acre, considering salts?
2. If no dilution water is available, what is the maximum annual application of undiluted storage pond waste? How many acres would be required to apply the entire contents of the waste storage pond, again only accounting for salts?

Enter figure 11–7 with an electrical conductivity of holding pond water of 2.7 millimhos per centimeter (2,700 µmhos/ cm). Proceed horizontally to the line for an electrical conductivity of irrigation water of 0.4 millimhos per centimeter (400 µmhos/cm). Read down vertically to a dilution factor of 3.8 (answer to first part of question 1). For every inch of wastewater applied, 3.8 inches of irrigation water is needed.

Total wastewater application:

$$\frac{\text{Annual application (in/acre)}}{\text{Diluted waste (in/in of wastewater)}}$$

$$\begin{aligned}\text{Diluted waste} &= 1 + \text{dilution factor}\\ &= 1 + 3.8\\ &= 4.8 \text{ in}\end{aligned}$$

Therefore, the wastewater application in inches per acre is:

$$\frac{28 \text{ in/acre}}{4.8 \text{ in/acre}} = 5.8 \text{ in/acre}$$

This is the answer to the second part of question 1.

To address the situation where no dilution water is available, enter figure 11–8 at an electrical conductivity of storage pond water of 2.7 millimhos per centimeter. Proceed horizontally to the curve for fine-textured soils. Read down to a maximum annual irrigation of 2 inches (answer to the first part of question 2).

Each acre of land should receive no more than 2 inches of waste per year. To empty the 5 acre-foot storage would require:

Application area:

$$\begin{aligned}&= \frac{\text{pond vol. (acre-ft)} \quad \text{12 in/ft}}{\text{annual irrigation (in)}}\\ &= \frac{\text{5 acre-ft} \quad \text{12 in/ft}}{\text{2 in}}\\ &= \frac{\text{60 acre-in}}{\text{2 in}}\\ &= \text{30 acres}\end{aligned}$$

This is the answer to the second part of question 2.

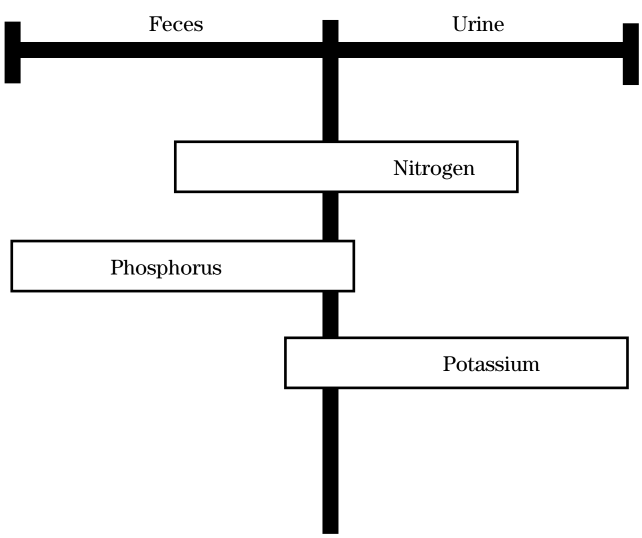
As will be covered in the next section, nutrients must also be considered when calculating application rates.

651.1104 Plant nutrients

Nitrogen (N), phosphorus (P), and potassium (K) are the major plant nutrients in manure. With reference to figure 11–9, the nitrogen is divided about half and half between the urine and the feces; but the preponderance of potassium is in the urine, and the vast majority of phosphorus is with the feces. Consequently, the importance of managing liquids and solids according to their nutrient availability and potential for transport with runoff is evident.

Nitrogen or phosphorus, or both, will in almost all cases be the nutrient that controls the planning and implementation of programs for land application of agricultural waste materials for crop production and environmental protection. Other constituents, such as pathogenic bacteria, oxygen demanding organic matter, and salts need to be considered when developing the nutrient management plan.

Figure 11–9 Distribution of nutrients between feces and urine



(a) Nitrogen

Nitrogen is a key element in plant growth and crop production and one of the most important elements in manure and organic waste, but it is a major pollutant if excess amounts move into water resources. Nitrogen is the most difficult of the major elements to manage because of the many pathways it can follow. Because of the complexities of the element, the nitrogen cycle and what drives it need to be understood. Figure 3–2 in chapter 3 of this handbook illustrates a nitrogen cycle. Nitrogen exists in one of three states in the environment—gas, liquid, or solid. It occurs in organic and inorganic forms. Although nitrogen can occur as an element, N, nitrogenous compounds (nitrogen in association with another element, such as hydrogen, H) are more important to agriculture. Ammonium (NH_4^+) and nitrate (NO_3^-) are primary plant nutrient forms.

Microbial decomposition of soil organic matter converts organic N into ammonium NH_4^+, a plant available form of nitrogen. The positively charged ammonium cation is held in the soil, and does not readily leach. Negatively charged soil clay minerals and soil organic matter hold the positively charged ion. This greatly restricts the movement of ammonium by percolating water (Bundy 1985). In addition to being attached to soil particles, ammonium nitrogen can be taken up by plants, consumed by micro-organisms, or transformed to ammonia gas and nitrates. Nitrification is the conversion of NH_4^+ to nitrate NO_3^- by soil bacteria and is a key reaction in the N cycle. NO_3^- is readily available to plants and is an important form of N to most crops; however, negatively charged nitrate remains in the soil solution and readily moves with water. Nitrates can also be reduced by bacteria, with nitrogen lost to the atmosphere in gaseous form. This process is called denitrification. In the nitrate form, nitrogen can leach through soil because it is an anion that has low sorptive capacity and does not form insoluble precipitates.

(b) Phosphorus

The phosphorus cycle (see fig. 3–3 in chapter 3 of this handbook) is different from the nitrogen cycle. Low solubilities of the mineral forms of phosphorus, when combined with calcium, iron, or aluminum, and their high potential for adsorption to clay particles result in a low tendency of leaching in most soils. The exception is in sandy soils that are low in clay content and organic material (carbon). Although the conversion rate of phosphorus in the soil to insoluble forms varies among soils, availability for plant uptake of phosphorus in the soil does decrease rapidly with time. Chemical reactions in the soil immobilize about half of the added soluble phosphate within the first day, with additional retention over the first month (Ghoshal 1974; Larsen 1965). Soil phosphorus can be a potential source of contamination to surface water for both sediment-attached and soluble phosphorus in runoff. Alum is sometimes used to bind soluble phosphorus in poultry litter that applied to pasture to reduce the availability of soluble phosphorus, thereby reducing its concentration in storm water runoff. Where the poultry litter can come in contact with the soil, as in cropland, the soluble phosphorus readily combines with elements in the soil without the use of Alum.

(c) Potassium

Potassium is a third major and important macronutrient for plant growth (see chapter 6 of this handbook). Native grasses that have an abundance of nitrogen available for uptake have been reported to show essentially no production when little to no potassium is available (Wagner 1968). Potassium is moderately soluble in water and is known to be available for transport in surface runoff or by leaching through the soil. It is also fixed in most soils, exchanging with such soil elements as calcium, sodium, magnesium, and ammonium. Water quality problems are not associated with potassium if the potassium is applied at agronomic rates; however, excessive potassium in the soil can block the uptake of other nutrients the plant needs. Excess potassium can contribute to a salt problem. High rates on application on clay soils can disperse the clay aggregates, degrade soil structure, and prevent infiltration.

651.1105 Nutrient management

A variety of factors must be considered in planning nutrient management systems. Production and environmental goals need to be balanced, and these goals might not always be compatible. Crop nutrient requirements should be met, and soil limiting features must be considered. In many cases, environmental and water resource considerations relate to nitrogen being the constituent of concern for groundwater and sea water, and phosphorus is of concern in fresh surface water; although, both can be limiting in either surface or groundwater. Phosphorus movement can be a problem, for example, in erodible soils that are on a sloping landscape and have a water supply reservoir in close proximity. Nitrogen leaching presents problems in areas having shallow aquifers used for drinking water.

Nutrient management applications must be planned for a limiting nutrient, which is usually either nitrogen or phosphorus. The ratio of phosphorus to nitrogen in manure is not the ratio needed by the crop. Applying manure to meet crop nitrogen needs of the crop will usually result in excess application of phosphorus needs of the crop. This is not often a problem if the soil has the ability to retain excess phosphorus for future crop use. However, once the soil has sufficient phosphorus, there is no production gained by adding more and as the phosphorus content of the soil increases so also the risk of the phosphorus leaving the field and reaching a sensitive water resource also increases.

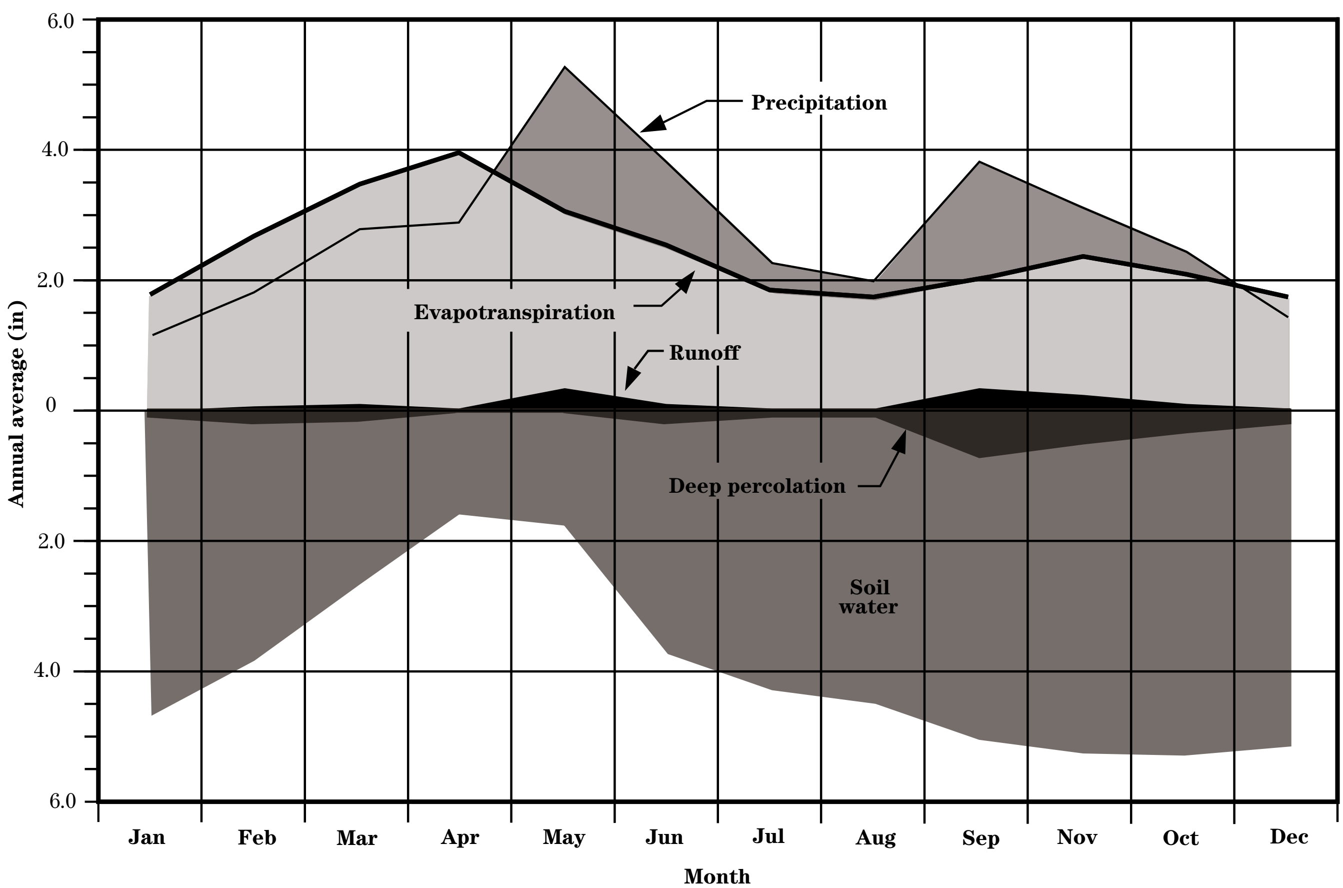
The Phosphorus Index (PI) is a tool that assesses the risk of phosphorus leaving a field and reaching a vulnerable water resource. The PI can be used to determine if the limiting nutrient for a manure application to a specific field should be nitrogen or phosphorus. Where there is little risk for phosphorus leaving the field, then nitrogen may be the limiting nutrient in the plan, but where the risk is high, then phosphorus should be the limiting nutrient. The PI is State specific. Because the science is not always conclusive, the professional judgment of the nutrient management specialist is incorporated into the PI. Because the PI is State specific, the interpretations of the results vary from State to State.

A nutrient management plan must consider all likely pathways of manure nutrient transformation and transport. Conservation Practice Standard (CPS) Code 590, Nutrient Management, should be followed in developing a nutrient balance for the cropping rotation. To meet regulatory requirements, the use of records for 5 years of crops is required. Plans should be based on soil tests, crop yields, manure nutrient analyses, and environmental concerns of the farm enterprise. The plan must account for the nutrients available in the manure, the crop residues, and the soil residues, the crop's requirement for the nutrients, and timing and method of application. The plan should be formulated to minimize the potential offsite losses of nutrients by runoff, leaching, and volatilization.

While nitrogen in manure is generally in higher concentrations and quantities than phosphorus, its availability and predictability of form are less certain. Though phosphorus is not considered a human health risk when found in high quantities in surface or groundwater, it is considered an environmental threat to fresh water because of the potential enrichment of water bodies that can lead to eutrophic conditions. Nitrogen nutrients can be fleeting in the soil and plant environment and only accumulate in some organic forms. Phosphorus does accumulate in the soil and can build to levels that become enriched. At higher levels, phosphorus is more susceptible to transport with sediment and runoff.

Monthly nutrient budgets are dependent on monthly water budgets. In areas that have groundwater concerns, figure 11–10 shows that nutrient application plans need to be structured to account for periods of excess movement of water into and over the soil.

Figure 11–10 Example of a water budget for winter wheat



Using figure 11–10, for example, the period of maximum deep percolation is August through November, with the deepest percolation occurring in September. Smaller quantities of deep percolation occur October through March and again in June.

Generally, if nutrients in organic form are applied in the fall, especially early fall, and mineralize, the soluble fraction tends to move with deep percolating water. If they are not incorporated, they move with surface runoff. Nutrients applied and incorporated late in spring or early in summer may not be available for percolation or runoff, but also may not be available when needed by the plants (as indicated by the shape of the evapotranspiration curve, which somewhat matches the nutrient uptake curve). Nutrient availability for the next crop can be improved with a conservation cover crop between crops. Without winter cover crops, the optimal time for nutrient application based on figure 11–10 would be late in winter or early in spring, when the nutrients will be readily available to plants. If the nutrients in a waste material are less available, such as with manure solids mixed with bedding giving a higher C:N ratio, incorporating the waste late in fall or early in winter allows additional time for the waste to mineralize, releasing nutrients as the plants begin growing in the spring. The objective is to match the timing of the crop's nutrient uptake requirement with the release of nutrients from the manure.

(a) Nutrient losses

Nutrient losses can come from volatilization during the storage and handling of the manure and by the application and incorporation process. Some nitrogen losses occur within the soil after manure has been incorporated. Nitrogen is lost from the soil primarily by leaching with the soil water and denitrification into the atmosphere; however, organic nitrogen must be transformed or mineralized for this to happen. Losses of phosphorus and potassium are minimal after incorporation, but the mineralization process does take place. To accurately determine the amount of nutrients reaching the ground, samples collected at the soil surface must be analyzed. Because this procedure generally is not done, the nutrient losses can be estimated using procedures that follow. Tabular values and calculations are included to demonstrate accounting for the major nutrients in manure.

(1) Losses from manure handling

Nutrient losses from manure before incorporation into the soil vary widely, depending on the method of collection, storage, treatment, and application. These losses must be considered when calculating the amount of nutrients available for plant uptake. Climate and management have the greatest effect on the losses. Volatilization losses are more rapid during warm weather and as the wind increases. They also increase with the length of storage or treatment. Microbial activity almost ceases when the temperature falls below 41 degrees Fahrenheit (5 °C). Thus, most volatilization losses cease in the late fall and do not resume again until spring. This is a natural conservation phenomenon.

Local information should be used if available. In the absence of local data, tables 11–5 and 11–6 give estimates that may be used.

Table 11–5 shows nutrients remaining for manure that has been stored or treated. It includes the consideration of losses during the collection process.

(2) Volatilization losses from manure application

Losses in the application process can be estimated using the information in table 11–6. These losses are in addition to those considered in table 11–5.

Timing of manure incorporation is critical to conserving the nitrogen in the manure. Volatilization loses increase with time, higher temperature, wind, and low humidity. To minimize volatilization losses, manure can be incorporated before it dries. The allowable time before a significant loss occurs varies with the climate. Manure applied to cool, wet soils does not dry readily and, thus, does not volatilize for several days. Manure applied to hot, dry soil dries quickly and loses most of the ammonia fraction within 24 hours, particularly if there is a hot, dry wind. If the manure has been stored under anaerobic conditions, more than 50 percent of the total nitrogen is in the ammonium form, which readily volatilizes on drying and is lost. Dried manure, such as that from a feedlot in an arid or semiarid climate, has already lost much of its ammonium nitrogen through formation of ammonia gas; after that there is little additional loss with time.

Table 11–5 Percent of original nutrient content of manure retained by various management systems

Management system	Beef			Dairy			Poultry			Swine		
	N	P	K	N	P	K	N	P	K	N	P	K
	Percent											
Manure stored in open lot, cool, humid region	55–70	70–85	55–70	70–85	85–95	85–95				55–70	65–80	55–70
Manure stored in open lot, hot, arid region	40–60	70–80	55–70	55–70	85–95	85–95						
Manure liquids and solids stored in a covered, essentially watertight structure	70–85	85–95	85–95	70–85	85–95	85–95				75–85	85–95	85–95
Manure liquids and solids stored in an uncovered, essentially watertight structure	60–75	80–90	80–90	65–75	80–90	80–90				70–75	80–90	80–90
Manure liquids and solids (diluted less than 50%) held in waste storage pond				65–80	80-95	80-95						
Manure and bedding held in roofed storage				65–80	80–95	80–95	55–70	80–95	80–95			
Manure and bedding held in unroofed storage, leachate lost	55–75	75–85	75–85									
Manure stored in pits beneath slatted floor	70–85	85–95	85–95	70–85	90–95	90–95	80–90	90–95	90–95	70–85	90–95	90–95
Manure treated in anaerobic lagoon or stored in waste storage pond after being diluted more than 50%	20–35	35–50	50–65	20–35	35–50	50–65	20–30	35–50	50–60	20–30	35–50	50–60

Table 11–6 Percentage of nitrogen of the applied manure still potentially available to the soil (ammonia volatilization causes the predicted losses) (Willrich, et al. 1974)

Application method	Percentage remaining/delivered		
Injection		95	
Sprinkling		75	
Broadcast (fresh solids)			
Days between application and incorporation	Warm dry	Soil conditions warm wet	Cool wet
1	70	90	100
4	60	80	95
7 or more	50	70	90

(3) Losses from leaching

As described earlier, nitrogen in the nitrate form is soluble and can pass through the root zone with percolating water. Water moving into the soil profile from rainfall, snowmelt, and irrigation drive soluble nutrients through the profile. In irrigated areas, good water management is needed to prevent excessive leaching of soluble nutrients. Some leaching will occur, however, if excess irrigation water is used to flush salts below the root zone.

The nutrient management plan should be developed with considerations to minimize leaching losses. In addition to the water budget, the rate of manure application, its timing, and the crop uptake requirement must be considered. For best results, the applications should be before or at the time of plant uptake and in harmony with the water budget. The Soil Leaching Index referred from section II of the Field Office Technical Guide (FOTG) can be used to estimate nitrate leaching. Table 11–7 should only be used to provide general guidance in planning, as shown in example 11–6.

Table 11–7 Estimate of inorganic nitrogen losses to leaching related to the Soil Leaching Index*

Leaching index	Inorganic N losses by leaching (%)
<2	5
2–10	10
>10	15

* This table should be used only to provide general guidance in planning.

The leaching index (LI) is a seasonably weighted estimate of nitrogen leaching potential. The probability of nutrients leaching below the root zone is dependent on the LI. An LI of less than 2 inches is unlikely to contribute to a problem, 2 to 10 inches is a possible contributor, and more than 10 inches is a likely contributor (Williams and Kissel 1991).

(4) Losses from denitrification

Nitrogen can also be lost from the root zone through denitrification. This occurs when nitrogen in the nitrate form is subject to anaerobic activity. If an energy source is available in the form of carbon (and it generally is within the root zone) and if other conditions favor the growth of anaerobic bacteria, the bacteria will convert the nitrates to the gaseous form as nitrous oxide or nitrogen gas, which then escapes into the atmosphere. Because manure is more carbonaceous than commercial fertilizer and carbon is a common energy source, some denitrification will most likely occur. Anaerobic conditions in the soil generally are controlled by soil water content (reflected in soil drainage classes) and available soil carbon (reflected in soil organic matter levels). Table 11–8 gives a gross estimate of the percent denitrification from all inorganic nitrogen in soils related to various drainage classes and organic matter content. This table assumes that nitrate concentrations are not limited, denitrifying microbes are present, and temperature is suitable for denitrification.

Table 11–8 Approximate N denitrification estimates for various soils—See footnote for adjustments because of tillage, manure N, irrigation, drainage,and special soil conditions (Meisinger & Randall 1991)

Soil organic matter content (%)	Soil drainage classification				
	Excessively well drained	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained
	% of inorganic N (fert., precip.) denitrified*				
<2	2–4	3–9	4–14	6–20	10–30
2–5	3–9	4–16	6–20	10–25	15–45
>5	4–12	6–20	10–25	15–35	25–55

* Adjust for tillage, manure, irrigation, and special soils as follows: for no-tillage, use one class wetter drainage; for manure N, double all values; for tile drained soils, use one class better drainage; for paddy culture, use values under poorly drained; for irrigation or humid climates, use value at upper end of range; for arid or semiarid nonirrigated sites, use values at lower end of range; for soils with compacted, very slowly permeable layer below plow depth, but above 4 feet deep, use one class wetter drainage.

(b) Nutrient mineralization

Once manure is in the soil, the nutrients available to a plant depend on the rate of mineralization (converted to the inorganic form) and from the amount remaining after losses through leaching and denitrification. Organic and inorganic manure nutrients are in the soil. The amount of inorganic nutrients available from manure depends on the rate of biological conversion from the organic state. The inorganic forms are soluble and available for plant uptake. The rate of conversion is called the mineralization or decay rate and is generally expressed as a decay series in terms of percent change of the original amount.

The rate for nitrogen mineralization depends on the:

- concentration of total nitrogen in the manure
- amount in the urea or uric acid form (organic nitrogen in the urine fraction)
- temperature and moisture conditions
- amount of organic N (or mineralizable N) already in the soil
- C:N ratio

Nitrogen is excreted in various forms, depending on the animal (Conn and Stumpf 1972). Fish excrete substantial amounts of nitrogen as ammonia (NH_3). Birds, including poultry, excrete a high percentage as uric acid. Mammals excrete about half of their nitrogen in urine as urea and the rest in the feces as undigested organic matter and synthesized microbial cells (Azevedo and Stout 1974). Uric acid and urea are unstable and are rapidly metabolized by micro-organisms and converted to the inorganic form, ammonium. The feces, however, is mineralized much more slowly.

Poultry manure has a faster mineralization rate than cattle or swine manure because it has a higher concentration of nitrogen, mostly in the form of uric acid. Fresh manure has a faster mineralization rate than that of old manure because it contains a higher percentage of the nitrogen in the urea form. Urea is easily transformed to ammonia. Generally, manure that has a higher concentration of nitrogen mineralizes faster than that with a low concentration.

The mineralization rate can also be affected by the C:N ratio. See chapter 4 of this handbook for some selected C:N values of manure. The common C:N ratio of excreted manure is below 20:1. If straw, sawdust, or other high carbon to nitrogen materials are used for bedding, the C:N ratio of the resulting material becomes higher and more of the nitrogen becomes immobilized by the micro-organism into the organic component. This nitrogen tied up by the microbes becomes less available for plant uptake during this interval. Consideration should be given to compensate for this temporary lag in nitrogen mineralization from the manure when developing the nutrient management plan.

A higher percentage of the total nitrogen in manure incorporated into the soil is converted to inorganic nitrogen in the first year than in the second. More is converted in the second year than in the third year. This occurs because the easily biodegradable part is mineralized quickly and the residue is mineralized slowly. Soil micro-organisms use the part of the waste that gives them the most energy first and the part that yields the least energy last. Again, the urine fraction is used first and the feces part last.

Research data on mineralization are limited. Pratt (1976) found the decay series for fresh bovine manure incorporated daily to be 0.75, 0.15, 0.10, 0.05. This means that 75 percent of the incorporated nitrogen becomes available the first year, 15 percent of the remaining nitrogen becomes available in the second year, 10 percent of the remainder in the third year, and so on. Theoretically, with enough time almost 100 percent of the incorporated nitrogen will be converted to the inorganic form.

For example, if fresh cattle manure is applied every year at the rate of 100 pounds of total nitrogen per acre, 75 pounds (75%) will be available the first year. In year 2, 15 percent of the remaining 25 pounds becomes available, or 4 pounds (rounded from 3.75).

In the second year, however, 75 pounds will also be available from the second manure application. Thus, 79 pounds are available in year 2. The nitrogen available in the third year would be the sum of that available from year 3, year 2, and year 1.

Although not as well documented as the nitrogen cycle, similar cyclic relationships exist for phosphorus and, to some extent, for potassium. The mineralization rate for phosphorus and potassium are generally more rapid than that for nitrogen, reflecting a larger proportion of the nutrients in available form as excreted.

Table 11–9 displays the rate of mineralization of nitrogen, phosphorus, and potassium for some typical manures and management conditions. As has been previously described, the rate of mineralization for nitrogen is proportional to the amount of the nutrient conserved in waste collection, storage, treatment, and application.

Microbial activity necessary for nitrogen mineralization is dependent on soil moisture. The mineralization is accelerated in moist soils as compared to the same soil where the profile is dry. Table 11–9 values for nitrogen should be reduced 5 to 10 percent in arid and semiarid areas where irrigation is not used. Local mineralization rates should be used if data are available.

(c) Nutrient requirements

Manure can provide part, all, or even excessive amounts of the nutrients required for plant production. The amount of nutrients required by plants must be determined in the development of the nutrient management plan. The most effective way to determine the crop's needs is to develop a comprehensive nutrient management plan based on CPS Code 590, Nutrient Management. The standard uses the components of a nutrient balance program starting with setting yield goals, soil and manure analysis, and plant nutrient availability for the growing season. A nutrient budget worksheet can be used to collect and calculate the information needed for a nutrient management plan. The local State's Cooperative Extension Service values for crop recommendations, production yields, manure nutrient mineralization rates, and soil test results can be used on the worksheet.

Two strategies can be used for manure utilization: management for maximum nutrient efficiency and management for maximum application rate of manure.

Strategy 1—Management for maximum nutrient efficiency. This strategy best realizes the value of the nutrients in the manure. The rate of application is based on the nutrient available at the highest level to meet the crop's needs. This element is often phosphorus. The manure rate is calculated to meet the requirement of phosphorus, and additional amounts of nitrogen and potassium are added from other sources

Table 11–9 Manure nutrients available to the crop from repeated applications

Waste and management	Years after initial application								
	1	2	3	1	2	3	1	2	3
	Nitrogen			Phosphorus			Potassium		
Fresh poultry manure	90	92	93	80	88	93	85	93	98
Fresh swine or cattle manure	75	79	81	80	88	93	85	93	98
Layer manure from pit storage structure	80	82	81	80	88	93	85	93	98
Swine or cattle manure stored in covered storage	65	70	73	75	85	90	80	88	93
Swine or cattle manure stored in open structure or pond (undiluted)	60	66	68	75	85	90	80	88	93
Cattle manure with bedding stored in roofed area	60	66	68	75	85	90	80	88	93
Effluent from lagoon or diluted waste storage pond	40	46	49	75	85	90	80	88	93
Manure stored on open lot, cool-humid	50	55	57	80	80	93	85	93	98
Manure stored on open lot, hot-arid	45	50	53	75	85	90	80	88	93

* Manure nutrients available to the crop include the nutrients in the year of their application and the organic nutrients mineralized from previous years applications. Table assumes annual applications at the same rate on the same site. If a one-time application for subsequent years following an application, the decay series can be estimated by subtracting year 1 from year 2 and year 2 from year 3. For example, the decay series for nitrogen from fresh poultry manure would be 0.02 for year 2, and 0.01 for year 3; the decay series for phosphorus from manure stored in open lot, cool-humid, would be 0.08 for year 2 and 0.05 for year 3. The decay rate becomes essentially constant after 3 years.

(generally commercial fertilizers). This rate is most conservative and requires the greater supplement of fertilizer, but applies nutrients in the quantities that do not exceed the recommended rates for the crop.

Strategy 2—Management for maximum application rate of manure. This is the strategy employed when the land available for application is limited, and it fails to fully realize the value of the nutrients in the manure. The most abundant element in the manure, generally nitrogen, is used to the greatest extent possible. The manure rate is calculated to meet the nitrogen need of the crop. Often the crop is chosen to maximize the nitrogen uptake. This maximizes the application rate of manure, but will overapply phosphorus and potassium for the crop's requirement. Over the long term, this will lead to an undesirable accumulation of phosphorus in the soil. Once a phosphorus threshold is reached, another strategy will need to be employed and manure will need to be applied elsewhere.

(d) Nutrient accounting

The traditional method for determining the nutrients available for plant growth when applying waste organic materials is to employ a nutrient accounting procedure. A procedure for determining manure application in wet tons (actual weight) per acre for solids and slurries and in acre-inches per acre for liquids is included. The procedure is reasonable for estimating the available nutrients, acres needed for application, and application rates. This is a procedure that is useful in the planning stage, especially in planning for a new confined animal feeding operation. It should not take the place of manure testing when implementing the nutrient management plan.

Variability of manure, differences in site and climate conditions, and the lack of localized research data are factors that influence accuracy of estimates. However, sampling of manure throughout the process will help minimize influences of variations and provide confidence in the accounting method. Also, the mineralization series and the accounting for previous applications of manure may be of no value unless the farm owner/operator keeps adequate records over the years so the history of each field is known. If the owner/operator does not have records, the soil should be tested or the application should be adjusted on the basis of experience or crop yields.

Due to the variables, assumptions, and estimates used when accounting for nutrients in the land application of manure, it is difficult to apply manure nutrients with precision. Precision nutrient application is best accomplished using commercial inorganic fertilizer.

(e) Accounting procedure

Figure 11–11 displays the following steps for nitrogen. In the absence of laboratory nutrient analysis of samples of manure ready to be applied to the field, that accounting procedure should begin at step one. If there is a reliable and consistent record of data showing the nutrient content of the manure actually applied to the field, this accounting procedure can begin at step 4.

Step 1 Estimate nutrients in the excreted manure.

The starting point for all calculations in this accounting procedure is to estimate the total nutrient content of the manure as excreted. Use State Cooperative Extension Service research or local information to derive the nutrient concentration (N, P_2O_5, K_2O) in the manure when available. If manure tests or local information is not available, the tables in chapter 4 of this handbook that show the average nutrient content for various animals can be used for preliminary estimates. The worksheets in chapter 10 of this handbook can be used to compute the total volume of manure production. Use caution when using these standard tables for a specific operation, and learn enough about the management of a specific operation to determine if it is consistent with the assumptions made in developing the standard tables.

Step 2 Add nutrients in wastewater, dropped feed, and added bedding.

Wastewater, such as feedlot runoff, milking center waste, and other process water, may also be applied to the soil for recycling of the contained nutrients (see the worksheets in chapter 10 of this handbook). Also see appropriate tables in chapter 4 for the nutrient content of wastewater. Because of the variability caused by dilution, feeding, and climate, wastewater samples should be analyzed to determine the nutrient content. Total the elemental nutrients from steps 1 and 2, and convert the elemental nutrients given in the tables in chapter 4 of this handbook to fertilizer equivalents (N, P_2O_5, K_2O) using the conversion factors in step 3.

Step 3 Subtract nutrients lost during storage.

Estimate the losses of nutrients in the manure from the time it is excreted until it is ready to be applied to the field. Table 11–5 gives a typical range of nutrients retained in the manure that has been stored or treated by various methods. Multiply the percent retained (table 11–5) by the total nutrients from step 2 to obtain the nutrient value after storage and at the time of field application.

In lieu of these first three steps, a better estimate of the nutrients content of the manure available can be obtained from a nutrient analysis of a sample of the manure that is to be applied to the field. A complete analysis will identify both the total nitrogen and the amount of that total that is in the organic and inorganic form. Nutrient values are sometimes given as elemental P and K. The conversion factors for phosphates and potash are:

$$\text{lb P} \times 2.3 = \text{lb } P_2O_5$$

$$\text{lb K} \times 1.2 = \text{lb } K_2O$$

Step 4 Estimate the plant available nutrients contained in the manure.

A large fraction of the inorganic nitrogen (the ammonium and nitrate), phosphorus, and potassium are plant-available the first year. Only a part of the organic nitrogen (the total nitrogen minus the inorganic nitrogen) is mineralized by microorganisms each year and made available to the plants. If localized data are not available, use table 11–9. It gives values plant availability of nitrogen, phosphorus, and potassium following land applications for several wastes and management options. The values in the columns represent plant availability of 1 year's manure application over a 3-consecutive-year period of cropping with additional manure application occurring each year. Use the value of year 3 for each subsequent year past year 3 that manure is applied. Multiply the factor for plant available nutrients for each of the nutrients by the total nutrients ready for land application (from step 3).

Step 5 Determine the nutrients required by the crop and soil to produce the yield goal.

Manure nutrient analysis, soil tests, and State Cooperative Extension Service recommendations are the best basis for managing nutrients. State Cooperative Extension Service guidelines for nutrient requirements are based on soil tests, crop yields, and local field trials. Soil fertility recommendations are given in Extension bulletins and soil test reports. In lieu of a soil test or local State Cooperative Extension Service crop nutrient recommendation, an estimate can be made of the nutrient requirements to produce the crop at the yield goal set. (Note: The following procedure is not recommended for calculating a nutrient budget for a nutrient management plan, but may be used for general planning and estimating land application area requirements.) The estimate accounts for the removal of the nutrients in the harvested crop and the anticipated loss because of denitrification and leaching in the soil, but nutrient additions can also occur. No attempt is made to account for losses caused by erosion, volatilization, or immobilization.

(1) Estimate the amount of nutrient removed by the harvested plant materials. The Crop Nutrient Tool in the USDA PLANTS Crop Database (http://plants.usda.gov/npk/AboutNutrient) provides an estimate of the nutrients concentration in the harvested part of the crop. Multiply the yield goal by the volume weight (in pounds per unit measure) and the fraction of the nutrient concentration. The values for phosphorus and potassium are expressed in the elemental form and must be converted to P_2O_5 and K_2O using the conversion factors in step 3.

(2) Add to the plant material requirement the soil potential for denitrification. Table 11–8 provides a rough estimate of potential denitrification losses that can be expected for a specific field condition. This estimate is for the inorganic fraction of the nitrogen available from the manure during the growing season and dependent on the soil drainage class and soil organic matter content. It is also dependent on the conditions in the soil being present for denitrification to take place. Only nitrogen will undergo this process.

(3) To the plant material requirement and the potential denitrification loss, add the potential loss that could occur when nitrate nitrogen

leaches below the root zone. Table 11–7 provides estimates of the percent of the inorganic nitrogen applied that can be lost by leaching based on the LI. Adding steps 5a, 1, 2, and 3 gives an estimate of the nitrogen balance in the system. Again, phosphorus and potassium are not considered.

Leaching losses are difficult to estimate on a site specific basis because it is dependent on local information, such as rainfall and nutrient additions. Local data may be available from field trial and nitrogen prediction models, such as Nitrate Leaching and Economic Analysis Package (NLEAP) (Shaffer et al. 1991). Leaching losses may range from 5 to 40 percent of the inorganic nitrogen available in the soil profile.

(4) Because additions to the nitrogen pool occur, they must be considered so that nutrients are not over applied. The sources of additional nitrogen are:

- mineralization of soil organic matter
- atmospheric deposition
- residue mineralization
- irrigation water
- credits from legumes

No adjustments for any of these additions are in the example, but they can be substantial. These additions need to be subtracted from the estimated nitrogen needed. General values for nitrogen mineralized per acre from soil organic matter (SOM) are 40 pounds per year for each 1 percent of SOM. Nitrogen from atmospheric deposition ranges up to 26 pounds per acre per year. (Local data must be available before adding this value.) Legumes can result in another 30 to 150 pounds of nitrogen per acre per year. Irrigation additions can be estimated by multiplying the nitrogen concentration in parts per million by the quantity of water applied in acre-inches by 0.227. Additions of nutrients from crop residue may be calculated using information in table 6–6, chapter 6 of this handbook and manure residual release of nutrients is given in table 11–9.

Step 6 Compute increased nitrogen to compensate for application losses.

Table 11–6 is used to estimate the volatilization of ammonium nitrogen that can occur when manure is applied to the soil.

Step 7 Select nutrient for calculation of manure application rates.

Consider the soil test levels, crop requirements, and environmental vulnerability in selecting the critical nutrient for calculating application rates of manure. The ratio of the nutrients (N, P_2O_5, K_2O) in the manure can be compared with the ratio of plant nutrients required. If ratio imbalance is present, every effort should be made to minimize applications that exceed soil test limits or crop requirements.

Step 8 Compute the acres on which manure can be applied to use the nutrients available.

Using the critical nutrient selected (step 7), divide the amount of plant available nutrients in the manure (step 4) by the amount of nutrients required per acre for production of the crop (step 6). This is the minimum number of acres that will be supplied by the selected nutrients for crop production. The manure can be applied to a greater number of acres, but supplemental nutrients will have to be supplied from other sources (for example, commercial fertilizer or nitrogen fixing cover crops) to complete the total crop and soil requirements for the selected yield goal.

Step 9 Determine application rate of manure.

Solid, semisolid, and slurry manure—Determine the application rate. Divide the weight of manure to be applied in tons by the acres required (step 8) to give the maximum tons per acre. As a rule of thumb for most applications, the volume of manure can be reasonably estimated by assuming that the density of manure is 60 pounds per cubic foot.

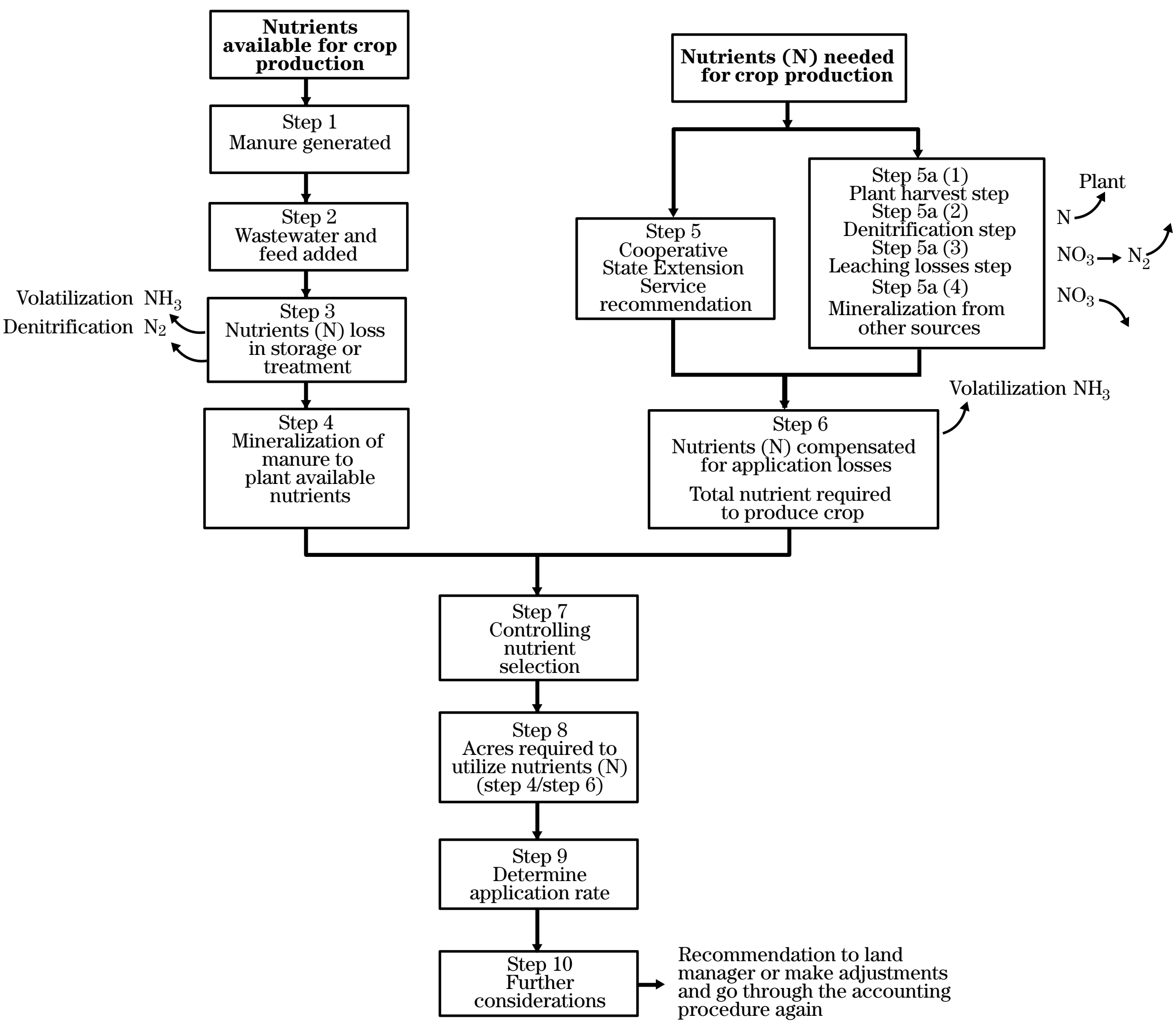
Liquid manure—These computations assume that the manure has been diluted enough to act as a liquid. Field application is normally by pipelines and sprinklers, but the manure can be hauled and applied. To determine the maximum application rate, divide the volume of manure and liquids to be applied in acre-inches by the acres required (step 8) to give acre-inches per acre.

Step 10 Further considerations.

Where the application rates solely based on one nutrient result in excessive amounts of other nutrients, the long-term impact must be considered. Continual over application of phosphorus or potassium may not be detrimental in soils that have a high affinity to adsorb and hold these nutrients from erosion and leaching. Yet in soils that do not have these holding characteristics, the contamination of water bodies is a potential hazard.

Nitrogen applications in excess of plant requirements should not be practiced because of the environmental and health problems that can occur. In some situations, the amount of land available is not adequate to use the total quantities of nutrients in the waste. Alternatives should be explored to use the excess manure produced. Some possibilities are additional land acquisition, agreement to apply on neighboring farms, decrease in animal numbers, composting and off-farm sales, and treatment to increase the nutrient losses in environmentally safe ways. It also may be possible to change the cropping rotation for greater utilization of the nutrients.

Figure 11–11 Nitrogen transformation in the accounting procedure



If no solution is apparent, a more detailed planning effort should be considered to formulate another alternative for the agricultural waste management system. (See chapter 2 of this handbook.) State and local laws, rules, and regulations regarding land application of organic materials must be met.

Example 11–6:
Given: 200 lactating dairy cows in central Wisconsin, average weight 1,200 pounds, are confined all year. The lactating cows produce about 100 pounds of milk per day per cow. All manure and milking parlor/milkhouse wastewater are pumped into an uncovered waste storage pond (CPS Code 313). The bottom of the pond is 60 by 200 feet, and the maximum operating depth is 12 feet. Side slopes are 2:1. Milking parlor plus milk-house wastewater amount equals 5 gallons per cow per day. Manure is applied every spring and incorporated within 1 day. No runoff from holding areas or adjoining fields is allowed to flow into the pond. Land is used for grain corn and has received manure for a number of years. Mean annual precipitation is 32 inches, evaporation from the pond surface is 12 inches, and the 25-year, 24-hour storm is 6 inches.

Soils on the sites for waste application are moderately well drained silt loam and have a LI of 6 (6 inches percolates below the root zone) and an organic matter content of 3 percent. The yield goal for grain corn is 180 bushels per acre. The soils are subject to frequent flooding and have 10 percent, by volume, rock fractions that are greater than 3 inches in diameter. Slopes range up to 10 percent. A 3,000-gallon tank wagon is available for spreading the liquid manure.

Questions and tasks:

1. What is the amount of nutrients available after mineralization (assume 3 consecutive years of application)?
2. What are the net available nutrients after leaching, denitrification, and other losses?
3. Estimate the area required based on nitrogen being the critical nutrient.
4. What area would be required to use the maximum amount of nutrients?
5. What is the application rate in tons per acre for the area that would provide maximum nutrient utilization?
6. How many trips with the tank wagon are required to apply the manure?
7. For an irrigation system design, determine the total depth of wastewater application for nutrients that have nitrogen control, and assess adjustments needed for phosphorus control.

Solution:

Step 1 Estimate the total nutrients (NPK) in the excreted manure. Nutrients per storage period = Number of animals × weight (lb) × daily nutrient production (lb/d/1,000 lb) × storage period (days).

Nutrient values for as excreted dairy cow manure are obtained from table 4–5, chapter 4 of this handbook. For lactating cows producing 100 pounds of milk per day, the daily nutrient production is 0.76 pounds N, 0.14 pounds P, and 0.35 pounds K per 1,000-pound animal unit per day.

$$N = \frac{200 \times 1,200 \times 0.76 \times 365}{1,000}$$
$$= 66,576 \text{ lb}$$

$$P = \frac{200 \times 1,200 \times 0.14 \times 365}{1,000}$$
$$= 12,264 \text{ lb}$$

$$K = \frac{200 \times 1,200 \times 0.35 \times 365}{1,000}$$
$$= 30,660 \text{ lb}$$

Step 2 Add nutrients contained in wastewater.

No field runoff enters the waste storage pond. Nutrients in the parlor/milkhouse wastewater are calculated as follows:

Based on observations and using table 4–6 as a guide, 5 gallons per cow per day was estimated to be representative.

Estimate the nitrogen, phosphorus, and potassium involved to be equal to the values provided in table 4–6, chapter 4 of this handbook of 1.7, 0.83, and 2.50 pounds per 1,000 gallons of wastewater. This results in a small amount of double accounting because some manure affected the values in table 4–6; however, the answer will still be reasonable and slightly conservative.

Nutrients in the wastewater = Number of animals × daily wastewater production (gal/d/cow) × daily nutrient production (lb of nutrient/1,000 gal) × number of days.

$$N = \frac{200 \times 5 \times 1.7 \times 365}{1,000}$$
$$= 620 \text{ lb}$$

$$P = \frac{200 \times 5 \times 0.83 \times 365}{1,000}$$
$$= 300 \text{ lb}$$

$$K = \frac{200 \times 5 \times 2.50 \times 365}{1,000}$$
$$= 910 \text{ lb}$$

Total nutrients produced:

$$\text{Total N} = 66,576 \text{ lb} + 620 \text{ lb}$$
$$= 67,196 \text{ lb}$$

$$\text{Total P} = 12,264 \text{ lb} + 300 \text{ lb}$$
$$= 12,564 \text{ lb}$$

$$\text{Total K} = 30,660 \text{ lb} + 910 \text{ lb}$$
$$= 31,570 \text{ lb}$$

Converting to fertilizer form:

$$\text{Total N} = 67,196 \text{ lb}$$

$$\text{Total } P_2O_5 = 12,561 \text{ lb} \times 2.3$$
$$= 28,771 \text{ lb}$$

$$\text{Total } K_2O = 31,570 \text{ lb} \times 1.2$$
$$= 38,200 \text{ lb}$$

Step 3 Subtract nutrients lost during storage.

From table 11–5, estimate values using entry for “manure liquids and solids held in waste storage pond (diluted less than 50 percent).” The lower values should be used because dilution is about equal to 50 percent. Multiply the percent retained (from table 11–5) by the total nutrients from step 2 to compute the amount of nutrients remaining after the storage losses.

Nutrients after storage losses equals total nutrients produced times fraction retained, which results in the amount available for land application.

$$\text{Total N} = 67,196 \text{ lb} \times 0.65$$
$$= 43,677 \text{ lb}$$

$$\text{Total } P_2O_5 = 28,771 \text{ lb} \times 0.80$$
$$= 23,017 \text{ lb}$$

$$\text{Total } K_2O = 38,200 \text{ lb} \times 0.80$$
$$= 30,560 \text{ lb}$$

Step 4 Determine the plant available nutrients.

Using table 11–9, estimate the amount of nutrients that will be available each year after the third consecutive year of application.

Plant available nutrients = Amount applied × fraction available

$$N = 43.677 \text{ lb} \times 0.49 = 21,402 \text{ lb}$$

$$P_2O_5 = 23,017 \text{ lb} \times 0.90 = 20,715 \text{ lb}$$

$$K_2O = 30,560 \text{ lb} \times 0.93 = 28,421 \text{ lb}$$

This is the answer to question 1.

Step 5 Determine the nutrients required by the crop and soil to produce the yield goal.

Generally, a soil analysis would be taken and the State Cooperative Extension Service recommendation would be used but for illustrative purposes, the method to estimate nutrient requirements given in chapter 6 is used. An example in chapter 6 of this handbook provides the nutrients removed by the harvest of 180 bushels of corn.

Step 5a (1) Estimate the amount of nutrients removed by the crop using the Crop Nutrient Tool from the PLANTS Database (http://plants.usda.gov/npk/AboutNutrient).

(See chapter 6, section 651.0606(b), Nutrient removal example.)

N = 143 lb/acre

P= 27

K= 30

Converting to fertilizer form:

$$N = 143 \text{ lb/acre}$$
$$P_2O_5 = 27 \times 2.3$$
$$P_2O_5 = 62$$
$$K_2O = 30 \times 1.2$$
$$K_2O = 36$$

Step 5a (2) Add to the plant requirements additional nitrogen to replace anticipated denitrification losses.

From table 11–8 for a moderately well-drained soil that has an organic matter content of 3 percent, the table gives a value of 26 percent denitrified. (Estimating 13 percent and doubling for manure gives 26 percent.)

Nitrogen needed considering denitrification = Plant requirements from step 5a (1) divided by the percent retained as a decimal after denitrification, which is 100 percent less the percent lost (from table 11–8).

$$N = \frac{143}{0.74}$$
$$= 193 \text{ lb}$$

An additional 50 pounds of nitrogen is needed to compensate for the anticipated denitrification losses.

Step 5a (3) Add to the plant requirements additional nitrogen to replace anticipated leaching losses.

From table 11–7, for a LI of 6 (6 inches of annual percolation below the root zone), the estimated loss is 10 percent. This means 90 percent of the nitrogen would be retained. Divide the amount of nitrogen required from step 5a (2) by the percent retained (0.90) to increase the nitrogen to provide adequate nitrogen for the plant after losses anticipated from leaching.

Nitrogen = Nitrogen required for the anticipated denitrification losses, divided by the percent retained (as a decimal) after leaching losses.

$$N = \frac{193}{0.9}$$
$$= 214 \text{ lb}$$

An additional 21 pounds of nitrogen are needed to compensate for the anticipated leaching losses.

Step 6 Add additional nitrogen to compensate for application losses.

From table 11–6, determine the nitrogen anticipated to be retained after application losses in the form of ammonia by volatilization. For broadcast manure incorporated within 1 day, use a delivered percentage of 95 (estimate for a wet soil in spring, between warm and cool temperatures).

Nitrogen to apply = Nitrogen anticipated from step 5a (3) divided by the percent delivered in decimal form (from table 11–6):

$$N = \frac{214}{0.95}$$
$$= 225 \text{ lb}$$

An additional 11 pounds of nitrogen is needed to compensate for application losses (volatilization).

The answer to question 2 would be:

$$N = 225 \text{ lb/acre}$$
$$P_2O_5 = 62$$
$$K_2O = 36$$

Note: Estimates for nitrogen additions to the field from soil organic matter, crop residue, atmospheric deposition, or legumes were not made.)

Step 7 Select nutrient for calculation of manure application rates.

To answer question 3, "How many acres are required to recycle nitrogen?" in this example, nitrogen is selected as the controlling nutrient.

Step 8 Compute the acres on which manure can be applied to use the nutrients available.

Required acres = Amount of plant available nutrients (from step 4) divided by the amount of selected nutrient for crop production (step 6).

Required acres:

$$\frac{21,402 \text{ lb N}}{225 \text{ lb N/acre}} = 95 \text{ acres}$$

This is the answer to question 3.

To answer question 4, "What area would be required to use the maximum nutrient utilization?" Return to step 7.

In this example, potassium is both the nutrient that is used least by the crop and also produced in most abundance, so it will control if maximum utilization of nutrients is desired. In less obvious cases, it may be necessary to go through step 8 to see which nutrient requires the most acres.

Step 8 Compute the acres on which manure can be applied to use the nutrients available.

Required acres = Amount of plant available nutrient (step 4) divided by the amount of selected nutrient for crop production.

28,421 lb K_2O (potash) is available

36 lb K_2O/acre are required by the crop

Therefore, the required acres are:

$$\frac{28,421 \text{ lb}}{36 \text{ lb/acre}} = 789 \text{ acres}$$

This is the answer to question 4.

The required acres for phosphorus are computed the same way.

20,715 lb P_2O_5 (phosphate) is available

62 lb P_2O_5/acre are required by the crop

Therefore the required acres are:

$$\frac{20,715 \text{ lb}}{62 \text{ lb/acre}} = 334 \text{ acres}$$

Only 95 acres are needed if the objective is to apply enough manure for the nitrogen requirement, but 789 acres are required if the objective is to prevent an overapplication of potash.

Step 9 Estimate application rate.

The waste storage pond contains the manure produced by the 200 cows plus the milk parlor wastewater. Precipitation and evaporation must be considered to obtain the total volume of stored material. Chapter 10 of this handbook describes procedures to account for climatic conditions.

Manure excreted per day = 1.9 ft^3/d/1,000 lb cow (table 4–5).

Total manure volume per year:

$$\frac{200 \times 1,200 \times 1.9 \times 365}{1,000} = 166,440 \text{ ft}^3$$

Total wastewater volume per year:

$$\frac{200 \times 5 \times 365}{7.5} = 48,670 \text{ ft}^3$$

Volume of precipitation = Average annual rainfall – Average annual evaporation:

32 – 12 = 20 inches precipitation storage

The 20 inches of precipitation translates to about 44,640 cubic feet. A waste storage pond with bottom dimensions of 60 by 200 feet, 2:1 side slopes, and 12 feet deep would have a maximum surface area of 26,784 square feet. The annual precipitation storage is:

$$\frac{20 \text{ in}}{12 \text{ in/ft}} \times 26,784 \text{ ft}^2 = 44,640 \text{ ft}^3$$

Total volume stored is:

$$166,440 + 48,670 + 44,640 = 259,750 \text{ ft}^3$$

Volume in acre-inches:

$$259,750 \text{ ft}^3 \times 12 \text{ in/ft} \times \frac{1 \text{ acre}}{43,560 \text{ ft}^2} = 72 \text{ acre} - \text{in}$$

Volume of water that has been added per cubic foot of manure is:

$$\frac{\left(48,670 \text{ ft}^3 + 44,640 \text{ ft}^3\right) \times 7.5}{166,440} = 4.2 \text{ gal additional water/ft}^3 \text{ of manure}$$

Total solids of manure as produced equals 12.5 percent (table 4–5). Resultant TS with wastewater and precipitation added equals 8.5 percent (fig. 11–2).

Calculate weight of stored material:

$$\frac{259{,}750\ \text{ft}^3 \times 62.4\ \text{lb/ft}^3}{2{,}000} = 8{,}104\ \text{tons}$$

From step 8, use application area of 95 acres for nitrogen utilization and 789 acres for maximum waste utilization (based on potassium). Application rate is calculated by dividing tons applied by the acres covered.

$$\frac{\text{Tons applied}}{\text{Application area}} = \text{Application rate (tons/acre)}$$

N accounting:

$$\frac{8{,}104\ \text{tons}}{95\ \text{acres}} = 85\ \text{tons/acre}$$

Maximum utilization:

$$\frac{8{,}104\ \text{tons}}{789\ \text{acres}} = 10\ \text{tons/acre}$$

This is the answer to question 5.

These application rates are approximately seven 3,000-gallon tank wagon loads (85 tons/acre) or approximately one 3,000-gallon tank wagon loads (10 tons/acre) per acre.

The following calculations demonstrate a method for adjusting waste applications to consider site characteristics.

Application by tank wagon:

Calculate the number of trips that will be required to apply the manure using a 3,000-gallon tank wagon load.

$$\frac{8{,}104\ \text{tons} \times 2{,}000\ \frac{\text{lb}}{\text{ton}}}{8.34\ \text{lb/gal} \times 3{,}000\ \text{gal/trip}} = 648\ \text{trips}$$

The answer to question 6 is 648 trips. When applying for nitrogen this amounts to a nearly 5 trips per acre. When applying for maximum utilization (potassium in this example) this is one trip for every 2 acres. It may be difficult to apply at this low a rate with a tanker wagon.

Application by sprinkler:

Exposing liquid manure to the air in small droplets will result in more nitrogen loss. Starting at step 5a(3), recompute the additional nitrogen required for sprinkler application losses. Nitrogen to apply = Nitrogen anticipated from step 5a(3) divided by the percent delivered (from table 11–6):

$$N = \frac{214\ \text{lb/acre}}{0.75} = 285\ \text{lb/acre}$$

$$P_2O_5 = 62\ \text{(no change)}$$

$$K_2O = 36\ \text{(no change)}$$

Note: Increased soil moisture from irrigation may increase soil losses by leaching and denitrification of nitrogen.

Returning to step 8, compute the acres required: Required acres = Amount of plant available nutrients (from step 4) divided by the amount of nutrient per acre (step 6). Required acres:

$$\frac{21{,}402\ \text{lb}}{285\ \text{lb/acre}} = 75\ \text{acres}$$

Using the 75 acres of corn that has been established for application of waste materials, determine the application quantities for nitrogen control and assess adjustments needed for a phosphorus control design. The solid contents and characteristics in the manure wastewater must be matched to the irrigation system. Large solids may need to be separated or reduced in a chopper pump. Traveling guns can handle up to 9 percent solids in the manure wastewater but typically, they will work better with a solids content at 6 percent or lower. For this example, assume the solids content is to be lowered to 4 percent by mixing manure wastewater and irrigation water in a mixing tank prior to pumping it through the irrigation system. At design depth, the waste holding pond contains 72 acre-inches of waste material at about 8.5 percent of TS (previously determined in step 9 using figure 11–2). The total amount of irrigation water that will need to be mixed with the manure waste water to lower the solids content from 8.5 to 4 percent water to add can be computed mathematically as follows:

$$\frac{7.48\ \text{gal/ft}^3 \times (8.5\% - 4\%)}{4\%}\% = 8.4\ \text{gal/ft}^3 \text{ of waste}$$

Before diluting the volume of wastewater was 259,750 cubic feet. An additional 8.4 gallons of water per cubic foot of wastewater was added for irrigation purposes. This adds 2,181,900 gallons (291,700 ft^3) of water to the waste stream, for a total waste water volume to apply of 551,450 cubic feet.

Determine the total depth of application for this example:

$$\text{Depth} = \frac{551{,}450\ \text{ft}^3 \times 12\ \text{in/ft}}{75\ \text{acres} \times 43{,}560\ \text{ft}^2\ /\text{acre}} = 2.0\ \text{in}$$

This is the answer to the first part of question 7.

For groundwater protection in sensitive aquifer areas, the 2 inches of wastewater application should be stored in the upper half of the root zone where most of the plant uptake occurs. Known from the example problem statement, the soils used to grow corn have an available water capacity of 5 inches in the top 60 inches of soil.

Normal irrigation design/operation techniques set 50 percent soil moisture depletion as the point at which irrigation operations are initiated.

$$5.0\ \text{in} \times 0.50 = 2.5\ \text{in}$$

Sprinkler irrigation efficiencies can be as low as 65 percent; therefore, the gross irrigation application would need to be increased to result in the soil receiving 3 inches of wastewater.

To assure that the leaching potential is minimized, the quantity (3 inches) can be split between two or three separate applications. Application rates in inches per hour must be set according to the intake rates established in local irrigation guides and adjusted for the soil texture and TS of the wastewater (tables 11–2 and 11–3).

Phosphorus application

For crop growth, 62 pounds per acre P_2O_5 are needed. By applying this manure to meet the nitrogen requirements of our crop, we are overapplying phosphorus. Since we are applying sufficient phosphorus for 334 acres on only 75 acres, we can compute the amount of phosphorus applied when applying this manure to meet nitrogen needs as follows:

$$46\ \text{lb}\ P_2O_5 \left(\frac{334\ \text{acres}}{75\ \text{acres}}\right) = 199\ \text{lb/acre}$$

This is almost 4.5 times the amount needed. A continual application of phosphorus at this excessive rate may result in very high soil phosphorus availability. Phosphorus losses by runoff, erosion, and, in certain soil conditions, leaching can present a serious water quality concern. To limit irrigation application to the phosphorous requirement, the application quantity would need to be reduced. The reduced application rate through irrigation can be computed as follows:

$$2\ \text{inches}\ (75\ \text{acres} / 334\ \text{acres}) = 0.45\ \text{inches}$$

The answer to the second part of question 7 is 0.45 inches.

(f) Adjustments for site characteristics

Land slope, soil surface texture, flooding potential, permeability, salinity, and soil depth all play a role in assessing pollution potential. This is particularly true where the preceding procedures are used to calculate the minimum area required to recycle nutrients based on nitrogen.

A procedure was developed in Oklahoma to consider site characteristics in assigning a pollution potential to any given field (Heidlage 1984). The procedure was used in one watershed, and after 4 years monitoring, no pollution from any of the farms studied was indicated (Watters 1984, 1985).

The following soil properties and features were considered in selecting suitable sites for land application of wastes:

Flooding was considered the most important feature in Oklahoma because waste applied to flood-prone soils can be readily transported into a watercourse.

Rock fragments greater than 3 inches affect the ease of tillage potential for waste incorporation and trafficability.

Texture primarily affects the trafficability of the soil and plant growth potential.

Slope affects the potential for runoff from the site.

Depth affects the thickness of the root zone, plant growth potential, and nutrient storage.

Drainage affects plant growth potential, the ease of travel or trafficability, tillage, nutrient conversion, and runoff potential.

Yield potential was an expression of the soil's ability to produce forage and, consequently, nutrient uptake.

In the Oklahoma procedure, a predominant or limiting soil is selected as being representative of the waste application site. Soil properties and site conditions are given a numerical rating, and these ratings are summed for the site. Heidlage (1984) weighted the numerical rating system so that those items, in his judgment, that could most contribute to potential surface water pollution were given more prominence.

The rating values were scaled so that the least degree of limitation imposed by the property or characteristic provides the highest value. The Oklahoma researchers recommended reducing or eliminating waste application on sites where the sum of the ratings fell below established levels. Where management or structural solutions are implemented to overcome the limiting factor(s), the limitation of the site is eliminated.

Similar reasoning to that done by Heidlage (1984) in Oklahoma can be used to factor soil and other site limitations into waste application strategies. Table 5–3 in chapter 5 of this handbook lists several soil characteristics, degrees of limitation, and recommendations for overcoming limitations. This understanding of soil limitations at application sites and methodology for overcoming the limitations provide a tool for identifying components of a waste application plan and, in some cases, further planning needs.

For example, if the field(s) to receive manure is subject to frequent flooding, table 5–3 in chapter 5 of this handbook shows a severe site limitation and recommends wastes be applied during periods when flooding is unlikely. A waste application strategy would need to recognize the periods when waste can be applied, and the waste storage component of the system would have to be adequately sized to provide storage between application opportunities. Other potential remedial actions might include waste injection to reduce opportunity for runoff of the manure during flood event and some form of structural measure to reduce flooding.

(g) Rule-of-thumb estimates

Tables 11–10, 11–11, 11–12, and 11–13 can be used for rule-of-thumb estimates of available nutrients in different manure for the common methods of manure management. Field offices can develop additional tables for other livestock handling methods that are customary in their areas. Tables 11–10, 11–11, 11–12, and 11–13 are limited to:

- solid and slurry manure applied in tons
- available nutrients, first year only
- situations where there is little carryover of nutrients from previous manure applications
- common methods of manure management

Manure liquids are not included because manure of this type will be diluted 4 to 10 times so that it can be flushed into storage or treatment facilities. With this method of manure management, a large loss of nitrogen can occur during storage, and tests should be made to determine the nitrogen concentration.

The amounts shown in the tables are in pounds of available nutrients per ton. The estimated nutrients vary considerably according to the climate and waste management system. (Refer to table 11–9 for nutrient mineralization rates.) The tables also show the estimated moisture content, which can be used as a guide. The tons are the actual weight of the manure as it is applied, which includes moisture and bedding. Use reliable local data if they are available. In most cases, manure changes weight during storage and treatment because it almost always gains or loses moisture.

The manure from beef cattle on the Texas High Plains provides an example of moisture loss. Mathers (1972) found that the manure on 23 feedlots ranged from 20 to 54 percent moisture content, averaging 34 percent. This compares to fresh manure that has 86 percent moisture content and 14 percent TS. The lot manure has an average TS content of 66 percent. The manure had to dry considerably for the TS content to increase from 14 percent to 66 percent. If no loss of volatile solids occurred, the manure would have shrunk about five times. Because some loss of solids always occurs, the shrinkage is even greater. Stated another way—of 5 tons of manure excreted, only 1 ton remains on the lot, although most of the constituents, such as salt, are retained.

An example of moisture gain is seen in waste management for dairy cows in the northern part of the country. Typically, the manure is placed in storage daily in either a covered tank or an open storage pond. The milking center wastewater is added, which amounts to about 5 or 6 gallons per cow per day (Zall 1972). If 5 gallons of washwater are added daily to the manure from a 1,400-pound cow, the volume is increased by about 35 percent. Similarly, if the original moisture content is 89 percent, it is increased to almost 92 percent. Consequently, it is then necessary to haul more than 13 tons of manure to the field for every 10 tons excreted if there is no drying or further dilution.

Table 11–10 Rule-of-thumb estimates of available nutrients in manure from dairy cows by management system

Management system	Final moisture	Nutrients available first year		
		N	P_2O_5	K_2O
	Percent	- - - - - - - - lb/ton - - - - - - -		
1. Fresh manure, collected and applied daily, incorporated before drying	89	7	3	5
2. Manure collected daily, 50% processing water added, stored in covered tank, applied semiannually, incorporated before drying	92	3	3	5
3. Manure placed daily in open storage pond; 30% processing water added; liquids retained; spread annually in fall; incorporated before drying; cool, humid climate; evap. = precip	92	3	3	4
4. Bedded manure, unroofed stacking facility (bedding is 10% by weight); spread in spring before drying; cool, humid climate; evap. = precip	82	3	2	4
5. Manure, no bedding, stored outside; leachate lost; spread in spring before drying; cool, humid climate	87	3	2.5	4
6. Open lot storage—see beef cattle				

Table 11–11 Rule-of-thumb estimates of available nutrients in manure from feeder swine by management system

Management system	Final moisture	Nutrients available first year		
		N	P_2O_5	K_2O
	Percent	- - - - - - - - - - lb/ton - - - - - - - - - -		
1. Fresh manure, collected and applied daily, no dilution or drying, incorporated before drying	90	9	7	10
2. Covered storage tank, applied and incorporated before drying, diluted with 50 percent additional water	93	4	6	6
3. Ventilated storage pit beneath slotted floors, diluted 1:1, emptied every 3 months, incorporated before drying	95	2.5	3	5
4. Open lot storage, removed in spring; incorporated before drying; warm, humid climate	80	6	10	12
5. Open lot storage, cleaned yearly and incorporated; hot, arid climate	40	9	28	52

Table 11–12 Rule-of-thumb estimates of available nutrients in manure from broilers and layers by management system

Management system	Final moisture	Nutrients available first year		
		N	P_2O_5	K_2O
	Percent	- - - - - - - - - - lb/ton - - - - - - - - -		
1. Fresh manure, collected and applied daily, incorporated before drying	75	27	21	15
2. Layer manure stored in shallow pit, cleaned every 3 months, incorporated before drying (Wilkinson 1974)	65	25	27	23
3. Layer manure stored in fan ventilated deep pit; cleaned yearly and incorporated; cool, humid climate (Sobel 1976)	50	23	45	42
4. Broiler manure on sawdust or shavings cleaned every 4 months and incorporated; warm humid climate (Wilkinson 1974)	25	36	35	40

Table 11–13 Rule-of-thumb estimates of available nutrients in manure from feeder beef by management system

Management system	Final moisture	Nutrients available first year		
		N	P_2O_5	K_2O
	Percent	- - - - - - - - - - lb/ton - - - - - - - - -		
1. Fresh manure, collected and applied daily, incorporated before drying	86	9	5	8
2. Manure collected daily, stored in covered tank, no dilution or drying, applied semiannually, incorporated before drying	86	7	6	8
3. Bedded manure pack under roof, cleaned in spring, incorporated before drying (bedding = 7.5% by wt)	80	5	5	7
4. Open lot storage, cleaned in spring, incorporated before drying, cold humid climate	70	7	9	14
5. Open lot storage, cleaned semiannually and incorporated; warm semi-arid climate	30	11	16	3
6. Open lot storage, cleaned biannually and incorporated; hot arid climate	20	6	15	36

Example 11–7

Given: Manure from a 50,000-layer operation in Georgia is stored in a shallow pit. The manure is spread every 6 months and incorporated. The land is used for silage corn. The recommended nutrient application rate is 150 pounds nitrogen per acre per year.

Questions:

1. What is the application rate using the rule-of-thumb tables?
2. What is needed to recycle the manure at this rate?

Solution, question 1:

From table 11–12, management system 2, about 25 pounds of nitrogen per ton of manure are available the first year per ton of manure applied.

$$\text{Rate} = \frac{150 \text{ lb N (State nutrient guide rate)}}{25 \text{ lb N/ton}}$$
$$= 6 \text{ tons/acre}$$

Solution, question 2:

1. Calculate weight of manure produced (see table 4–11 in chapter 4 of this handbook). Weight of layers = 50,000 birds × 4 pounds average weight = 200,000 pounds, or two hundred 1,000-pound units.

$$\text{Manure} = \frac{57 \text{ lb/d}}{1{,}000 \text{ lb}}$$

$$\text{Weight} = \frac{200 \times 57 \times 365 \text{ d/yr}}{2{,}000 \text{ lb/ton}}$$
$$= 2{,}080 \text{ tons/yr}$$

2. Calculate weight of manure applied since manure can change weight while in storage. From table 11–12, management systems 1 and 2, moisture content can be estimated as 75 percent (fresh) and 65 percent (applied). Thus, TS content is 25 percent (fresh) and 35 percent (applied).

$$\text{Applied weight} = \frac{25\%}{35\%}$$
$$= 0.71 \text{ of weight produced}$$
$$= 0.71 \times 2{,}080 \text{ tons}$$
$$= 1{,}477 \text{ tons/yr}$$

3. Calculate area required:

$$\text{Area} = \frac{1{,}477 \text{ tons / yr}}{6 \text{ tons/acre (from question 1)}}$$
$$= 246 \text{ acres required}$$

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