## *Chapter 2*

# Management of Manure From Beef Cattle in Feedlots and From Minor Classes of Livestock

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When animals graze in pastures and rangelands, manure is dispersed across a large area and little management is needed because the material is spread over a wide area and decomposes on the soil. However, when animals are concentrated in a small area, the quantity of manure and the need for management increases significantly. In the United States, beef cattle are raised mainly in the central and southern Great Plains. Leading states for cattle raising in 1993 were Nebraska, Texas, Kansas, Iowa, and Colorado. These five states accounted for two-thirds of the U.S. beef cattle. Approximately 84 percent of the cattle are fed in feedlots having a capacity of 1,000 or more head (Krause 1991). The handling and use of the manure produced in these large feedlots is a significant environmental problem that must be addressed.

Manure from feedlots is an important resource for crop production and soil sustainability because this manure is a potential source of macronutrients (N, P, and K) as well as secondary and micronutrients. Manure is also an excellent source of organic matter when added to soils. However, manure produced by beef cattle can potentially be a source of water, air, and land pollution. These products can pollute the surface water and groundwater with excess nitrates, salts, microorganisms, and pathogens. Production of greenhouse gases from the feedlots is another factor to consider when managing animal manure.

The purpose of this chapter is to review present practices and knowledge relating to beef cattle manure production and use. Emphasis is put on manure production in confined beef feedlots because, although this represents no more than one-third of the total beef cattle population in the United States, problems related to manure management are much greater for feedlots than for pastures and ranges.

In addition to beef cattle, several other types of livestock are often raised in confinement, including sheep, goats, horses, veal calves, and mink. The production and uses of manure from these livestock are also discussed briefly.

### Manure Production and Composition

There were about 99 million head of cattle and calves in the United States in 1990 (table 9). This is a reduction from the 102 million head in 1987 and 132 million head in 1975 (U.S. Department of Agriculture 1990). About 84 million of these cattle and calves are grown for beef production. If each animal excretes

**Table 9. Number of cattle and calves in the United States at different times**

| | Number of cattle and calves (millions) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Beef cows | Milk cows | Bulls | Calves >227 kg | Calves <227 kg | Total cattle & calves | Cattle slaughtered | Calves slaughtered |
| 1975 | 45.7 | 11.2 | 3.0 | 35.8 | 36.3 | 132.0 | 41.5 | 5.4 |
| 1980 | 37.1 | 10.8 | 2.5 | 33.3 | 27.6 | 111.2 | 34.1 | 2.7 |
| 1985 | 35.4 | 10.8 | 2.4 | 34.7 | 26.4 | 109.7 | 36.6 | 3.4 |
| 1990 | 33.7 | 10.1 | 2.2 | 33.9 | 19.3 | 99.3 | 34.1 | 2.2 |

Source: U.S. Department of Agriculture (1990).

56.2 kg N and 16 kg P annually, total production of N and P are about 4.72 and 1.34 million Mg, respectively. This is about 61 and 64 percent of all N and P, respectively, excreted by all classes of livestock in the United States. However, about two-thirds of these cattle and calves are raised on pastures or ranges, and the manure from pastures and ranges cannot practically be collected and used elsewhere.

About 28 million head of cattle were fattened on grain and concentrates in the United States in 1987 (U.S. Department of Commerce 1987); 64 percent of these cattle were located in the Great Plains area, compared to 58 percent in 1982. At any one time, there are about 10 million head of beef cattle on feed (table 10), and each excretes approximately 145 g of N in fresh manure daily (Overcash et al. 1983a). After the manure is collected from the feedlot, however, the N collected per head per day is 124.9 g. Thus, approximately 457,900 Mg of N (505,000 tons) is collectible annually in the manure from these cattle (table 10). Comparable values for P and K in this manure—based on 42.7 g P and 131.5 g K excreted per head per day (Overcash et al. 1983a)—are 157,000 Mg P (173,000 tons) and 482,000 Mg K (531,000 tons). If purchased as fertilizer, the value of the N, P, and K in this manure would be approximately \$111 million, \$180 million, and \$170 million, respectively—for a total value of \$461 million annually. The total value does not include the value of the minor elements in beef feedlot manure. The N from manure on feedlots is sufficient to fertilize almost 4.6 million ha of grain crops or 8.4 percent of the corn and wheat acreage in the United States at a rate of 100 kg N $ha^{-1}$.

**Table 10. Annual manure production from feedlot beef cattle in the major cattle-producing states and N, P, and K quantities in the manure**

| State or country | No. of animals (millions) | Manure production* (millions of Mg) | Manure content (thousands of Mg) N | P | K | N value of manure† (million \$) |
|---|---|---|---|---|---|---|
| California | 0.39 | 0.94 | 17.9 | 6.1 | 18.8 | 4.4 |
| Colorado | 0.90 | 2.16 | 41.0 | 14.0 | 43.2 | 10.0 |
| Illinois | 0.30 | 0.72 | 13.7 | 4.7 | 14.4 | 3.3 |
| Iowa | 1.02 | 2.45 | 46.6 | 15.9 | 49.0 | 11.3 |
| Kansas | 1.70 | 4.08 | 77.5 | 26.5 | 81.6 | 18.8 |
| Minnesota | 0.33 | 0.79 | 15.0 | 5.1 | 15.8 | 3.6 |
| Nebraska | 2.15 | 5.16 | 98.0 | 33.5 | 103.2 | 23.8 |
| Oklahoma | 0.32 | 0.77 | 14.6 | 5.0 | 15.4 | 3.6 |
| S. Dakota | 0.27 | 0.65 | 12.4 | 4.2 | 13.0 | 3.0 |
| Texas | 2.11 | 5.06 | 96.1 | 32.9 | 101.2 | 23.4 |
| U.S.A. | 10.06 | 24.1 | 457.9 | 156.7 | 482.0 | 111.4 |

* Based on 2.4 Mg of manure produced per animal per year and 1.9 percent N content.

† Based on \$243.2 per Mg N.

Sources: Overcash et al. (1983a) and U.S. Department of Agriculture (1990).

For the approximately 54 million head of beef cattle on pastures and ranges, their manure is dispersed across a large area. This manure is not normally collected and usually does not constitute an animal waste management problem. The effect of this manure on the environment is also minimal since the dispersed manure is decomposed on the soil. Overgrazing of pasturelands and rangelands, however, can be a potential problem by creating soil erosion and loss of riparian vegetation and by causing surface water contamination by manure.

In addition to beef cattle, several other types of livestock are often raised in confinement, including sheep, goats, horses, veal calves, and mink. Manure production and use from these livestock is also discussed briefly. There are approximately 11 million sheep and 2.5 million horses in the United States (table 11). The N and P excreted by a 45-kg sheep is estimated to be about 10 percent of that excreted by a 450-kg beef cow. Calves raised for veal produce about 20 percent as much N and P in their manure as a beef cow. We estimate that about 50 percent of horse manure is produced in confinement. Manure produced by mink has an N and P content similar to that produced by broilers. Very few goats are kept in confinement, so the amount of manure recovered from them is negligible. The total N and P recoverable (produced in confinement) from horse manure is 75 and 16 thousand Mg per yr, respectively. The next largest producer of manure is sheep. Five million head of sheep are in confinement, and the manure N and P produced in the confined feedlots of these sheep is approximately 46 and 7 thousand Mg per year, respectively. Manure N production by confined veal calves and mink totals only a few thousand Mg per yr, and manure P production of these animals amounts to only hundreds of Mg. The total recoverable manure N and P from all five species shown in table 11 is only about 129 thousand Mg of N and about 25 thousand Mg of P. Although on the national scale, total quantity of N and P from manure of these five species is negligible, some is often produced on the fringe of urban areas where manure handling, use, and odors are more critical.

Several factors that may affect mineral composition of animal manure are animal size and species, housing and rearing management, ration fed, manure storage, and climate. Typical nutrient concentrations of manure from cattle raised in feedlots are given in table 12. Overcash et al. (1983a) found that N contents of cattle manure were 3.1, 4.2, 2.7, and 1.9 percent of total solids when collected from scrapings under slotted floors, in pits or tanks, in bedded units, and in feedlots, respectively. Westerman et al. (1985) found that fresh and scraped manure from beef cattle had P contents of 1.1 and 0.7 percent of dry weight and had K contents of 2.5 and 2.0 percent, respectively. Overcash et al. (1983b) indicated that N content of urine and feces increased with increasing N content of feed. Nitrogen is often lost by ammonia volatilization from stored

**Table 11. Number of sheep, goats, horses, veal calves, and mink in the United States and N and P content of their manure**

| | Number of head | | N and P production per year in manure | | | |
|---|---|---|---|---|---|---|
| | | | Per head | | Total from all confined livestock | |
| Species | Total | Confined | N | P | N | P |
| | ------------thousands------------ | | ------------kg------------ | | -----thousands of Mg---- | |
| Sheep | 11,000 | 5,000 | 9.1 | 1.4 | 45.5 | 7.0 |
| Goats | 2,000 | – | – | – | – | – |
| Horses | 2,500 | 1,250 | 59.6 | 13.1 | 74.5 | 16.4 |
| Veal | 350 | 350 | 9.1 | 3.1 | 3.2 | 1.1 |
| Mink | 4,600 | 4,600 | 1.2 | 0.3 | 5.5 | 1.3 |

Sources: Overcash et al. (1983) and U.S. Department of Agriculture (1990).

**Table 12. Nutrient and trace element concentrations in dry feedlot manure**

| | Concentration (percent) | |
|---|---|---|
| **Nutrient** | **Range** | **Average** |
| N | 0.55–4.00 | 1.9 |
| P | 0.12–1.60 | 0.65 |
| K | 0.29–3.20 | 2.00 |
| Ca | 0.17–3.60 | 1.30 |
| Mg | 0.19–1.50 | 0.69 |
| Na | 0.10–2.80 | 0.74 |
| Fe | 0.12–1.25 | 0.56 |
| Zn | 0.001–0.014 | 0.008 |
| Cu | 0.0001–0.003 | 0.002 |
| Mn | 0.006–0.115 | 0.038 |
| B | 0.014 | 0.014 |
| Cl | 1.4 | 1.4 |
| S | 0.5 | 0.5 |
| Cd | 0.0002 | 0.0002 |
| Al | 0.52 | 0.52 |
| Li | 0.0009 | 0.0009 |
| Pb | 0.0002 | 0.0002 |

Source: Overcash et al. (1983a).

manure. However, losses are highly variable (0 to over 50 percent) and depend on a number of factors, including type of storage.

Nutrient and trace element concentrations of the dry solids collected from feedlots are given in table 12. Almost all of the P excreted by cattle (96 percent) is found in the feces, and only trace amounts are excreted in the urine; in contrast most of the K excreted by cattle (73 percent) is in the urine (Safley et al. 1985). About 58 percent of N is excreted in the urine, most of it as urea (Overcash et al. 1983a). The main form of N in fresh cattle feces is organically bound N. Fresh cattle manure also contains urea and small amounts of ammonium N (Kirchmann and Witter 1992). Fresh manure from a 454-kg beef animal contained 37 percent urine (Overcash et al. 1983b). Total P, K, Ca, Mg, and Na contents of fresh cattle manure are 1.1, 2.4, 1.5, 0.55, and 0.46 percent of total solids, respectively (Overcash et al. 1983a). In the feedlot, these percentages were 0.65, 2.0, 1.3, 0.69, and 0.74 percent, respectively (table 12).

## Manure Management Systems

Approximately 84 percent of the beef cattle fattened in 1989 were fed in lots with a capacity of over 1,000 head, and 50 percent were fed in lots with a head capacity of greater than 16,000 (Krause 1991). Because so many cattle are raised in concentrated feedlots, manure management and available land for application are important factors to consider. Manure management guidelines must consider (1) the effects of different management systems on nutrient content of manure at the time of spreading, (2) various methods for spreading and incorporating manure and the effects of these methods on nutrient availability, (3) methods to assist farmers in determining application rates to achieve a desired crop yield, and (4) safe manure application rates that will not cause undue losses of N and other nutrients to surface and groundwater (Bulley et al. 1980).

Feedlot manure from cattle contains considerable amounts of nutrients that can be used for crop production. Nitrogen loss from manure during storage, handling, and after application is a major problem in effectively using this resource. Up to 50 percent or more of the N in fresh livestock manure may be in ammonium form ($NH_4$) or may be converted to ammonium form in a very short time following excretion and is therefore subject to volatilization loss (Vanderholm 1975). In a laboratory study simulating cattle feedlot surface conditions, Stewart (1970) found N losses from urine to be 25 to 90 percent, largely due to ammonia volatilization. Adriano et al. (1971) found that nearly 50 percent of total N was lost from manure on simulated feedlot surfaces, which was consistent with their 40-percent loss from corral surfaces in the field. In studying solid waste from feedlot surfaces, Gilbertson et al. (1971) recovered 42 to 55 percent of estimated excreted N, indicating that the rest was lost. Losses of N from the feedlot are primarily through runoff or gaseous emissions ($NH_3$ volatilization and denitrification).

Most cattle feeding occurs in confined open lots; only a small percentage occurs in closed housing. Manure normally accumulates in the pens of cattle feedlots until animals in a pen are marketed (usually 90–180 days). At a minimum pens are cleaned out once each year. Because a high percentage of beef cattle are fed in drier climates, the mechanisms by which nutrients are lost from open feedlots are much different than those from confined housing operations, especially confined operations in which water is used to flush manure into pits for storage. Typically in the central and southern Great Plains, cattle feedlot manure is scraped from feedlots. The manure collected from these scrapings can contain up to 50 percent soil. This manure is then stockpiled until fall. Spreading on cropland normally occurs after harvest in the fall or in early spring before crops are planted.

Much of the lamb fattening in the United States occurs in open pens (similar to how beef cattle are fed). Feedlots for lambs are cleaned with the same frequency as those for beef—usually once or twice per year. Lamb feeding, however, is more seasonal, and therefore feedlots for lambs may be idle part of the year. The idle period may lead to more mineralization and a greater possibility for nitrification, but no research has been done to prove this. Lamb feeding occurs primarily in western states, such as California, Texas, Wyoming, and Oregon. Numbers of lambs fattened declined from 7.8 million in 1975 to 5.4 million in 1989.

Horses are generally kept in pastures or in stables or corrals or a combination of the two. While very few draft horses exist in the United States, saddle horses are found throughout the nation. In western states, these horses are used primarily on cattle ranches for working and managing beef cattle. Few of these horses are kept in confinement for appreciable time periods. In the last several decades, the number of pleasure riding horses has increased greatly, mostly on small farms surrounding urban centers. Many of these horses are kept in pens or stables for considerable time periods, requiring the periodic removal of manure. Often only a few horses are kept on each farm, so there is usually sufficient pasture land on which to spread manure. There are a limited number of instances (such as racing stables and other large stables) where manure disposal from horses is a problem. Usually horse manure is applied to land for crop production, similar to beef cattle manure. There are some specialized uses of horse manure, such as for mushroom production in several northeastern states. The spent manure from these operations is then applied to land.

Mink are produced entirely in confinement, so eventually all manure produced from mink is collected and used. Approximately 1,000 mink ranches exist in the United States (about the same as in 1975). States with the largest number of mink operations are Wisconsin, Minnesota, Oregon, Idaho, and Utah. The total quantity of manure produced on these ranches is relatively small. Many mink operations are located near urban areas on limited land bases, so arrangements are often made with local farmers for the manure to be used.

If traditional methods for collecting manure from beef feedlots are used, often over 50 percent of the N in the manure is lost before the manure is removed from the feedlots (Gilbertson et al. 1979b, Overcash et al. 1983b). For example, in Nebraska, Gilbertson et al. (1971) found that 80 percent of the N fed to beef cattle was excreted in the manure, but only 48 percent of this N was in the manure collected from the feedlot (39 percent of the total N in the feed was in the manure collected). For dairy barnlots, Safley et al. (1986) measured N, P, and K losses of 23, 0, and 10 percent, respectively. Depending upon how the manure is handled and field applied, as much as 50 percent of the N remaining in the manure after removal from feeding pens may be lost by the time the manure is spread and incorporated. Thus, often only a fraction (about 25 percent) of the N excreted in feedlot manure is applied to the field for the growing crop.

There is a tremendous opportunity to improve the efficiency of recovery and use of the N in feedlot manure. Several practices might be used to reduce N losses from the manure deposited during the feeding operation. These might include more frequent cleaning, use of bedding, and use of additives to reduce volatilization and denitrification losses of N. Other options might include the use of such materials as nitrification inhibitors, urease inhibitors, acidifying materials (phosphoric acid, pyrite, ferrous sulfate, sulfur), and precipitants or stabilizers (alum, quick lime, or cement kiln dust). Although there have been a few studies using some of these materials on poultry or swine manure, essentially no comprehensive research has been conducted on their use for beef cattle feedlot manure.

Temperature, moisture, pH, and C/N ratio are among the important factors in determining the amount of N lost from manure. Muck and Richards (1983) concluded that little N is lost if daily temperatures are below 5 °C, but 40 to 60 percent of total manurial N is lost through ammonia volatilization at temperatures between 5 °C and 25 °C. Adriano et al. (1974) found that at 10 °C, average losses of N from cattle manure were 26 and 39 percent at 60 and 90 percent moisture levels, respectively. At 25 °C, 40 and 45 percent N losses were observed for the 60 and 90 percent moisture levels, respectively. Manure application rate did not have a significant effect on the percentage of N lost. When manure was mixed with soil and incubated in large soil columns, Peters and Reddell (1976) found a 10-percent loss of total N at a soil pH of 7.5 and a 20-percent loss at a soil pH of 12. Stevenson and Wagner (1970) stated that losses of N as free ammonia are particularly serious on calcareous soils. Webber and Lane (1969) reported that a soil pH > 8.0 is favorable for ammonia volatilization.

A large C/N ratio in manure may reduce volatilization loss of N. Bedding placed in the feedlot helps absorb urine and helps reduce volatilization losses of N during drying by immobilizing more N. However, Hensler et al. (1970) concluded that the use of bedding results in a reduction of manure N availability because it causes the manure to have a large C/N ratio. They also found that when manure was applied to corn, total dry matter of corn was not affected by manure containing up to 8 percent bedding; however, when the bedding was increased from 8 to 16 percent, yields were usually less than they were from manure having no bedding.

Composting manure is a useful method of producing a stabilized product that can be stored or spread with little odor or fly-breeding potential (Sweeten 1988). Composting also kills pathogens and weed seeds and improves handling characteristics of manure by reducing its volume and weight (Willson and Hummel 1975). Decomposition of manure occurs through biological action and spontaneous chemical reactions. The initial chemical and biological composition of manure is a function of ration fed, animal age, bedding used in feedlots, and other factors that can influence the decomposition process. In a constant temperature and humidity chamber, ammonia volatilization from beef cattle manure resulted in a 35-percent decrease in N content of the material during composting (Stone et al. 1975). In the compost, ammonia was only 3 to 4 percent of the total N and 0.05 to 0.1 percent of the dry manure. The greatest loss of ammonia occurred at 48.8 °C and 70 percent moisture.

Eghball and Power (1994) found up to 40 percent N loss during open composting of beef feedlot manure. The amount of N loss was proportional to the initial manure N content, and ammonia volatilization accounted for more than 92 percent of the N loss. They also found significant runoff losses of K and Na but minimal loss of P from composting windrows. Wells et al. (1969) also showed that N is lost as ammonia during composting. Martin et al. (1972) indicated that increasing the C/N ratio of the waste decreases the amount of N lost during composting. Loehr (1974), however, stated that composting conserves much of the nutrient content, including N. Compared to fresh manure, 3-mo-stabilized farmyard manure had significantly greater concentrations of total N, water-soluble substances, and lignin and had less organic C, lipids, and hemicellulose and a lower C/N ratio (Levi-Minzi et al. 1986).

Nitrogen loss during composting depends on the conditions under which the material is being decomposed. Willson and Hummel (1975) found that while moisture content, pH, and material bulk have little effect on N loss, periods of anaerobic activity during composting may increase N loss. Since N losses are more than offset by the reduction in volatile solids due to biooxidation, N concentration during composting usually increases. During composting, N can be lost from manure in runoff and by nitrate leaching. The quantity of N lost by these processes is affected mainly by site-specific conditions.

Composted manure can be applied to soil as an odorless and drier source of nutrients as compared to noncomposted manure. In addition, Kirchmann (1990) found that applying composted poultry manure to soil caused plants to take up more soil N than they did when fresh poultry manure was applied. Composted manure with low available energy caused a positive N interaction, while energy-rich fresh manure caused a negative N interaction and a subsequent lower soil N uptake.

The amount of manure to be applied to a particular soil depends on crop requirements for N and P, composition of the manure, and environmental conditions. Manure applications to provide adequate N for crops may result in soil buildup of salt, P, K, and other ions in areas where rainfall is limited. It is usually best to base manure application rates on the P needs of a crop and to supply additional N with fertilizer if needed. This method of supplying N and P helps to avoid adverse environmental effects, especially nitrate leaching, runoff losses, and high P levels in runoff.

After manure is applied to soil, nutrient loss depends on degree of incorporation and environmental conditions. In laboratory and field experiments, Steenhuis et al. (1981) showed that most N loss from manure spread on frozen soil was in water soluble forms (mainly nitrate and ammonium-N). The first meltwater contained the highest concentration of readily available N. Dairy manure applied at 35, 100, and 200 Mg ha$^{-1}$ in 1972 resulted in average runoff losses of 16, 1, and 0.2 kg inorganic N ha$^{-1}$ in 1972, 1973, and 1974, respectively (Klausner et al. 1976). Phosphorus losses from the manure during these 3 yr were 3.5, 0.7, and 0.01 kg ha$^{-1}$, respectively.

## Land Application of Manure

There were about 390 million ha of land in farms in the United States in 1993. Of this farmland, 133 million ha were cropland and 265 million ha (650 million acres) were pasture and rangeland (U.S. Department of Agriculture 1993). Nationally this provides an ample base for land application of animal manure. In only a limited number of counties nationwide, mostly in coastal states where few beef cattle are produced, does the supply of livestock manure greatly exceed the cropland available for manure use. Other potential uses of manure are landfilling, burning, converting to methane, and refeeding to other animals. However, for beef cattle feedlot manure, particularly that produced in the central and southern Great Plains, these other options offer limited opportunity for manure use. Factors to consider for land application of manure are transportation and spreading-equipment problems and related costs, land base available, problems in collecting a representative manure sample for nutrient analysis, and application rates that provide the crop with sufficient nutrients without having adverse effects on the environment.

Transport of animal manure to the application site is an important part of any management system. Manure can be in solid, slurry, or liquid (<5 percent dry matter) form, and each requires a different management practice. Beef cattle feedlot manure, valued for its N and P nutrient content, is an economical substitute for commercial fertilizer. Freeze and Sommerfeldt (1985) found that the cost of hauling manure from large feedlots (>500 head capacity) is justified up to about 15 km. If the manure is hauled a greater distance, the cost of hauling will exceed the value of nutrients in the manure. They also found that manure from small feedlots (<500 head capacity) can also be economically hauled up to 15 km if noncash costs and labor charges are disregarded. Fortunately, in the area of the United States where most beef cattle are fed (Iowa to Colorado to Texas), most of the land is under cultivation, so there is seldom a shortage of farmland for application of manure. If an animal excretes 145 g N per day, this would provide about 53 kg N per yr—about enough to fertilize 0.3 ha of irrigated corn, assuming the N is 100 percent effective and no N losses occur. Thus the manure from a 10,000-head feedlot should be spread on 3,000 ha or within a radius of about 3 km of the feedlot, and the manure from a 50,000-head feedlot should be spread on about 15,000 ha or within a radius of about 7 km of the feedlot.

Manure spreaders are the most typical device for transporting and spreading animal wastes with moisture contents <80 percent (Overcash et al. 1983b). These spreaders can be either box-type or of the open-tank design. Box spreaders can be pull-type or truck mounted. Slurries may be transported with either a mobile tank or by pipeline. Some agitation is necessary before removing liquid material from storage areas or pits. Liquid waste with hydraulic behavior like water is normally transported in tanks, although this is more expensive than using irrigation equipment for transport. The liquid wastes can be applied with surface (furrow, flooding, or border) irrigation, but better distribution can be obtained by using a sprinkler irrigation system, a traveling gun, or a center-pivot system.

Solids, slurries, and liquids can be applied to the surface or incorporated into the soil. Applying animal manure below the soil surface has advantages in that it prevents an unsightly appearance to the field, reduces odor and fly problems, reduces volatilization and runoff losses, and generally results in better conservation of nutrients for use by crops (Barlett and Marriott 1971). Large-bore irrigation nozzles can be used on sprinkler irrigation systems to handle slurries as well as liquid wastes.

Recent farm legislation in the United States requires producers to protect highly erodible soils from erosion. Therefore, when crop residues are sparse, it may not be possible to incorporate manure and still meet conservation compliance requirements. Unfortunately there have been few experiments conducted using beef cattle feedlot manure in no-tillage cropping systems, but considerable ammonia would probably be lost by volatilization because of lack of incorporation.

Effective use of manure and determining the best agronomic rates of application depend on proper sampling of the manure. Since animal manure is highly variable in nutrient content, collecting a representative sample for analysis is essential for determining proper application rates. Manure applied in excess of the crop needs for any nutrient can contribute to surface water and groundwater contamination. Soil sampling should be done prior to manure application to assess the nutrient additions needed for the crop and to determine the proper application rate based on manure nutrient content. Because plant availability and crop uptake of nutrients in manure are affected by many variables, it is usually desirable to adhere to Extension Service recommendations in each state to determine proper application rate. Gilbertson et al. (1979b) estimated that on the average, about 35 percent of the N and 20 percent of the P in cattle manure were utilized the first year after application to a corn crop but that these values can range widely depending on conditions.

## Alternative Uses of Cattle Feedlot Manure

Cattle manure has been used for algae and fish production in lagoons, reclamation of sandy and mined soils, recovery of energy (collection of methane gas), and refeeding (Umstadter 1980). Anaerobic bacterial decomposition of cattle manure generates methane gas, which can be collected and used for various purposes. About one-third of the manure N can be refed to animals, depending on the type of manure and type of animal consuming the manure (Overcash et al. 1983b). Manure can also be used in pyrolysis, hydrogasification, oil conversion processes, composting, and fish farming. Pyrolysis is a process in which animal manure is pretreated by thermochemical processes in a closed system at elevated temperatures of 204 to 800 $^{\circ}$C. This process results in the production of the following three fractions: a solid fraction termed ÒcharÓ, a gas fraction that when condensed is an oil or fuel, and a gas fraction that when condensed is aqueous in nature. Hydrogasification is a process in which cellulose in the presence of hydrogen is partially converted to a gas rich in methane. This process requires high pressure and temperature. A process similar to liquidification of coal can be used to convert manure to an oil-like product.

Composting is the aerobic treatment of manure in the thermophilic temperature range (40 to 65 $^{\circ}$C). Compost is an odorless, fine-textured, low-moisture-content material that can be used in bulk as a fertilizer or bagged and sold for use in gardens, potting media, or nurseries. The heat generated during composting also can be harvested.

Although there are a number of potential uses for cattle feedlot manure, in practice only a small fraction of manure is used for purposes other than land application. Part of this probably results from the fact that most beef cattle manure is produced in agricultural regions where demand for other products (methane gas, energy, etc.) is better provided by other sources. Although this manure, when processed, can be fed to poultry, the distance between concentrated cattle feeding and poultry production centers is generally too great for this practice to be economical.

In the Far East, manure has been used in aquaculture for centuries. Wohlfarth and Schroeder (1979) found that maximum yields per unit area in aquaculture are higher when high-protein feeds are used instead of manure, but the high-protein feed costs more. Best results were obtained in fish ponds with frequent applications of manure. Incorporating manure into high-protein feeds for aquaculture resulted in reduced growth and failed to reduce feed cost per unit area.

## Agronomic and Environmental Effects of Manure Application

Beef cattle manure is a valuable resource because of its nutrient and organic matter contents and can be effectively used for crop production and soil improvement. Manure contains N, P, K, and micronutrients that are necessary for plant growth. Organic matter content of soil can be increased by adding manure to the soil. Organic matter is an ion exchange material, a chelating agent, a buffering material, and an important agent in soil aggregation. Total organic C, Kjeldhal N, and potentially mineralizable N in manure-amended surface soils (0 to 7.5 cm) were 22 to 40 percent greater than in nonmanured soils receiving fertilizer or herbicide or both (Fraser et al. 1988). Application of cattle feedlot manure significantly increased soil organic matter and total N and lowered the C/N ratio in the top 30 cm of soil in (Sommerfeldt et al. 1988). Soil organic matter, available P, and exchangeable K, Ca, and Mg increased on a loam and a sandy loam soil with increasing rates of manure application (Vitosh et al. 1973).

Manure application can improve soil physical properties such as infiltration, aggregation, and bulk density, which in turn results in reduced runoff and reduced wind and water erosion. Manure also decreases energy needed for tillage and reduces impedance to seedling emergence and root penetration. Increased soil aggregation and subsequently better soil water infiltration also result =from manure application (Mielke and Mazurak 1976, Boyle et al. 1989). However, excess manure application may have adverse consequences. In addition to increased potential for surface water and groundwater pollution, excess manure application may increase soil electrical conductivity and the sodium adsorption ratio and may decrease soil pH (Chang et al. 1991). An increased sodium adsorption ratio may reduce soil water infiltration rates.

Conservation of nutrients in storage and during handling and more timely incorporation of manure to conserve N and other nutrients could reduce the cost of crop production. These practices offer the commercial crop and livestock producer an opportunity to achieve a greater degree of self-sufficiency in recycling nutrients and using energy efficiently (Stonehouse and Narayanan 1984). When farmyard manure was priced on the basis of its total N and P contents, net returns for applications of 11 and 22 Mg manure $ha^{-1}$ averaged \$48 and \$100 $ha^{-1}$, respectively (Holt and Zentner 1985).

Beef cattle manure application can increase the yield of most crops. In several published results, the yield of corn silage, corn grain, grain sorghum, forage sorghum, and perennial forage crops were increased with applications of cattle manure or manure effluents (Sukovaty et al. 1974, Swanson et al. 1974, Mathers et al. 1975, Magdoff and Amadon 1980). Manures, if properly handled, are a good substitute for fertilizers as a source of nutrients and have the added benefit of improving soil physical characteristics.

Manure should be managed and applied at rates that do not adversely affect the environment. Manure applications supplying available N in excess of crop requirements can be a potential source of groundwater contamination. For grass swards grown on a deep and well-drained soil, manure supplying approximately double the crop's total N requirement contributed nitrate-N to the groundwater (Marriott and Bartlett 1975). Plots treated with 22 to 224 Mg of manure $ha^{-1}$ had nitrate-N amounts ranging from 100 to 2,400 kg $ha^{-1}$ in the top 1.8 m of soil (Mathers et al. 1975). Deep-rooted crops can be used to extract nitrate-N from soil depths greater than that of the root zone of most annual crops (usually 1 to 1.5 m). Alfalfa grown on heavily manured plots removed water and nitrate-N to a depth of 1.8 m the first year and to 3.6 m the second year. Schuman and Elliott (1978) also reported significant removal of nitrate-N by alfalfa from an abandoned feedlot area with elevated nitrate content (> 2,000 kg nitrate-N $h^{-1}$) to a soil depth of 4.6 m. Corn was not as effective as alfalfa in removing nitrate-N and contained too much nitrate in the forage to be safely used by livestock (Schuman and Elliott 1978).

High rates of manure application will cause a significant buildup of N, other nutrients, and salt in the soil. Large applications of manure (> 22.4 Mg $ha^{-1}$) can also cause a significant buildup of soil exchangeable K and extractable P (Vitosh et al. 1973). Bray and Kurtz No. 1 P soil-test values increased linearly from 45 to 391 mg $kg^{-1}$ with manure applications of 0 to 361 Mg $ha^{-1}$ (Vivekanandan and Fixen 1990). These high soil P levels could have adverse effects on the availability of some minor elements. In areas with heavy rainfall and natural leaching, salinity buildup from manure application is not a major problem; however, in irrigated and low-rainfall areas, application of materials containing salt must be limited to prevent salt accumulation (Gilbertson et al. 1979b). The amount of NaCl salt in the beef ration directly affects Na concentration in the manure, which in turn affects the exchangeable Na and sodium adsorption ratio in soil (Horton et al. 1975). Sodium accumulation results in soil dispersion and greatly reduces infiltration. The quantity of NaCl in rations today is considerably less than 20 yr ago, so the problem is less acute than it was when much of the reported research was conducted.

Manure in the feedlot can be a source of pollution. Nitrate-N in abandoned feedlots averaged 7,200 kg $ha^{-1}$ in a 9.1-m soil profile, whereas adjacent cropland had only 570 kg $ha^{-1}$ nitrate-N in the same soil depth (Mielke and Ellis 1976). Some abandoned feedlots had as much as 18,200 kg nitrate-N $ha^{-1}$ in a 9.1-m soil core. However, Ellis et al. (1975) took soil cores from 15 active eastern Nebraska beef cattle feedlots and showed that most were not a nitrate pollution hazard to groundwater. In active feedlots compaction from hoof action coupled with NaCl in the manure resulted in essentially no water infiltration or leaching (Mielke and Mazurak 1976); hence little accumulation of nitrate occurred in the subsoil (Lorimor et al. 1972). Mechanical removal of manure from feedlots also reduced the opportunity for nitrate movement into the soil, helped to maintain the surface of the feedlot in an aerobic condition, and minimized odor (Lorimor et al. 1972).

Runoff from cattle feedlots can contaminate surface waters. Pollutants in this runoff include chemicals, microorganisms, organic materials, and soil sediments. Proper assessment of the pollution potential depends not only on the size, stocking rate, and other physical characteristics of the feedlot but also on the intensity, duration, and frequency of rainfall (Swanson et al. 1971). During a rainfall event, runoff will begin sooner from a feedlot than from adjacent cropland because of the lower infiltration rate in a feedlot. Ammonium and nitrate-N are transported in the initial runoff from the feedlot surface and add to the surface water pollution problem (Swanson et al. 1975). Under Nebraska conditions, typically only 3 to 6 percent of the manure deposited in a feedlot is removed in runoff (Gilbertson et al. 1979a). Erosion in the feedlot depends on the land slope, slope length, infiltration rate, and physical properties of the soil. Methods of surface water control have been developed for feedlots to reduce or collect the runoff water, such as the use of terracing, check dams or porous dams, settling basins, tiled infiltration beds, lagoons, and vegetative filters. Wetlands can be constructed that use vegetative filters to remove solids and some soluble nutrients from runoff water before it is impounded in a shallow basin.

Runoff loss also can occur from the fields receiving manure and can contribute to pollution of surface waters. The amount of runoff is influenced by time, rate, and method of application and by soil and cropping management practices (Khaleel et al. 1980). Application of manure to frozen soils often results in the loss of organically bound N and P with snowmelt runoff. High nutrient loss also may result from runoff events occurring shortly after application. Therefore, it is best to apply manure when runoff events are least likely. Incorporation of manure after application reduces runoff loss, conserves manure nutrients, and improves soil physical properties. The amount of runoff loss usually increases with increasing rate of application. Patni et al. (1985) found no consistent differences in bacterial quality of runoff from manured and nonmanured fields when the manure had been incorporated.

Manure can be a source of air pollution because several gases are formed and volatilized during decomposition. Considerable dust may also be added to the air. Gases such as carbon dioxide, methane, ammonia, nitrous oxides, and hydrogen sulfides may contribute to the greenhouse effects (warming of the atmosphere by trapping of heat). The magnitude of the contribution of these gases to global warming is not known. Ammonia is readily volatilized from the urea in urine and often increases atmospheric $NH_3$ concentrations severalfold near feedlots (Elliott et al. 1971). However, ammonia is readily washed back into the soil by precipitation, so air contamination is usually local. Nitrous oxides escape to the atmosphere when nitrates are denitrified, usually under wet conditions such as rain-soaked feedlots. Nitrous oxides can be a major contributor to the greenhouse gases. Unfortunately essentially no data are available to quantify the amount of nitrous oxides emitted from beef cattle feedlots annually.

Agronomic and environmental effects of the manure produced by the other five species of livestock discussed in this section do not differ greatly from those discussed above for beef cattle. Almost all the manure produced from these five species is used for land application (an exception being horse manure used for mushroom production). No recent data exist on the decomposition rate or nutrient availability of these manures, but they are presumed to perform similarly to manure from beef cattle.

### Effective, Nonpolluting Uses of Cattle Feedlot Manure

Education is the key to a proper animal manure management system. Water quality protection, particularly from nonpoint sources or unregulated point sources, is one of the issues that needs to be addressed by increased research, technology transfer, public policy initiatives, and private action on the part of the producers (Sweeten 1992). Other issues include air quality protection, emissions of greenhouse gases, land and soil sustainability, animal welfare, water use, societal and producer's benefits from animal manure, energy recovery from animal manure, effects of pollution from animal manure on the animals themselves, and ability of livestock to convert nonedible plants into human food products (Sweeten 1992).

Point sources of water pollution from livestock can be minimized or eliminated by use of proper management systems that include selection of appropriate sites for concentrated animal-feeding operations, proper design of manure storage areas, wastewater collection and application to croplands, and application of nonexcessive rates of manure to croplands. Air-quality impacts of animal manure can be lessened by aeration, anaerobic digestion, composting, and capture of odorless and odorous gases. However, reducing the impacts of manure on water and air quality will require development of economically viable management alternatives for diverse feedlot settings.

Government regulations can greatly alter the management system used in a beef cattle production operation. The Federal regulatory approach to animal manure management emerged in the early 1970's as the U.S. Environmental Protection Agency initiated its regulatory programs to implement the goals of the Clean Water Act of 1972. U.S. Environmental Protection Agency regulatory efforts initially focused on point sources of pollution, which at the time were mainly effluents and solids from urban and industrial areas. Agriculture was largely seen as a nonpoint source of pollution. However, in 1973 the U.S. Environmental Protection Agency identified concentrated animal-feeding operations (CAFO’s) as point sources of pollution and from that point on required the issuing of National Pollutant Discharge Elimination System (NPDES) permits. CAFO’s included operations in which more than 1,000 animal units (cattle or equivalent for poultry and other animals) were confined and fed for at least 45 days or in which pollutants were discharged following storms smaller than a 25-yr, 24-hr storm event. Medium-sized feedlots with 300 to 1,000 animal units that discharge pollutants directly into navigable waters were also made subject to NPDES permits. Land application of animal manure was also considered a nonpoint source and was not subject to NPDES permits. Nonpoint sources of pollution became the target of U.S. Department of Agriculture and state voluntary programs for improved animal manure management. State regulatory approaches are basically consistent with NPDES requirements but vary from state to state depending on differences in climate, rainfall amounts, and the number and mix of livestock.

Best management practices are essential for the effective use of beef cattle manure for crop production and pollution prevention. Nutrient conservation is the first step toward a best management system. Nitrogen is the most susceptible nutrient to loss by volatilization and leaching and subsequently should be conserved as much as possible. Factors that affect N loss include temperature, moisture, pH, aeration status, rainfall, and C/N ratio. These factors should be considered when planning the uses of animal manure. Most other nutrients (for example P, K, and Ca) are lost only through runoff and erosion of organic material. Reducing erosion and controlling runoff will considerably reduce the loss of all nutrients.

Proper rate and method of manure application are vital to nutrient conservation and can greatly improve soil sustainability and crop production. Manure should be applied at a rate that provides adequate but not excessive nutrients to the crop. Incorporation of manure after application greatly reduces nutrient volatilization and runoff loss. If incorporation is not possible because of the increased soil erosion hazard from incorporation, ammonia volatilization will probably be greater, but there is essentially no long-term research evaluating these effects.

Beef cattle manure can be effectively and economically used by crops if a proper land base area is available to the cattle feeding operation. Manure can be an economical substitute for commercial fertilizers when it is transported no more than about 15 km from the source (Freeze and Sommerfeldt 1985). Because most of the major beef feeding operations in the United States are located in rural areas away from centers of population, there are relatively few problems with odors or fly populations.

## Research Needs for Improved Management of Cattle Feedlot Manure

When beef cattle feedlot manure is considered as potentially a major source of N for the crops produced in the United States, several facts are apparent. Present feedlot management systems result in about a 50-percent loss of N from the manure before it is removed from the feedlot. In addition, another 25 percent of the N excreted in the feedlot may be lost as the manure is hauled, spread, and incorporated into the soil. Thus, often only about 25 percent of the manure N is actually applied to cropland. Consequently, considerable additional research is needed to develop practical feedlot and manure management practices that will reduce these losses of N to the environment. This approach would also reduce the magnitude of environmental damage that is now associated with beef feedlot operations.

We presently have some evidence that several changes in feedlot management may have some potential for reducing N losses from manure. These include such practices as frequent cleaning and the use of carbonaceous bedding (straw, cornstalks, paper), inhibitors (chemicals that decrease the rate of nitrification or urea hydrolysis), and various types of stabilizers (acids or acidic materials, quick lime, and alum). However, considerable research needs to be conducted to determine the benefits, costs, and practicality of these new methods.

There are many unanswered questions and problems in determining the proper rate of application of manure to land. Suitable methodology is lacking for making rapid and economically acceptable field determinations of the nutrient content of manure—a necessary step in calculating acceptable rates of application. Also we lack dependable and practical equipment to accurately spread manure on soils at the desired rates. We need considerably more research and new models to determine the best application rate for a given situation. Considerable basic research on the soil microbiology associated with manure decomposition is needed to accurately predict availability and release rates of nutrients in manure. We also need to know how decomposition processes are affected by climatic conditions at those times of the year when it is practical to apply manure. In addition, we need to evaluate the effects of manure on concentrations and availability of minor elements in different soils, and we need to define acceptable upper limits for enhanced soil-P availability resulting from repeated manure application.

It is known that manure application results in changes in soil aggregation and tilth, which in turn affect soil, water, and air relationships. It is also known that changes in soil, water, and air relationships affect microbial activity. However, in order to better define these changes and quantify relationships that exist between all these factors, we need greatly improved technology for characterizing these properties and parameters. Factors that affect soil properties and microbial activity also affect the potential losses of nutrients from the soil by leaching, runoff, volatilization, or denitrification. We have very little information for quantifying denitrification losses.

Several other problems associated with feedlot management require additional research. These include the management of understocked or abandoned feedlots where the potential for nitrate leaching is great. Additions of soluble C, such as alcohol, to these sites could possibly denitrify the nitrate present at the sites. Also, as was pointed out in an earlier discussion in this section, we need to develop technology whereby manure can be used with no-tillage systems to maintain residues on the soil surface for erosion control. Likewise, especially in drier regions, we still need to establish soil-loading rates that will prevent undesirable salt buildup. The circulation, amounts, and effects of ammonia gas in the atmosphere near feedlots also require more study.

One could continue for some length on this list of information needed for improved management of beef cattle feedlot manure. The paramount problem, as stated earlier, is to develop methodology whereby one can greatly reduce the loss of nutrients (especially N) from manure into the environment. If these losses are substantially reduced, many of the other factors listed above will be at least partially addressed.

Complementary to the research program outlined above, a corresponding technology transfer program is needed to get the information into the hands of the users. This will require some detailed economic analyses of different situations, which can probably be best addressed through the development of suitable computer models. It is disheartening to see how little use is presently being made of the information that is available, much of which was published 15 to 25 yr ago.

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