

**Cattle Feedlot**  
**Waste Management Practices**  
*For Water and Air Pollution Control*

# Cattle Feedlot Waste Management Practices For Water and Air Pollution Control

John M. Sweeten\*

## Water Pollution and Wastewater Management

This bulletin outlines some of the basic regulatory requirements, research results and waste-management system operating practices that have been developed in the United States over the last 20 years to address environmental concerns.

Concentrating cattle in feedlots has numerous advantages in terms of productivity and quality control and is a widely accepted practice in the United States. Texas leads the nation in fed-beef production, cattle feedlot capacity and slaughter plant capacity.

However, concentration of cattle in feedlots results in a quantum increase in the *potential* for both water and air pollution. To prevent potential problems from developing into real problems, feedlot operators must be proactive in establishing technically sound programs and systems to control rainfall runoff, to manage solid manure and to maintain the feedlot surface and wastewater handling facilities. Both research and educational programs are needed to establish proper design and operating criteria for local conditions, to assist the industry with implementing solutions and to allay public concerns.

### Water Quality Impacts of Cattle-grazing Operations

To place the potential for cattle feedlot water pollution in the proper context, it is necessary to first examine and contrast water quality effects of livestock grazing operations. Research in recent years has determined the effects of cattle grazing operations on runoff quantity and water quality in streams (Robbins, 1978; Duda and Finan, 1983; Powell et al., 1983). Research indicates that unconfined livestock production is an environmentally sound water quality management practice (USEPA, 1984). In many cases, the presence of unconfined cattle on range or pasturelands cannot be discerned from natural or background levels of water pollutants.

Watersheds containing cattle grazing sometimes show increased concentrations of bacterial indicator organisms, primarily coliforms and streptococcus, in the adjacent streams (Dixon, 1983A; Milne, 1976). Reported effects are erratic and detectable only for short distances downstream. Fecal deposits along drainage ways may contribute a disproportionate share of the bacteria from grazed watersheds. Often the effects of cattle on the watershed are indistinguishable from the effects of wildlife (Doran et al., 1981; Dixon, 1983B). Water quality standards for coliform indicator organisms, which were developed for point sources, have questionable value for assessing water quality effects of cattle grazing operations, according to U.S. Environmental Protection Agency research (Doran et al., 1981; White et al., 1983; Saxton et al., 1983).

The annual amount of nutrients transported off of grazed pastureland (Table 1) ranges from 0.5 to 8.7 lbs nitrogen/acre/year, and from 0.04 to 4.1 lbs phosphorus/acre/year (Doran et al., 1981). These nutrient levels are far less than transported from cattle feedlots (Table 2) and are comparable to cropland, forests and rainfall (Loehr, 1974). In fact, runoff from livestock pastures often does not exceed nutrient levels in runoff from ungrazed pasturelands, forests or dryland farms (Saxton et al., 1983). Nutrient losses and runoff amounts are greater for overgrazed pastures than for properly managed grazing systems (Smeins, 1977). Detectable water pollution from unconfined cattle operations does not appear to be related to cattle numbers or manure quantity, but rather to conditions that contribute to rapid surface runoff or sediment movement (Dixon, 1983A).

The most common change in stream water quality from unconfined livestock production is elevated concentrations of bacteria and sediment (Milne, 1976; Saxton et al., 1983). Chemical pollutants are sometimes increased slightly but do not usually exceed federally-approved stream quality standards.

Unconfined livestock may decrease vegetative cover and increase runoff, erosion, transport of sediment, plant nutrients and oxygen demand. Particularly at high-impact feeding and watering sites, the sediment

\*Associate Department Head and Extension Program Leader for Agricultural Engineering, Texas Agricultural Extension Service, The Texas A&M University System, College Station, Texas 77843-2121 (409/845-7451).

**Table 1. Average annual nutrient yields in runoff from some grazed pasturelands in the U.S. (Doran et al., 1981).**

Location	Management System	Total Nitrogen lbs/acre	Total Phosphorus lb/acre
Nebraska	Rotation grazing	2.5	0.62
	Rotation grazing	1.7	0.17
Oklahoma	Continuous grazing	8.7	4.11
	Rotation grazing	1.9	1.16
	Rotation grazing	4.6	0.04
Ohio	Rotation grazing	0.5-2.9	0.3-1.15
Minnesota	Prairie	0.7	0.10

**Table 2. Annual yield and concentrations of nitrogen and phosphorus in land runoff (Loehr, 1974).**

Source	Total Nitrogen		Total Phosphorus	
	ppm	lb/ac/yr	ppm	lb/ac/yr
Precipitation	1.2-3.3	5.0-8.9	0.02-0.04	0.04-0.05
Forested land	0.3-1.8	2.7-11.6	0.01-0.11	0.03-0.8
Cropland runoff	9	0.1-11.6	0.02-1.7	0.05-2.6
Irrigated cropland in western U.S.	0.6-2.2	2.7-24.1	0.2-0.4	0.9-3.9
Urban land drainage	3	6.3-8.0	0.2-1.1	1.0-5.0
Feedlot runoff	920-2100	89.3-1430	290-360	8.9-554

load can be minimized by management practices, which include protecting fragile stream banks, maintaining vegetative cover, stocking at low or moderate levels, distributing salt and water, and providing feed, salt or water away from streams (Sweeten and Melvin, 1985).

### Runoff from Cattle Feedlots

Runoff from cattle feedlots contains relatively high concentrations of nutrients, salts, pathogens and oxygen-demanding organic matter-measured as BOD<sub>5</sub> (biochemical oxygen demand) or COD (chemical oxygen demand) (USEPA, 1973; Reddell and Wise, 1974). Some typical concentrations of cattle feedlot runoff are shown in Table 3 (Clark, 1975A) and Table 4 (Sweeten et al., 1981; Clark et al., 1975B). Other researchers (Wells et al., 1969; USEPA, 1973) showed that BOD<sub>5</sub> concentrations of around 2,000 mg/l (about eight times the concentration in raw domestic sewage) were commonplace. Runoff can contain 100 times more nitrogen and phosphorus than runoff from grazing land. When feedlot runoff enters streams, the excess organic matter and nutrients can cause oxygen depletion and eutrophication, which leads to fish kills (Paine, 1973B).

### Feedlot Water Pollution Regulations

Feedlots in the Great Plains and southwestern United States, beginning in the late 1960's and 1970's, have had to control discharges and meet state and/or federal regulations that do not allow any discharge of wastewater from off the feedlot property. The feedlot capacity in Texas that did not have adequate water pollution controls was reduced from about 98 percent of fed cattle in 1968 to 2 percent of capacity in 1975. Moreover, this outstanding record of pollution abatement occurred at the same time the cattle feedlot capacity doubled, increasing from about 1.4 million head on feed in 1968 to almost 3 million head in 1974. Several cattle feeding states including Texas instituted an individual permit program in the late 1960's. The U.S. Environmental Protection Agency adopted feedlot effluent guidelines (1974) requiring no-discharge and a federal permit system (1976) for feedlots over 1,000 head that discharge from less than a 25-year, 24-hour duration storm event. Subsequently, probably few industries in the United States achieved a better record of compliance more rapidly than the cattle feedlot industry.

The Texas Water Commission (TWC) developed and implemented a set of state regulations (TWC,

**Table 3. Average chemical characteristics of runoff from beef cattle feedyards in the Great Plains.<sup>1</sup>**

Location	Total Solids, ppm	Electrical Conductivity, mmhos/cm	Chemical Oxygen Demand, ppm	Total Nitrogen ppm	Total Phosphorus ppm
Bellville, TX	9,000	-	4,000	85	85
Bushland, TX	15,000	8.4	15,700	1,080	205
Ft. Collins, CO	17,500	8.6	17,800	-	93
McKinney, TX	11,430	6.7	7,210	-	69
Mead, NE	15,200	3.2	3,100	-	300
Pratt, KS	7,500	5.4	5,000	-	50
Sioux Falls, SD	2,990	-	2,160	-	47

Location	Sodium, ppm	Calcium, ppm	Magnesium, ppm	Potassium, ppm	Chloride, ppm
Bellville, TX	230	-	-	340	410
Bushland, TX	588	449	199	1,320	1,729
Ft. Collins, CO	-	-	-	-	-
McKinney, TX	408	698	69	761	450
Mead, NE	478	181	146	1,864	700
Pratt, KS	511	166	110	815	-
Sioux Falls, SD	-	-	-	-	-

<sup>1</sup>All data from Clark et al. (1975A).

**Table 4. Average concentration of nutrients, salts and other water quality parameters from stored cattle feedlot runoff in Texas.<sup>1,2</sup>**

Water Quality Parameters	South Texas <sup>3</sup> Holding Ponds	Texas High Plains <sup>4</sup>		
		Runoff, Fresh	Holding Ponds	Playas
Nitrogen, ppm	180	1,083	145	20
Phosphorus, ppm	-	205	43	12
Potassium, ppm	1,145	1,320	445	60
Sodium, ppm	230	588	256	54
Calcium, ppm	180	449	99	55
Magnesium, ppm	20	199	72	30
Chloride, ppm	1,000	1,729	623	86
COD, ppm	1,100	-	-	-
Total Solids, ppm	2,470	-	-	-
Sodium Adsorption Ratio (SAR)	4.2	5.3	4.6	1.4
Electrical Conductance, mmhos/cm	4.5	8.4	4.5	1.0

<sup>1</sup>To convert to lbs/acre-inch, multiply concentrations (ppm) by 0.226.

<sup>2</sup>Quality of runoff after it had been in the runoff holding pond for several weeks. Playas typically catch runoff from areas other than the feedlot; thus, there is a greater dilution effect.

<sup>3</sup>From Sweeten et al. (1981).

<sup>4</sup>From Clark et al. (1975B).

1987) with active participation and cooperation of livestock commodity groups and agricultural agencies. The TWC regulation states that it is the policy of the State of Texas that there shall be no discharge from livestock feeding facilities, but rather the animal waste materials must be collected and utilized or disposed of on agricultural land. The regulation has three major types of requirements: (a) surface water protection, (b) groundwater protection and (c) proper land application of manure and wastewater. Beef cattle feedlots with over 1,000 head of cattle on feed have to get a state permit (comparable numbers apply to other animal species). With less than 1,000 beef cattle on feed, feedlots still have to meet the no-discharge requirements for water pollution control but do not have to get a permit. Local governmental involvement in permits is minimal, including the opportunity to respond to public notification, review and comment.

When obtaining a TWC permit, feedlot operators have to estimate daily and annual production of manure, wet and dry basis, and the major constituents including volatile solids, nutrients (N, P, K), salts (Na, Cl, etc.) and oxygen demand. The calculations amount to a nutrient balance from manure produced by the livestock, through collection and land application. The basis for these calculations is a set of standards *Manure Production and Characteristics*, D-384.1, revised in 1988 and published by the American Society of Agricultural Engineers. In Texas, we use the mean plus one standard deviation for all manure production and constituent calculations. If you have a confinement building, you have to collect the semi-solid or liquid manure and wastewater, and provide storage structures with a minimum capacity that increases from west to east across the state according to annual rainfall and evaporation.

Surface water-protection measures for open dirt-surfaced feedlots include diverting the clean water around the feedlot and collecting the rainfall runoff. For purposes of runoff collection, a feedlot/concentrated animal feeding facility is identifiable as (a) a manure-covered surface that does not sustain the growth of forage, crops or other vegetation, and (b) has feeding facilities within a fence or enclosure. Runoff retention facilities must be built out of the 100-year flood plain. Retention facilities must be dewatered within 21 days after they are half full or more with rainfall runoff. Irrigation is the most effective and popular means of dewatering, but in very dry areas evaporation is an alternative.

## Runoff to be Collected

Runoff holding ponds must be designed to collect and store all runoff from a 25-year frequency, 24-hour duration storm. This design rainfall event is approximately 5 inches in our main cattle feeding regions of the Southern High Plains. To calculate runoff from

the design storm, the TWC regulation (TWC, 1987) requires using the SCS-USDA Soil Cover Complex Curve #90. So for a design rainfall of 5 inches from the 25-year, 24-hour storm, the design runoff is about 3.8 inches, which is between 75 and 80 percent of the rainfall.

Research was conducted on feedlot runoff vs. rainfall relationships in the 1970's by state Agricultural Experiment Stations and the Agricultural Research Service USDA when the feedlots were faced with controlling water pollution (Gilbertson et al., 1981; Clark et al., 1975A). Researchers have determined that it takes about 0.5 inches of rainfall to induce runoff from a cattle feedlot (Gilbertson et al., 1980). Thereafter, the rainfall versus runoff relationships predict less runoff per inch of rainfall in dry climates than in wetter climates (Clark et al., 1975A). Nevertheless, holding ponds should be designed using the SCS Curve #90.

The annual amount of runoff expected is about 20 to 33 percent of rainfall in the Great Plains cattle feeding regions (Phillips, 1981). Therefore, a 200-acre feedlot in a 24-inch rainfall area will produce an average of 1,200 acre-inches of runoff per year to be disposed of by irrigation.

## Seepage Control

Groundwater quality is protected by the Texas feedlot regulations, which have set standards for seepage control (TWC, 1987). A runoff holding pond or lagoon must be built in, or lined with, a compacted thickness of at least 12 inches of soil material with 30 percent or more passing a No. 200 mesh sieve, a liquid limit (LL) of 30 percent or more and a plasticity index (PI) of 15 or more. These three criteria basically require a sandy clay loam, clay-loam or clay soil and together are consistent with attaining a permeability coefficient of around  $1 \times 10^{-7}$  centimeters per second (cm/sec), which has been stipulated in some permits.

Research data is available to show that holding ponds and manure treatment lagoons are partially self-sealing (Sweeten, 1989A). For example, research from California involving an unlined cattle manure storage pond showed the seepage rate was  $1.3 \times 10^{-4}$  cm/sec initially, but after six months, the seepage rate was reduced nearly a hundred-fold (i.e. 2 orders of magnitude) to  $3.5 \times 10^{-6}$  cm/sec (Robinson, 1973).

Research in Canada showed that clogging of soil pores by bacterial cells and organic matter is the mechanism responsible for self-sealing (Barrington and Jutras, 1983). The initial fresh water infiltration rate in 10 feet deep holding ponds was  $10^{-2}$ ,  $10^{-3}$  and  $10^{-4}$  cm/sec for sand, clay and loam, respectively. After only two weeks of storage, the infiltration rates of dairy lagoon effluent were reduced to only  $10^{-6}$

cm/sec in loam and sandy soils as compared to  $0.1.8 \times 10^6$  cm/sec after a year for all three soils.

Research concerning seepage beneath feedlot holding ponds has shown reduced seepage (Lehman and Clark, 1975) and very little nitrate or chloride movement (Lehman et al., 1970; Clark, 1975). After five years, nitrates had leached less than 3 feet below the bottom of a natural playa lake with about 3 feet thickness of montmorillonite clay bottom used to collect feedlot runoff. With these favorable soil conditions, there was apparently minimal groundwater hazard from nitrate contamination.

Measurable nitrate was found in the groundwater beneath 22 feedlots out of more than 80 sampled from monitoring wells (Miller, 1971). These feedlots were over the Ogallala Aquifer in the Texas High Plains where groundwater depth was typically 100 to 300 feet. Nitrate concentrations ranged from less than 1 to 12 mg/l and were higher below the holding ponds than beneath the feedlot surface. Since this research was conducted 18 years ago, it would be very interesting to re-sample the groundwater at these locations.

Beneath a dairy manure storage pond in Canada the nitrate concentrations at 5 to 10 feet soil depth below the pond were 0.4 mg/l for a clay soil, 1.2 mg/l for a loam soil and 17 mg/l for a sandy soil (Phillips and Culley, 1985). This data underscores the importance of lining a holding pond with clay soil.

## Land Application of Feedlot Runoff

Feedlot runoff collected in holding ponds needs to be disposed of by land application and/or evaporation. Feedlot runoff characteristics are illustrated in Tables 3 and 4. Sprinkler irrigation is the preferred approach to land application of feedlot runoff. With sprinklers you can control the application rate to as little as 0.5 inch per application, if necessary, to prevent runoff. With furrow irrigation, it is difficult to apply less than 4 inches to get complete coverage of a field, and this usually creates a tailwater problem in fine textured soils, resulting in high application rates for nutrients and salts. Level borders are a good way to apply feedlot effluent. You can control the application rate on laser-leveled borders to 3 or 4 inches with uniform distribution and prevent tailwater. We are doing a study of level border irrigation at a Texas feedyard and it is working very well.

Swanson et al. (1977) described a serpentine waterway system for relatively small feedlot (below 1000 head). The runoff flows through a settling basin to reduce the solids content and then enters the serpentine waterway, which reduces runoff concentrations and volume being discharged. Effluent flows through parallel vegetated terraces with a baffle or weir

between terraces (Swanson et al., 1977). Serpentine waterways have been shown to be effective in removal of up to 80 percent of the solids and chemical oxygen demand from feedlot runoff. Size of the vegetated area should be 1 to 2 acres per acre of feedlot surface (Swanson et al. 1974 and 1977; Dickey et al., 1977).

Feedlot runoff application rates are usually limited either by nitrogen, salinity or sodium content (Butcbaker, 1973). Nitrogen concentrations are 89 to 364 mg/l (Table 5), with 80 percent or more in the form of ammonium (Sweeten, 1989B). Feedlot runoff stored in holding ponds generally has an electrical conductivity (EC) of 1 to 10 millimhos per centimeter (mmhos/cm), depending on factors such as cattle ration and degree of evaporation. Clark et al. (1975B) determined a mean value of 4.5 mmhos/cm for feedlot runoff stored in holding ponds in the Texas High Plains, and Butcbaker (1973) found a mean value of 5.5 mmhos/cm for Kansas. Most of the salinity is in the forms of potassium and chloride, although sodium and ammonium are also important parameters. A relationship between EC and soluble sodium percentage (SSP) for feedlot runoff is shown in Figure 1, which can be used as a guideline for sodium and salinity hazard in the soil (Butcbaker, 1973).

Runoff held in evaporation ponds has shown extremely high salt concentrations with electrical conductivity of over 20 mmhos/cm, which equates to around 12,000 to 15,000 ppm of total dissolved solids. Evaporation pond effluent may not be suitable for irrigation. It is an asset for a feedlot to have irrigation water available for adding dilution water to reduce salt content when irrigating with feedlot runoff (Powers et al., 1973). Methods of estimating the needed dilution ratios are shown in Sweeten (1976).

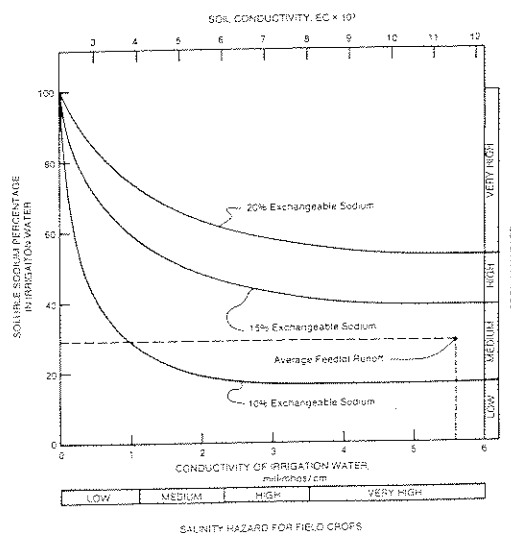


Figure 1. Sodium and salinity hazards of average (Kansas) feedlot runoff for soils of medium texture (Butcbaker, 1973).

**Table 5. Nitrogen, phosphorus and solids concentrations in typical cattle feedlot runoff holding pond contents.<sup>1</sup>**

Feedlot	Sample Date	No. Samples	Total N	NH <sub>3</sub> -N	P	Total Solids	Salinity Index	
							EC <sup>2</sup>	SAR <sup>3</sup>
..... ppm .....								
<b>A. Effluent Used for Irrigation</b>								
ST-W	8/23/88	5	173	151	28	4,264	5.1	2.9
ST-E	10/26/88	1	129	119	33	2,370	3.8	2.4
LB	10/1/88	4	217	161	96	14,425	14.9	7.2
AVS	10/13/88	1	118	107	148	3,770	4.3	3.5
AVS	8/ /88	2	172	148	10	5,315	9.1	6.8
AVS	5/27/88	1	89	61	9	8,990	8.4	11.7
AVS	1/21/88	6	136	98	56	5,242	4.6	7.6
AVS	8/14/87	3	181	120	12	4,403	8.0	5.4
TBP	10/8/84	2	90	75	-	3,215	3.8	3.3
SW	12/8/87	2	364	282	-	7,865	8.2	16.3
Mean			167	132	49	5,986	7.0	6.7
SD (Standard Deviation)			81	62	50	3,589	3.5	4.4
<b>B. Agitated Sediment and Effluent</b>								
ST-E	10/17/89	2	211	162	45	26,700	4.2	2.4
ST-E	10/20/89	3	198	154	276	21,700	3.8	1.2
ST-E	10/26/89	3	202	151	42	28,400	4.0	2.3
Mean			204	156	121	25,600	4.0	2.0
SD (Standard Deviation)			7	6	134	3,483	0.2	0.7

<sup>1</sup>Source: Sweeten, J. M., Unpublished data. Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 1989B.

<sup>2</sup>EC = Specific conductance or electrical conductivity, mmhos/cm.

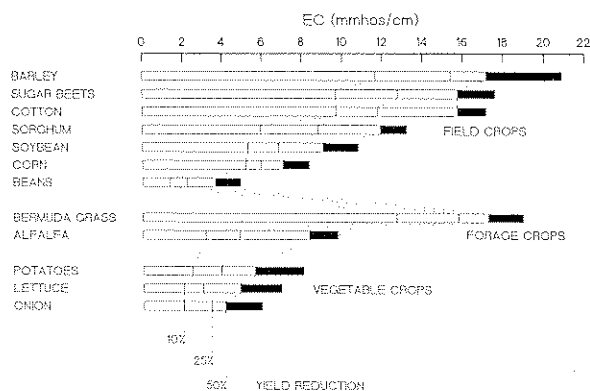
<sup>3</sup>SAR = Sodium absorption ratio = (Na/0.5 (Ca + Mg)\*\* 0.5), where Na, Ca and Mg concentrations are milliequivalents per liter.

Salt tolerance has been established for most crops (FAO, 1985; Stewart and Meek, 1977). Salinity levels in soil and applied effluent that will cause 10, 25 and 50 percent reduction in yields are shown in Figure 2 (Stewart and Meek, 1977). Salt tolerant crops such as sorghum, barley, wheat, rye and bermudagrass

are good choices for feedlot runoff application (Butchbaker, 1973), while corn is less salt tolerant but is a high nitrogen user.

Runoff may not be low enough in concentration to use without dilution on corn. Research in Kansas showed that about 10 inches of undiluted feedlot runoff applied per year for three years produced peak yields of corn forage, but beyond that level it began to reduce crop yield (Wallingford et al., 1974). By comparison, cattle feedlots in Texas reported using 2 to 6 inches per year of undiluted runoff (Sweeten and McDonald, 1979).

Research on germination of crops that received feedlot runoff showed soybean germination was 0 to 30 percent; hence, it is a poor crop to choose for runoff disposal (Coleman et al., 1971). Cotton and grain sorghum germinated much better, especially for 2 to 6 inch applications of dirt lot runoff, as shown in Table 6. Yields of cotton, grain sorghum and bermudagrass were increased as a result of applying 1 to 2 inches of runoff from dirt or concrete surface



**Figure 2. Effect of soil salinity on crop growth (Stewart and Meek, 1977).**

feedlots every 2 weeks during a 14 week irrigation season (Coleman et al., 1971). Total applications were 7 and 14 inches, as compared to groundwater (Table 7).

Research by Wells et al. (1969) showed drastic reductions in most chemical constituents in leachate when 17.4 inches of feedlot runoff was applied to cotton, sorghum and Midland bermudagrass and percolated through 30 inches of soil. As compared, to fresh runoff, removals of BOD<sub>5</sub>, COD, total nitrogen and volatile solids in leachate were 99.5

percent, 95 to 98 percent, -48 to +76 percent, and 77 to 82 percent, respectively.

### Solid Manure: Land Application

Feedlot manure contains about 2 to 2.5 percent nitrogen, 0.8 to 1 percent phosphorus (P<sub>2</sub>O<sub>5</sub>) and 1.5 to 2 percent potassium (K<sub>2</sub>O) on a dry weight basis (Arrington and Pachek, 1981). Manure application rates depend on many factors including manure analysis, physical and chemical soil characteristics, type of crop, yield goal, soil drainage, climate,

**Table 6. Germination of plants using runoff from concrete and dirt surfaced feedlots, Lubbock, Texas (Coleman et al., 1971).**

Treatment	Surface Inches Applied	Cotton			Grain Sorghum			Soybeans		
		A	B	C	A	B	C	A	B	C
Water	2	60	75	68	72	90	85	27	10	2
	4	61	73	72	83	95	97	22	5	2
	6	65	62	75	98	93	98	20	5	15
	8	42	57	42	48	88	77	0	3	5
Dirt Lot Runoff	2	63	67	65	68	90	85	28	5	32
	4	47	35	68	93	73	85	23	2	12
	6	53	20	45	82	52	65	5	0	3
	8	32	3	25	48	18	60	7	0	0
Concrete Lot Runoff	2	65	73	48	72	92	70	0	0	0
	4	38	13	22	47	77	63	0	7	2
	6	13	22	27	7	25	48	0	0	0
	8	15	25	3	8	25	45	0	2	0

#### Timing of Applications

- A. Treatment and planting together
- B. Plant in moist soil; one week later treatments applied
- C. Treatment applied; one week later planted

**Table 7. Yields of plant materials produced by two-year old plots receiving seven bi-weekly irrigation treatments as shown, grams dry weight basis (Coleman et al., 1971).**

Treatment, inches <sup>1</sup>	Cotton*	Grain Sorghum**	Bermudagrass***
Check	257	1006	599.3
1 Water	317.8	1806	920
2 Water	794.5	1389	1036.5
1 Dirt	567.5	1545	1010.5
2 Dirt	1430.1	1740	1318.5
1 Concrete	363.2	1315	1386
2 Concrete	1089.6	1388	1816

<sup>1</sup>Dirt and concrete refer to types of lot surfaces from which irrigation water was obtained.

\*grams bolls per plot

\*\*grams total plant material per plot

\*\*\*grams total plant material

groundwater depth and geology. The feedlot manager should work with a professional agronomist to determine the proper application rate. Over-application of feedlot manure can depress yields, as well as waste manure and increase water pollution potential by applying nutrients that are not taken up by crops.

In most cases, manure application rates should be selected on the basis of plant-available nitrogen and phosphorus (Gilbertson et al., 1979A). Soil fertility guides are available to explain how many pounds of N-P-K it takes for a specific crop and yield goal. For grain sorghum with a yield goal of 7,000 lbs/acre, each year the crop will require about 150 lbs/ac N, 80 lbs/ac P<sub>2</sub>O<sub>5</sub>, and 120 lbs/ac K<sub>2</sub>O. To meet these requirements with feedlot manure in which about 40 to 50 percent of the nitrogen is available, you should apply manure at the rate of about 8 tons/acre dry basis.

Alfalfa yield data was obtained from test plots in a desert climate in Mexico using dairy cattle manure from earthen corrals, as compared to commercial fertilizer (Castellanos and Munoz, 1985). They applied commercial nitrogen fertilizer versus cattle manure at 13.4 tons/acre. Total yields from 18 alfalfa cuttings per year averaged 18 tons/acre from both unfertilized check plots and from plots receiving commercial fertilizer. With manure applied at 13.4 tons/acre on plowed or disked plots, annual alfalfa yields were 22.6 and 21.7 tons/acre, respectively. At least 25 percent more yield was obtained with the manure than from commercial fertilizers. Research at Texas A&M University determined yields of corn silage and grain sorghum that resulted from feedlot manure application rates (at 36 to 51 percent moisture) applied at rates of 0, 10, 25, 50, 100, 150, 300, 600 and 900 tons/acre for two years (Reddell, 1974). Peak yield occurred at the 25 ton/acre application rate for sorghum grain and at 10 and 25 tons/acre for corn silage. The highest application rate in which manure was stacked about 1 foot deep before deep plowing, reduced yields to 33 to 38 percent of the peak yields with lower rates. However, two annual applications of 150 tons/acre or less did not significantly reduce yields of either crop.

Crop yield data (relative to check plot yields) from three cattle feeding states in the U.S. using manure application rates of 0 to 268 tons/acre/year (dry basis) is shown in Figure 3 (Stewart and Meek, 1977). The effects of soluble salt on crop yields was studied. At Brawley, California (desert climate), peak yields of sorghum grain occurred at 33 tons/acre and yield reduction occurred at higher rates or 33 to 129 tons/acre. Near Amarillo, Texas (Bushland), irrigated sorghum yield on a Pullman clay loam soil peaked at a manure application rate of only 10 tons/acre, then decreased at higher application rates due to minimal leaching. For corn silage in Kansas, yields peaked at 45 to 90 tons/acre and decreased at 90 to 268

tons/acre. However, the harmful salinity effects of these high application rates generally do not persist, as illustrated in Figure 4 (Stewart and Meek, 1977).

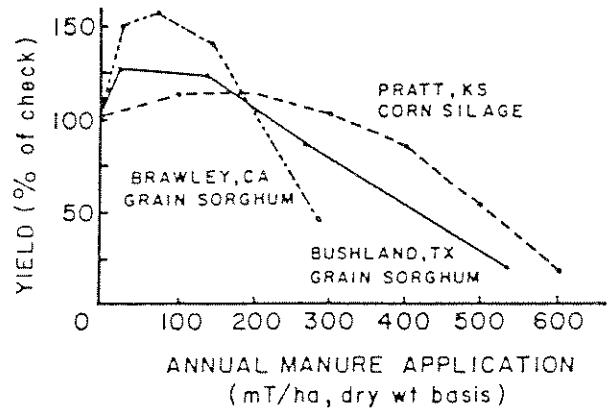


Figure 3. Effect of cattle feedlot manure on plant yields (Stewart and Meek, 1977).

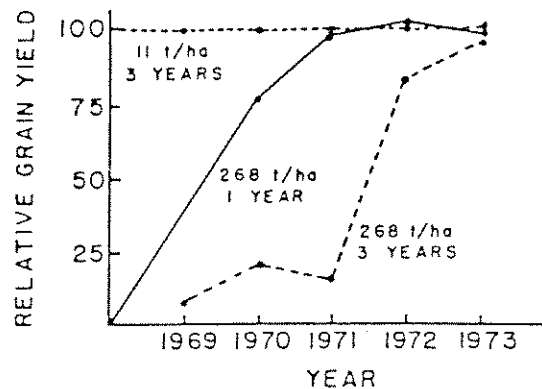


Figure 4. Recovery of grain sorghum yield from plots receiving 11 and 268 dry tons of cattle manure per hectare, Bushland, Texas (Stewart and Meek, 1977).

Research by USDA-Agricultural Research Service involved applying feedlot manure at various application rates to sorghum near Amarillo, Texas over a seven-year period (Mathers et al., 1975). As Table 8 indicates, yield of sorghum grain with no manure applied was 4,490 lbs/acre. Two different rates of commercial fertilizer produced 6,400 to 6,500 lbs/acre of sorghum, an increase of over 40 percent. When feedlot manure was applied at annual rates of 10, 30, 60 and 120 tons/acre with an average of about 40 percent moisture content, grain yields increased as compared to no fertilizer. Peak yields occurred at 10 tons per acre per year, which produced an average of 6,640 lbs/acre per year.

Cost benefits of the sorghum yield vs. application rate results of Mathers et al. (1975) were calculated

**Table 8. Value of feedlot manure in grain sorghum production, 1969 - 1973, Bushland, Texas (Mathers et al., 1975).**

Annual Treatment	Average Yield lb/ac/yr	Yield Increase* lb/ac/yr	Incremental Yield Value	
			\$/ac/yr	\$/t
Check—no fertilizer	4,490	-	-	-
N (240 and 120 lb N/acre)	6,440	1,950	87.75	-
N-P-K (240 and 120 lb N/acre)	6,410	1,920	86.40	-
Manure—10 ton/acre	6,640	2,150	96.75	9.70
30 ton/acre	6,490	2,000	90.00	3.00
60 ton/acre	6,360	1,870	84.15	1.40
120 ton/acre	5,120	630	28.35	.24
240 (3 yr treatment and 2 yr recovery)	900/6,800	-1,230	-55.35	-.23
240 (1 yr treatment and 4 yr recovery)	330/6,750	976	43.92	.18

\*Assumes price of sorghum grain is \$4.50 per 100 pounds.

**Table 9. Crop yields from feedlot manure application, Bushland, Texas 1969-1980, USDA-ARS (Mathers and Stewart, 1984).**

Treatment tons/acre	Number of Years		Average Yields, lbs/acre/yr		
	Applied	Recovery	Sorghum	Corn	Wheat
			Grain 1969-73	1975, 77, 79	1976, 78, 90
0	11	0	4,490	8,350	1,400
0 (N)	11	0	6,440	13,390	4,050
0 (NPK)	11	0	6,410	13,560	4,290
10	11	0	6,640	13,920	3,430
30	11	0	6,490	13,400	4,530
60	5	6	6,360	14,340	4,000
120	5	6	5,120	13,950	4,260
240	3	8	900	15,260	4,330
240	1	10	330	12,100	2,810

by Sweeten (1984). The lowest application rate of 10 ton/acre was the most cost-effective, yielding nearly \$10 in grain per ton of manure applied as compared to \$3.50 to \$4.00/ton for manure hauling and spreading in most cases. However, at the 60 ton/acre application rate and above, the incremental yield increase of \$1.40 per ton of manure is less than the hauling and spreading cost. Again, the greatest benefits result from using relatively low application rates that match the crop fertilizer requirements.

In the same study, at the highest application rate 120 tons/acre, soil nitrate concentration built up to about 50 ppm in the soil (Mathers and Stewart, 1971). Successively lower nitrate concentrations occurred with lower application rates. The lowest application rate gave about the same soil nitrate concentration

as when no fertilizer was applied. Apparently, part of the excess nitrogen applied (not taken up with the crop) has potential for leaching.

The effects of manure on sorghum, corn and wheat for various time intervals at Bushland, Texas are shown in Table 9. Residual benefits of manure at high rates on corn and wheat were evident in terms of sustained yields after application of manure ceased (Mathers and Stewart, 1984).

Residual nitrogen in the soil from using livestock manure was also shown to benefit crop production in experiments at Auburn University in Alabama (Lund et al., 1975; Lund and Doss, 1980). Solid dairy manure was applied to bermudagrass on two different soil types. A commercial fertilizer (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O)

application of 400-200-420 lbs/acre was compared with three rates of dry manure: 20, 40 and 60 tons/acre per year on two sandy loam soils. On soil type A, during the three years that manure was applied, slightly higher hay yield occurred with 40 and 60 tons/acre manure than with commercial fertilizer (Table 10). However, when they ceased applying any fertilizer for the next three years, the yield on the commercial fertilizer plots dropped by 54 percent, while that from the manure-treated plots kept increasing because of residual nutrients. Similarly, on soil type B there was little difference among the treatments in terms of crop yield for three years during application of fertilizer and manure except that the 20 tons per acre produced the lowest yields. However, for the three years after fertilizer and manure treatment ceased the commercial fertilizer plots had almost no yield (reduced by 84 percent), but yields were sustained on plots that received manure. Hence, for the six year program, the manure treatments produced 18 to 88 percent more hay than commercial fertilizer on soil type B, and 31 to 85 percent more yield for soil type A, which shows the benefits of residual nutrient value from manure.

Manure has also been known to correct micronutrient deficiencies, such as iron chlorosis in sorghum, which

is caused by iron deficiency. In research near Lubbock, Texas where feedlot manure was applied to a calcareous soil (Arch fine sandy loam), grain sorghum yields increased from 2320 lbs/acre with no manure to 6210 lbs/acre with 5 tons/acre manure and to 5820 lbs/acre with 15 tons/acre manure. Commercial N and P fertilizer actually caused a 49 percent yield decrease versus the control. Manure is a good form of fertilizer on calcareous soils due to slow release of nutrients and chelating of ions (Mathers et al., 1980; Thomas and Mathers, 1979).

A technical guide for determining proper manure application rates based on nitrogen content was developed by the USDA Agricultural Research Service (Gilbertson et al., 1979A). This technical guide takes into account the slow rate of release of organic nitrogen in manure and the nitrogen concentration on a dry basis. Recommended manure application rates per 100 pounds of available nitrogen are shown in Table 11. For example, suppose cattle manure contains 2.0 percent nitrogen (dry basis). As shown in Table 11, it takes 7 tons/acre of manure dry basis the first year to supply 100 lb/acre of available nitrogen. In succeeding years, release of residual organic nitrogen lowers the manure requirement to 5.8 tons/acre in the second year and to 4.4 tons/acre

**Table 10. Total yields of coastal bermudagrass hay (tons/acre) during and after three years of dairy manure treatment, 1971-76 (Lund et al., 1975; Lund and Doss, 1980).**

Fertilizer Treatment	Dothan Loamy Sand			Lucedale Fine Sandy Loam		
	3 years during	3 years after	Total 6 years	3 years during	3 years after	Total 6 years
Check (420-200-420)	19.7	9.1	28.8	23.6	3.8	27.4
Dairy Manure, dry tons/acre						
20*	17.4	20.2	37.6	17.7	14.7	32.4
40*	21.1	26.2	47.3	24.4	22.0	46.4
60	23.0	30.2	53.2	26.8	24.9	51.7

\*Combined average results for liquid and solid manure.

**Table 11. Dry tons of manure needed to supply 100 pounds of available nitrogen over the cropping year (Gilbertson et al., 1979A).**

Length of Time Applied (years)	Nitrogen Content of Manure, % dry basis					
	1.0	1.5	2.0	2.5	3.0	4.0
	----- Tons of dry manure/100 lb N -----					
1	22.2	11.6	7.0	4.6	3.1	1.4
2	15.6	9.0	5.8	3.9	2.8	1.4
3	12.7	7.7	5.1	3.6	2.6	1.4
4	11.0	6.9	4.7	3.4	2.5	1.3
5	9.8	6.3	4.4	3.2	2.4	1.3
10	6.9	4.9	3.7	2.8	2.2	1.3
15	5.6	4.2	3.3	2.6	2.0	1.2

in the fifth year. Because of nitrogen losses after manure is applied to soil, application rates listed in Table 11 should be increased by approximately one-third if manure is to be surface-applied rather than incorporated into the soil.

The best returns from using manure for fertilizer usually result from applying manure on those soils and crops that need both nitrogen and phosphorus; using a low application rate (e.g. 5 to 10 dry tons/acre/year); and applying manure on poor soils with a chemical imbalance, such as iron deficiency problem. You can expect to get some benefit both from residual nutrients and micro-nutrients. Finally, over a period of years even at low application rates, you can realize an improvement in soil physical properties, such as improved water infiltration rate, greater nutrient holding capacity and greater soil

aggregate stability (Mathers and Stewart, 1981; Sweeten and Mathers, 1985).

To summarize some key points, a feedlot operator or farmer using manure should first determine the nutrient content of the manure through sampling and analysis, conduct soil testing, and then match soil and crop needs to the manure nutrient content and availability. Make sure enough land is available. Timing of application is important. To retain nutrients apply manure just prior to planting and incorporate the manure into the soil. Avoid steep sloping land and do not apply manure within 100 to 200 feet of a stream bank (Gilbertson, 1983). Protect against soil erosion and sediment discharge using cover crops, conservation tillage, strip cropping, terracing and vegetated waterways.

## Air Pollution

Odor and dust emissions are sometimes a major concern for cattle feedlots and neighbors. Some feedlots are located near a town yet do not experience complaints from neighbors, while other feedlots have generated community complaints.

### Feedlot Dust

In hot dry weather, feedlot cattle can create high dust concentrations especially for about two hours around dusk when cattle activity increases, but dust is usually minimum in early morning (Elam et al., 1971). Under calm conditions, feedlot dust can drift over nearby highways and buildings. In 1970, the California Cattle Feeders Association (CCFA) sponsored a study of dust emissions at 25 cattle feedlots (Algeo et al., 1972). Standard high volume samplers were stationed upwind and downwind of the feedlots to monitor dust concentrations. The U.S. Environmental Protection Agency's primary and secondary standards for total suspended particulate (TSP) has been 260 and 150 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) respectively. The range measured in the CCFA research project was 54 to 1268  $\mu\text{g}/\text{m}^3$ , and the overall average for the 25 feedlots was 654  $\mu\text{g}/\text{m}^3$ , more than four times the federal secondary standard (Algeo et al., 1972; Peters and Blackwood 1977). Some feedlot dust emissions were lower than the USEPA standards, due possibly to sprinkling or other management practices.

Based on the California data, the USEPA established some "emission factors" for beef cattle feedlots (USEPA, 1986; Peters and Blackwood, 1977). These are based on essentially worst-case assumptions.

A research project on feedlot dust emissions was sponsored by the Texas Cattle Feeders Association and was conducted at Texas A&M University. Measurements were taken at three feedlots and were replicated three times (Sweeten et al., 1988). A mean net increase was found in TSP concentration of 412  $\mu\text{g}/\text{m}^3$  (difference between upwind and downwind dust concentrations), and the range was 16 to 1700  $\mu\text{g}/\text{m}^3$ . These values were generally lower than found in the California dust emission studies, possibly because Texas receives more precipitation in its cattle feeding regions than California feedlots, but the Texas values were still well above the state and federal TSP standards in effect until 1987.

In July, 1987, the U.S. Environmental Protection Agency (USEPA, 1987) changed the basis for ambient air quality standards for particulate emissions from total suspended particulates to the PM-10 standard (i.e. median aerodynamic particle size of 10 microns). Accordingly, in the Texas studies, two different types of PM-10 monitors were used to sample feedlot dust and compare with USEPA's new PM-10 standards of 150  $\mu\text{g}/\text{m}^3$  for 24 hours and 50  $\mu\text{g}/\text{m}^3$  for annual average. In general PM-10 dust concentrations were 19 and 40 percent below the TSP measurements for the same sampling sites. With one type of PM-10 sampler (Wedding and Associates), property line results were obtained that were below the new USEPA ambient 24 hour standard and with the other type (Andersen) our results were above the new 24 hour standard (Sweeten et al., 1988).

Mean particle sizes for feedlot dust were 8.5 to 12 microns ( $\mu\text{m}$ ). However, only 2 to 4 percent of the total collected dust was respirable dust, which is

**Table 12. Moisture in fresh manure produced in beef cattle feedlots versus stocking rate—equivalent annual depth on feedlot surface.**

Animal Size lbs/hd	Average Animal Spacing ft <sup>2</sup> /d				
	100	150	200	250	300
	Annual Moisture Produced				
	in.	in.	in.	in.	in.
400	13.9	9.3	6.9	5.6	4.6
600	20.8	13.9	10.4	8.3	6.9
800	27.8	18.5	13.9	11.1	9.3
1000	34.7	23.2	17.4	13.9	11.6
1200	41.7	27.8	20.8	16.7	13.9
1600	55.6	37.1	27.8	22.2	18.5

Calculated from manure characteristics data in ASAE, 1988.

considered to be 2 microns and below (Sweeten et al., 1988).

Dust control methods include watering unpaved roads, watering feedlot surfaces with mobile tankers or solid-set sprinklers, and controlling cattle stocking rate in relation to precipitation and evaporation (Sweeten, 1982). The amount of manure moisture generated by cattle varies directly with live weight and inversely with stocking rates (Table 12). Large cattle on tight spacing can easily double the effective "precipitation" on the feedlot surface, which has implications for both dust and odor control.

Mobile tankers are an excellent way to apply water both to roads and feedlot surfaces (Sweeten, 1982). Using a specially-designed nozzle, water is applied in a fan pattern to cover 60 to 80 percent of pen surfaces (not including shaded areas). About 0.1 to 0.2 inches water per day is applied as needed by operating the tanker along the feed alleys and cattle alleys (if possible).

Scraping the feedlot surface frequently with a box scraper to remove loose powdery manure before it adds to the dust problem is an excellent dust control method and reduces the amount of water that has to be applied. The data indicated that if you can keep the surface manure moisture (w.b.) above 30 percent, dust concentrations (net TSP) will be less than 150  $\mu$ g/m<sup>3</sup>, according to a linear regression relationship established from the field data (Sweeten et al., 1988).

## Feedlot Odor and Control

Odor is more likely to cause complaints further downwind of a feedlot than dust emissions and is perhaps more difficult to manage. Odor complaints are most likely to occur following significant precipitation when pens are wet, especially in warm weather. Odor from manure is made up of 45 or more different compounds (Miner, 1974). Odor

control encompasses three major approaches: manure treatment, capture and treatment of odorous gases and odor dispersion (Sweeten, 1988B). An engineering practice standard has been published for odor control (ASAE, 1983).

For open cattle feedlots, manure treatment for odor control consists of maintaining aerobic conditions to the extent possible. Primary odor control approaches are (1) to keep manure dry and (2) to maintain a minimum inventory (Sweeten and Miner, 1979). It is important for all pens to be well drained. Standing water in a feeding pen on a hot day will produce intense and offensive odor (Paine, 1972). Conversely, keeping the feedlot surface, alleys and ditches cleaned and graded to shed water rapidly, rather than absorbing moisture, speeds recovery after rainfall. Manure on the concrete apron behind the feedbunks is usually damp and needs to be collected at least monthly. Another way to improve moisture control is to orient feedpens so they have a favorable sun angle on the feedlot surface much of the day. Keeping runoff holding ponds pumped down properly is another odor control step. If a community is nearby, aeration of holding pond effluent may help reduce odor. When necessary, certain types of chemical treatments are available, including oxidizing chemicals, odor absorbent compounds and bacterial/enzyme products (Paine, 1973A; Miner and Stroh, 1976; Ritter, 1980).

A survey of Texas cattle feedlots determined that odor control measures being utilized by operators included maintaining good drainage in feed pens and rapid dewatering of holding ponds (Sweeten and McDonald, 1979). Frequent manure collection and watering system maintenance to prevent spillage are also considered effective. Relatively few feedlot managers have been using biochemical agents or odor masking chemicals, and essentially none go to the expense of aerating holding ponds for odor control.

In contrast to indoor facilities, there are few opportunities to capture and treat odorous gases from an open cattle feedlot. Possibilities include use of odor masking chemicals and dense plantings of trees that have some hope of filtering out dust particles. Odor can be dispersed through separation distance. Klarenbeck (1985) reported separation distance factors used in the Netherlands. With inversions (stable conditions) less dispersion of odor occurs than under unstable conditions, such as a hot summer day when there is vertical turbulence, i.e. air is rising.

Data on wind direction and atmospheric stability is available for large cities and airports and is a very helpful tool for feedlot site selection. Selecting a site with minimum probability of wind direction toward neighbors, especially at times of unfavorable atmospheric stability, can compensate partly for limited distance. Try to choose a site in which there is less than 5 percent probability of wind carrying odors toward the nearest neighbor or towns under stable atmospheric conditions.

**Table 13. Summary of U.S. regulations for ambient odors.**

State or Political Subdivision	Regulatory Limit ( $\geq$ Values Indicated)			
	Residential	Commercial	Industrial	Other
<b>1. Measurement Device—scentometer, dilutions to threshold (D/T)</b>				
<b>States</b>				
a. Colorado	7	7	15	127
b. Illinois	8	8	24	16
c. Kentucky	7	7	7	7
d. Missouri	7	7	7	-
e. North Dakota	2	2	2	2
f. Nevada	8	8	8	-
g. Oregon	-	-	2	-
h. Wyoming	7	7	7	-
<b>Cities or Air Quality Regions</b>				
a. District of Columbia	1	1	1	-
b. Dallas, Texas	2	1	1	-
c. Southwest Washington State AQMA	1-2	1-2	8-32	8-32
d. Polk County, Iowa	7	7	7	7
e. Cedar Rapids, Iowa	4	8	20	8
f. Omaha, Nebraska	4	8	20	8
g. Chattanooga, Hamilton County, Tennessee	0	4	4	4
<b>2. Syringe Dilution (ASTM 1391-57 as amended) (D/T)</b>				
<b>States</b>				
a. Connecticut (Mills adapt.)	120	120	120	-
b. Minnesota (Benforado adapt.)		1	1	24
c. Illinois (rendering only Mills, adapt.)	120	120	120	-
<b>Local</b>				
Chattanooga and Hamilton County, Tennessee (Mills, adapt.)	0	4	4	4
<b>3. Dynamic Olfactometer (D/T)</b>				
Bay Area AQMD	4	4	4	-
<b>4. Butanol Olfactometer (E-544), ppm 1-butanol</b>				
Louisiana	522	522	522	-

D/T = dilutions to threshold

Concentrations of various odorous gases in and downwind of feedlots can be a useful measure of odor dispersion. Propionic acid, ammonia and hydrogen sulfide have been used by researchers to approximate odor release and dispersion patterns. Research by Kowalewsky et al. (1979) in the Netherlands showed that propionic acid concentrations dropped rapidly (e.g. 90 percent reduction) within 650 feet downwind.

Modeling is sometimes used to predict odor dispersion (Janni, 1982). Models are nearly all based on equations for Gaussian (normal) distribution of concentrations across the odor plume (National Research Council, 1979). Conventional models may not be capable of accounting for complex chemical reactions in the air. Odor dispersion modeling involves the mass emission rate for odorants (Smith, 1968; Janni, 1982). Odor models are limited to short distances and to non-reactive odorants (National Research Council, 1979). Odor strength (intensity) is a logarithmic function of odor concentration (Dravnieks and O'Neill, 1979).

There are several sensory methods of measuring odor including static (syringe) dilution and forced choice triangle dynamic olfactometer (ASTM, 1975; ASTM, 1978; ASTM, 1979; Dravnieks and O'Neill, 1979; National Research Council, 1979). A portable butanol olfactometer was developed at Texas A&M University to enable panelists to measure odor in terms of equivalent parts per million of butanol (Sorel et al., 1983; Sweeten et al., 1983). The butanol olfactometer is useful and sufficiently accurate for ambient odor measurement at area sources including open cattle feedlots.

A commonly-used sensory method is the Scentometer, available since 1960, in which air is filtered

through a charcoal bed (Barnebey-Cheney, 1973). The human panelist breathes air in different dilutions and determines the least dilution at which he/she can detect the odor. The Scentometer provides readings of 2, 7, 31 and 170 dilutions to threshold (D/T). Newer models include two additional dilutions at 15 and 350 D/T. Two D/T is a very weak odor and 170 or 350 D/T a very strong odor. The Scentometer has several limitations (Sweeten et al., 1983). Several states and a few cities in the U.S. have adopted odor intensity regulations (Leonardos, 1974; Prokop, 1978) based on the Scentometer (Table 13), and limits of 2, 7 or 8 D/T at the property line are most often specified.

There are no federal standards or laws for odor in the United States (National Research Council, 1979). In Texas, odors are regulated by the Texas Air Control Board, which requires getting a construction permit (in addition to the state water pollution control permit) in order to build a new feedlot or to expand beyond 1,000 head. In reviewing the permit application, site selection, design and management are evaluated carefully and public notification and comment are received. Subsequently, an operating permit has to be obtained.

Both public and private nuisance laws also exist. Public nuisance involves interference with the normal use and enjoyment of property. Of course, any resident can sue a feedlot as a private nuisance regardless of agency actions. Most states have adopted Right-to-Farm Laws that provide some protection against unwarranted private nuisance lawsuits as long as the operation is in compliance with applicable state laws and regulations.

## Shades

Sometimes cattle feedlots are built in hot, humid climates in which shades may be helpful for a few months in the summer. However, because cattle spend a lot of time under them, shades can contribute to moist manure and odor. If built, shades should be oriented on a north and south axis so the sun can reach all parts of the feedlot surface during the day to help with drying conditions. Shades should cover an

area of about 16 to 22 square feet per head. Galvanized roofing panels fastened to tension cables are commonly used. They do not have to be solid but can have 6 to 12 inch gaps between panels to improve ventilation and solar drying of manure. Fabric sun screens are sometimes used for partial shading but are less durable.

## Managing Settled Solids in Holding Ponds

One of the better ways to remove sediment from settling basins or small holding ponds without drying is to use a commercially-available propeller agitator on a 20 to 24 foot shaft (PTO driven) that will agitate and homogenize the sediment into a slurry for irrigation through a traveling or portable big-gun sprinkler. Field demonstrations have been conducted in which sediment with 3 to 14 percent solids content was applied at a depth of 0.5 to 0.75 inch, which provided adequate fertilization of coastal bermudagrass (Lindemann et al., 1985).

To avoid or postpone having to clean out large holding ponds, feedlots should use sedimentation basins or traps that allow solids to settle in smaller, more accessible locations, which are conducive to rapid drying and frequent collection when using conventional equipment such as a wheel loader and spreader truck. Types of settling basins include shallow earthen basins or concrete pits 3 to 4 feet deep with a grooved concrete entry ramp for solids removal. Outlets consist of a buried culvert with vertical riser pipe with perforations or vertical slot openings 0.75 to 1.0 inch wide (Loudon et al., 1985) protected by an expanded metal trash rack or weirs. Another method of solids settling is an earthen channel with less than 1 percent slope placed just outside feedpens, which discharges supernatant to a holding pond by weir overflow and/or vertical slot inlet pipe. Rock weirs (gabions) are another type of baffle outlet for settling channels and basins.

Settling systems on research feedlots provided 70 to 80 percent reduction in total suspended solids using a relatively flat channel with a simple screen-wire baffle attached to a wooden frame (Swanson et al., 1977).

As discussed earlier, feedlot runoff control systems usually consist of a series of small settling basins that overflow into one or more large runoff retention ponds that need to be pumped down rapidly after each runoff event (Shuyler et al., 1973; Swanson et al., 1973). Settling basins should be cleaned out promptly to restore their capacity and remove wet manure to reduce odor and fly breeding sites.

Holding pond sediment is part manure and part soil. After the liquids are removed by pumping, and after several months of drying the sediment will form a dried crust leaving wet or semi-solid material (for example, 80 percent moisture content) in the interior that is very difficult to remove efficiently. Methods of sediment removal from sediment basins and runoff holding ponds include dragline, dozer, wheel loader, elevating scraper, floating dredge and slurry agitation/pumping (Sweeten et al., 1981; Lindemann et al., 1985; Sweeten and McDonald, 1979). Because hauling

and spreading is usually a slow process due to limited numbers of dump trucks, spreader trucks or wagons available at one time, the sediment that cannot be hauled immediately should be placed or stacked in a drying area alongside the basin or pond. After further drying, which may require several weeks, it needs to be reloaded, hauled and spread.

In a field study, runoff sediment sampled from the dragline bucket contained only 17 percent total solids content wet basis (83 percent moisture) (Sweeten et al., 1981). About 55 percent of the total solids was volatile (biodegradable) solids and 45 percent was ash. The nutrient content in runoff holding pond sediment was substantial with more than 3 percent total nitrogen and over 1 percent phosphorus. Potassium and sodium were usually low because they are leached out with the liquid fraction, so the potential salt hazard is less than with the runoff itself.

Runoff settling channels should be designed with 0.5 hour detention time for runoff from the 10 year, 1-hour storm (Loudon et al., 1985). For example, if the design storm is 2.5 inches per hour, the debris basin or settling channel should have a capacity equivalent to 0.6 to 1.2 inch depth over the contributing watershed. The flow velocity should be less than 1 ft/sec to deposit suspended solids.

As a general rule, a shallow basin with a long flow path will be more effective than a short, deep settling basin. For example, a study was performed on a 11,700 cubic feet settling basin on an open lot dairy farm in Texas with two concrete-lined parallel settling basins about 40 feet wide by 80 feet long and about 3 feet deep. Flow of both liquid manure and open lot runoff was diverted alternatively into one half of the settling basin while the other side dried up. A 15 to 60 percent reduction (45 percent average) in volatile solids concentration was measured.

The USDA Agricultural Research Service conducted research on several Nebraska feedlots (Gilbertson et al., 1979) and concluded that a runoff sediment basin adjacent to the feedlot should have a volume equivalent to 1.25 inches runoff depth (1.25 acre-inches per acre of feedlot surface). If the settling basin is remote from the holding pond, the volume should be as much as 3 acre-inches per acre (i.e. 3 inches equivalent runoff depth). The conditions under which this research was conducted were rather extreme, for example, 15 percent slope, cattle spacings 300 to 400 square feet per head, and humid climate with cold winter weather. Thus, sediment basins designed for 1.25 to 1.5 acre-inch per acre should be adequate for most feedlot conditions. In the Nebraska studies, the amount of sediment removed by debris basins located outside of feed

pens was 1.6 to 6.6 tons of dry sediment per acre-inch of runoff processed. On an average annual basis, this sediment volume is equivalent to a depth of around 0.43 to 1.61 inches across the feedlot.

Building sediment basins inside feed pens is not recommended, because water should be rapidly drained out of pens instead of trapping it.

## Feedlot Slope

For good drainage, feedpen slopes should be 2 to 6 percent (Paine et al., 1976). The main slope should be away from the feedbunk and toward the back of the pen. Building feedlots on steep slopes (greater than 8 percent) is unwarranted and may lead to erosion problems. Long slopes with pen-to-pen drainage through a series of pens are undesirable due to excess runoff and sediment transport. In prolonged wet weather, this can lead to sediment accumulation in the lower pens.

Measures should be taken in feedlot design to shorten the flow path for runoff to travel before entering a drainage collection channel. For large feedlots with bunks laid from top to bottom of the slope, the flow path can be shortened by shaping pens to drain diagonally across the pen from the feedbunk to the cattle alley or intercepting drain channel. For small feedlots, bunks can be laid across the slope with drainage toward a collection channel across the back of each pen. Successive rows of pens downslope then will have their separate feed alley, cattle alley and drainage channel. This arrangement takes more land area.

## Cattle Spacing

Cattle spacing has an influence on manure moisture content and hence on dust, odor, runoff and muddy lot conditions. Large commercial cattle feedlots in the United States utilize cattle spacings of as little as 110 square feet per head in arid climates such as Southern California (i.e. below 10 inches annual rainfall), to around 160 to 215 square feet/head in

20-inch rainfall zones, and 300 to 400 square feet/head or greater in humid climates of over 30 inches annual rainfall.

During dry seasons, a higher stocking density (i.e. lower pen spacing) is suitable due to high evaporative removal of excess moisture. In fact reducing the pen spacing in dry seasons can be a dust control strategy. But high stocking rates should be avoided in normally wet, cool seasons, due to low evaporation and prolongation of wet manure into warmer weather.

Nienaber et al. (1974) measured the effect of lot slope and animal density on beef cattle performance in Nebraska over a 4-year period. Cattle spacings of 100 and 200 square feet/head did not have a significant effect on cattle performance, nor did pen slopes of 3, 6 and 9 percent.

## Mounds

Many feedlot managers provide mounds in feed pens. If you have a well-drained feedlot, you probably do not need mounds. But in flat feed pens (i.e. 0 to 2 percent slope), well-constructed and well-drained mounds are an asset that provide cattle a dry place to stand or lay down on, rather than standing on a saturated surface.

Extension has published a Great Plains fact sheet on the correct way to build a feedlot mound (Sweeten et al., 1988). A mound that is tall and steep is more of a liability than an asset because few cattle can stand or lie down on it. Feedlot mounds should be about 3 to 4 feet high with side slopes of 5:1 (horizontal to vertical) so most of the cattle can stand or lie down at once. We recommend 25 square feet per head on each side of the mound and a crown 4 feet wide. One way to build mounds is down the center of the pen in such a way that it does not block the drainage. An alternative is to build mounds down the fence line with half the mound in adjacent pens. Besides improving drainage conditions, mounds provide a wind break from cold wind.

## Managing the Feedlot Surface

The feedlot profile usually contains a compacted interfacial layer of manure and soil that provides a biological seal that reduces water infiltration rate to less than 0.002 inches per hour (Mielke et al., 1974; Mielke and Mazurak, 1976). This zone of low infiltration restricts leaching of salts, nitrates and ammonium into the subsoil and potentially to groundwater (Schuman and McCalla, 1975).

Bulk density of the manure layer was measured at 47 to 58 lb/ft<sup>3</sup> (Mielke et al., 1974), which is less dense than water. Immediately below this manure layer, the compacted manure/soil interfacial layer had a density of 62 to 106 lbs/ft<sup>3</sup>. The density of the underlying soil was 75 to 100 lbs/ft<sup>3</sup>.

Since feedlot manure has about half the density of

the underlying soil, less energy should be needed when collecting just the organic matter and leaving the soil. The manure itself usually has a shear plane that facilitates manure collection above the interfacial layer.

## Groundwater Protection

Leaving a compacted layer of manure on the feedlot surface reduces the leaching of nutrients and salts into the underlying soil profile. In California feedlots, Algeo et al. (1972) found that soil nitrate levels at 0 to 2 feet below the feedlot surface were only slightly higher (60 to 180 ppm) than in adjacent fields. Below 4 feet of soil depth, soil nitrate levels were the same beneath the feedlot and the cropland (20 to 40 ppm  $\text{NO}_3\text{-N}$ ). Chloride concentrations showed similar trends.

Beneath a Nebraska feedlot, nitrate concentrations were 7.5 ppm in the top 4 inches of soil depth (Schuman and McCalla, 1975). Below 20 cm, however, nitrate dropped to less than 1 ppm  $\text{NO}_3\text{-N}$  due to denitrifying conditions and the presence of a manure/soil seal. Ammonia content also decreased with soil depth from 35 ppm at 0 to 2 inches to less than 2 ppm below 4 inches.

Norstadt and Duke (1982) measured soil nitrate levels that decreased from 80 ppm at the top of feedlot soil profiles to less than 10 ppm at 3 to 5 feet depth. Nearly the same result was obtained both for a clay loam soil and a layered soil that consisted of 2.5 feet sand over 2.5 feet of clay loam.

In Florida, Dantzman et al. (1983) measured salt concentrations in soil profiles (fine sand) 10 and 15 years after operation of cattle pens. After 15 years, organic matter in the soil tripled to 15 percent and the soluble salts accumulated to 4,000 ppm in the top 10 to 12 inches but were less than 500 ppm below 1.7 feet, which is a relatively low-soluble salt level. By comparison, at a nearby control location, soluble salt concentration was 150 ppm throughout the soil profile. Phosphorus levels rose from less than 4.6 ppm in check fields to over 1500 ppm after 10 and 18 years.

Elliott et al. (1972) collected soil water samples at 1.5, 2.3 and 3.5 feet beneath a level cattle feedlot surface on silt loam/sand soil profile. Nitrate concentrations were generally less than 1 ppm as compared to 0.3 to 101 ppm in the top 3 inches. The low nitrate-nitrogen values below 3 inches indicate that denitrification takes place beneath the soil surface due to anaerobic conditions.

The only time that a feedlot operator needs to collect all the manure from feeding pens is when he decides to close the feedlot. Unless the manure is removed when the feedlot is abandoned, there is potential for

eventual nitrate and salt leaching, erosion of manure that fills up settling channels and runoff holding ponds, and overflow of contaminated effluent. So when a feedlot begins to become inactive, that is the time to totally clean un-used pens down to the bare earth and probably revegetate them with a salt tolerant harvested forage such as coastal bermuda-grass to remove nutrients and protect against erosion.

## Solid Manure Collection

The proper approach for manure collection should be that of "manure harvesting" rather than "cleaning pens." Guidelines and instructions for machine operators should emphasize "manure harvesting" by methods designed to maintain a surface seal, to promote good drainage, and to collect a high quality product.

Solid manure can be collected in several ways, as studied several years ago (Sweeten and Reddell, 1979; Sweeten, 1979). Where manure is collected once a year, the most efficient method (tons per hour) is to use a chisel plow to reduce particle size, followed by a wheel loader to stack in the pens and load into a truck. We measured collection rates, normalized to 100 percent operating efficiency, of 160 tons/hour with an overall energy requirement of 1.3 horsepower (hp) hours/ton. However, the chisel plow/wheel loader method runs a strong risk of disturbing the compacted manure/soil interfacial seal that should be left to protect against leaching.

Most of our Texas feedlots utilize just the wheel loader for collection, but most of them now recognize the importance of leaving a compacted manure layer to seal the feedlot surface. A skilled wheel loader operator can efficiently harvest just the manure and leave the compacted manure/soil layer. It is not easy to accomplish with a wheel loader because the operator has to shift gears four times per bucket load while traveling in a forward/reverse/forward/reverse motion and simultaneously guide vertical movement of the bucket. The emphasis has to be on operator skill. The wheel loaders provide collection rates of 106 tons/hour and energy requirements of 1.33 to 1.72 horsepower hours/ton.

The elevating scraper is a superior piece of equipment that performs a high collection rate (114 tons/hour) with the highest energy efficiency (1.18 hp-hrs/ton). Moreover, the elevating scraper is a precise cutting machine that can slice through the manure, leaving the undisturbed manure/soil layer on the surface. The operator travels continuously forward in an oval-shaped pattern instead of rapid forward and reverse cycles necessary with a wheel loader. The result is usually a relatively smooth feedlot surface after collection.

Box-scrapers (tractor drawn) are frequently used for collection of loose surface manure for dust and odor control, for maintaining a smooth surface for drainage, and for mound building. Road graders are sometimes used for collecting damp manure from feedbunk aprons and for precise collection of surface manure. Road graders form windrows for later collection by wheel loaders or elevating scrapers.

In connection with characterizing feedlot manure as a fuel feedstock for combustion or gasification for electricity generation, data has been published on feedlot manure characteristics resulting from manure collection (Sweeten et al., 1985). For example, an elevating scraper collected 2.5 inches of manure and left about 1.5 inches of undisturbed manure on the surface. Ash content in the collected manure was only half that of the uncollected manure that was left on the surface (32 percent vs. 61 percent ash, respectively). Nitrogen content and heat of combustion were also higher in the harvested manure.

Size of pens may limit the ability to use an elevating scraper or road grader, which require a pen of at least 100 to 150 feet on each side. However, this equipment along with box scrapers leave the smoothest pen surface and facilitate frequent manure collection.

Another important aspect of manure handling is to frequently collect manure that accumulates beneath fence lines because, if left unattended, it can pond water on the feedlot surface. Secondly, fence line manure is a potential breeding site for flies and frequent collection is needed for control. House fly larvae are no match for 1,200 pound steers in the feedpen, but ridges of manure beneath fence lines offer protection for flies, as does spilled feed around feed bunks and manure in hospital pens, horse pens and working facilities.

The effect of mud on cattle performance was evaluated at South Dakota State University (Bruce, 1985). With a 4 to 8 inch depth of mud or wet manure, average daily gain of cattle was reduced by 14 percent (Sweeten et al., 1988). And, with an average of 24 inches of mud, average daily gain was decreased by 25 percent. Feed intake and feed efficiency were similarly reduced. Therefore, it is important to control muddy lot conditions for economic reasons as well as for odor control.

Excessive rainfall (or snowfall) results in wet manure, particularly in the winter time with low evaporation or with improper pen drainage conditions. It is especially important to collect manure from all pens prior to expected periods of cold and/or wet weather leaving a firm manure pack. Much of this manure falls within about 50 feet of the feedbunk.

A critical location to manage is the feedbunk apron where a ridge of manure forms just behind the cattle, traps moisture and usually remains moister than the pen surface in general. The feed bunk apron should receive frequent collection, using a wheel loader, elevating scraper or road grader. The concrete apron needs to be at least 8 to 12 feet wide, or one width of the tire tracks to facilitate collection. A 20-foot apron width would be even better.

If the feedpens do become muddy, the best strategy is often to collect manure down to a firm base and allow the surface to dry out more quickly. It will usually be necessary to move cattle to an empty pen to speed up collection. It is inefficient and expensive to collect and haul wet manure. The material usually can only be stacked away from the feedpens and allowed to partially dry for several months. Reloading and spreading this manure can be an odorous process. To accelerate drying and stabilization of wet manure by partial composting, it should be stacked in windrows about 12 feet apart to allow turning when wind conditions are right.

### **Solid Manure Collection Practice In Texas Feedlots**

Solid manure from open dirt unpaved feedlots in Texas are collected mainly by private contractors. Each contractor usually serves several feedlots and may also be involved in silage hauling or other activities. Manure is collected and loaded into a fleet of trucks that haul and spread manure at typical application rates of 5 to 25 tons per acre wet basis.

In 1985, 13 contractors who collected manure from 61 Texas cattle feedlots having 1.5 million head of cattle on feed were surveyed (Sweeten, 1985) to obtain information concerning their payments to feedlots, charges to farmers and manure application rates on crops. At that time contractors were paying feedlots as much as \$1.00 per ton (or in some cases were being paid as much as \$0.50 per ton) for manure collected, loaded and weighed at the feedlot scales. The contractor then sells the manure to farmers on a haul and spread basis. As of 1985, the farmers were paying contractors an average of \$2.70 per ton plus \$0.125 per ton-mile.

The survey was repeated in 1989 and manure costs were even lower: \$2.15 per ton plus \$0.12 per ton-mile. So for a 10 mile one-way haul distance, the cost to the farmer averages only \$3.35 per ton of applied manure. Thus, for a 10 ton per acre application rate, the cost is \$33.50 per acre for manure fertilizer. Most manure is being hauled 5 to 15 miles, although in a few places where vegetable crops are grown on sandy land, for example, manure is occasionally hauled 30 miles.

For haul distances over about 10 miles, it often becomes more practical to haul manure using a larger truck (i.e. 18 wheel, 40 cubic yard), which is unloaded at the farmer's field and later spread. It is encouraging that more and more manure is being hauled in this manner and that feedlots are less dependent on crop cycles to have pens cleaned and manure hauled. Temporary stockpiles need to be carefully located to avoid surface and groundwater pollution problems, however.

Our 1985 contractor's survey showed that crops are being fertilized with manure at an average rate of 11 tons per acre per year wet or as received basis on irrigated land. The range is 8 to 15 tons/acre per year on grain and vegetable crops and 5 to 10 tons/acre per year on cotton. Application rates for dryland crops are about half those for irrigated crops.

## Stockpiling and Storage of Manure

Solid manure is frequently placed in stockpiles outside of feedpens while awaiting reloading, hauling and spreading. The purpose of a stockpile should be to allow pens to be cleaned regularly even though spreader trucks or cropland is not available. The volume of stockpiles should be kept to a minimum since manure is a perishable commodity and should be used promptly. Manure stacked in feedpens should be promptly hauled to a stockpile unless properly shaped and used for a mound.

Manure stockpiles are subject to smoldering or spontaneous combustion (which produces air pollution emissions). If manure is stockpiled deeper than about 6 feet, it should be compacted to partially exclude oxygen. Generally, the hottest zone in a stockpile is roughly 1 to 3 feet below the crown. Relatively wet manure is another cause of fire in manure stockpiles. Fires in manure stockpiles are difficult to extinguish. Consequently, small, discrete stockpiles are preferable to large stockpiles, especially for wet manure.

State water pollution abatement regulations require stockpiles to be isolated by dikes or diversion terraces to prevent entry of rainfall runoff. Likewise, stockpile runoff has to be collected in holding ponds.

## Composting

Many feedlots and contractors practice composting (aerobic thermophilic treatment) by placing the manure in windrows 3 to 6 feet high and turning it one or more times. To speed up composting, manure should be turned frequently, an average of once per week for 6 to 8 weeks. Different methods of turning windrows include wheel loaders and mobile units with rotary-spiked drums or augers (Sweeten, 1988A).

The purpose of turning windrows is to aerate, increase temperature, release excess heat and promote evaporation of excess moisture.

The second approach to composting consists of aerated bins in which air may be blown or suctioned through a relatively shallow bed of composting material, for example, 3 feet deep in a concrete bin. Turning is done either by a spiked drum or flighted conveyor mounted on rails. Stable, good quality compost can be produced in four weeks with daily turning.

Important variables for composting include moisture content (40 to 60 percent), particle size or structure, and aeration (Sweeten, 1988A). The carbon-nitrogen ratio should be about 30:1 for ideal composting, as compared to only 10 to 15:1 for fresh manure. Addition of crop residues or finished compost can raise this ratio in fresh manure. Temperatures should range from 113 to 175°F, with an ideal temperature of 140 to 160°F. These temperatures are sufficient to reduce pathogenic organisms by a hundred or thousand-fold and kill more than 95 percent of the weed seeds (Wiese, 1977).

## Energy Conversion

There are two major technologies for converting manure into energy in the form of fuel gas, heat or electricity. One of these is anaerobic digestion for methane production in which manure in slurry form (6 to 10 percent solids content) is placed in a heated sealed container with periodic mixing at temperatures of around 95°F for 15 to 30 days, or at 130°F for 5 to 10 days. The product biogas contains 50 to 65 percent methane and 35 to 50 percent carbon dioxide (Sweeten and Reddell, 1985). Methane production from cattle manure has been the subject of much research worldwide in the past two decades.

The second technology is combustion or gasification in a fluidized bed combustion chamber with a temperature of 1100 to 1500°F (Sweeten et al., 1986; Annamalai et al., 1987). Residence time in the combustion unit is only a few seconds. Air is provided in limited amounts at strategic locations to maintain fluidization (circulation) and prevent hot-spots that can cause slagging. Feedlot manure with 25 percent moisture and 33 percent ash might yield electricity at the rate of 300 to 475 kwh per ton of manure.

Both technologies (anaerobic digestion and combustion/gasification) have been investigated and commercially developed in a few instances in recent years. However, economic incentives have generally not been great enough to adopt such alternate energy technologies at cattle feedlots instead of using fossil fuels.

## Cattle Confinement Buildings

Confinement buildings with concrete floors (slatted or solid) are sometimes used especially in high rainfall or cold areas. Cattle on concrete floors are allowed a spacing of about 20 to 35 square feet per head.

The manure is usually collected beneath slotted floors using a cable scraper system in the form of a slurry (about 8 to 10 percent solids concentration), which must be pumped and irrigated or transported in a tank wagon (Miner and Smith, 1975; Beauchamp, 1979; Evans, 1979). With dilution water to reduce the solids content to less than 2 to 3 percent, the manure can be discharged into earthen lagoons for anaerobic decomposition and storage and/or irrigated directly

as a slurry. Another method of manure collection beneath slotted floors is a flush system using either high-rate pumping or various types of sudden-release devices. Lagoon effluent usually has a solids content of 1 to 1.5 percent and is usually recycled for flushing. Another type of a cattle confinement facility consists of an open concrete floor with circular flumes beneath narrow parallel grooves in the floor. Water (usually recycled lagoon effluent) is pumped through the flumes and as fresh manure gets pressed by cattle hooves into the flumes, it is carried away into a lagoon. The lagoon liquid has to be irrigated onto the land several times yearly and periodically needs to be agitated for sludge removal.

## Summary

In summary, there are five main reasons for feedlot managers to focus attention on manure and waste-water management: (a) to control air pollution, (b) to control water pollution, (c) to maintain or increase cattle productivity by providing well-maintained feedlot conditions, (d) to recover nutrients in the form of fertilizer, feedstuffs or energy, and (e) to maintain or

increase efficiency of the feedlot by avoiding operational obstacles such as sloppy pen surfaces, full runoff holding ponds and settling basins, odors, dust and excessive stockpiled manure. All these are good reasons why cattle feeders should be willing to focus greater attention on feedlot waste-management and water and air pollution abatement.

## References

- Algeo, J. W., C. J. Elam, A. Martinez and T. Westing. 1972. Feedlot air, water and soil analysis: Bulletin D, How to Control Feedlot Pollution. California Cattle Feeders Association. Bakersfield, California. 75 p.
- American Society for Testing and Materials. 1979. Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits. E-679-79, American Society for Testing and Materials, Philadelphia, Pennsylvania.
- American Society for Testing and Materials. 1975. Standard Recommended Practices for Referencing Suprathreshold Odor Intensity. E544-75, 1975 **Annual Book of Standards**, American Society of Testing and Materials, Philadelphia, Pennsylvania.
- American Society for Testing and Materials. 1978. Standard Test Method for Measurement of Odors in Atmospheres (Dilution Method). D-1391-78, American Society for Testing and Materials, Philadelphia, Pennsylvania.
- Annamalai, K., M. Y. Ibrahim and J. M. Sweeten. 1987. Experimental studies on combustion of cattle manure in a fluidized bed combustor. **Journal of Energy Resources Technology**, (Transactions of the American Society of Mechanical Engineers), 109(2):49-57.
- Arrington, R. M. and C. E. Pachek. 1981. Soil nutrient content of manures in an arid climate. In: **Livestock Waste: A Renewable Resource**, Proceedings of the Fourth International Symposium on Livestock Waste, 1980, pp. 150-152. American Society of Agricultural Engineers, St. Joseph, Michigan.
- American Society of Agricultural Engineers. 1983. Control of Manure Odors. ASAE EP-379, **Agricultural Engineers Yearbook of Standards**, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 431-432.
- American Society of Agricultural Engineers. 1988. Manure production and characteristics. ASAE D-384-1, American Society of Agricultural Engineers, St. Joseph, Michigan.
- Barnebey-Cheney. 1973. Scentometer: An Instrument for Field Odor Measurement. Barnebey-Cheney Company, Columbus, Ohio. 3 p.
- Barrington, S. F. and P. J. Jutras. 1983. Soil Sealing by Manure in Various Soil Types. Paper 83-4571, American Society of Agricultural Engineers, St. Joseph, Michigan. 28 p.
- Beauchamp, E. G. 1979. Liquid cattle manure—corn yield and ammonia losses. Presented at 1979 Summer Meeting, American Society of Agricultural Engineers and Canadian Society of Agricultural Engineers, Winnipeg, Manitoba, Canada.
- Bruce, B. 1985. Personal Communication. South Dakota State University. Brookings, South Dakota.
- Butchbaker, A. F. 1973. Feedlot Runoff Disposal on Grass or Crops. L-1053, Texas Agricultural Extension Service, Texas A&M University. (GPE-7521, Great Plains Beef Cattle Feeding Handbook.) 4 p.
- Clark, R. N. 1975. Seepage Beneath Feedyard Runoff Catchments. In: **Managing Livestock Wastes**, Proceedings of the Third International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 289-296.
- Clark, R. N., C. B. Gilbertson and H. R. Duke. 1975A. Quantity and Quality of Beef Feedyard Runoff in the Great Plains. In: **Managing Livestock Wastes**, Proceedings of the Third International Symposium on Livestock Wastes, Proc-275, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 429-431.
- Clark, R. N., A. D. Schneider and B. A. Stewart. 1975B. Analysis of Runoff from Southern Great Plains Feedlots. **Transactions of the ASAE**, 15(2):319-322.
- Castellanos, J. Z. and J. A. Munoz. 1985. Soil Physical Properties and Alfalfa Yields as Affected by Manure Application to a Low Infiltration Clay Soil. In: **Agricultural Waste Utilization and Management**, Proceedings of Fifth International Symposium on Agricultural Wastes, ASAE, St. Joseph, Michigan. pp. 222-228.
- Coleman, E. A., W. Grub, R. C. Albin, G. F. Meenaghan and D. M. Wells. 1971. Cattle Feedlot Pollution Study - Interim Report No. 2, WRC-71-2. Water Resources Center, Texas Tech University, Lubbock, Texas.
- Dantzman, C. L., M. F. Richter and F. G. Martin. 1983. Chemical Elements in Soils Under Cattle Pens. **Journal of Environmental Quality**, 12(2):164-168.
- Dickey, E. C., D. H. Vanderholm, J. A. Jackobs and S. L. Spahr. 1977. Vegetative Filter Treatment of Feedlot Runoff. ASAE Paper No. 77-4581, American Society of Agricultural Engineers, St. Joseph, Michigan.
- Dixon, J. E. 1983A. Comparison of runoff quality from cattle feeding on winter pastures. **Transactions of the ASAE**, 26(4):1146-9.
- Dixon, J. E. 1983B. Controlling water pollution from cattle grazing and pasture feeding operations. In: (J.H. Smits, ed.) **Profit Potential of Environmental Protection Practices of Cattlemen**. National Cattlemen's Association, Englewood, Colorado. pp. 107.
- Doran, J. W., J. S. Schepers and N. P. Swanson. 1981. Chemical and Bacteriological Quality of Pasture Runoff. **J. Soil and Water Conservation**, 36(3):166-71.
- Dravnieks, A. and H. J. O'Neill. 1979. Annoyance Potentials of Air Pollution Odors. **American Industrial Hygiene Association Journal**, 40:85-95.
- Duda, A. M. and D. S. Finan. 1983. Influence of livestock on nonpoint source nutrient levels in streams. **Transactions of the ASAE**, 26(6):1710-1716.
- Elam, C. J., J. W. Algeo, T. Westing, et al. 1971. Measurement and Control of Feedlot Particulate Matter: Bulletin C, How to Control Feedlot Pollution, California Cattle Feeders Association, Bakersville, California. January.
- Elliott, L. F., T. M. McCalla, L. N. Mielke and T. A. Travis. 1972. Ammonium, Nitrate and Total Nitrogen in the Soil Water of Feedlot and Field Soil Profiles. **Applied Microbiology**, 23(April):810-813.
- Evans, S. D. 1979. Manure application studies in west central Minnesota. ASAE Paper No. 79-2119. American Society of Agricultural Engineers, St. Joseph, Michigan.
- FAO. 1985. Water Quality for Agriculture. Irrigation and Drainage Paper 29, Revision 1, Food and Agriculture Organization of the United Nations, Rome. pp. 34-35.
- Gilbertson, C. B. 1983. Controlling water pollution from land application of cattle manure. In: (J. H. Smits, ed.) **Profit Potential of Environmental Protection Practices of Cattlemen**. National Cattlemen's Association, Englewood, Colorado. pp. 9-13.
- Gilbertson, C. B., R. N. Clark, J. C. Nye and N. P. Swanson. 1980. Runoff Control for Livestock Feedlots: State of the Art. **Transactions of the ASAE**, 23(5):1207-1212.

- Gilbertson, C. B., J. A. Nienaber, J. L. Gartrung, J. R. Ellis and W. E. Splinter. 1979A. Runoff Control Comparisons for Commercial Beef Feed lots. **Transactions of the ASAE**, 22(4):842-849.
- Gilbertson, C. B., F. A. Nordstadt, A. C. Mathers, R. F. Holt, A. P. Garnett, T. M. McCalla, C. A. Onstad and R. A. Young. 1979B. Animal waste utilization on cropland and pastureland: A manual for evaluating agronomic and environmental effects. USDA Report No. URR-6, U.S. Department of Agriculture, Science and Education Administration, Hyattsville, Maryland. pp. 32-34.
- Gilbertson, C. B., J. C. Nye, R. N. Clark and N. P. Swanson. 1981. Controlling Runoff from Feedlots—A State of the Art. Agricultural Information Bulletin 441, U.S. Department of Agriculture, Agricultural Research Service, Washington, DC 20250. 19 p.
- Janni, K. A. 1982. Modeling Dispersion of Odorous Gases from Agricultural Sources. **Transactions of the ASAE**, 25:1721-1723.
- Klarerbeek, J. V. 1985. Odour Emissions of Dutch Agriculture. In: **Agricultural Waste Utilization and Management**, Proceedings of the Fifth International Symposium on Agricultural Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 439-445.
- Kowalewsky, H. H., R. Scheu and H. Vetter. 1979. Measurement of Odor Emissions and Immissions. In: **Effluents from Livestock** (J.K.R. Gasser, Editor). Applied Science Publishers, London, U.K. pp. 609-625.
- Lehman, O. R. and R. N. Clark. 1975. Effect of Cattle Feedyard Runoff on Soil Infiltration Rates. **Journal of Environmental Quality**, 4(4):437-439.
- Lehman, O. R., B. A. Stewart and A. C. Mathers. 1970. Seepage of Feedyard Runoff Water Impounded in Playas. MP-944, Texas Agricultural Experiment Station, Texas A&M University, College Station, Texas. 7 p.
- Leonardos, G. 1974. A critical review of regulations for the control of odors. **Journal of the Air Pollution Control Association**, 24:456-468.
- Lindemann, E. R., J. M. Sweeten and J. P. Burt. 1985. Sludge Removal from Dairy Lagoons. In: **Agricultural Waste Utilization and Management**, Proceedings of the Fifth International Symposium on Agricultural Wastes, Chicago, Illinois, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 653-659.
- Loehr, R. C. 1974. Characteristics and comparative magnitude of nonpoint sources. **Journal of Water Pollution Control Federation**, 46(8):1849.
- Loudon, T. L., D. D. Jones, J. B. Petersen, et al. 1985. Livestock Waste Facilities Handbook. MWPS-18 (2nd ed.), Midwest Plan Service, Iowa State University, Ames, Iowa. pp. 2.1-2.2; 5.1-5.9.
- Lund, Z. F. and B. D. Doss. 1980. Coastal Bermudagrass yield and soil properties as affected by surface-applied dairy manure and its residue. **Journal of Environmental Quality**, 9:157.
- Lund, Z. F., B. D. Doss and F. E. Lowry. 1975. Dairy cattle manure—its effect on yield and quality of coastal Bermudagrass. **Journal of Environmental Quality**, 4(3):358.
- Mathers, A. C. and B. A. Stewart. 1971. Crop Production and Soil Analysis as Affected by Application of Cattle Feedlot Waste. **Livestock Waste Management**, Proceedings of the Second International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 229-231, 234.
- Mathers, A. C. and B. A. Stewart. 1981. The effect of feedlot manure on soil physical and chemical properties. In: **Livestock Waste: A Renewable Resource**, Proceedings of the Fourth International Symposium on Livestock Waste, 1980, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 159-162.
- Mathers, A. C. and B. A. Stewart. 1984. Manure Effects on Crop Yields and Soil Properties. **Transactions of the ASAE**, 27(4):1022-1026.
- Mathers, A. C., B. A. Stewart and J. D. Thomas. 1975. Residual and annual rate effects of manure on grain sorghum yields. In: **Managing Livestock Wastes**, Proceedings of the Third International Symposium on Livestock Wastes, 1975. American Society of Agricultural Engineers, St. Joseph, Michigan.
- Mathers, A. C., J. D. Thomas, B. A. Stewart and J. E. Herring. 1980. Manure and inorganic fertilizer effects on sorghum and sunflower growth on iron-deficient soil. **Agronomy Journal**, 72(Nov-Dec):1025-1029.
- Mielke, L. N. and A. P. Mazurak. 1976. Infiltration of Water on a Cattle Feedlot. **Transactions of the ASAE**, 19(2):341-344.
- Mielke, L. N., N. P. Swanson and T. M. McCalla. 1974. Soil Profile Conditions of Cattle Feedlots. **Journal of Environmental Quality**, 13(1):14-17.
- Miller, W. D. 1971. Infiltration Rates and Groundwater Quality Beneath Cattle Feedlots, Texas High Plains. Final Report No. 16060 EGS, Water Quality Office, U.S. Environmental Protection Agency, Washington, D.C. 55 p.
- Milne, C. M. 1976. Effect of a livestock wintering operation on a western mountain stream. **Transactions of the ASAE**, 19(4):749-752.
- Miner, J. R. 1974. Odors from confined livestock production. EPA-660/2-74-023. U.S. Environmental Protection Agency, Washington, D.C. 130 pp.
- Miner, J. R. and R. J. Smith. 1975. Livestock waste management with pollution control. Midwest Plan Service Handbook MWPS-19, North Central Res. Publication No. 222., Iowa State University, Ames, Iowa.
- Miner, J. R. and R. C. Stroh. 1976. Controlling Feedlot Surface Odor Emission Rates by Application of Commercial Products. **Transactions of the ASAE**, 19:533-538.
- National Research Council. 1979. Odors from Stationary and Mobile Sources. National Academy of Sciences, Washington, D.C.
- Nienaber, J. A., C. B. Gilbertson, T. J. Klopfenstein, S. D. Farlin and T. M. McCalla. 1974. Animal Performance and Lot Surface Conditions as Affected by Feedlot Slope and Animal Densities. Proceedings from International Livestock Environment Symposium, Lincoln, Nebraska. pp. 130-137.
- Norstadt, F. A. and H. R. Duke. 1982. Stratified Profiles: Characteristics of Simulated Soils in a Beef Cattle Feedlot. **Soil Science Society of America Journal**, 46(4):827-832.
- Paine, M. D. 1972. Feedlot Odor, L-1101, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 2 p.
- Paine, M. D. 1973A. Chemical control of manure odor. Great Plains Beef Cattle Feeding Handbook, L-1188, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 2 p.
- Paine, M. D. 1973B. Confined animals and public environment. GPE-7000, Great Plains Beef Cattle Feeding Handbook, Cooperative Extension Service, Oklahoma State University, Stillwater, Oklahoma. 4 p.

- Paine, M. D., N. Teter and Paul Guyer. 1976. Feedlot Layout. GPE-5201, Great Plains Beef Cattle Handbook, Cooperative Extension Service, Oklahoma State University, Stillwater, Oklahoma. 6 p.
- Peters, J. A. and T. R. Blackwood. 1977. Source Assessment: Beef Cattle Feedlots. Monsanto Research Corporation, EPA 600/2-77-107, U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. 101 p.
- Phillips, P. A. and J. L. B. Culley. 1985. Groundwater Nutrient Concentrations Below Small-Scale Earthen Manure Storage. In: **Agricultural Waste Utilization and Management**, Proceedings of the Fifth International Symposium on Agricultural Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 672-679.
- Phillips, R. L. 1981. Maps of Runoff Volumes from Feedlots in the United States. In: **Livestock Waste: A Renewable Resource**, Proceedings of the Fourth International Symposium on Livestock Waste, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 274-277.
- Powell, J., F. R. Crow and D. G. Wagner. 1983. Rangeland watershed water budget and grazing cattle waste nutrient recycling: Project Summary. EPA-600/S2-83-017. U.S. Environmental Protection Agency, Ada, Oklahoma.
- Powers, W. L., R. L. Herpich, L. S. Murphy, D.A. Whitney, H.L. Manges and G.W. Wallingford. 1973. Guidelines for Land Disposal of Feedlot Lagoon Water. C-485, Cooperative Extension Service, Kansas State University, Manhattan, Kansas.
- Prokop, W. H. 1978. Developing Odor Control Regulations: Guidelines and Considerations. **Journal of Air Pollution Control Association**, 28:9-16.
- Reddell, D. L. 1974. Forage and Grain Production from Land Used for Beef Manure Disposal. In: **Proceedings and Management of Agricultural Wastes**, Cornell University, Ithaca, New York. pp. 464-483.
- Reddell, D. L. and G. G. Wise. 1974. Water quality of storm runoff from a Texas beef feedlot. Texas Agricultural Experiment Station, PR-3224, College Station, Texas.
- Ritter, W. F. 1980. Chemical Odor Control of Livestock Wastes, Paper No. 80-4059, American Society of Agricultural Engineers, St. Joseph, Michigan. 16 p.
- Robbins, J. S. 1978. Environmental impact resulting from unconfined animal production. EPA-600/2-78-046. U.S. Environmental Protection Agency, Ada, Oklahoma.
- Robinson, F. E. 1973. Changes in Seepage Rates from an Unlined Cattle Waste Digestion Pond. **Transactions of the ASAE**, 16(1):95-96.
- Saxton, K. E., L. F. Elliott, R. I. Papendick, M. D. Jawson and D. H. Fortier. 1983. Effect of animal grazing on water quality of nonpoint runoff in the Pacific Northwest: Project Summary. EPA-600/S2-82-071. U.S. Environmental Protection Agency, Ada, Oklahoma.
- Schuman, G. E. and T. M. McCalla. 1975. Chemical Characteristics of a Feedlot Soil Profile. **Soil Science**, 119(2):113-118.
- Shuyler, L. R., D. M. Farmer, R. D. Kreis and M. E. Hula. 1973. Environment Protecting Concepts of Beef Cattle Feedlot Wastes Management. National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Corvallis, Oregon. July.
- Smeins, F. E. 1977. Influence of vegetation management on yield and quality of surface runoff. Final Report No. TR-84, Texas Water Resources Institute, Texas Agricultural Experiment Station, Texas A&M University, College Station, Texas.
- Smith, M. 1968. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. American Society of Mechanical Engineers, New York, New York.
- Sorel, J. E., R. O. Gauntt, J. M. Sweeten, D. L. Reddell and A. R. McFarland. 1983. Design of a 1-Butanol Scale Dynamic Olfactometer for Ambient Odor Measurements. **Transactions of the ASAE**, 26:1201-1206.
- Stewart, B. A. and B. D. Meek. 1977. Soluble salt considerations with waste application. Chapter 9. In: **Soils for Management of Organic Wastes and Wastewaters** (L. F. Elliott and F. J. Stevenson, editors). Soil Science Society of America, Madison, Wisconsin. pp. 219-232.
- Swanson, N. P., C. L. Linderman and L. N. Mielke. 1974. Direct Land Disposal of Feedlot Runoff. In: **Managing Livestock Wastes**, Proceedings of the Third International Symposium on Animal Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 255-257.
- Swanson, N. P., J. C. Lorimor and L. N. Mielke. 1973. Broad Basin Terraces for Sloping Cattle Feedlots. **Transactions of the ASAE**, 16(4):746-749.
- Swanson, N. P., L. N. Mielke and J. R. Ellis. 1977. Control of Beef Feedlot Runoff With a Waterway. ASAE Paper No. 77-4580, American Society of Agricultural Engineers, St. Joseph, Michigan.
- Sweeten, J. M. 1988A. Composting manure and sludge. L-2289, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 4 p.
- Sweeten, J. M. 1985. Cost of manure for fertilizer. Paper presented at Extension Seminars on Feedlot Manure Utilization for Fertilizer, Etter and Stratford, Texas, June 17-18. 5 p.
- Sweeten, J. M. 1976. Dilution of Feedlot Runoff. MP-1297, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 8 p.
- Sweeten, J. M. 1982. Feedlot Dust Control. L-1340, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 7 p.
- Sweeten, J. M. 1989A. Groundwater quality protection for livestock feeding operations. L-2348, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 8 p.
- Sweeten, J. M. 1979. Manure Management for Cattle Feedlots. L-1094, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. 6 p.
- Sweeten, J. M. 1988B. Odor measurement and control for the swine industry. **Journal of Environmental Health**, 50(5):282-286.
- Sweeten, J. M. 1985. Removal and Utilization of Feedlot Runoff and Sediment. In: Proceedings, Great Plains Cattle Feeders Conference and Oklahoma Cattle Feeders Seminar, Guymon, Oklahoma, May 8-9. pp. G1-G16.
- Sweeten, J. M. 1989B. Unpublished data. Texas Agricultural Extension Service, Texas A&M University, College Station, Texas. May 11.
- Sweeten, J. M. 1984. Utilization of Cattle Manure for Fertilizer. **Beef Cattle Science Handbook**, Volume 20 (F. H. Baker and M. E. Miller, editors), Westview Press, Boulder, Colorado. pp. 59-74.
- Sweeten, J. M., R. P. Egg, D. L. Reddell, F. Varani and S. Wilcox. 1985. Characteristics of Cattle Feedlot Manure in Relation to Harvesting Practices. In: **Agricultural Waste Utilization and Management**, Proceedings of the Fifth International Symposium on Agricultural Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 329-337.

- Sweeten, J. M., J. Korenberg, W. A. LePori, K. Annamalai and C. B. Parnell. 1986. Combustion of cattle feedlot manure for energy production. **Energy in Agriculture** (Elsevier Science Publishers, Amsterdam), 5(1986):55-72.
- Sweeten, J. M., L. Lubinus, R. Durland and B. Bruce. 1988. Feedlot Mounds. GPE-7525, Great Plains Beef Cattle Handbook, Cooperative Extension Service, Oklahoma State University, Stillwater, Oklahoma.
- Sweeten, J. M. and A. C. Mathers. 1985. Improving Soils with Livestock Manure. **Journal of Soil and Water Conservation**, 40(2):206-210.
- Sweeten, J. M. and R. P. McDonald. 1979. Results of TCFA Environmental and Energy Survey—1979. Texas Cattle Feeders Association, Amarillo, Texas.
- Sweeten, J. M., and S. W. Melvin. 1985. Controlling water pollution from nonpoint source livestock operations. In: Perspectives on Nonpoint Pollution, EPA 440/5-85-001, U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C. pp. 215-217.
- Sweeten, J. M. and J. R. Miner. 1979. What feedlots can do to help avoid nuisance lawsuits. **Beef Business Bulletin**, National Cattlemen's Association, Englewood, Colorado. July 27. 4 p.
- Sweeten, J. M., C. B. Parnell, R. S. Etheredge and D. Osborne. 1988. Dust Emissions in Cattle Feedlots. In: (J. L. Howard, ed.) **Stress and Disease in Cattle, Veterinary Clinics in North America: Food Animal Practice**, Vol. 4, No. 3 (Nov):557-578.
- Sweeten, J. M. and D. L. Reddell. 1985. Anaerobic Digestion for Methane Production. Chapter 3. In: **Biomass Energy: A Monograph** (E. A. Hiler and B. A. Stout, editors.), Texas A&M University Press, College Station, Texas. pp. 77-112.
- Sweeten, J. M. and D. L. Reddell. 1979. Time-Motion Analysis of Feedlot Manure Collection Systems. **Transactions of the ASAE**, 22(1):138-143.
- Sweeten, J. M., D. L. Reddell, A. R. McFarland, R. O. Gauntt and J. E. Sorel. 1983. Field Measurement of Ambient Odors with a Butanol Olfactometer. **Transactions of the ASAE**, 26:1206-1216.
- Sweeten, J. M., L. M. Safley and S. W. Melvin. 1981. Sludge Removal from Lagoons and Holding Ponds: Case Studies. In: **Livestock Waste: A Renewable Resource**, Proceedings of the Fourth International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 204-210.
- Texas Water Commission. 1987. Control of Certain Activities by Rule. Chapter 321, Subchapter B, Part IX, (31 TAC 321.31-321.41). Austin, Texas. **Texas Register**, March 17, 1987, pp. 904-909.
- Thomas, J. D. and A. C. Mathers. 1979. Manure and iron effects on sorghum growth on iron deficient soil. **Agronomy Journal**. 71:792.
- U.S. Environmental Protection Agency. 1973. Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Feedlots Point Source Category. EPA-440/1-73/004, USEPA, Washington, D.C. pp. 59-64.
- U.S. Environmental Protection Agency. 1984. Report to Congress: Nonpoint Source Pollution in the U.S. Environmental Protection Agency, Office of Water Program Operations, Washington, D.C.
- U.S. Environmental Protection Agency. 1986. Supplement A to Compilation of Air Pollution Emission Factors, Section 6.15 Beef Cattle Feedlots, Volume 1: Stationary Point and Area Sources. AP-42, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. 3 p.
- U.S. Environmental Protection Agency. 1987. 40CFR50, Revisions to the National Ambient Air Quality Standards for Particulate Matter and Appendix J—Reference Method for the Determination of Particulate Matter as PM-10 in the Atmosphere. **Federal Register**, 52(126):24634, and 24664-24669.
- Wallingford, G. W., L. S. Murphy, W. L. Powers and H. L. Manges. 1974. Effect of Beef Feedlot Lagoon Water on Soil Chemical Properties—Growth and Composition of Corn Forage. **Journal of Environmental Quality**, 3(1):74-78.
- Wells, D. M., E. A. Coleman, W. Grub, R. C. Albin and G. F. Meenaghan. 1969. Cattle Feedlot Pollution Study - Interim Report No. 1, WRC-69-7, Water Resources Center, Texas Tech University, Lubbock, Texas.
- White, R. K., R. W. VanKeuren, L. B. Owens, W. M. Edwards and R. H. Miller. 1983. Effects of livestock pasturing on nonpoint surface runoff: Project Summary. EPA-600/S22-83-011. U.S. Environmental Protection Agency, Ada, Oklahoma.
- Wiese, A. F., D. E. Lavake, E. W. Chenault and D. A. Crutchfield. 1977. Effect of Composting and Temperatures on Weed Seed Germination. Abstract, **Proceedings of Southern Weed Science Society**, 30:167.