Beef Feedlot Design and Management in Michigan
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TECHNICAL Information

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PREFACE

This report contains research results from one of five subprojects of a research program entitled "Ecosystem Design and Management" financed by the RANN division of the National Science Foundation (NSF GI-20, 7/1/72 - 6/30/74). This subproject was conducted concurrently with a project entitled "Economics of Livestock Waste Management in U.S. Fed-Beef and Dairy Production Regions," which was cooperatively sponsored by the Economic Research Service of the U.S. Department of Agriculture and the Michigan State University Agricultural Experiment Station. Although the results of the two projects are highly complementary, the ERS-station sponsored project emphasized firm- and industry-level problems and economic impacts of adjusting to legislated environmental controls, whereas the subproject reported here emphasizes firm-level feedlot design and management questions.

The research was carried out through the coordinated efforts of L. J. Connor (subproject leader), J. R. Black and D. L. Forster, Department of Agricultural Economics; J. B. Johnson, agricultural economist, ERS, USDA; J. B. Holtman and H. A. Hughes, Department of Agricultural Engineering; D. C. Adriano, Department of Crop and Soil Sciences; and R. L. Tummala, Department of Electrical Engineering and Systems Science. Specific contributions of individuals are identified insofar as possible in the text of the report.

SUMMARY

The major purpose of this study was to analyze the technical design and functional management of beef feedlots relative to possible impacts on environmental quality concerns and energy usage and monetary costs incurred by producers. The specific objectives were:

1. To evaluate the chemical composition of cattle manure as affected by housing system, and the nitrate and salt status of cropland to which manure was applied.

2. To estimate the capital outlays, annual costs and energy usage associated with alternative technology-output levels for fed beef.

3. To appraise the economic impacts resulting from the possible imposition of selected pollution control measures.

Although the data and results from this research pertain specifically to southern Michigan, they also apply to larger areas of the Corn Belt. Beef feedlots in the Corn Belt differ from their counterparts in western states in that there are large numbers of small feedlots (generally less than 1,000 head marketed per year) which produce most of the feed consumed by the animals. In recent years, the structure of the Michigan beef feeding industry has been characterized by a few large feedlots and a large number of small-capacity feedlots. Production, measured in annual marketings, is concentrated in small operations of less than 1,000-head capacity, although their percentage declined from 98% to 80% over the 1964-1972 period. Although five basic types of housing technologies are commonly used in producing fed beef in Michigan, drylot feedlots account for over 90% of the total number of feedlots.

To evaluate the chemical composition of beef feedlot wastes as affected by various housing systems, and the nitrate and salt status of cropland receiving this manure, fresh fecal samples and soil samples were taken from six Michigan feedlots.

Results indicated that the organic content of manure was highest for open lots, followed by drylots and total confinement systems. The nitrogen content of manure from open lots was generally low. Manure from drylot and total confinement systems had more than twice the nitrogen of open lot manure. Phosphorus content of manure in open lots was less than that in fresh feces, whereas the phosphorus content of fresh feces and manure was about equal in dry lot and confinement systems. Field data indicated generally higher levels of nitrate and chloride concentrations in manured cropland than in cropland to which no manure was applied. However, no significant salt buildup was detected in cropland to which manure had been applied.

The results suggest that feedlot manures have significant amounts of nutrients and can be conserved by having a housing type that would minimize evaporation and eliminate runoff and leaching. The use of moderate manure application rates to cropland, such as found in this study, should not reduce yields or create excessive nutrient and salt buildup in the soils.

Energy usage and monetary costs were calculated for feedlots for a variety of feasible technological components. Technological components considered were alternative housing, feed storage, ration and waste handling systems, along with alternative sex and animal types.

Analysis of energy usage and monetary costs for feedlots with varying technologies indicated that economies of size are present for all energy and monetary cost items except fuel. Fuel consumption increased with the capacity of the feedlot for all technology combinations studied. Fuel consumed in field and materials transport operations was approximately 15% higher for the 1,000-head capacity lot than for the 100-head lot.

Land requirements per cwt of beef produced were relatively constant for all technologies studied. However, some differences were noted in land requirements per cwt of gain for various technologies used for fed beef production.

Most economies of size that were found for labor, electricity, capital and annual production costs were realized at relatively low capacity levels (250-300 head). Average costs were generally the highest, in terms of economic and energy items, with the open lot and lowest for the confined housing system. The average initial capital investment was also lower with confined housing because of higher feeding efficiencies and turnover rates.

Capital economies of size can be attributed in large part to the unavailability of system components small enough to be fully utilized on the smallest lots. Labor economies of size can be attributed to two factors: 1) larger equipment and 2) spreading management time over larger volumes. Many of the cost and energy usage variations among alternative technologies can be attributed to variations in feeding efficiency.

The economic impacts resulting from the imposition of selected pollution control measures on beef feedlots were analyzed. The pollution control alternatives considered were those that might be employed by federal and state agencies to regulate possible pollution generated from fed beef production. Alternatives considered were:

A. EPA effluent guidelines limitations (and standards of performances) for beef feedlots announced in February 1974 would be expanded to all beef feedlots. Facilities must be constructed and operated to control runoff from a local 10-year, 24-hour storm and process generated wastewater by 1977.

B. All beef feedlots must construct and operate facilities by 1977 to control runoff from a local 25-year, 24-hour rainfall and process generated wastewaters.

C. All beef feedlots must construct and operate facilities by 1977 to control all runoff from the rainfall occurring in any 6-month interval.

D. All beef feedlots must construct and operate facilities by 1977 to control all runoff from rainfall occurring in any 6-month interval. Additionally, the feedlot may not spread solid (or slurry) feedlot wastes during winter months.

The additional capital outlays to comply with stated pollution control measures and the changes in annual production costs were determined for each of the alternative rules considered. The implementation of these alternatives has differential impacts on the investment requirements of existing beef feedlots. The open lot feedlot was generally affected most and the confined housing feedlot least.

Economies of size and additional capital outlays were noted for all rules considered except the one that required winter storage of solid wastes. For the various pollution control measures considered, additional capital outlays per head capacity ranged from 60¢ to over $42. The changes in average total cost per head marketed annually attributable to compliance with the various pollution control rules considered ranged from approximately 30¢ to over $6.50. The various pollution control rules considered were those that might conceivably be enforced in the future as well as those already in existence.

Limitations of Study

The results and conclusions drawn from this study are specifically applicable to southern Michigan, although they are generally applicable to many areas in the Corn Belt. However, individual feedlot situations may differ in technology and production practices assumptions specified in this study. Thus, caution should be exercised in applying these results to specific feedlot situations. Also, recent inflationary trends have resulted in larger prices for some inputs than those assumed for this study. The models and procedures used in this study can easily incorporate different assumptions relative to input and product prices and various technologies.

INTRODUCTION

The production of fed beef in the United States has received increased public attention in recent years. Beef feedlots were one of many forms of economic activity singled out when public concern for environmental quality surfaced in the late '60s and early '70s. Animal wastes, pesticides, fertilizers and soil erosion and sedimentation were identified as the major sources of agricultural by-products possibly contributing to water pollution. In recent years, increasing prices for fed beef again focused public attention on beef feedlots. In some areas of the country, consumers boycotted meat in protest to retail beef prices. Current concerns over energy have caused researchers to examine all sources of economic activity, including agriculture and fed beef production.

The major purpose of this study was to analyze the design and management of beef feedlots relative to the possible impacts on environmental quality and the energy usage and monetary costs incurred by producers. Although the data and results from this research pertain specifically to southern Michigan, the results are generally applicable to many areas of the Corn Belt. Specific objectives were:

1. For Corn Belt conditions, to evaluate the chemical composition of fed beef cattle manures as affected by housing systems, and the nitrate and salt status of cropland to which manures were applied.
2. To estimate the capital outlays, annual costs and energy usage with alternative technology-output levels for fed beef.
3. To appraise the economic impacts resulting from the possible imposition of selected pollution control measures.

THE MICHIGAN FED BEEF INDUSTRY

The structure of the Michigan beef feeding industry is indicative of that which exists in the north central region of the United States (Lake States and Corn Belt). Historically, beef feeding has been concentrated on farms capable of producing all shelled corn and corn silage feed requirements. In recent years, the Michigan beef feeding industry has been characterized by a few large feedlots and a large number of small-capacity feedlots (Table 1). Production, measured in annual marketings, is concentrated in the small-capacity operations, although their percentage declined from 98% to 80% over the 9-year 1964-1972 period (Table 1).

Table 1. Feedlots, marketings and cattle marketed per feedlot, by capacity, Michigan, 1964, 1968 and 1972

Feedlot capacity (head)	Feedlots number	Feedlots percent	Marketings head (000)	Marketings percent	Cattle marketed per feedlot number
			1964		
Under 1,000	1,994	99.7	203	97.6	101
1,000 and over	6	0.3	5	2.4	833
1,000-1,999	6	0.3	5	2.4	833
2,000 and over	—	—	—	—	—
Total	2,000	100.0	208	100.0	104
			1968		
Under 1,000	1,735	99.1	226	93.0	130
1,000 and over	15	0.9	17	3.0	1,133
1,000-1,999	12	0.7	13	5.4	1,083
2,000 and over	3	0.2	4	1.6	1,333
Total	1,750	100.0	243	100.0	138
			1972		
Under 1,000	1,675	98.5	200	79.7	119
1,000 and over	25	1.5	51	20.3	2,040
1,000-1,999	16	0.9	24	9.6	1,500
2,000 and over	9	0.6	27	10.7	3,000
Total	1,700	100.0	251	100.0	147

Source: Michigan Department of Agriculture, *Michigan Agricultural Statistics*, Michigan Crop Reporting Service, SRS, USDA, Lansing, Michigan, July 1973.

Five basic types of housing technologies are commonly used in producing fed beef in Michigan (Fig. 1). The drylot paved feedlot consists of a shelter with an open front allowing access to a paved outside lot. The drylot unpaved feedlot has a shelter area with an unpaved outside lot. With the open lot, no shelter is provided for the animals and the facility consists solely of a dirt lot. Total confinement housing may be one of two types. In the first type, feeders are completely confined in a shelter with a solid concrete floor. Manure is scraped from the floor regularly and either spread immediately or stored to be spread later. Alternatively, a total confinement system may have a slotted floor with a pit below for waste storage. The waste is pumped into wagons and spread on fields several times a year.

The distribution of Michigan feedlots by capacity and housing technology (basic production technology) has been estimated (Table 2). The majority of the feedlots in 1969 were of small capacity; over 1,100 of the 1,686 lots had a capacity of less than 100 head. Drylot feedlots account for over 90% of the total number of feedlots.

Table 2. Number and percentage distribution of feedlots by capacity and housing type, Michigan, 1969

Housing Types	Capacity (head): Less than 100	100-199	200-499	500-999	1,000 and over	Total
			Number of feedlots			
Drylot paved	461	110	77	20	5	673
Drylot unpaved	584	157	117	26	9	893
Open lot	33	14	8	2	3	60
Completely covered lot	44	8	6	2	0	60
Total	1,122	289	208	50	17	1,686
			Percent of feedlots			
Drylot paved	41.1	38.1	37.0	40.0	29.5	39.8
Drylot unpaved	52.0	54.3	56.3	52.0	52.9	53.0
Open lot	2.9	4.8	3.8	4.0	17.6	3.6
Completely covered lot	4.0	2.8	2.9	4.0	0.0	3.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: Johnson, J. B. and G. A. Davis, "Economic Effects of Surface Water Runoff Controls on Michigan Beef Feedlots," *Michigan Farm Economics* No. 374, Mich. State Univ., March 1974.

CHEMICAL CHARACTERISTICS OF BEEF FEEDLOT WASTES AS AFFECTED BY HOUSING TYPE[1]

Climate influences decomposition of manure and transformation of its constituents. Of the various climatic parameters affecting these processes, temperature and moisture are perhaps the most important. Various housing types of feedlots modify this climatic influence. Thus, various housing types can influence the decomposition of manures and transformation of its constituents.

In Michigan, there are several feedlot housing types that provide varying degrees of protection of animals from weather exposure (Fig. 1). The greatest runoff problems may be expected in open lot systems because of lack of roof covering; in total confinement systems this problem is nonexistent. Leaching could occur in open lot and drylot unpaved systems.

Because of the smaller area per animal provided in drylot and paved total confinement systems, scraping and hauling of manure is required more frequently. Paved drylot housing systems generally require a much smaller exposed area per animal than open lot and unpaved drylot systems. Bedding is often used in drylot and total confinement systems.

[1]This research was conducted by D.C. Adriano, Department of Crop and Soil Sciences.

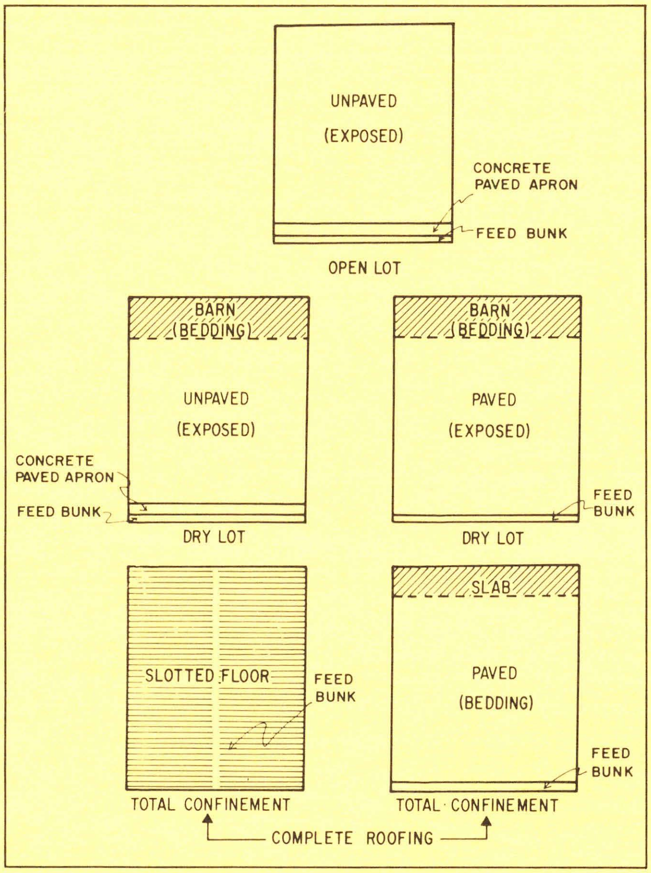

Fig. 1. Beef housing technologies used in Michigan.

This study was undertaken to evaluate: 1) the chemical composition of beef feedlot wastes with emphasis on the nitrogen, phosphorus and potassium contents of manure as affected by various housing systems, and 2) the nitrate and salt status of cropland that received this manure.

Research Procedures

Six feedlots, located in the same geographic area to achieve similarity to climatic conditions, were involved in this study. Physical characteristics of these feedlots, rations fed and manure management practices were determined (Table 3). Feedlot 1 had about 1,000 head; 820 were in an open lot and the rest were in a total confinement system. The open lot system was fenced into four sections, with 600- to 700-lb animals confined in two adjacent sections, and 800- to 900-lb animals confined in the other two. Manure pack had formed in these sections.

In the total confinement system, animals were in the 800- to 1,200-lb weight range. Feedlot 2 had about 1,400 head, with about 350 head in each of two adjacent open lots and the remainder in a paved drylot. One open lot was unpaved, the other paved. The animals in open lots weighed between 450 and 700 lb, and those in the drylot weighed between 700 and 1,100 lb. Feedlot 3 had about 800 head, weighing between 900 and 1,200 lb, housed in paved drylots. In this feedlot, manure in the exposed areas was flushed with water and collected in a concrete sump. There were about 400 head in Feedlot 4 in a paved drylot housing system. The animals weighed from 500 to 1,200 lb.

Feedlot 5 had about 400 head housed in total confinement with a slotted floor. The animals weighed from 500 to 1,150 lb, and were housed in five sections. Wastes were collected in concrete pits about 8 ft deep. Feedlot 6 had about 3,000 head, with about 675 animals housed in paved total confinement and the balance in open lots. The confined animals weighed from 600 to 1,100 lb.

The total confinement systems provide the least footage area, ranging from 20 to 60 ft^2/head. Open lots provided the largest areas per animal, ranging from 350 to 870 ft^2. The scraping frequency varied between the various housing systems, from as often as once in 2 weeks in a paved total confinement (Feedlot 6) and paved drylot (Feedlot 2) to almost none in two open lots, in which exposed areas were not surfaced. Each of the feedlot operators also grows crops, primarily corn, for feed.

Manure and ration samples were collected from spring to fall of 1973. These samples were collected four times at bi-monthly intervals, starting the last week of March. The composite samples for old manure were collected by digging manure packs in three to four different areas in a pen. The old manure consisted of feces, urine and bedding materials, generally straw. From each pen, fractions of six to eight freshly defecated mounds were composited to represent fresh fecal samples, which were considered to be urine-free.

The ration samples were collected from the feed bunks. Ration, manure and fecal samples were placed in plastic bags and frozen until chemical analysis could be conducted. Prior to freezing, fractions were separated for air drying to determine moisture content gravimetrically for calculating the organic matter contents.

Soil samples were taken from farmland to which manure had been applied. Samples were taken to a 2-ft depth with a soil auger. To compare the nitrate and salt status of the soil profiles, three manured and two unmanured sites were sampled. At each site, two borings within 10 ft of each other were drilled and composited at depth separations of 0 to 6 in., 6 to 12 in. and 12 to 24 in. Sampling was done four times during the corn growing season, beginning when the plants were about 1 ft tall and ending when the grains were in the milk stage. Soil samples were placed in plastic bags and stored in a cold chamber at

Table 3. Description of the southern Michigan feedlots included in sample

Feedlot No.	Housing system	Approximate range in animal size, lb.	Approximate animal density, ft^2/head	Approximate scraping frequency	Type of ration
1	Open lot (unpaved)	600 - 900	870	once in 2-3 years	corn silage
	Total confinement (paved-bedding)	800 - 1,200	50	twice a year	corn silage
2	Open lot (unpaved)	450 - 700	350	none	corn silage and grain
	Open lot (paved)	450 - 700	350	once in 3 weeks	corn silage and grain
	Drylot (paved — no bedding)	700 - 1,100	60	once in 2 weeks	corn silage and grain
3	Drylot (paved — bedding)	1,000 - 1,200	60	twice a year	corn silage and grain
4	Drylot (paved — bedding)	500 - 1,200	30	once a month	corn silage, grain and hay
5	Total confinement (slotted floor)	700 - 1,200	20	twice a year	corn silage and grain
6	Total confinement (paved — bedding)	600 - 1,100	60	once in 2 weeks	corn silage
	Open lot (unpaved)	800 - 900	730	none	corn silage

4°C. After chemical analysis, the samples were air dried for moisture determination.

Wet manure and fecal samples were analyzed for total Kjeldahl nitrogen using a semi-micro acid digestion and distillation technique (6). Analysis of wet samples for Kjeldahl nitrogen prevented ammonia loss by drying. Ration samples were first air dried and ground before the Kjeldahl nitrogen analysis. (Kjeldahl nitrogen includes proteinaceous and ammonia nitrogen.)

For total elemental determinations, dried and ground samples were predigested with nitric acid using the micro-Kjeldahl apparatus prior to digestion with perchloric acid. Phosphorus was determined colorimetrically (14). Potassium and sodium were determined using a flame photometer. Calcium, magnesium, iron, manganese, zinc and copper were determined with an atomic absorption spectrophotometer.

Wet soil samples (20 g) were placed into 125-ml Erlenmeyer flasks and 50 ml of $CaSO_4$ solution (1.33 g $CaSO_4$ per liter of deionized water) were added. Samples were placed on a platform shaker and shaken for 30 min at 200 rpm. Samples were allowed to stand for a few minutes, then 25 ml of the supernatant were transferred into a 50-ml beaker, stirred, and nitrate and chloride specific electrodes were used to calculate the nitrate and chloride concentrations, respectively.

RESULTS

A 1,000-lb beef cow excretes about 0.40, 0.05 and 0.30 lb of total nitrogen, phosphorus and potassium daily (20). This would be equivalent to about 145, 18 and 110 lb/year of nitrogen, phosphorus and potassium, respectively.

The hypothetical input and output of nutrients in a typical feedlot operation are depicted in Fig. 2. Also depicted is the hypothetical pathway of losses of nutrients or minerals from the time manure is defecated. Manure is defined here as the mixture of feces and urine alone, or the mixture of the two plus bedding.

The three major nutrients — nitrogen, phosphorus and potassium — are emphasized in the following discussion because of their significance in crop production. The nutrients originate from feed, although some phosphorus comes from salt blocks. Nitrogen excreted by cattle is primarily in the organic form. Approximately 50% of this nitrogen is in the urine as urea $CO(NH_2)_2$, and 50% is in the feces as proteinaceous nitrogen. Urea in urine is quickly hydrolyzed to ammonium carbonate, $(NH_4)_2CO_3$, and ammonia, NH_3, which can either be adsorbed by the clay particles or evolved to the atmosphere.

High temperature, low or high moisture contents of the manure and soil, and soils with low cation exchange capacities (sandy soils) would promote large nitrogen losses through NH_3 volatilization.

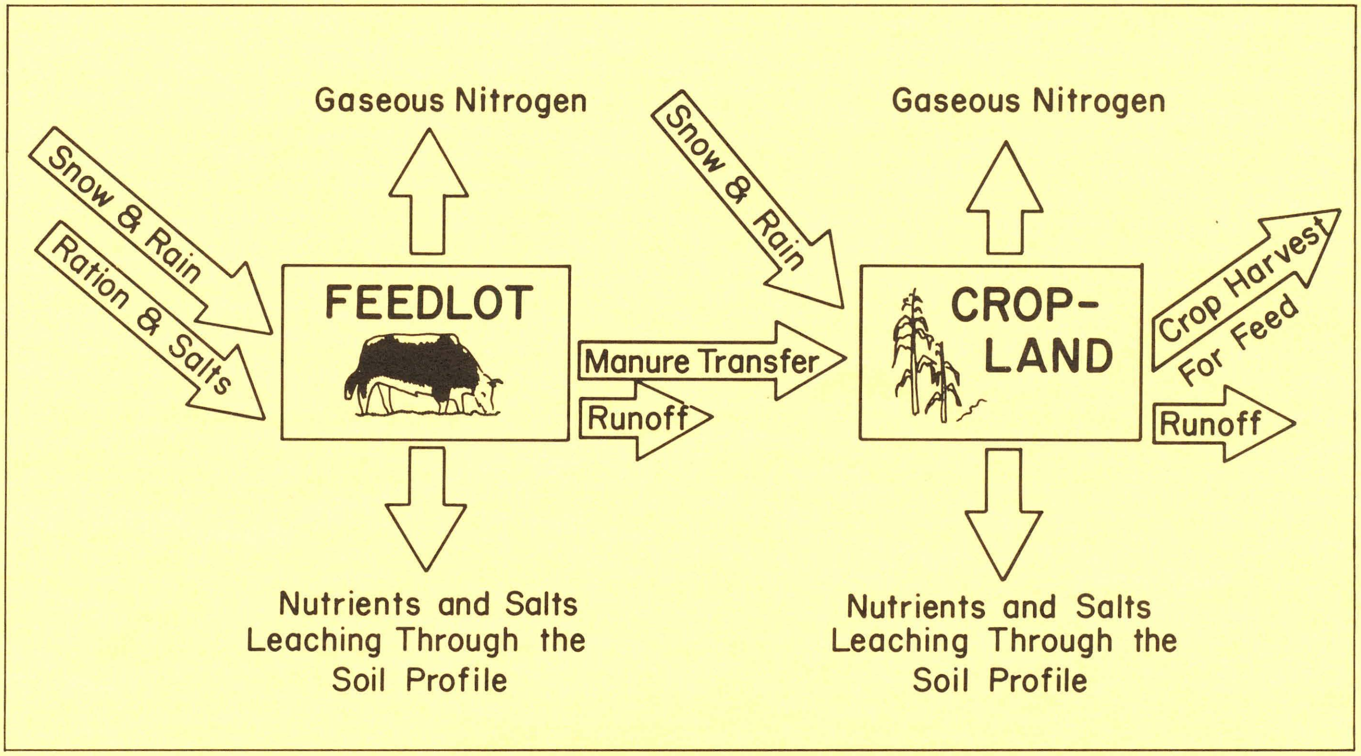

Fig. 2. Input and output of nutrients in a typical feedlot operation.

Large losses of nitrogen through this pathway have been reported by several investigators (1, 4, 25). High concentrations of NH_3 and related nitrogen compounds were detected in the atmosphere above or near a large dairy area and a feedlot (9, 18).

These findings suggest that large fractions of the nitrogen excreted are lost to the atmosphere through this pathway. Increased volatilization of NH_3 with increasing evaporation from a wet soil surface has been demonstrated to occur in the laboratory (25), the greenhouse (3) and a feedlot (9). Evidence indicates that a large percentage of evolved NH_3 came from the urine fraction of the manure (1, 2, 4, 25). Estimates indicate that in arid regions about 40% of the total nitrogen excreted in corrals or feedlots could be lost by NH_3 volatilization, with another 10% subject to loss after hauling and before manures are incorporated into the soil (22).

The most common housing type for feedlots and dairies in arid areas is the open lot where manure remains in corrals or feedlots for much longer periods. Under Michigan conditions, manure losses by NH_3 volatilization prior to land application are expected to be lower than the estimates for southern California. This can be attributed to the higher mean annual temperature of southern California since evaporation is temperature-dependent.

Through the process of nitrification, NH_4^- will be transformed to nitrate, NO_3. This form of nitrogen is very soluble in water and moves along with water in the soil profile. Unlike NH_3, nitrate, is not fixed by the clay particles. However, NO_3 can be lost in gaseous form to the atmosphere before it is leached any deeper in the profile. This pathway of nitrogen loss is called denitrification, the biological reduction of NO_3^- to gases such as nitrous oxide, N_2O, and elemental nitrogen, N_2. This mode of nitrogen loss was shown to be responsible for low NO_3^- concentrations in leachates beneath a feedlot in Nebraska (10).

Two other modes of nitrogen loss from manures in feedlots are possible. First, some of the NO_3^- that is not denitrified or absorbed by the plants can leach through the soil profile and contaminate the groundwater. Several studies in southern California indicated that NO_3 leached through the profiles at high concentrations beneath some dairy corrals, beef feedlots and croplands receiving dairy and feedlot manures (3, 7, 19). The other mode of nitrogen loss is by surface runoff. Organic and inorganic forms of nitrogen in feedlot manures can be subject to this type of loss and were detected in barnloft runoffs in Ohio (8).

From an environmental standpoint, the forms of nitrogen discharged through volatilization as NH_3, leaching as NO_3, and runoff with organic and inorganic fractions could degrade the qualities of both surface and subsurface waters. However, the gases N_2O and N_2 from denitrification are considered environmentally harmless.

Phosphorus and potassium are not subject to volatilization losses. Nevertheless, like nitrogen, they are subject to runoff and leaching losses. Phosphorus in manure is mainly in the organic form and must be decomposed or mineralized before becoming available for plant use. Mineralized phosphorus can be fixed or precipitated by iron, aluminum or calcium in the soil system and becomes difficult to leach.

Potassium in manure is mostly water soluble and more immediately available to plants. Potassium can be fixed by certain clay minerals. Both phosphorus and potassium move to some extent down the soil profile with the percolating water. As revealed by the study by Edwards *et al.*, these two nutrients can be lost through runoff as manure components or manure-soil components (8). This is perhaps the main pathway of loss for these two nutrients which pose serious and immediate environmental hazards. However, environmental problems attributable to the leaching of these two nutrients would not be of as immediate concern as nitrate, since they are relatively immobile.

To summarize, the primary source of these three nutrients is the ration (Fig. 2). Volatilization of NH_3 from feedlots will depend on the climate and housing type. Volatilization losses can be expected to be high in open lots. Denitrification can be high in feedlots with dense manure packs. There will be no runoff problems in feedlots with total confinement housing systems. Open lot feedlots are most susceptible to runoff. Leaching will be absent in paved lots.

The fertilizer benefits that can be derived from land application of manure are perhaps a main reason most operators prefer this method of manure disposal. The nutrients from manure can be recycled by crop utilization, thereby preventing excessive nutrient accumulation in the soil.

Average data for chemical composition of old manure and fresh feces from various housing types are shown in Table 4. The "range" and coefficient of variation (C.V.) values for the various parameters are presented separately by housing types in Appendix Tables 2, 3 and 4.

Fresh feces have an average organic matter content of 21% as compared with about 51% for old manure from open lots (Table 4). Old manure from unpaved, paved and piled areas in open lots had about equal organic matter content. Manure from paved drylots and the paved floor total confinement system was 30% organic matter. Manure from the slotted floor total confinement housing contained 22% organic matter. The organic matter contents of manure from the various housing systems indicate the degree of exposure of manure to climatic effects. In feedlots with conditions more favorable for evaporation, such as open lot and drylot systems, organic matter was high. Organic matter was low in manure from slotted floor confinement systems where evaporation is apparently minimal. The amount of ash is not taken into account in the organic matter computations.

The nitrogen content of manure from open lots averaged 1.1%. Manure from drylot and total confinement systems had more than twice the nitrogen of manure from open lots. This suggests that greater amounts of this nutrient were lost from open lots,

Table 4. Average chemical composition of manure and feces (on dry weight) by housing type, sample of southern Michigan beef feedlots

	No. of samples	Org. matter	Kjel. N	Total P	Total K	Total Ca	Total Mg	Total Na	Total Fe	Total Mn	Total Zn	Total Cu	EC mmho/cm	pH
		% (a)								ppm				
OPEN LOT														
Old manure														
Unpaved	18	51	1.28	.40	.90	3.55	1.07	.21	1.25	586	103	26	3.41	7.9
Paved	4	49	1.03	.72	.70	.93	.39	.14	.99	500	138	59	4.50	6.4
Piled	6	52	.94	.49	.85	2.03	.77	.16	1.17	494	119	27	3.10	8.4
Fresh feces	18	21	2.05	.65	.95	1.19	.38	.30	.30	222	150	40	2.60	6.8
DRYLOT (PAVED)														
Old manure	18	30	2.47	.67	2.18	1.10	.53	.38	.26	144	104	23	6.40	7.3
Fresh feces	18	22	2.08	.91	1.20	.98	.40	.24	.089	134	131	33	3.40	6.4
TOTAL CONFINEMENT														
Old manure														
Slotted floor	4	22	2.56	.75	2.57	.81	.54	.17	.069	70	83	16	6.30	7.6
Paved (bedding)	23	28	2.77	.63	2.56	1.74	.70	.33	.30	418	130	32	6.43	8.4
Fresh feces	23	20	2.25	.68	1.15	1.45	.43	.24	.087	144	144	30	3.20	7.1

(a) Organic matter is on a wet weight basis, and nutrients are on a dry weight basis.

possibly by NH_3 volatilization. As previously discussed, relatively larger quantities of nitrogen were lost through NH_3 volatilization under favorable evaporative conditions.

On the average, fresh feces had 2.1% nitrogen (on a dry weight basis), about double that of manure from open lots but slightly lower than in manure from drylot and total confinement systems. Bedding or litter, usually straw or corncobs, is commonly used in Michigan drylots. These materials are low in nutrient content and will dilute the nutrient contents of manure. But bedding or litter would prevent large losses of nitrogen from the urine fractions by volatilization. Nitrogen content of manure is quite variable for open lots and rather stable in total confinement systems with slotted floor (Appendix Tables 2, 3, 4).

Phosphorus is mainly excreted through the fecal fraction (5). In open lots, the phosphorus content of old manure tended to be lower than of fresh feces, probably caused by runoff or leaching losses (Table 4). However, in total confinement systems, phosphorus content of old manure was about equal to that of fresh feces. The average phosphorus content of old manure was 0.40% for the unpaved open lot, compared with 0.75% for the total confinement system with slotted floor. Phosphorus content of manure in open lots was quite variable, ranging from 0.11% to 1.41%.

Potassium is excreted mainly through the urinary fraction, which accounts for about 70% of the total excreta (5). Thus, fresh feces had lower potassium than old manure except in open lots (Table 3). The modes of losses for this nutrient are quite similar to those for phosphorus. The potassium content of old manure was generally low in open lots, with an average of 0.82%; manure from drylot and total confinement systems contained more than 2% potassium.

Elements such as calcium, magnesium, iron, manganese, zinc and copper are also essential nutrients for plants. The first two are classified as secondary nutrients and the rest belong to the category micronutrients since only trace amounts are required by plants for normal nutrition. Sodium is included because it is a derivative of the feeding operation with fractions coming from salt supplement. This element could affect the infiltration rate of most soil because of its ability to disperse the clay particles.

The percentages of calcium and magnesium in old manure from open lots were generally high (Table 4). There was a tendency for the percentages of calcium and magnesium to increase in paved drylots and paved total confinement systems. The sodium content of old manure was about equal in unpaved, paved and piled areas in open lots. The iron content of old manure averaged 1.14% in open lots, 0.26% in drylots and 0.1% in total confinement systems. The manganese, zinc and copper portions of old manure were also generally high in open lots. Electrical conductivity, a measure of the soluble salt concentration in manure, was generally high in drylot and total confinement systems. No meaningful pattern could be detected for manure pH from the various housing types. The pH levels ranged from 6.4 in the paved open lot to 8.4 in paved total confinement and piled open lot.

Average values for the various parameters for the ration, manure and fecal samples from all lots were calculated (Table 5). Fresh feces contained larger percentages of nitrogen and phosphorus than the rations. Apparently, these differences are attributable to the animal digestion process. Cattle are inefficient in utilizing the nutrients in feeds. It has been estimated that about 75% to 89% of the nitrogen, 70% to 85% of phosphorus and 80% to 90% of potassium feed in ration is excreted (5). On a dry weight basis, the amount of organic matter defecated is less than that fed. This probably causes the higher nutrient concentrations in feces by concentrating nutrients in the smaller amount of organic matter defecated.

Some other elements are generally highly concentrated in old manure and less concentrated in rations. Iron is being added as a diet supplement, but only a small fraction is retained in the animals' bodies, which could explain the remarkably high concentration of this element in old manure (23). Sodium, zinc and copper concentrations in

Table 5. Average chemical composition of ration and manure taken from southern Michigan sample feedlots [a]

	No. of samples	Org. matter	Kjel. N	Total P	Total K	Total Ca	Total Mg	Total Na	Total Fe	Total Mn	Total Zn	Total Cu	EC mmho/cm	pH
		%								ppm				
Ration	50	40	1.65	.40	1.02	.53	.22	.15	.034	43	58	21	—	—
Fresh feces	59	21	2.13	.75	1.10	1.21	.40	.26	.16	185	142	34	3.07	6.8
Old manure	73	39	1.84	.61	1.63	1.69	.66	.23	.67	369	113	30	5.02	7.7

[a] All values are expressed on dry weight basis (except organic matter). These values are derived from Appendix Tables 1, 2, 3 and 4 by combining data from the various housing types.

fresh feces and old manure were about equal on the average. The electrical conductivity of 5.02 mmho/cm for old manure was significantly higher than the 3.07 mmho/cm for fresh feces. Old manure generally had higher pH than fresh feces.

Manure from the various feedlots is being applied to croplands, mainly corn fields. Interview data indicate that the quantity of manure applied to cropland in 1973 ranged from 25 to 50 wet tons/acre/year, with an average rate of about 32 wet tons (Table 6). Based on the average manure composition estimates (Table 5), the 32-ton rate would provide about 460 lb nitrogen, 152 lb phosphorus and 407 lb potassium.[2]

Table 6. Nutrient availability for crop usage per year based on the organic matter content by indicated manure application data [(a)]

	Org. matter	Kjel. N	Total P	Total K
	tons/acre	lb/acre		
Range (wet basis):				
25 ton/acre	9.8	361	120	319
50 ton/acre	19.6	721	239	639
Average (wet basis):				
32 ton/acre	12.5	460	152	407

(a) The application rates were obtained through personal interviews with the feedlot operators. Values were based on nutrient data in Table 4.

Not all of the nutrients in the manure applied are released for plant use in the first year. Most of potassium is made available for the first year. Under Michigan conditions, estimates indicate that 3 to 4 years of decomposition would be needed for nitrogen and phosphorus in manure to be completely available to the plants. Field losses can be great in the case of nitrogen. These quantities of nutrients are too high for a single crop to utilize. Long-term research at Michigan State University shows corn for silage removes about 110 lb nitrogen, 18 lb phosphorus and 85 lb potassium/acre/year. Corn for grain removes even less (29). Therefore, some excesses of N, P and K may accumulate when application rates approach those described.

The nitrate and chloride status of soil profiles in manured and unmanured fields was determined (Tables 7 and 8). Nitrate has been used as an indicator of excess nitrogen in soil and of groundwater quality, while chloride indicates salt accumulation and movement. Although nitrate is usually biologically unstable in the soil-plant environment, it becomes rather stable once it moves past the root

Table 7. Nitrate-nitrogen status of manured and unmanured cropland [(a)]

	Soil depth in.	Feedlot 1	2	3	4	5	6	Average for 6 feedlots
		ppm NO_3^--N [(b)]						
MANURED	0 - 6	9.1	12.2	12.0	9.7	27.9	19.0	15.0
	6 - 12	8.5	16.6	10.2	10.9	78.6	15.9	23.4
	12 - 24	4.1	15.5	7.7	5.9	31.6	8.0	12.1
Depth average		7.2	14.8	10.0	8.8	46.0	14.3	16.8
UNMANURED	0 - 6	6.0	7.6	9.1	12.7	24.2	12.8	12.1
	6 - 12	9.5	5.4	5.1	16.6	46.1	16.9	16.6
	12 - 24	6.0	4.7	3.5	4.3	10.3	9.7	6.4
Depth average		7.2	5.9	5.9	11.2	26.9	13.1	11.7

(a) Lot 1= open lot; lots 2, 3 and 4= drylot; lots 5 and 6= total confinement. These farms received manures ranging from 25 to 50 tons/acre/year, with an average of 32 tons (wet basis).

(b) Each value is the average for four sampling periods during the crop growing season. All values are expressed on dry soil weight basis.

zones to deeper soil strata. In deeper soil strata, the number of denitrifying microorganisms decreases and the amount of organic carbon is usually insufficient to promote significant denitrification. The data were for soil zones occupied by the roots (0-2 ft); nevertheless, they provide information on the potential amount of nitrate and salt that can be leached.

Data show that these two ions were generally higher in manured areas, especially where manure was applied from Feedlots 2, 3 and 5. On the average, the manured areas had 16.8 ppm nitrate-nitrogen, compared with 11.7 ppm for the unmanured fields. No definite pattern for nitrate and chloride in soils could be detected during the sampling period. These data indicate that potentially higher quantities of nitrates are available for leaching to the groundwaters from the manured fields. No significant salt buildup in soil is expected in

[2] 152 lb P× 2.27= 345 lb P_2O_5.
407 lb K× 1.20= 488 lb K_2O.

Table 8. Chloride status of manured and unmanured cropland

	Soil depth in.	Feedlot 1	2	3	4	5	6	Average for 6 feedlots
		ppm Cl^- [(b)]						
MANURED	0 - 6	6.9	18.5	145.0	12.5	3.1	9.9	32.6
	6 - 12	8.6	9.1	67.0	14.4	8.3	8.7	19.4
	12 - 24	8.1	7.3	60.2	18.7	20.2	8.9	20.6
Depth average		7.9	11.6	90.7	15.2	10.5	9.2	24.2
UNMANURED	0 - 6	4.3	3.8	3.7	7.8	2.3	6.0	4.6
	6 - 12	5.4	5.0	4.1	10.7	5.9	5.6	6.1
	12 - 24	8.3	5.2	6.8	12.0	12.2	7.8	8.7
Depth average		6.0	4.7	4.9	10.2	6.8	6.5	6.5

(a) Lot 1 = open lot; lots 2, 3 and 4 = drylot; lots 5 and 6 = total confinement. These farms received manures ranging from 25 to 50 tons/acre/year, with an average of 32 tons (wet basis).

(b) Each value is the average for four sampling periods during the crop growing season. All values are expressed on dry soil weight basis.

Michigan cropland because of relatively adequate precipitation and moderate rates of manure application.

A field study in southern Alberta, Canada, where about 31 tons/acre/year of feedlot manure have been applied for 40 years revealed no significant buildup of nitrogen, phosphorus or salts in the soil (24). The field had been planted continuously to cereal grains during this period. However, in field studies in Texas and Kansas (20, 21), where various rates of feedlot manures were applied, high nutrient levels in soils were detected, and after a few years of high manure application rates crop yields were depressed. In Kansas, corn silage yield was reduced after only 2 years of application. The yield reduction was attributed to accumulation of soluble salts in surface soils. High levels of nitrate were detected to about 6 ft deep. The manure application rates used in Kansas ranged from 10 to 320 tons/acre/year on a dry weight basis. In Texas, the manure rates ranged from about 10 to 400 tons/acre/year (dry weight) applied for 2 or 3 successive years to irrigated corn. These high manure application rates reduced corn silage yields, caused nitrate and salt accumulation in the soil and increased nitrate concentration in the forage.

The various findings on feedlot manure application to cropped fields suggest that with moderate manure application rates, such as those used in Michigan, nutrient and salt buildup in soils would be minimal.

SUMMARY

Climate influences the decomposition of manure and the transformation of its constituents. Temperature and moisture are perhaps the most important climatic influences affecting these processes. The type of feedlot housing employed modified climatic influences. Thus, the type of housing in use affects the decomposition and composition of manure.

Six southern Michigan feedlots, each with one or more types of housing in use, were chosen to evaluate 1) the chemical composition of manure with emphasis on nitrogen, phosphorus and potassium, as affected by various housing types, and 2) the nitrate and salt status of cropland receiving manure applications. Manure and fresh fecal samples were collected at the feedlot facilities. Soil samples to a depth of 2 ft were taken from manured and unmanured areas of cropland during the corn growing season.

The organic matter content of manure probably indicates its degree of exposure to climate as affected by housing type. In lots with more favorable evaporative conditions, organic matter was high. The organic content of manure was highest for open lots, followed by drylots and total confinement systems.

The nitrogen content of manure from open lots was generally low. Manure from drylot and total confinement systems had more than twice the nitrogen of open lot manure. This suggests that greater amounts of nitrogen were lost from open lots, possibly by ammonia volatilization. The nitrogen content of fresh feces averaged 2.1% nitrogen, about double that for manure in open lots, but slightly less than the manure in drylot and total confinement systems.

Phosphorus content of manure in open lots is less than that in fresh feces, indicating phosphorus losses are caused by runoff or leaching. However, in drylot and total confinement systems, the phosphorus contents of fresh feces and manure were about equal. Potassium content of open lot manure was generally low, with an average of 0.82%, whereas manure from drylot and total confinement systems contained more than 2% potassium.

Calcium and magnesium contents of old manure were generally high in open lots. Sodium content of manure was about equal in unpaved, paved and piled areas in open lots. But there was a tendency for the sodium content of manure to increase in paved drylot and total confinement systems. Iron, manganese, zinc and copper portions of manure were generally high in open lots.

Field data indicate generally higher levels of nitrate and chloride concentrations in manured cropland than in cropland to which no manure was applied. However, no significant salt buildup was detected in cropland to which manure had been applied.

Results from this study suggest that feedlot manures have significant amounts of nutrients and can be conserved by having a housing type that would minimize evaporation and eliminate runoff and leaching. The use of moderate manure application rates to cropland, such as those used in Michigan, should not reduce yields or create excessive nutrient or salt buildup in the soils.

CAPITAL OUTLAYS, ANNUAL COSTS AND ENERGY USAGE FOR FED BEEF PRODUCTION[3]

To study the tradeoffs associated with technology and size of operation in beef production, it was necessary to evaluate capital outlays, annual costs

[3] This section is largely based on the thesis by Hughes (13).

and energy usage over a range of firm sizes employing various forms of technology. Measured in dollar terms were the capital outlays for the various size-technology combinations under consideration and the annual costs/cwt of feedlot gain (measured as the sum of variable costs and annual charges assessed fixed production factors). Measured in the quantity dimension were labor, fossil energy, electrical energy and land (as a proxy for solar energy), which were expressed in man-hours, horsepower hours, kilowatt hours and acres units, respectively.

METHODOLOGY

The conceptual framework adopted follows Koenig and Tummala (17). The mass-energy-economic characteristics of the beef feedlot are obtained utilizing the models developed by Tummala and Connor (27). The conceptual framework and models provide a technique to account for the mass flows and energy and monetary requirements. Associated with each material flow into or out of a component is a vector of attributes describing the capital outlays, energy requirements and dollar costs required to produce the material. This vector is referred to as the energy cost vector.[4] Each element of the vector is referred to as an energy cost.

To facilitate presentation of the models, the beef production system is subdivided into three subsystems: 1) feed production, 2) beef feedlot, and 3) waste collection, storage and distribution.

Feed Production Subsystem

The feed production subsystem includes shelled corn production and transportation components, silage production and transportation components, and a component for mixing and storing the ration to be fed to the cattle.

A notational scheme has been adopted for the formulation of component models. Material flow rates of material i into or out of component j are denoted Y_{ij} (i.e., Y_{ij} has units of quantity of material per unit of time).

The corn and silage production components are shown in Figs. 3 and 4, respectively. Two components have similar inputs, but the units of output are different, being bu/year of shelled corn and tons/year of corn silage, respectively.

The material flow model for corn production is:

$$Y_{i1} = K_{i1} Y_{01} \qquad i = 1, 2, \ldots, 6 \quad (1)$$

where K_{i1} is the quantity of material il required to produce one unit (bu) of shelled corn and the various materials implied by i are identified in Fig. 3. The output, Y_{01}, determines the quantities of the

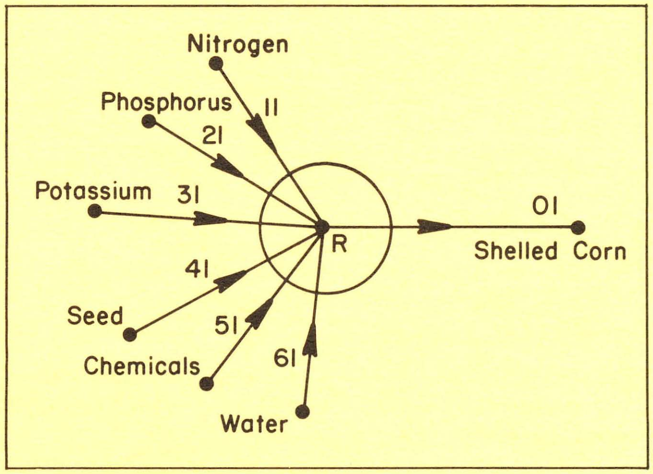

Fig. 3. Corn production component.

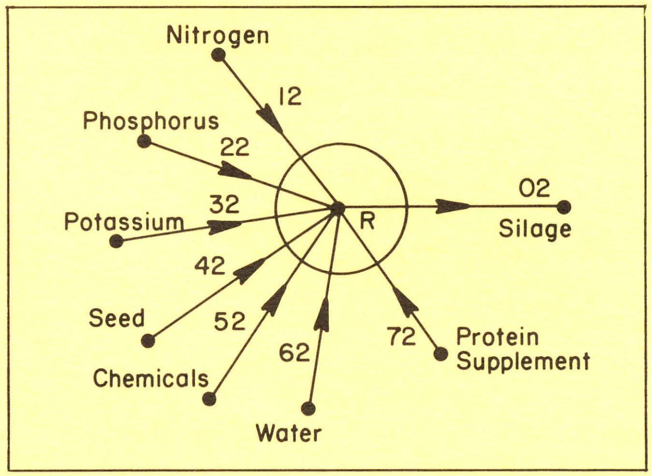

Fig. 4. Silage production component.

other flows and is called the stimulus variable. Flows other than the stimulus are called response variables and are proportional to the stimulus variable. The K_{i1}'s are the technical coefficients of proportionality for the component.

Similarly, the material flow model for silage production is:

$$Y_{i2} = K_{i2} Y_{02} \qquad i = 1, 2, \ldots, 7 \quad (2)$$

Ration production, another material combination component, is shown in Fig. 5. Ration is produced by combining corn and silage in the proper amounts. It is assumed that corn silage had protein supplement added to it before storage. The mathematical expression for the material combination is:

$$Y_{i3} = K_{i3} Y_{03} \qquad i = 1, 2 \quad (3)$$

Associated with each material flow is a vector of values representing the monetary cost, capital outlays and energy per unit of the material required to

[4] We are measuring real energy requirements and traditional economic variables. Computationally, it is convenient to lump these variables together, as the method of accounting for them is identical.

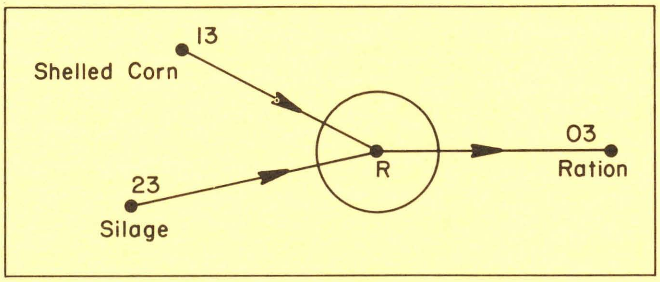

Fig. 5. Ration combination component.

put the material into its current state. Elements of the energy cost vector are denoted by X^m_{ij} (m indicates the energy cost type) where:

- m = 1: capital ($)
- m = 2: labor (man-hours)
- m = 3: fossil energy (horsepower hours)
- m = 4: electrical energy (kilowatt hours)
- m = 5: land (acres)
- m = 6: dollar cost ($)

Land is included to serve as a proxy for solar energy. Examples of energy costs are: X^5_{41} is the land required to produce 1 bu corn and X^2_{02} is the labor in man-hours needed to produce 1 ton of silage.

Employment of the conservation of energy principle implies that the net energy flow into the component (energy content of the input materials) plus the applied processing energy must equal zero. The expression:

$$\sum_{i=1}^{6} K_{i1} \quad X^m_{i1} \qquad m = 1, 2, \ldots, 6$$

represents an accumulated energy cost of type m in the input materials required to produce 1 bu shelled corn. While this sum could be evaluated for each energy cost type, it was evaluated only for m = 6; i.e., costs of input materials were accounted for only in terms of dollar cost.

Processing energy costs include the cost of machinery, buildings, labor, fuel, taxes, depreciation, etc.; i.e., the costs internal to the system. The processing energy cost function is typically a nonlinear function of the production level. It accounts for the size economies to energy usage and monetary costs associated with the processing unit. The processing energy m required for 1 bu shelled corn is:

$$f^m_1(Y_{01}) \qquad m = 1, 2, \ldots, 6$$

Energy relations in each of the m types are expressed below for the shelled corn, silage and ration components, respectively:

$$X_{01} = -\sum^{6} K_{i1}X^m_{i1} - f^m_1(Y_{01})$$

$$m = 1,2, \ldots, 6 \qquad (4)$$

$$X_{02} = -\sum^{7} K_{i2}X^m_{i2} - f^m_2(Y_{02})$$

$$m = 1,2, \ldots, 6 \qquad (5)$$

$$X_{03} = -\sum_{i=1}^{2} K_{i3}X^m_{i3} - f^m_3(Y_{03})$$

$$m = 1,2, \ldots, 6 \qquad (6)$$

After each crop has been harvested, it is transported to storage. The model contains components of the type shown in Fig. 6 for the transportation of both feeds. Since the same material flows into and out of a transportation component and it is assumed that no losses are incurred, only processing energy costs need be considered. The models for the transportation components for shelled corn and silage are:

$$X^m_{2T} = -f^m_{2T}(Y_{2T})$$

$$m = 1,2, \ldots, 6 \qquad (7)$$

$$X^m_{3T} = -f^m_{3T}(Y_{3T})$$

$$m = 1,2, \ldots, 6 \qquad (8)$$

Feedlot Subsystem

The feedlot subsystem is a transformation process whose inputs and outputs are identified in Fig. 7. Following the same procedures outlined in the previous section, we obtain the following model:

$$Y_{i4} = K_{i4}Y_{04}$$

$$i = 1,2, \ldots, 7 \qquad (9)$$

and

$$X^m_{04} = -\sum_{i=1}^{7} K_{i4}X^m_{i4} - f^m_4(Y_{04})$$

$$m = 1,2, \ldots, 6 \qquad (10)$$

The waste material flow from the feedlot is decomposed into the flows Y_{14}, Y_{24}, Y_{34} and Y_{44}. The first three are recyclable nutrients N, P and K (nitrogen, phosphorus and potassium), respectively. The flow Y_{44} represents the flow of wastewater and the other (referred to as nonnutrient) portions of the animal manure.

Waste Processing Subsystem

As described in the previous section on chemical characteristics of beef feedlot wastes, there are actu-

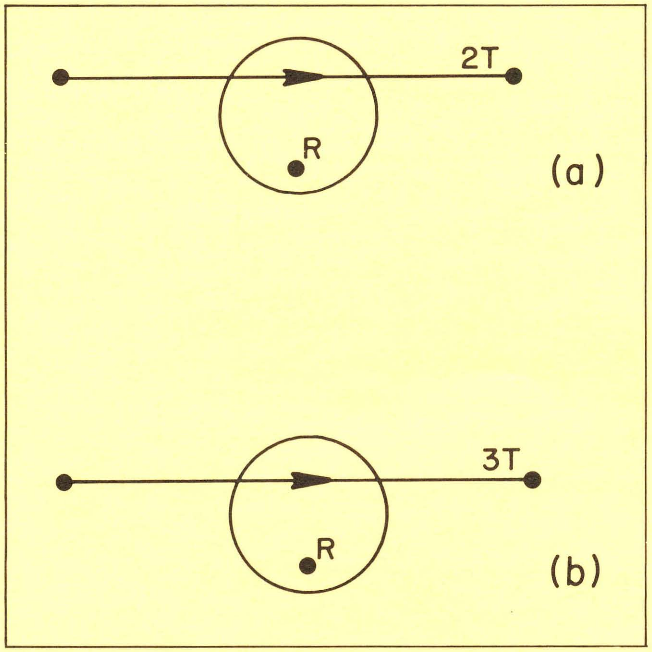

Fig. 6. Transport components for feed: (a) component 2T for shelled corn, (b) component 3T for silage.

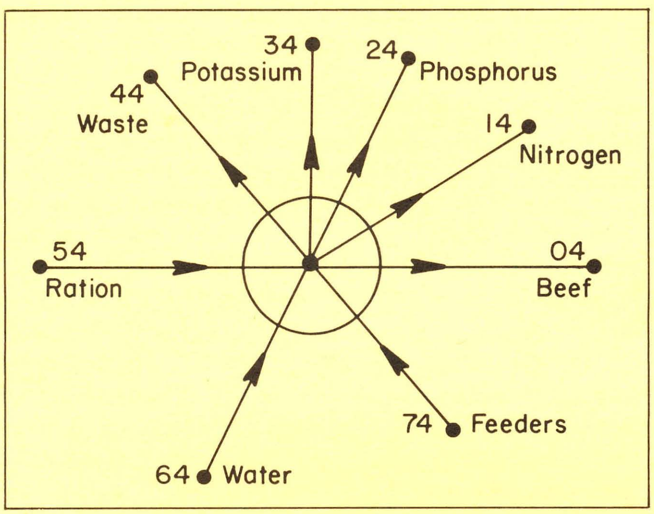

Fig. 7. Beef feedlot component.

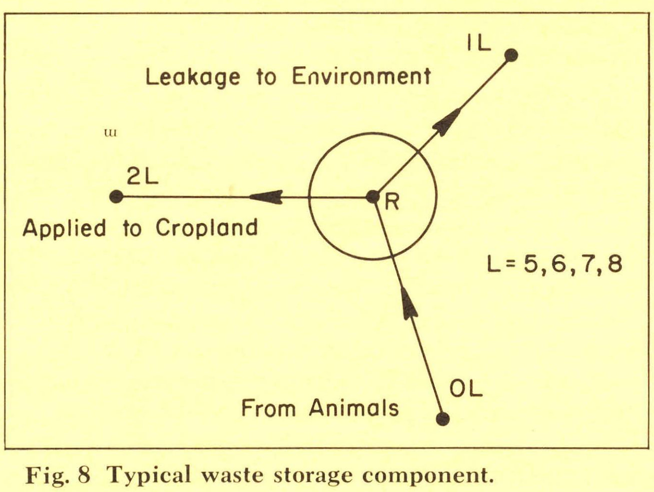

Fig. 8 Typical waste storage component.

ally several modes of nutrient loss to the environment. There are components to account for the loss for each of the waste material flows of the type shown in Fig. 8. The mathematical form of the model is:

$$Y_{iL} = K_{iL} Y_{0L}$$

$$i = 1,2 \; : \; L = 5,6,7,8 \qquad (11)$$

and

$$X^{m}_{0L} = -\sum_{i=1}^{2} K_{iL} X^{m}_{iL} - f^{m}_{L}(Y_{0L})$$

$$m = 1,2, \ldots, 6 \qquad (12)$$

where:

L= 5 : nonnutrient material
L= 6 : potassium
L= 7 : phosphorus
L= 8 : nitrogen

The nonnutrient waste and fertilizer equivalents of N, P and K that remain after storage losses have occurred must be transported to the field for application to the soil. The waste transport component is shown in Fig. 9. The energy costs for the component are evaluated using the "common carrier" concept discussed by Koenig and Tummala (17).

The quantity of each fertilizer constituent (N,P,K) required is determined by the crop production components. A steady-state nutrient equilibrium was assumed. (Nutrients applied equals nutrient uptake by plants plus losses.) The amount of each nutrient to be applied as commercial fertilizer is the difference between the quantity required by crops and the quantity available from the waste.

The energy cost X^{m}_{0i}, i= N,P,K: m= 1,2, . . . , 6 of the commercial fertilizer purchased is the cost of the material supplied to the farm.

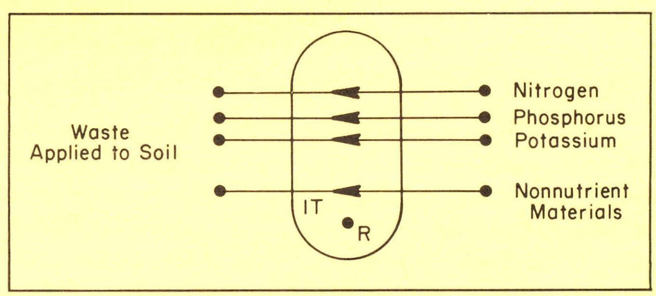

Fig. 9. Waste transport component.

Beef Farm Model

The complete beef production system is shown in Fig. 10. Well-known graph theoretic concepts discussed in many engineering texts have been extended to these processes by Koenig and Tummala

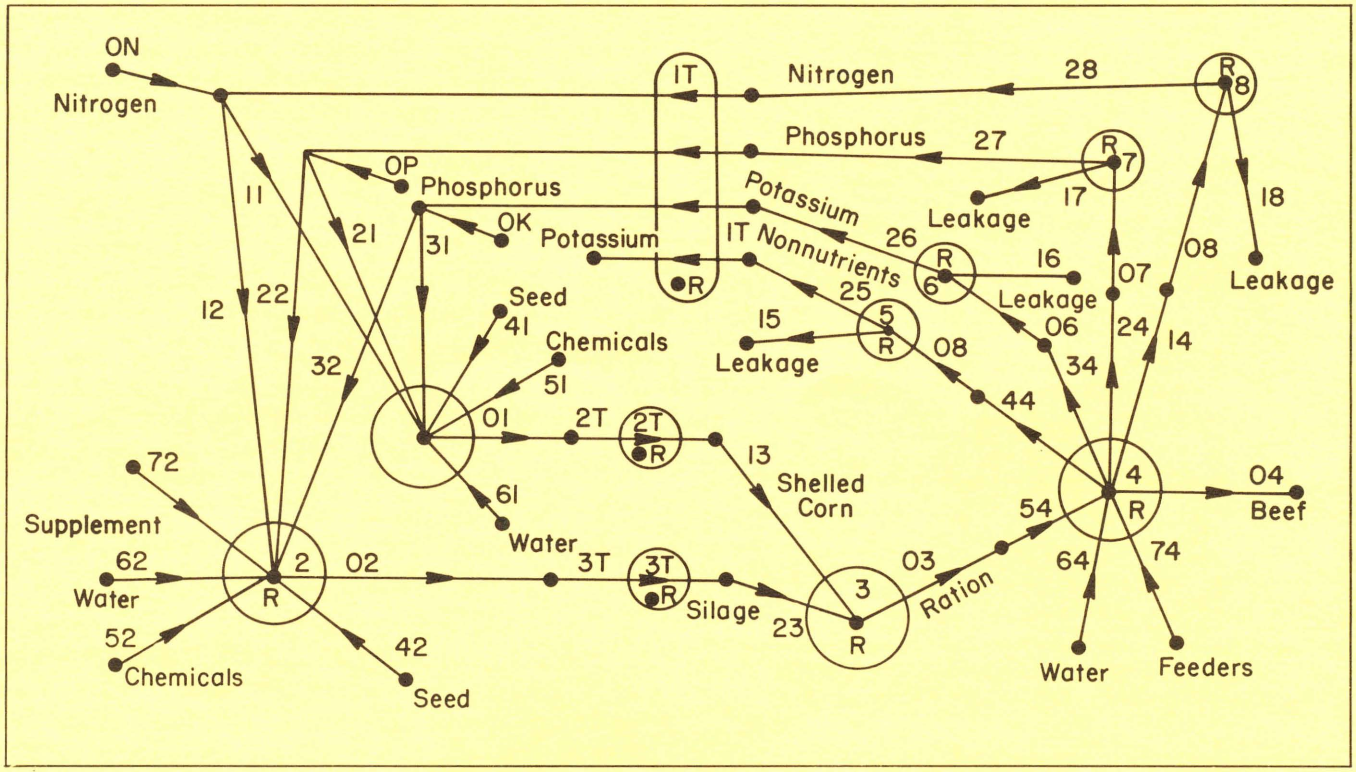

Fig. 10. Material flows in a beef production system.

(17), and illustrated by Holtman *et al.* (12). Use of these methods provides the system model presented by Hughes (13).

Many of the technical coefficients for each component and technology were obtained from the literature. Recommendations of research and extension specialists in the area of concern were sought. The required processing energy functions depicting the relationships of energy cost to size for each technology were generally unavailable. Therefore, it was necessary to develop prototypal designs for each component. To facilitate energy cost calculations over the ranges of size and technology considered, subsystem models were computerized: 1) field machinery, 2) farmstead, and 3) transport.

The primary function of the field machinery subsystem model is to select a realistic complement of machinery required to produce the quantities of shelled corn and corn silage determined by the ration requirements. It was assumed that soil type and crop yields and the field operations performed were invariant with farm size. The fraction of work days in which field work was possible was estimated using Tulu's tractability model (26).

The common usage of equipment by the corn and corn silage components required that they be analyzed simultaneously. The effect of the interaction between the silage and corn components on machinery requirements is dealt with by estimating total required horsepower using the procedure illustrated in Fig. 11. The work requirement distribution over time is then used to size the power units and select the machinery. The machinery complement is selected according to a criterion of meeting the field work needs in a manner that results in machinery complements comparable to those found commercially. However, no attempt is made to find a minimum economic cost selection. Each particular machine is assumed to be available in a range of sizes and to operate properly over a range of speeds. An iterative search is then used to identify a complement of machines which meets established time limits for job completion, satisfies the size and speed constraints, and properly matches implement power requirements and the selected power units.

The farmstead subsystem model automates the design and energy cost calculations for the structures required: feedlot, feed storages and the liquid waste tank, if needed. A standard feedlot layout specified by five input parameters was assumed. The parameters are length of feedbunk per animal, final average weight of the animals, areas of open lot and shelter per 100 lb of final animal weight and feedlot capacity in number of animals. Feed storage facilities considered were sealed tower silos for high-moisture corn, and tower and bunker storage for corn silage storage. A minimum required capital criterion was employed in the feed storage design.

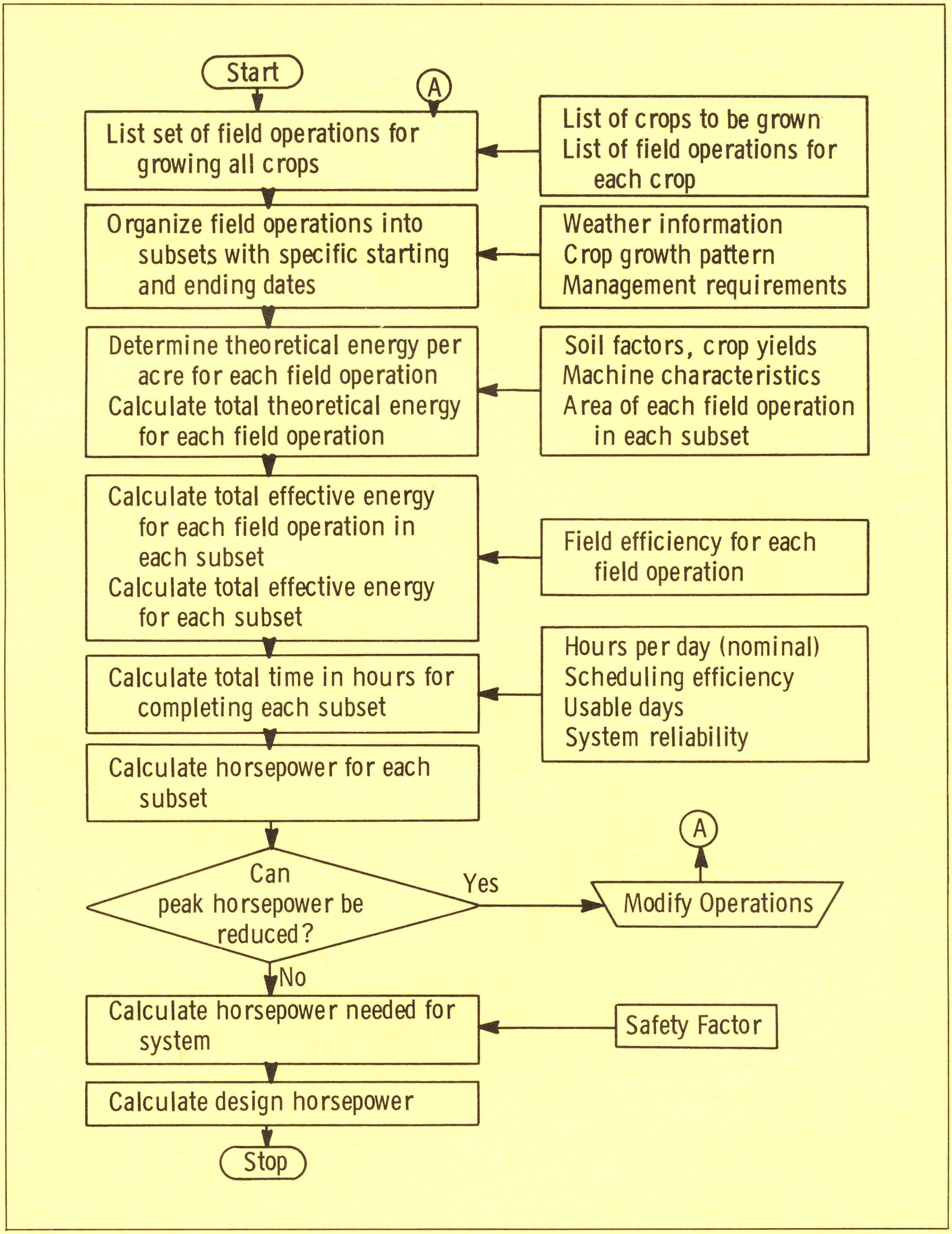

Fig. 11 Procedure for estimating horsepower requirement.

Transport equipment was selected by a procedure based upon the following assumptions:

1. A relationship exists between average effective transport distance (field to farmstead) and farmstead area which is the same for harvested crops and the wastes, i.e., it was assumed that over a period of years the wastes are uniformly distributed over the cropland.
2. Transport system component parameters are fixed and the only computation made by the model was to determine the number of units required.
3. An average transport speed exists which is independent of transport distance.

Computation details and design parameters used are described by Hughes (13).

Results

Results are shown for feasible combinations of housing, feed storage, ration, waste handling, animal and sex types (Table 9). The curves in the various figures are identified by feedlot number as explained in Table 9. The curves were developed from the methodology specified in the previous section, and were smoothed and plotted on an X-Y plotter controlled by the computer.

The curves shown in some of the figures in the section contain "local" irregularities. The irregularities are the results of discrete changes in the surplus of equipment items required. The curves shown in the subsequent figures are not fully analogous to the conventional long-run average cost curve specified in economics textbooks. The curves are different in that they approximate a locus of points connecting the minimum points on the short-run average total cost curves instead of the points of tangency of the short-run average total cost curves to the long-run average cost curve. In this analysis, the size level of the various components was matched to the desired level of output.

The analysis is based on initial weights of 450 lb for calves and 750 lb for yearlings, and final weights of 1,050 lb for calves and 1,150 lb for yearlings. Turnover rates are based on animal types and average daily gains achieved with various ration-animal-feedlot combinations (see Appendix Table 5).

Effect of Housing Type and Feedlot Capacity on Capital Outlays, Annual Cost and Energy Usage

The effect of housing type and feedlot capacity on capital outlays, annual cost and energy usage is shown in Table 10 and in Figs. 12-16. The results are summarized by each monetary and energy category. Feedlots 1-4 are compared in this analysis (see Table 9).[5]

Table 9. Specification of feedlots by technological components

Component	Feedlot Identification Number									
	1	2	3	4	5	6	7	8	9	10
A. Type of Housing										
Partial shelter, unpaved lot	X									
Partial shelter, paved lot		X								
Open, unpaved lot			X							
Completely covered				X	X	X	X	X	X	X
B. Type of Feed Storage										
Moist corn storage, tower silos for silage					X					
Moist corn storage, bunker silos for silage	X	X	X	X				X	X	X
Tower silos for silage						X				
Bunker silo for silage							X			
C. Type of Ratio										
All silage						X	X			
Corn and silage	X	X	X	X	X			X	X	X
D. Type of Waste Handling										
Liquid								X		
Solid	X	X	X	X	X	X	X		X	X
E. Type of Animal										
Calves									X	X
Yearlings	X	X	X	X	X	X	X	X		
F. Sex of Animal										
Steers	X	X	X	X	X	X	X	X	X	
Heifers										X

Land

Under the assumptions of this study, no economies of size for land were found for any of the feedlots analyzed. Differences were observed, however, in the land requirements for the various housing types for a given capacity size (Table 10). The open, unpaved lot (Feedlot 3) required the largest acreage and land/cwt of gain. The variation in land requirements observed in this study primarily result from variations in acreage required for producing crops. Crop yields and feed efficiencies largely determine land requirements.

Electricity

Economies of size were obtained for electricity consumption per cwt of gain for the four basic housing types (Fig. 12). Reduction in consumption with an increase in system capacity is due to the lighting energy being spread over more animals. The light specified for large units is assumed to be adequate to

[5] Feedlot 4 is used as the base feedlot for all comparisons.

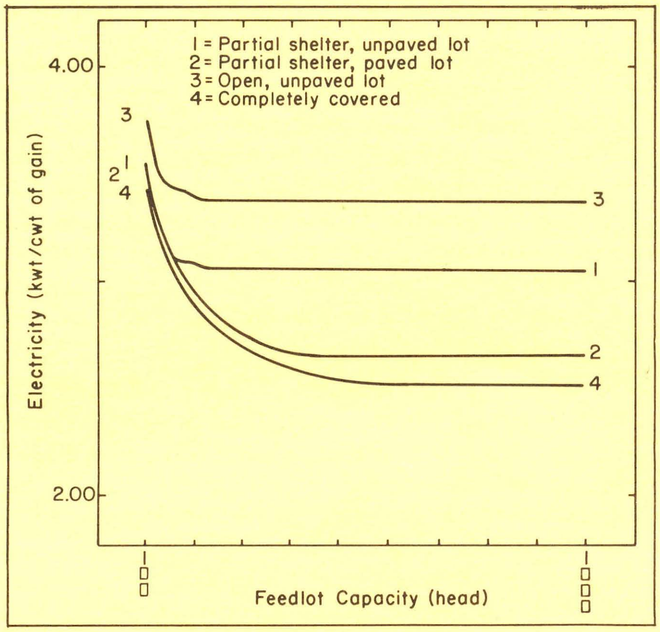

Fig. 12. Electricity requirements per cwt of gain by housing type and feedlot capacity.

light 1 acre of feedlot. One light was required for each complete acre or fraction of an acre.

Other electricity consumption for water pumping and feed handling is directly related to the amount of material used. Differences in energy consumption between systems shown in Fig. 12 result from the higher feed efficiency of the animals in the sheltered systems. The open unpaved lot had the highest electricity requirements, and the completely covered lot had the lowest electricity consumption per cwt of gain.

Electricity cost is small when compared with other monetary costs in the system. The typical electricity cost amounts to only about 23¢/head.

Table 10. Land requirements for 1,000-head capacity feedlots, by alternative housing technology

Feedlot identification number [a]	Total land (acres)	Cwt of gain	Land/cwt of gain (acres/cwt)
1 (partial shelter, unpaved lot)	1,051	8,395	.125
2 (partial shelter, paved lot)	1,051	8,395	.125
3 (open, unpaved lot)	1,069	7,847	.136
4 (completely covered)	1,051	8,577	.123

[a] See Table 9 for specification of feedlot components.

Fuel

Fuel consumption per cwt of gain for the four basic housing types is shown in Fig. 13. Diseconomies of size were noted for all housing types for fuel consumption.

Fuel is consumed for the field operations, in the feedlot, and for transportation. Variation in energy consumption with system capacity is attributable mostly to transportation. Fuel consumption per cwt of gain in the feedlot is a small percentage of the total and is nearly constant. Fuel per cwt of gain for field operations is also independent of capacity. Transport energy increases monotonically, but at an ever decreasing rate, because the required fractional increase in average transport distance is smaller than the fractional increase in system capacity. The major differences in fuel consumption between various housing types is attributable to differences in feeding efficiency. The open, unpaved lot had the highest consumption and the completely covered feedlot had the lowest consumption per cwt of gain.

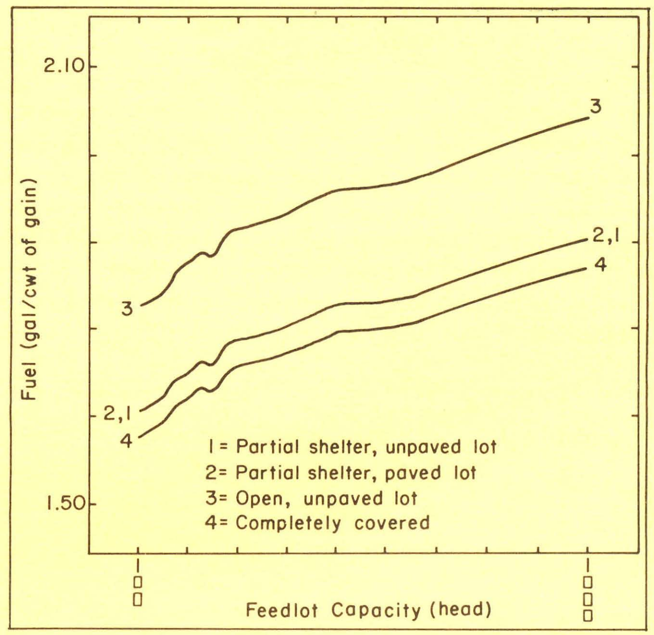

Fig. 13. Fuel requirements per cwt of gain by housing type and feedlot capacity.

Labor

Economies of size for labor were noted for the major housing types, but were realized mostly at low capacities (approximately 200-head capacity). Labor requirements were lowest for the fully sheltered systems and highest for the open systems because of feeding efficiency of the animals in the systems.

The shape of the labor requirement curves results from the use of labor by various parts of the system. For systems with low capacity, the administration time per cwt of gain is high, since total administra-

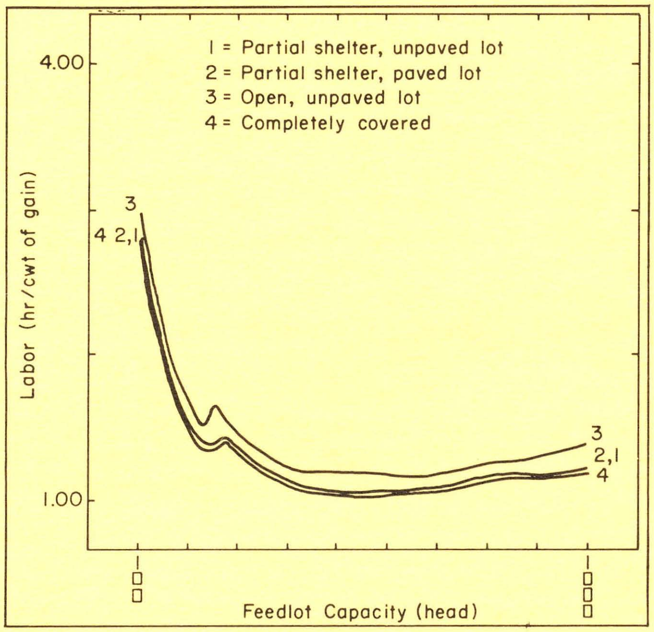

Fig. 14. Labor requirements per cwt of gain by housing type and feedlot capacity.

tion time is assumed to be constant for all systems. Field crop production labor per cwt of gain is high for small systems because small machines are used, which tends to spread machine use over the allowable subset time. At the upper end of the capacity range, the decrease in administrative labor is small. In this region, the upper limit on monetary size has been reached and there is no decrease in field labor requirements. The total labor increases after reaching a minimum, as shown in Fig. 14, because of increasing time required for transportation.

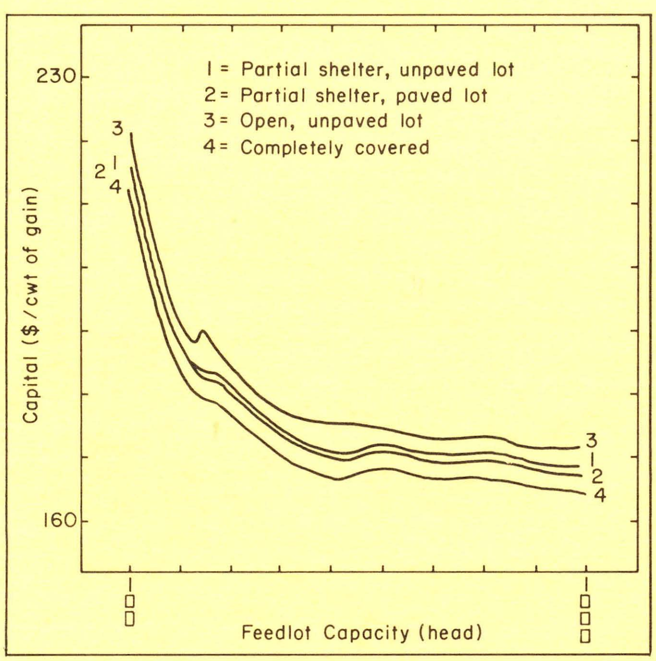

Fig. 15. Capital requirements per cwt of gain by housing type and feedlot capacity.

Capital

Economies of size were present for all major housing types, but were largely attained with 300-head capacity feedlots (Fig. 15). Small systems used small field equipment and small feed storages which tend to have higher initial costs/bu or ton of feed handled than the larger units. In some instances, the smaller feedlot does not fully utilize the capacity of the smallest item available. This high initial capital cost accounts for the high capital cost per cwt of gain for the small systems.

The largest and smallest capital per cwt of gain were required for the open feedlot and the completely covered feedlot, respectively. The partial shelter lots had capital requirements midway between the other two systems. Although the open lot had the lowest total capital requirement, the lower feed efficiency brought about by lack of shelter resulted in the lowest cwt of gain. Surprisingly, this resulted in a higher capital cost per cwt of gain than for the other housing types.

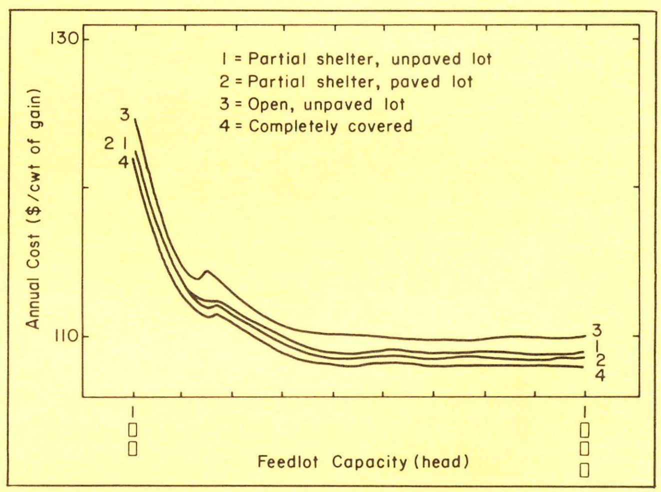

Fig. 16. Annual cost per cwt of gain by housing type and feedlot capacity.

Annual Cost

Annual cost includes all nominal costs of production. The lowest annual cost was for the confined, completely covered feedlot and the highest cost was for the open, unpaved lot (Fig. 16). The economies of size were largely exhausted at approximately 300-head capacity levels.

Prices assumed for this analysis were approximate 1972-1973 prices for inputs and products. Based on these price assumptions, the annual cost/cwt of animals sold would be approximately $36. This would be the break-even price required to cover the producer's annual costs.

Effect of Ration, Feed Storage System and Capacity of Feedlot on Capital Outlays, Annual Cost and Energy Usage

The effect of ration, feed storage system and feedlot capacities on capital outlays, annual cost and energy usage is shown in Figs. 17-21. Feedlots 4-7 were selected to illustrate the effect of ration and feed storage (Table 11).

Table 11. Land requirements for 1,000-head capacity feedlots, by ration and feed storage system

Feedlot identification number [a]	Total land (acres)	Cwt of gain	Land/cwt of gain (acres/cwt)
4 (moist corn storage, bunker silos for silage)	1,051	8,577	.123
5 (moist corn storage, bunker silos for silage)	1,022	8,577	.119
6 (tower silos for silage)	801	7,482	.107
7 (bunker silo for silage)	839	7,482	.112

[a] See Table 9 for specification of feedlot components.

Total land and land per cwt of gain were highest for Feedlot 4 and lowest for Feedlot 7 (Table 11). Feedlots using corn and silage rations required more acreage than feedlots using all silage rations. Because of higher silage losses in bunker silos, these silos required more land than tower silos.

Electricity

Economies of size were again noted for all feedlots. The systems using tower silos required more electric energy than bunker silo systems because of the extra load on the silo unloaders. Where bunker silos were used, the electrical energy consumption was higher for the system utilizing the mixed ration. This was expected because of the energy required for unloading and grinding corn. However, when tower silos were used, the electrical energy for handling the all-silage ration was higher than for the mixed ration because of the greater quantity of the material handled (Fig. 17).

Fuel

Fuel consumption is shown in Fig. 18. Again, diseconomies of size were noted for all systems. Systems with bunker silos require less fuel than tower silo systems. The packing operation consumes less energy than blowing silage into tower silos (the difference depends on silo height), but part of the advantage is lost in the energy expended to produce and transport the extra silage needed to compensate for higher bunker silo losses.

The mixed rations require more fuel/cwt gain than the all-silage ration. This result is not immediately

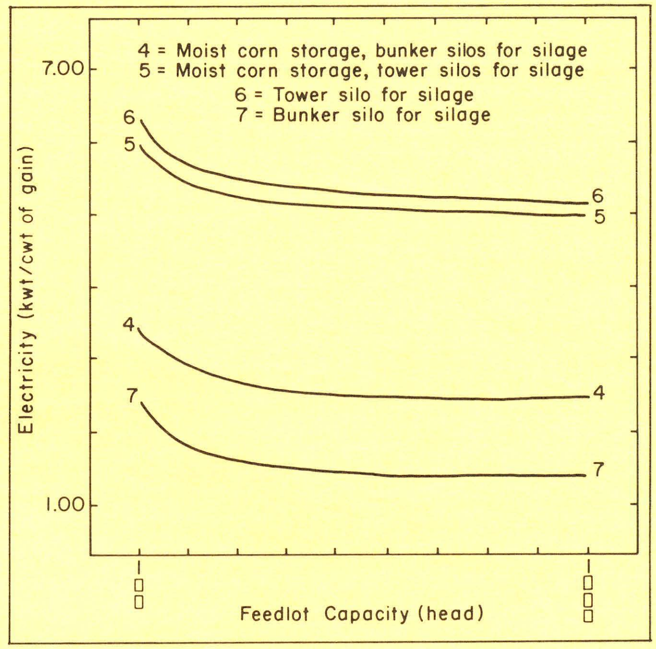

Fig. 17. Electricity requirements per cwt of gain, completely covered feedlot, by alternative rations and feed storage systems and feedlot capacity.

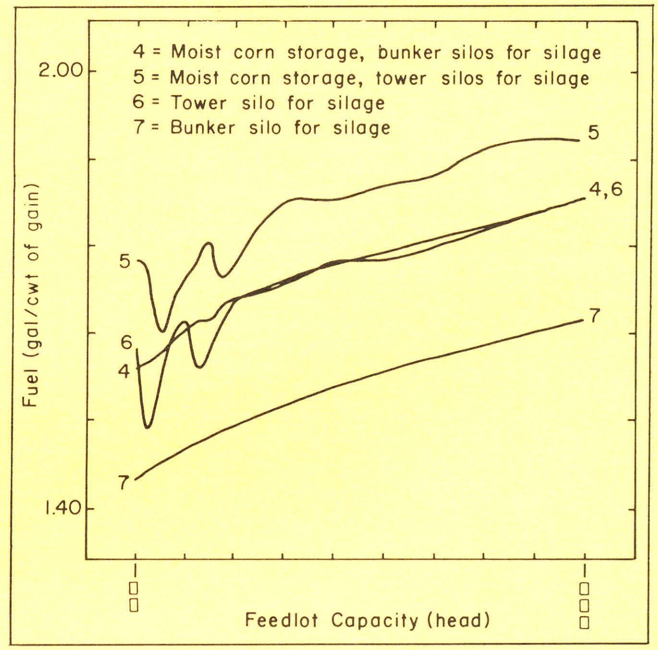

Fig. 18. Fuel requirements per cwt of gain, completely covered feedlot, by alternative rations and feed storage systems and feedlot capacity.

obvious as there are several factors involved. More fuel is used in tillage and planting for the mixed ration as approximately 9% more acreage of corn is involved. More transport energy is required for the silage ration. There is also a trade-off between silage chopping and corn combining. In the bunker systems, shelled corn is elevated, whereas the silage is not. The net result is a fuel advantage for the all-silage rations.

Labor

The plots of labor requirements show that for small systems the corn and silage ration requires the same or more labor as for all-silage rations, and for systems larger than 250-head capacity, the all-silage systems require more labor (Fig. 19). The higher labor requirement for the large all-silage systems results from two factors. More labor is required in the field to complete the harvest and more transport labor is consumed. The all-silage system requires more loads of silage than total loads of both feeds when the mixed ration is used.

Again, economies of size were noted but were largely utilized at 250-head capacities. However, diseconomies of size also eventually occurred because of transportation demands for labor.

Capital

Capital requirements are shown in Fig. 20. The all-silage system had the lowest capital requirements for all sizes if bunker silos were used. Because

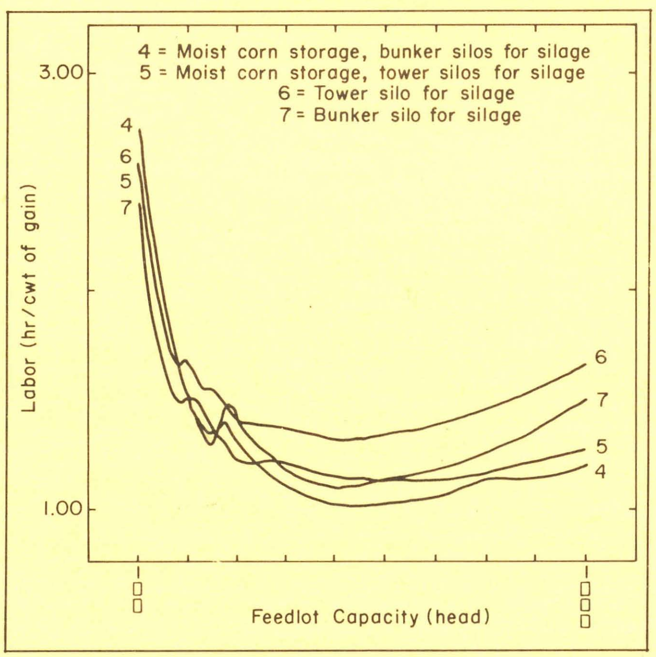

Fig. 19. Labor requirements per cwt of gain, completely covered feedlot, by alternative rations and feed storage systems and feedlot capacity.

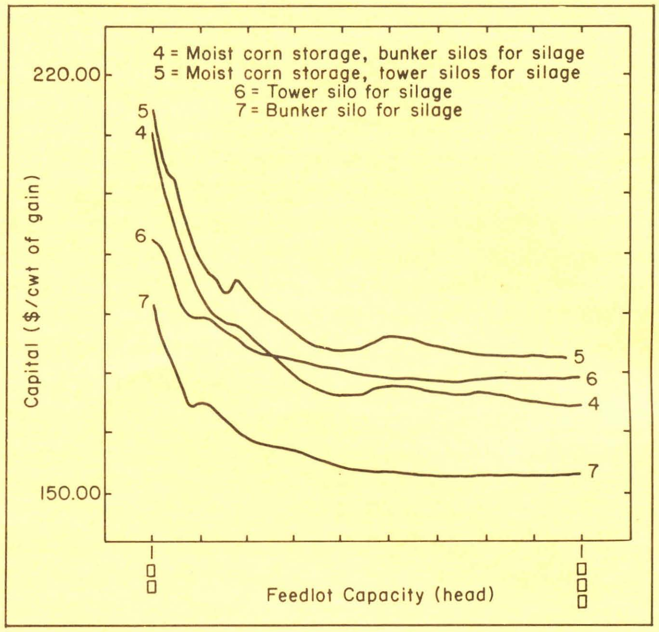

Fig. 20. Capital requirements per cwt of gain, completely covered feedlot, by alternative rations and feed storage systems and feedlot capacity.

of the greater land cropping required, the mixed ration requires more capital than the all-silage ration.

Annual Cost

The annual cost of beef production is lower for systems using bunker silos than for systems using tower silos for all capacities evaluated (Fig. 21). For most capacities, the mixed ration had a lower cost than the all-silage ration. Economies of size were again realized at low-capacity levels (approximately 200 head).

Effect of Waste System and Capacity of Feedlot on Capital Outlays, Annual Cost and Energy Usage

For the completely covered lot, liquid and solid waste handling systems were evaluated (Feedlots 4 and 8). The two systems are identical with the exception of the waste system.

Land

The two systems had identical land requirements (Table 12).

Electricity

The systems have approximately identical electricity requirements (Fig. 22). It is assumed that the liquid manure pump is powered by the feedlot tractor.

Fuel

The fuel requirements, as shown in Fig. 23, are higher for the liquid system. The additional liquid

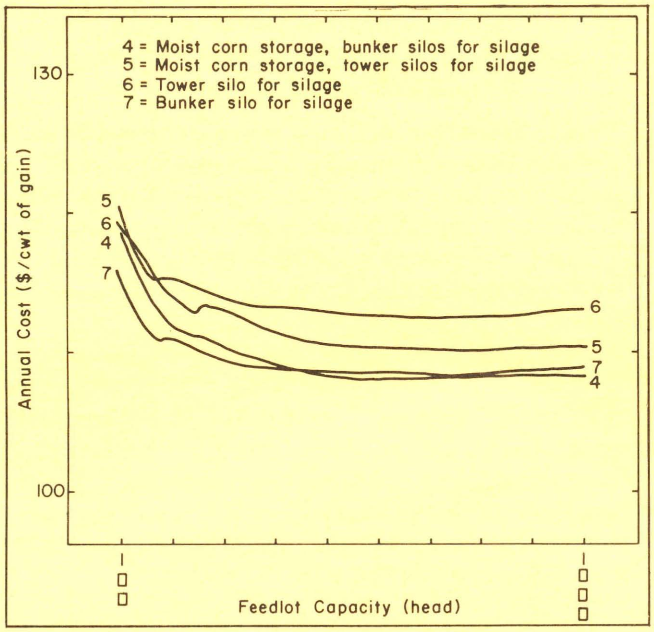

Fig. 21. Annual cost per cwt of gain, completely covered feedlot, by alternative rations and feed storage systems and feedlot capacity.

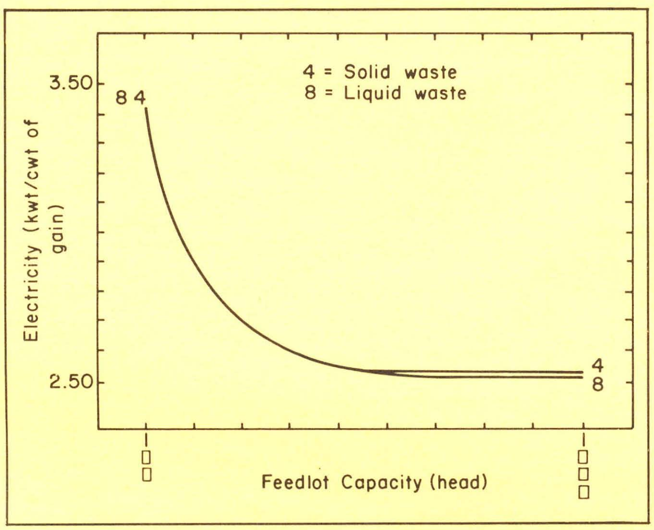

Fig. 22. Electricity requirements per cwt of gain, completely covered feedlot, by alternative waste systems and feedlot capacity.

Table 12. Land requirements for 1,000-head capacity feedlots, by alternative waste systems

Feedlot identification number [(a)]	Total land (acres)	Cwt of gain	Land/cwt of gain (acres/cwt)
4 (solid waste)	1,051	8,577	.123
8 (liquid waste)	1,051	8,577	.123

[(a)] See Table 9 for specification of feedlot components.

material which must be handled requires more energy for loading and transporting. (The reader should remember that the fuel required for commercial fertilizer production was not included in the analysis.)

Labor

The labor required for the liquid system is slightly higher than that for the solid system because of the greater transport effort needed for the liquid (Fig. 24). The irregularity in the labor curve at 275-head capacity occurs because of a change in the field machinery system and is not related to the waste handling systems.

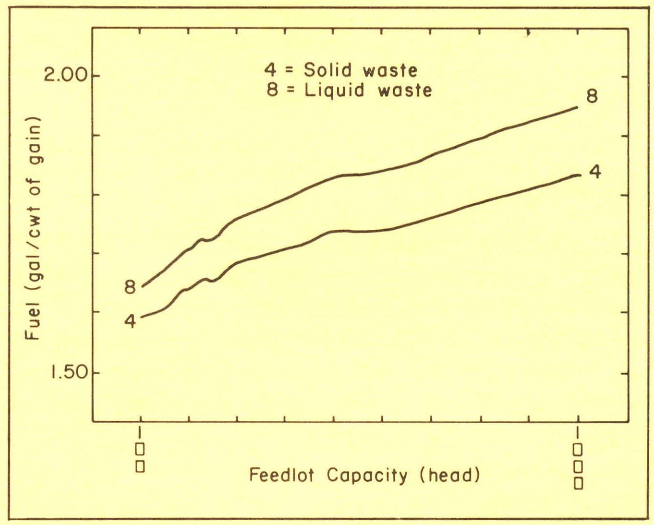

Fig. 23. Fuel requirements per cwt of gain, completely covered feedlot, by alternative waste systems and feedlot capacity.

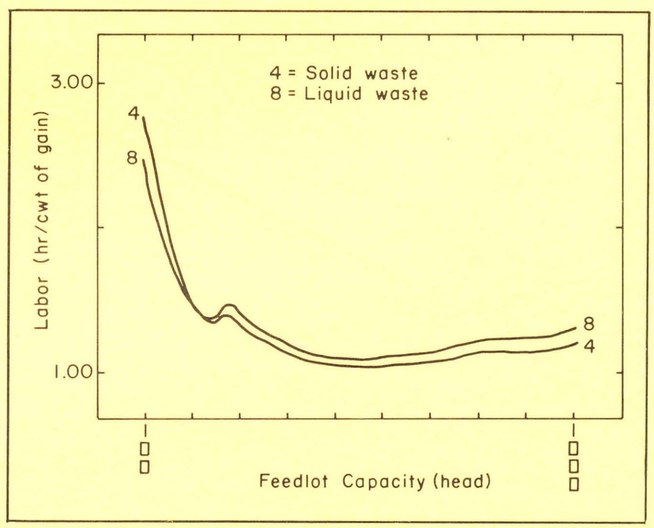

Fig. 24. Labor requirements per cwt of gain, completely covered feedlot, by alternative waste systems and feedlot capacity.

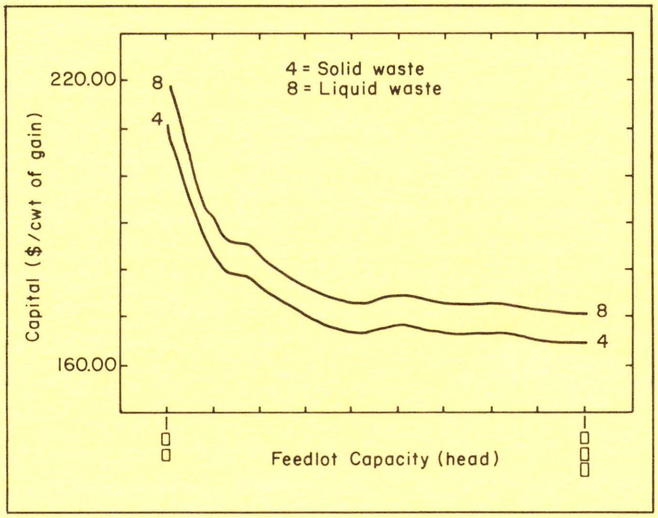

Fig. 25. Capital requirements per cwt of gain, completely covered feedlot, by alternative waste systems and feedlot capacity.

Capital

Capital requirements are higher for the liquid system for all levels of output (Fig. 25). The liquid tank, slotted floor and liquid manure pump are capital expenditures needed by the liquid system that are not required with a solid system. Also, since more liquid material is moved, extra spreaders may be required for some systems.

Annual Cost

The annual cost for producing beef is higher when the liquid manure system is used. The increased cost reflects the greater capital, labor and fuel requirements for the liquid system (Fig. 26).

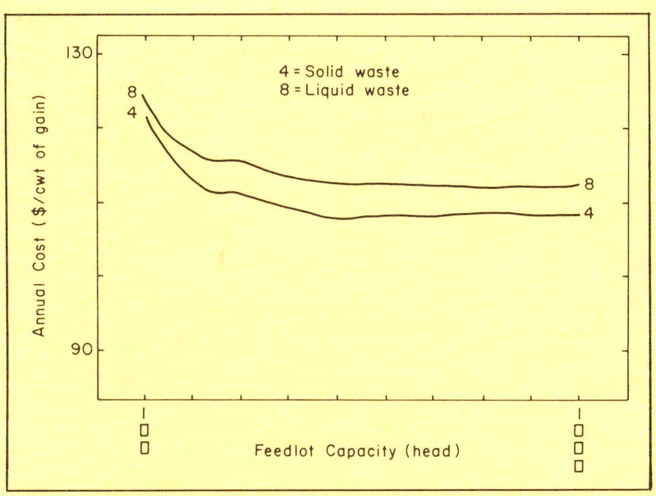

Fig. 26. Annual cost per cwt of gain, completely covered feedlot, by alternative waste systems and feedlot capacity.

Effect of Type and Sex of Animal and Feedlot Capacity on Capital Outlays, Annual Cost and Energy Usage

Two alternative systems were compared with Feedlot 4 to determine the effect of type and sex of animal (Feedlots 9 and 10). Feedlot 9 resembles Feedlot 4, except that calves are fed out instead of yearlings. Feedlot 10 is identical to Feedlot 4 except that heifer calves are fed out in place of yearling steers.

Electricity

Electricity requirements are higher for yearlings than for heifer calves, except for lots with less than 200-head capacity, where heifer calves have higher electricity requirements. Feedlots utilizing steer calves have the lowest electricity requirements for all capacity levels (Fig. 27).

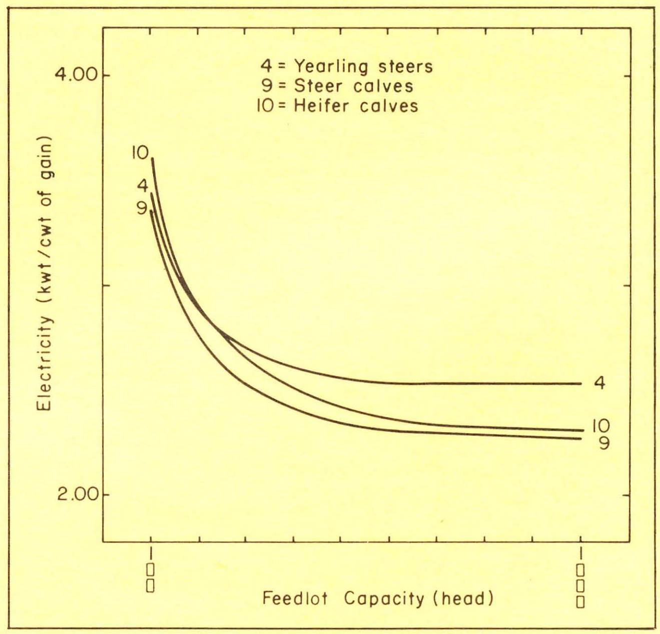

Fig. 27. Electricity requirements per cwt of gain, completely covered feedlot, by yearlings, steer calves, heifer calves and feedlot capacity.

Fuel

Fuel requirements are higher for yearlings for all capacity levels (probably because of feeding efficiencies). The lowest fuel requirements per cwt of gain are achieved by the system utilizing steer calves. Diseconomies of size are again shown for all types and sexes of animals (Fig. 28).

Labor

The technology requiring the least labor varies with the specific capacity level. Yearlings have the lowest labor requirements up to approximately 275

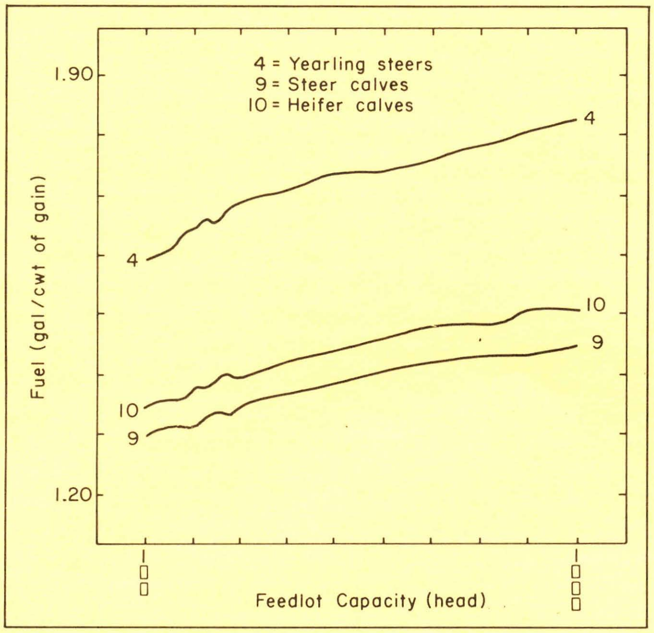

Fig. 28. Fuel requirements per cwt of gain, completely covered feedlot, by yearlings, steer calves, heifer calves and feedlot capacity.

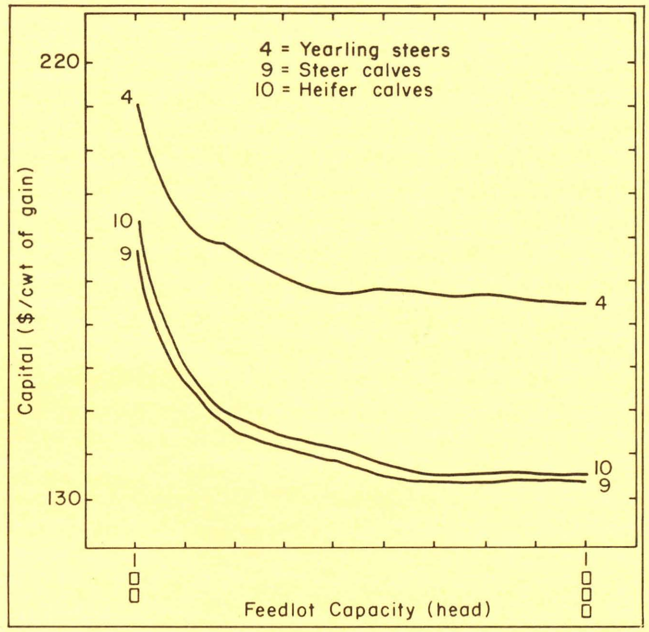

Fig. 30. Capital requirements per cwt of gain, completely covered feedlot, by yearlings, steer calves, heifer calves and feedlot capacity.

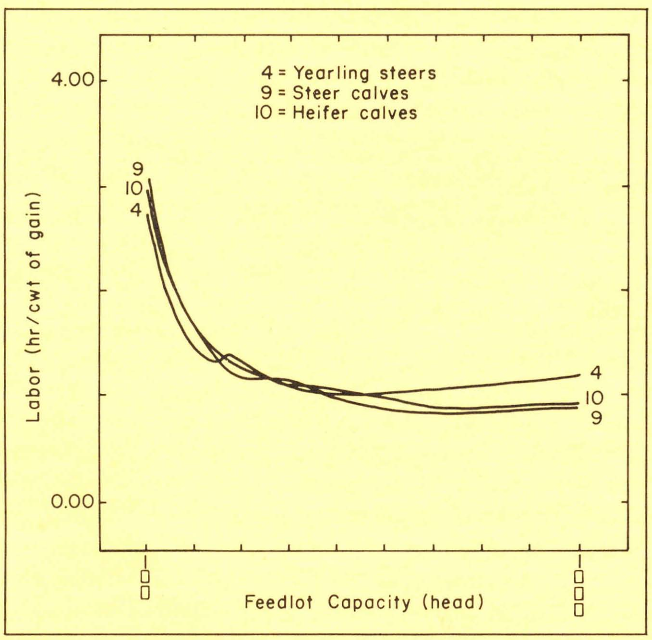

Fig. 29. Labor requirements per cwt of gain, completely covered feedlot, by yearlings, steer calves, heifer calves and feedlot capacity.

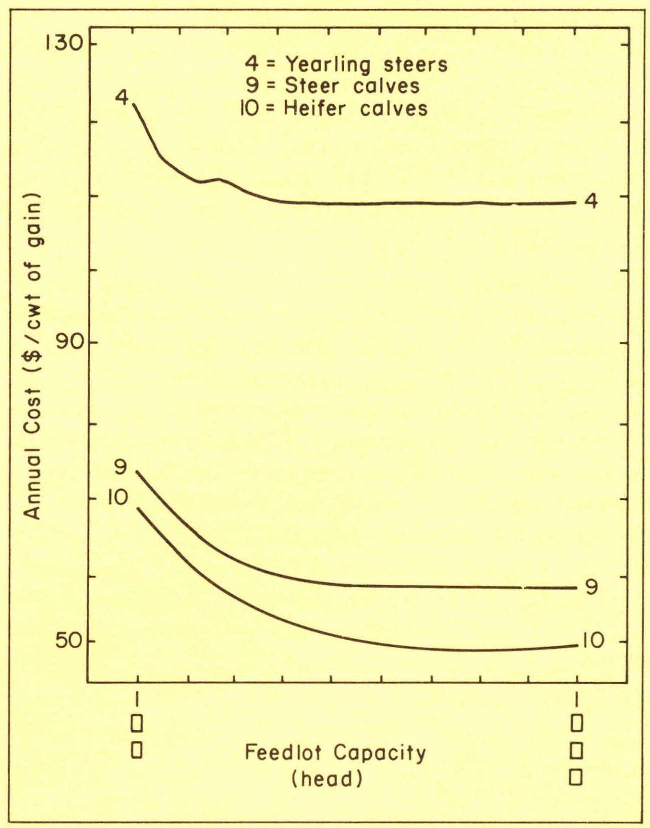

Fig. 31. Annual cost per cwt of gain, completely covered feedlot, by yearlings, steer calves, heifer calves and feedlot capacity.

head, but have the highest labor requirements at capacity levels of 600 head or greater. Steer calves have the highest labor requirements for low-capacity levels, and the lowest labor requirements for capacity levels of 500 head or greater (Fig. 29).

Capital

Yearlings have the highest capital requirements for all capacity levels because of the capital tied up with animals (Fig. 30). The lowest capital requirements for all capacity levels are for the system with steer calves.

Annual Cost

The inclusion of the cost of input animals in annual costs naturally led to a much higher cost per cwt of gain for the yearling system (Fig. 31). However, these annual costs do not necessarily favor the production of calves in the feedlot. At feedlot capacities where the economies of size have been virtually exhausted (300 head and greater), the average total cost/cwt of animals sold is approximately $36 for yearlings and $34 for steer calves, respectively. Thus, the cost/cwt of animals does not differ much for yearlings and calves (Table 13).

Table 13. Land requirements for 1,000-head capacity feedlots, by type and sex of animal

Feedlot identification number [(a)]	Total land (acres)	Cwt of gain	Land/cwt of gain (acres/cwt)
4 (yearling steers)	1,051	8,577	.123
9 (steer calves)	746	7,482	.0997
10 (heifer calves)	685	6,610	.103

[(a)] See Table 9 for specification of feedlot components.

ECONOMIC IMPACTS RESULTING FROM THE IMPOSITION OF SELECTED POLLUTION CONTROL MEASURES[6]

Amendments to the Federal Water Pollution Control Act in the Water Quality Act of 1965 provided a major impetus for the development of state water quality statutes and rules for their implementation. Provisions of the Water Quality Act of 1965 required each state to develop water quality standards applicable to interstate waters. Water quality standards were developed by states which identified streams and lakes according to use. Water bodies were classified for human consumption, industrial consumption, recreation and other definable uses. In addition, the states developed rules for implementing the use class standards.

A 1971 survey indicated that all major cattle-feeding states had water quality statutes establishing standards and rules for their implementation that were applicable to the management of feedlot wastes (16). Cattle feedlots were not explicitly cited in the water quality statutes of each state, but general implementation plans provided for the control of water quality problems associated with cattle feedlot production. All states had rules to control surface water pollution associated with feedlot production and waste handling facilities; several states had rules to control surface water pollution caused by application of feedlot wastes to land or by other means of disposal.

With increased concern about surface water pollution, the potential use of the Refuse Act of 1899 was recognized. With this act's focus on discharge, it was seen as an enforcement tool complementary to the stream quality provisions of the Water Quality Act of 1965. By executive order on Dec. 23, 1970, the President directed the establishment of a federal permit program. Effective July 1, 1971, certain cattle feedlots that discharged their wastes into navigable waters or their tributaries were required to apply for a permit.

Cattle feedlots required to obtain a permit were those with 1,000 head or more one-time capacity using man-made drains from which waterborne wastes were regularly discharged, where a flowing stream traversed the feeding areas or where there was a frequent overflow of a waste retention facility into surface waters. Runoff from production facilities due only to natural causes was not considered a discharge.

On Dec. 21, 1971, the Refuse Act permit program was suspended through court action for a variety of legal reasons. Subsequently, the U.S. Environmental Protection Agency was given authority to administer another permit program for cattle feedlots.

The Federal Water Pollution Control Act Amendments of 1972 provide direct authority for the U.S. Environmental Protection Agency to specify effluent guidelines for point source dischargers contributing to water pollution, develop a permit program for effluent guidelines implementation, and announce acceptable methods and practices to effect control of nonpoint sources of water pollution. Cattle feedlots were identified in these amendments as one category of point source dischargers. Nonpoint sources of water pollution, including agriculture, were identified.

Final effluent limitations guidelines for beef feedlots with point source discharges were announced by the Environmental Protection Agency in February 1974. For existing beef feedlot operations with capacities of 1,000 head or more, these require:

1. After the application of the best practicable control technology available on or prior to July 1, 1977, there shall be no discharge of wastewater pollutants to navigable waters except that

[6] This section is largely based on the Ph.D. thesis by Forster (11).

process waste pollutants in the overflow may be discharged to navigable waters whenever rainfall events, either chronic or catastrophic, cause an overflow of process wastewater from a facility designed, constructed and operated to contain all process generated wastewaters plus the runoff from a 10-year, 24-hour rainfall event for the location of the point source.

2. After the application of the best available technology economically achievable on or prior to July 1, 1983, there shall be no discharge of wastewater pollutants to navigable waters except that process waste pollutants in the overflow may be discharged to navigable waters whenever rainfall events, either chronic or catastrophic, cause an overflow of process wastewaters from a facility designed, constructed and operated to contain all process generated wastewaters plus the runoff from a 25-year, 24-hour rainfall event for the location of the point source.

The effluent guidelines went into effect on April 15, 1974. Existing feedlot firms are expected to make adjustments towards achieving the technology levels prescribed for 1977 and 1983. New feedlots entering the beef feeding industry (or existing feedlots making substantial revisions in their physical production facilities) are expected to employ the best available technology economically achievable. Where the individual situation of a particular discharger dictates, regional administrators of the Environmental Protection Agency or state pollution agencies can adjust the requirements of the effluent limitations guidelines for existing beef feedlots and standards of performance for new feedlots.

Pollution Control Measures Considered

The water pollution control rule alternatives considered in this analysis are those that might be employed by state and federal agencies to regulate externalities generated from beef production. The alternatives considered were:

A. EPA effluent guidelines limitations (and standards of performances) for beef feedlots which were announced in February 1974 would be expanded to all beef feedlots. Facilities must be constructed and operated to control runoff from a local 10-year, 24-hour storm and process generated wastewater by 1977.

B. All beef feedlots must construct and operate facilities by 1977 to control runoff from a local 25-year, 24-hour rainfall and process generated wastewaters.

C. All beef feedlots must construct and operate facilities by 1977 to control all runoff from the rainfall occurring in any 6-month interval.

D. All beef feedlots must construct and operate facilities by 1977 to control all runoff from rainfall occurring in any 6-month interval. Additionally, the feedlot may not spread solid (or slurry) feedlot wastes during winter months.

Rules A and B are based on the Environmental Protection Agency announced rules for control of point source discharges from beef feedlots. Rule C closely follows the practices being followed by feedlot operators in the more humid states who have invested in technology for the control of runoff from feedlot production facilities. Regional administrators of the Environmental Protection Agency, in cooperation with state pollution control agencies, can be expected to encourage the use of control facilities with several months' storage capacity in localities where winter application of feedlot runoff would be on frozen or snow-packed farmlands.

Rule D is a composite rule for controlling runoff from feedlot facilities and for controlling runoff from waste-treated farmland. The latter portion of the rule is implied in a set of acceptable methods and practices recently announced by the Environmental Protection Agency for controlling runoff from waste-treated land. In essence, this latter portion of Rule D requires the feedlot operator to store waste solids during those periods of the beef production cycle when disposal of such wastes would result in waste application on wet, steep, frozen or snowcovered land.

Representative Feedlot Situations Considered

It is expected that the implementation of alternative rules for water pollution control will have differential economic effects on beef feedlots. The capital outlays required for adjustment and the ensuing changes in production costs will, in large part, be dependent on the size of the feedlot and the production technology in use. Feedlots 1, 2, 3, 4 and 8, as specified in Table 9, were considered in this analysis. The drylot paved, drylot unpaved and open lot feedlots may require runoff abatement control to contain runoff from exposed feeding areas. For each of these five feedlots, three capacity levels were considered: 100, 500 and 900 head.

Economic Impacts

The economic impacts of alternative rules for pollution control are partially determined by the economic characteristics of the beef feedlot prior to rule implementation. Under the general assumption that individual feedlot operators are price takers in the product market (fed beef) and in the input markets (feeder cattle and other off-farm supplied inputs), the changes in firm profit conditions after rule implementation will depend in part on industry changes in such markets. In addition, the means of implementing a rule can have differential effects on profit and cost situations even in the absence of any product or input price changes.

The investment outlays of representative firms are characterized, based on 1974 replacement values, prior to any rule implementation (Table 14). As will be noted, there are investment economies which accrue as feedlot capacity increases within any particular housing technology. Within any particular feedlot capacity, the open lot type of housing requires the lowest investment per head.

Table 14. Investment per head of capacity in beef feedlot facilities and equipment, by feedlot capacity and housing type, 1974 replacement values[a]

Housing type	Capacity (head)		
	100	500	900
Drylot paved	$336.50	$255.23	$253.78
Drylot unpaved	$320.57	$238.74	$237.23
Open lot	$268.91	$186.00	$184.37
Confinement, solid floor	$346.72	$265.99	$264.58
Confinement, slotted floor	$436.83	$334.17	$328.15

(a) These investment estimates include the feedlot structures, feeding equipment, manure handling equipment, and feed storage structures prior to the application of any water pollution control rules. The feed storage system included in these estimates is tower silos. If the alternative of bunker storage facilities was considered, these estimates would not be altered appreciably.

The average total costs per head of fed-beef production are influenced by the level of per head investment in production facilities and the efficiencies achieved in the use of these facilities. Housing systems with the lowest per head investments (Table 14) do not necessarily achieve the lowest average total cost per head of fed-beef production (Table 15).

Through the imposition of the alternative rules for water pollution control, capital outlay requirements and production cost changes accrue to these representative beef feedlot firms. The following sections discuss incremental changes in capital outlays and production costs attributable to implementation of the alternative rules.

Incremental Capital Changes

The implementation of the alternative rules for runoff control at feedlot storage and the initiation of winter storage of solid wastes (or slurry) to eliminate potential field runoff can be expected to have differential impacts on the investment requirements of existing beef feedlots. The capital outlays for necessary control equipment will vary for each rule by housing type and feedlot capacity (Table 16).

Table 15. Average total cost per head marketed, by feedlot capacity and housing type, 1974 input prices [a]

Housing type	Capacity (head)		
	100	500	900
Drylot paved	$502.89	$400.16	$390.10
Drylot unpaved	$501.77	$399.00	$388.94
Open lot	$527.06	$412.86	$401.68
Confinement, solid floor	$508.72	$406.12	$396.09
Confinement, slotted floor	$512.17	$407.49	$404.71

(a) These cost estimates are based on a "whole-farm" synthesis approach. In addition to the ownership and operation of components for which investment estimates were made in Table 14, these cost estimates would also include the ownership charges for facilities and equipment and operating expenses for crop production, feed harvesting and transport activities.

Table 16. Additional capital outlays per head capacity required to comply with alternative water pollution control rules by housing type and feedlot capacity, 1974 prices

Water Pollution Control Rule and Housing Type [a]	Capacity (head)		
	100	500	900
A. Control of runoff from 10-year, 24-hour storm:			
Drylot paved	$26.56	$ 6.86	$ 4.55
Drylot unpaved	$32.33	$12.17	$ 9.76
Open lot	$34.72	$14.42	$11.98
B. Control of runoff from 25-year, 24-hour storm:			
Drylot paved	$26.73	$ 6.99	$ 4.67
Drylot unpaved	$32.98	$12.64	$10.21
Open lot	$35.43	$15.04	$12.58
C. Control of runoff from a 6-month interval of rainfall:			
Drylot paved	$28.20	$ 8.17	$ 5.78
Drylot unpaved	$38.01	$17.15	$14.60
Open lot	$42.07	$20.96	$18.35
D. Requirement for winter storage of solid wastes (or slurry):			
Drylot paved	$ 0.96	$ 3.45	$ 2.34
Drylot unpaved	$ 0.78	$ 3.27	$ 2.17
Open lot	$ 0.60	$ 0.68	$ 2.06
Confinement, solid floor	$ 2.27	$ 4.76	$ 3.44
Confinement, slotted floor	$ 6.81	$ 6.13	$ 4.03

(a) Confinement facilities are not expected to have serious runoff problems. Therefore, the confinement housing types (solid and slotted floors) were not considered under rule alternatives A, B and C.

A four-component system was considered for the control of runoff from feedlot facilities. The system consists of diversion terraces, a settling basin, retention pond and pump-irrigation equipment to accommodate the spreading of runoff onto farmland. Length of diversion terraces is primarily a function of the physical configuration of the feedlot. Settling basin size is largely a function of the area of exposed feedlot areas. Only the capacities of retention ponds and the pump-irrigation equipment are influenced by the magnitude of the rainfall. Because of the indivisibilities in pump-irrigation equipment, increases in pump capacity for a feedlot of a given area were not evident over the range of rainfall events considered.

The analysis assumes each feedlot firm would be required to achieve runoff control through the use of the four-component system (in essence, this is rule implementation by regulation). There are obvious internal design economies for the diversion terraces and retention ponds, and indivisibilities in available pump-irrigation equipment. Capital outlays per head of feedlot capacities reflect these economies and indivisibilities.

Economies of size are realized in capital outlays for feedlot runoff control facilities. Within any particular housing type, capital outlays per head decrease as feedlot capacity increases.

For rules A, B and C, the per head investment is least for drylot paved systems within each capacity level. This is expected because typical drylot paved systems require less square footage (per animal) of area exposed to rainfall than drylot unpaved and open lot systems.

Rule D, requiring the winter storage of waste solids (or slurry), tends to require lower per head capital outlays by small-capacity feedlots than those incurred in large-capacity beef feeding operations. As feedlot capacity increases, the limited time period available for field spreading increases the capital requirements for waste loading and spreading equipment. The winter storage requirement requires comparatively large capital outlays for those systems handling manure as a slurry; i.e., the slotted floor confined systems. The additions of winter storage for such systems require the construction of additional waste holding pits.

Changes in Production Costs

The previous section demonstrated the differential effects that imposition of water pollution control rules would create for existing beef feeding operations with varying housing types and feedlot capacities. Differential effects, in the costs of ownership and operation of control facilities, can be expected by feedlot firms.

Table 17. Increases in average total costs per head marketed annually attributable to compliance with alternative water pollution control rules by housing type and feedlot capacity, 1974 prices

Water Pollution Control Rule and Housing Type [a]	Capacity (head)		
	100	500	900
A. Control of runoff from 10-year, 24-hour storm:			
Drylot paved	\$4.65	\$1.19	\$0.73
Drylot unpaved	\$5.09	\$1.61	\$1.13
Open lot	\$5.88	\$1.98	\$1.45
B. Control of runoff from 25-year, 24-hour storm:			
Drylot paved	\$4.67	\$1.20	\$0.74
Drylot unpaved	\$5.16	\$1.66	\$1.18
Open lot	\$5.95	\$2.05	\$1.52
C. Control of runoff from a 6-month interval of rainfall:			
Drylot paved	\$4.80	\$1.31	\$0.85
Drylot unpaved	\$5.64	\$2.09	\$1.59
Open lot	\$6.66	\$2.68	\$2.11
D. Requirement for winter storage of solid wastes (or slurry):			
Drylot paved	\$0.29	\$0.41	\$0.41
Drylot unpaved	\$0.32	\$0.41	\$0.42
Open lot	\$0.31	\$0.45	\$0.46
Confinement, solid floor	\$0.35	\$0.42	\$0.42
Confinement, slotted floor	\$0.57	\$0.54	\$0.42

(a) Confinement facilities are not expected to have serious runoff problems; therefore, there are no changes in costs for runoff control for these systems.

In the absence of water pollution control rules, drylot unpaved housing systems would have the lowest average total costs per head of beef marketed for each capacity level considered (Table 15). However, when rules that require control of runoff at feedlot facilities are implemented, additional costs are greatest for open lot systems and least for drylot paved housing systems within each capacity level (Table 17).

The effects of changing the rainfall event are minimal. For instance, the control of runoff from a 10-year, 24-hour rainfall would increase costs per head marketed by \$5.88 for an open lot system with 100 head; for a feedlot of identical capacity and housing type, control of runoff from rainfall over a 6-month interval would increase per head costs to \$6.66, or \$0.78 more than the 10-year, 24-hour rainfall (Table 17).

As the cost increases per head marketed for control of feedlot facility runoff, some existing feedlots may be expected to cease production. Existing feedlots that install and construct runoff control facilities will generally do so with no modification of their existing housing systems.

Through time, as existing feedlots replace housing systems, consideration will be given to housing systems which are economically efficient and compatible with environmental constraints. New producers of fed-beef will give similar consideration to such factors in the selection of housing systems. For instance, current Environmental Protection Agency rules require firms building new feedlots to adopt the best available technology currently achievable; i.e., to comply with Rule C. A new producer will have to consider both the capital outlays and production costs associated with alternative housing systems. For a producer interested in a 500-head capacity operation, the following calculations would guide him in his choice between two alternatives — drylot paved and confinement, solid floor:

Capital and Cost Items	Drylot Paved	Confinement, solid floor
Initial capital outlay	$ 255.23	$ 265.99
Capital outlay for runoff control	6.93	0
Total capital outlay per head	$ 262.16	$ 265.99
Cost per head without runoff control	$ 400.16	$ 406.12
Additional cost for runoff control	1.20	0
Average total cost per head marketed	$ 401.36	$ 406.12

For the two alternatives considered, and on the basis of static economic evidence a new firm would select the drylot paved system. Total capital outlays per head capacity are about $4 less for the drylot paved system than for the confinement system. Likewise, the average total costs per head marketed are nearly $5 less for the drylot paved system. However, small adjustments on turnover rates or small changes in input prices for feeder calves could alter these relationships. In essence, the firm considering the use of these two systems would be indifferent. Planners interested in advising on such decisions can employ the basic capital outlay and production cost estimates presented (Tables 14-17).

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Appendix Table 3. Chemical characteristics of manure from feedlots in southern Michigan with paved drylot system[a]

	No. of Samples	Organic Matter %	Kjeldahl N %	Total P %	Total K %	Total Ca %	Total Mg %	Total Na %	Total Fe %	Total Mn ppm	Total Zn ppm	Total Cu ppm	EC mmho/cm	pH
DRY LOT (PAVED)														
OLD MANURE:	18													
Range		17-52	1.56-3.19	.30-1.31	1.28-3.81	.73-1.93	.41-.65	.16-.64	.049-.76	60-251	65-283	12-39	3.10-10.0	5.4-9.0
Average		30	2.47	.67	2.18	1.10	.53	.38	.26	144	104	23	6.40	7.3
C.V. (%)		31	17	35	32	27	13	38	138	46	46	33	32	17
FRESH FECES:	18													
Range		14-31	1.40-3.06	.56-1.53	.76-1.65	.58-1.40	.26-.61	.12-.41	.052-.15	85-213	72-401	12-100	2.30-4.40	4.2-8.4
Average		22	2.08	.91	1.20	.98	.40	.24	.089	134	134	33	3.40	6.4
C.V. (%)		20	18	27	20	25	24	31	37	31	64	58	19	26

[a] Organic matter is on a wet weight basis and nutrients are on a dry weight basis.

Appendix Table 4. Chemical characteristics of manure feedlots in southern Michigan with total confinement systems[a]

	No. of Samples	Organic Matter %	Kjeldahl N %	Total P %	Total K %	Total Ca %	Total Mg %	Total Na %	Total Fe %	Total Mn ppm	Total Zn ppm	Total Cu ppm	EC mmho/em	pH
TOTAL CONFINEMENT														
OLD MANURE:														
SLOTTED FLOOR	4													
Range		15-36	2.22-2.83	.69-.89	1.93-3.41	.60-1.04	.48-.63	.09-.24	.066-.071	64-75	65-94	14-17	5.40-6.90	6.9-8.0
Average		22	2.56	.75	2.57	.81	.54	.17	.069	70	83	16	6.30	7.6
C.V. (%)		43	10	13	28	27	15	44	3	8	19	10	10	7
PAVED BEDDINGS	23													
Range		18-49	1.36-4.39	.15-1.08	1.55-4.02	.98-6.50	.37-247	.05-.69	.038-3.31	68-4.240	41-310	15-107	3.80-12.0	6.5-9.3
Average		28	2.77	.63	2.56	1.74	.70	.33	.30	418	130	32	6.43	8.4
C.V. (%)		26	30	48	29	67	67	53	86	216	44	68	30	8
FRESH FECES:	23													
Range		16-30	1.31-3.14	.26-1.10	.55-1.68	.71-2.86	.21-.72	.08-.51	.036-.22	52-336	86-281	13-83	2.20-8.20	4.2-8.3
Average		20	2.25	.68	1.15	1.45	.43	.24	.087	144	144	30	3.20	7.1
C.V. (%)		19	25	42	27	36	31	49	47	46	51	55	40	16

[a] All organic matter is on a wet weight basis and nutrients are on a dry weight basis.

Appendix Table 5. Relationship between animal type, housing type and ration

	CALVES Housing Type			CALVES Housing Type		
Item	**Open lot**	**Partial shelter**	**Complete shelter**	**Open lot**	**Partial shelter**	**Complete shelter**
Initial Weight (lb)	450	450	450	750	750	750
Final Weight (lb)	1050	1050	1050	1150	1150	1150
Ration 1						
Daily Corn (lb)	---	---	---	---	---	---
Daily Silage (lb)	45.23	44.06	44.06	65.10	63.70	63.70
Average Daily Gain (lb/day)	1.55	1.75	1.80	1.85	2.00	2.05
Ration 2						
Daily Corn (lb)	6.40	6.40	6.40	8.20	8.20	8.20
Daily Silage (lb)	32.80	31.60	31.60	49.10	47.70	47.70
Average Daily Gain (lb/day)	1.80	2.00	2.05	2.15	2.30	2.35

2-76—5M