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Contents

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Summary

1. Total solids content averaged 26.7% wb for high and low roughage ration feces, 19.3% wb for medium roughage ration feces, and 21.7 and 45.2% wb for manure from housed and outdoor feedlots, respectively.

2. Volatile solids increased inversely with ration roughage content and decreased with particle size. Volatile solids were 86.9%, 89.4%, and 93.9% db for feces from cattle fed high, medium, and low roughage rations. Manure from housed and outdoor feedlots were 85.8% and 24.0% volatile, respectively.

3. Thirty-five to 40% of voided solids from cattle fed HR, MR, and LR rations were greater than 500 microns in size; while 19.5%

and 8.6% of the manure from HF and OF waste were retained on a 500-micron screen.

4. Gross energy averaged 4469 cal/gm for HR, MR, LR ration and HF waste and 980 cal/gm for OF waste.

5. Digestibility of voided solids from HR, MR, and LR ration fed cattle was 27.4%, 36.4% and 61.5% of the total solids, respectively. The less than 53-micron fraction was two times more digestible than the unsieved waste for the LR ration and HF solids. The HR ration solids digestibility was low for all fractions except 53 micron.

6. Protein and fat content of the less than 53-micron fraction was 1.7 and 1.98 times greater, respectively, than those of the unsieved waste. Crude fiber increased with ration roughage content. The less than 53-micron crude fiber content was less than 30% that of the unsieved waste.

7. The less than 53-micron fraction contained 1.5 to 2.1 times more N than the unsieved waste, while the concentration of P in the less than 53-micron fraction was less than 60% of unsieved waste. Total carbon was not affected by ration roughage content. Total carbon averaged 35% of the volatile solids concentration for the HR, MR, and LR ration feces and 47% for the HF manure.

8. The chemical oxygen demand (COD) of beef cattle waste was not affected by the ration roughage content.

9. The ration roughage content did not have a predictable effect on the element content of waste. The element content for the less than 53-micron fraction was 1.2 to 2.5 times higher than for the unsieved waste.

10. Recycling animal waste as feed is limited by the quantity of digestible solids and would appear useful for high roughage content rations.

11. All nutrients and elements except digestible solids, fat, and Mn are available in sufficient quantities to satisfy the daily requirements for finishing cattle.

12. An estimated two tons of dry waste from HR ration cattle and OF, and one dry ton of MR and LR ration waste applied to cropland contains sufficient nutrients to yield one ton of dry corn plant based on N content.

13. Animal waste is a nutrient source for plants and animals by recycling to cropland and feed rations, respectively.

14. Separating solids greater than 500 microns will improve material handling techniques by reducing plugging and distribution problems for field spreading by irrigation techniques, and the solids separated may be transported by conventional loading and hauling equipment.

Nutrient and Energy Composition Of Beef Cattle Feedlot Waste Fractions

C. B. Gilbertson, J. A. Nienaber, J. R. Ellis, T. M. McCalla, T. J. Klopfenstein, and S. D. Farlin[1]

Introduction

The cattle feeding industry is growing in numbers of animals fed annually and per feedlot. This expanding industry faces increased waste management problems. Research has emphasized water-treatment techniques as a means of waste management and pollution control (19, 32). The emphasis on energy and food conservation has increased the awareness that cattle feedlot waste is a "by-product" with unknown recoverable properties.

Animal waste was used as fertilizer until commercial fertilizer made field application uneconomical (31). Concentration of animals and larger feeding units have caused "disposal" problems. Large quantities of waste are being applied to cropland to enhance crop production and to provide sanitary disposal (13, 14).

Other research stresses "recycling" waste through animals. Published research results are available for poultry waste as a feed supplement (7, 9, 11, 15, 16, 17, 23, 26, 29, 34). Published information is not as extensive for swine and beef waste refeeding (2, 6, 10). Harmon and Day (22) have shown that aerobically treated swine waste may be fed to pigs without serious problems. Other research has been started to determine profitable areas in which to market beef cattle manure (36).

Anthony (1, 3) has completed a research study on refeeding cattle manure to steers as wastelage. All the manure generated may be refed in this manner, since dry hay is mixed with manure to reduce the moisture content to a level for ensiling (3, 4, 5). Materials handling and processing equipment must be developed into a system(s) before recycling waste as part of a ration (18).

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This bulletin describes nutrient and energy composition of beef cattle waste fractions as a function of the ration roughage level and type of feedlot. Results can be used to plan engineering system approaches and research to develop handling and processing equipment necessary for recovery of the most valuable portion of waste.

Procedures

Sampling

High-, medium-, and low-roughage ration feces (HR, MR, and LR) were collected from animals fed in metabolism crates.[2] Thymal was mixed with the feces to prevent decomposition and mold growth (18).

During December 1972 through May 1973, samples of diluted manure were obtained from a 96-head capacity, open-front, housed feedlot (HF). Samples of outdoor feedlot (OF) waste were obtained from research lots during June and November 1972 cleanings. The HF and OF cattle were fed at the University of Nebraska Field Laboratory near Mead, Nebraska. All samples were frozen until tested. Ration compositions fed are summarized in Table 1.

Laboratory Analysis

Total solids (TS), fixed solids (FS), and volatile solids (VS) were determined using procedures outlined in Standard Methods (33) except the drying temperature was lowered to 75C to reduce volatile solids loss (12).

Particle size distribution was determined by wet sieve analysis using 2000, 1000, 500, 250, 105, and 53 micron sieves (18). The dry solids retained in each sieve and the dry solids passing the 53 micron sieve were accumulated in individual containers for analysis. Subsamples of the dry solids fractions were analyzed for FS, gross energy (E), in vitro dry matter digestibility (IVDMD), feedstuff (crude protein, fat, and fiber), chemical characteristics [Kjeldahl nitrogen (N), nitrate nitrogen ($\overset{-}{NO_3}$-N), ammonia nitrogen ($\overset{+}{NH_4}$-N), total phosphorous (P), total carbon (C), chemical oxygen demand (COD)], and elements [potassium (K), calcium (Ca), sodium (Na), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu)].

Gross energy was determined by procedures outlined by the Calorimeter Manufacturers (24). Standard procedures were used to determine IVDMD (35) and crude protein, fat and fiber (27). Nitrogen, $\overset{-}{NO_3}$-N, $\overset{+}{NH_4}$-N, and COD were determined using Standard

[2] For purposes of this paper, "manure" will be referred to as a feces, urine, and dilution water mixture. "Waste" is a combination of feces, urine, precipitation and soil from outdoor feedlots.

Table 1. Composition of beef cattle rations.

Ration fed	% db	Ration analysis: Protein	Crude fiber
		- - - - - % db	- - - - -
High Roughage Ration			
Chopped Brome Hay	100	8.26	32.00
Medium Roughage			
Corn Silage	100	9.32	18.00
Low Roughage		12.37	5.50
Urea	1.00		
Corn	82.45		
Corn cobs	10.00		
Molasses	5.00		
Potassium chloride	0.13		
Dicalcium phosphate	0.07		
Limestone	0.80		
Salt	0.50		
Trace minerals	0.03		
Vitamin A & D premix	0.018		
Housed Feedlot (Low Roughage)		12.00	5.76
Dec. 1972/May 1973			
Corn	85.27		
Hay	10.00		
Molasses	2.50		
Urea	0.80		
Salt	0.30		
Limestone	0.70		
Dicalcium phosprate	0.40		
Trace Minerals	0.03		
Vitamin A & D premix	+		
Outdoor Feedlots (Low Roughage)		12.00	4.37
May 1972/October 1972			
Corn	87.77		
Corn silage	10.00		
Urea	0.80		
Salt	0.30		
Limestone	0.70		
Dicalcium phosphate	0.40		
Trace Minerals	0.03		
Vitamin A	+		

Methods (33), P by the vandomolybdophosphoric yellow method (8, 25), and C by the induction furnace method (8). Elements were determined by the atomic absorption technique.

Chemical characteristics, feedstuff, digestibility, and elements were calculated on a dry weight basis at a drying temperature of 103°C.

The average dry matter consumed (28) was multiplied by digestion coefficients (20) to obtain solids voided (Table 2). The housed

Table 2. **Estimated feed consumed and solids voided by beef cattle fed high, medium, and low roughage rations and in housed and outdoor feedlots.**

Animal weight (lb)[a]		Dry feed consumed (30)	Digestion coefficient (20)	Waste dry matter
Low	High	(lb/an.-day)	(%)	(lb/an.-day)
High roughage ration				
400	600	10.8	63	4.00
Medium roughage ration				
600	850	16.0	73	4.32
Low roughage ration				
850	1000	20.4	81	3.88
Housed feedlot (low roughage ration)				
750	1100	16–20	73–81	4.00[b]
Outdoor, unpaved feedlot (low roughage ration)				
700	1100	11–20	63–81	14.05 (20)

[a] The ration roughage levels are normally fed, but not restricted to the weight ranges of cattle indicated.

[b] Estimated dry matter voided was determined by measurement from a housed beef cattle feedlot at the University of Nebraska–Lincoln Field Laboratory near Mead, Nebraska, during the period December 1972 through May 1973.

and outdoor feedlot waste volume was determined by field measurement and laboratory testing for TS, VS, and FS.

The quantity of TS, VS, and FS, chemicals and elements were calculated and the percent of daily nutrient requirements for finishing beef cattle and the dry matter corn plant yield possible from one ton of dry solids were estimated.

Results

Total and Volatile Solids

The HR, MR, and LR feces TS content averaged 26.3, 19.3, and 27.1% wet basis (% wb), respectively. The TS content of the manure from the housed feedlot and outdoor feedlots averaged 21.7 and 45.2% wb. The solids were 86.9, 89.4, 93.9, 85.8 and 37.2% volatile for the HR, MR, LR, HF, and OF, respectively.

Particle Size Distribution

The quantity of feces solids retained on sieves greater than 400 microns increased with decreased ration roughage content while those retained on sieves smaller than 400 microns decreased with ration roughage content (Figure 1). Thirty-five to 40% of solids from HR, MR, and LR rations may be separated on a 500-micron screen; however, 19.5 and 8% of solids from the housed and outdoor lots were retained.

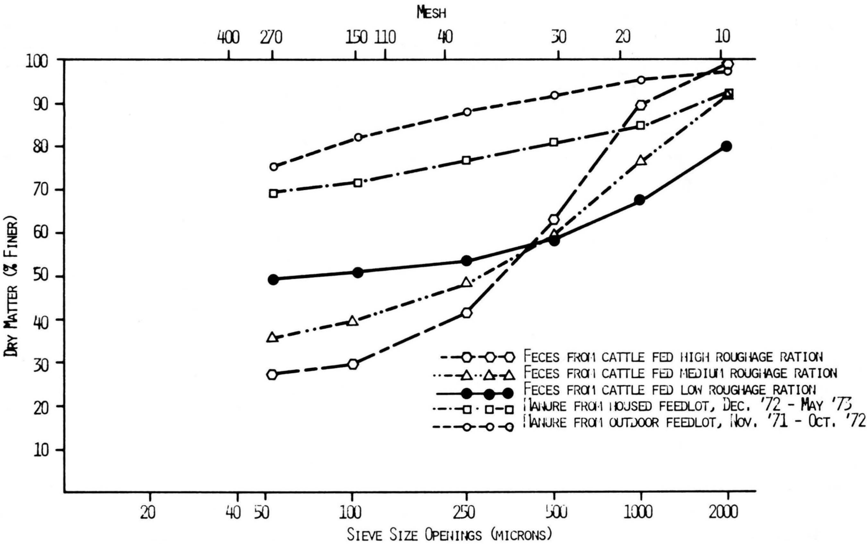

Figure 1. Particle size distribution of cattle waste as affected by ration fed and feedlot operation.

Agitation and pumping used to mix the HF manure before sampling was assumed to physically break down larger particles; therefore, more solids passed each respective sieve. An average of 10% more solids from the OF were finer than the HF solids for each sieve size. Mixing of soil and manure plus physical breakdown of particles from animal activities within the OF possibly caused the finer particle distribution.

Volatile solids retained on each sieve (% of TS) decreased with smaller particle size and increased with decreased ration roughage content for all waste studied (Figure 2). The low volatile solids content for the outdoor feedlot was possibly a result of decomposition between cleaning periods and soil manure mixing by animal activities.

Gross Energy

The ration fed did not significantly affect the gross energy of manure fractions (Table 3). The energy of the OF waste was 20% that of other waste studied. Gross energy for the HR, MR, LR, and HF waste decreased with particle size to the less than 53-micron fraction, then increased; the OF fraction decreased in energy through the less than 53-micron fraction. No temperature differential could be produced in the bomb calorimeter with the less than 53-micron fraction of the OF waste.

Digestibility

IVDMD increased with decreased ration roughage content and

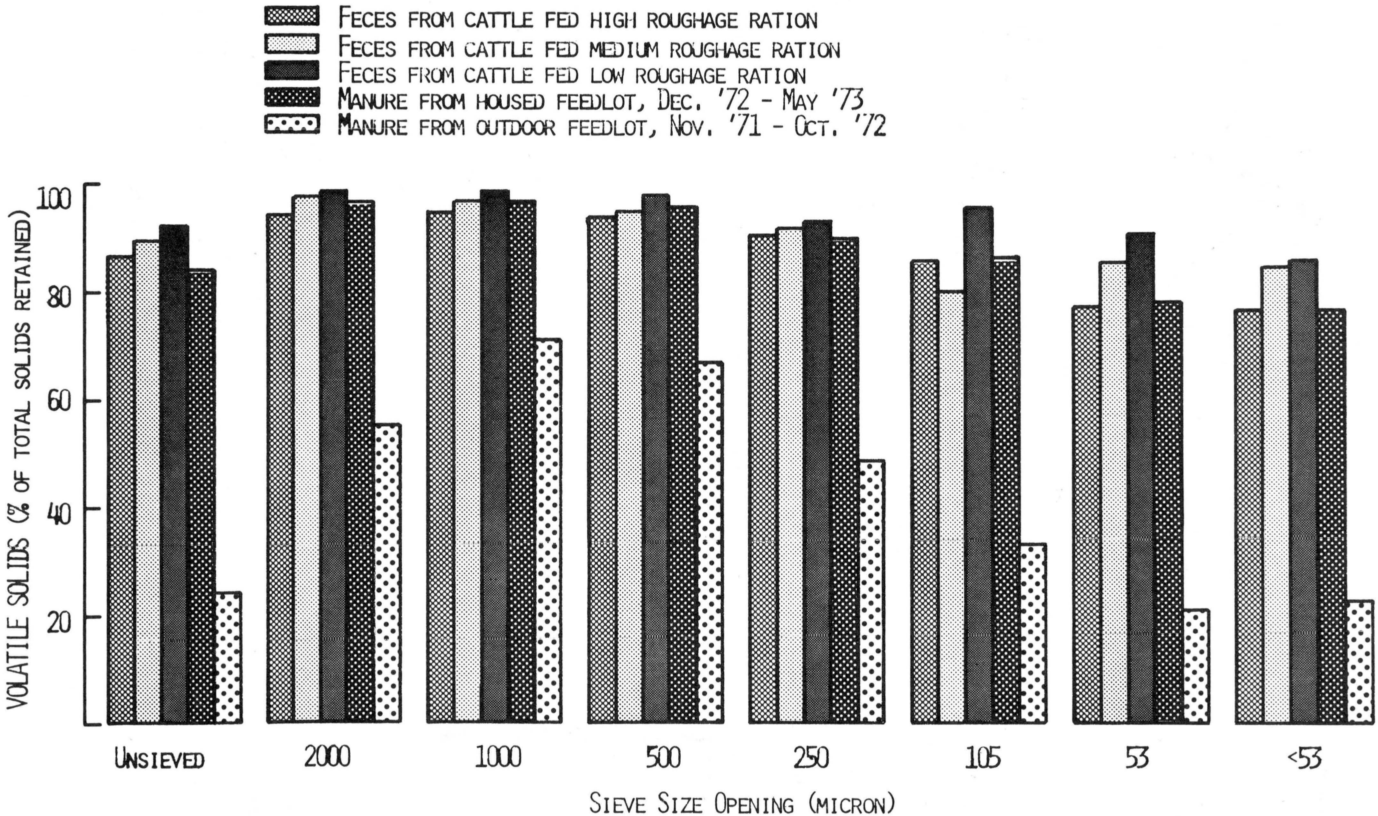

Figure 2. The effect of ration fed on volatile solids in beef cattle waste fractions.

Table 3. The effect of ration roughage content and feedlot operation on gross energy of beef cattle waste fractions.

Waste fraction[a]	Ration roughage level				
	High	Medium	Low	Low manure[b]	Low waste[b]
	- - - - - Feces[b] - - - - -				
	- - - - - Gross energy (Cal/gm) - - - - -				
Unsieved	4340	4527	4657	4347	980
2000	....	....	5296	4333	....
1000	5640	....	6074	4283	3110
500	4527	4564	....	4520	3055
250	4250	4368	....	4163	2133
105	4278	3858	....	3756	1246
53	....	....	....	3467	427
$<$53	4506	4034	4729	3998	........[c]
$<$37	....	....	....	4422	....

[a] Waste fractions are sieve size openings in microns unless otherwise indicated.

[b] Feces were collected from animals confined in metabolism crates. Manure was feces, urine, and dilution water collected from animals confined in a housed feedlot. Waste was material from OF during cleaning.

[c] Measurable energy was not detected with the calorimeter used.

decreased with particle size to the 53-micron fraction (Table 4). The LR feces was 2.24, 1.70, and 1.13 times more digestible than the unsieved MR and LR ration feces and the HF manure, respectively. Digestibility of OF waste was not completed since volatile solids and gross energy were low.

Feedstuffs

Ration fed did not significantly affect protein and fat contents of feces solid fractions, except HR ration feces protein was 42 to 50% of the MR, LR, and HR waste fractions (Table 5). The less than 53-micron fraction averaged 1.7 times more protein and 2.0 times more fat than the unsieved solids for all the wastes studied.

The crude fiber content increased with decreased particle size through the 250-micron fraction, then decreased to less than 30 percent of the unsieved solids for HR, MR, LR, and HF waste. Crube fiber of the HR and MR ration feces was twice that of the LR and HF waste.

Chemical Characteristics

Nitrogen content increased with decreased ration roughage level and ranged from 0.61 to 4.75% db for the HR, MR, LR, and HF waste fractions (Table 6). The concentration of NO_3^--N and NH_4^+-N ranged from 0.003 to 0.08% db and 0.003 to 0.009% db, respectively, for the HR, MR, and LR ration feces.

Table 4. Digestibility of beef cattle waste fractions as affected by ration roughage content.

Waste fraction[a]	Ration roughage level: High	Medium	Low	
	Feces[b]			Low manure[b]
	% In vitro dry matter digestibility			
Unsieved	27.4	36.4	61.5	54.4
2000	6.8	33.9	67.2	67.8
1000	19.2	22.2	49.7	40.8
500	5.9	29.0	55.3	29.2
250	16.5	25.4	54.0	19.6
105	16.5	22.2	53.0	30.9
53	12.9	19.4	68.3	30.9
<53	56.3	61.5	66.3	57.3

[a] Waste fractions are sieve size openings in microns unless otherwise indicated.

[b] Feces were collected from animals confined in metabolism crates. Manure was feces, urine, and dilution water collected from animals confined in a housed feedlot. Waste was material removed from OF during cleaning.

The concentration of P for the HR and MR ration solids was 1.5 to 3.3 times greater than the LR and HF solids through the 53-micron fraction. The P concentration for the less than 53-micron fraction ranged from 0.41 to 0.58% db for all wastes studied.

The concentration of C ranged from 24.6 to 46.8% db for all fractions of the HR, MR, LR, and HF waste and was not affected by ration roughage content.

COD of feedlot waste was not affected by ration roughage content or feedlot operation except the less than 53-micron fractions were 30 to 71% of the COD for unsieved fraction of HR, MR, and HF waste. COD ranged from 950 x 10^3 to 1250 x 10^3 ppm (db) for the HR, MR, and LR ration waste. The COD of the unsieved HF waste was 1.5 to 2.0 times higher than the HR, MR, and LR feces. The urine mixed in with the HF waste may have affected the COD.

Elements

The ration roughage level fed did not have a predictable effect on the element concentration of the solids fractions (Table 7). The concentration of elements for the less than 53-micron fraction was 1.2 and 2.5 times higher than the unsieved fraction for all micronutrients except copper.

Discussion

Engineering requirements for integrating materials handling, processing, and treatment equipment into a feasible waste recovery system depend upon the desired result. The desired result will be possible only if components can be engineered economically and management is feasible. Broad categories of application may include:

1. Disposal (biological and chemical stabilization for pollution control).

Table 5. The effect of ration roughage level and feedlot operation on crude protein, fat, and fiber of beef cattle waste fractions.

Waste fraction[a]	Ration roughage level			
	High	Medium	Low	Low manure[b]
	Feces[b]			
		Crude protein (% db)		
Unsieved	8.2	15.0	15.4	20.0
2000	5.2	7.1	9.6	11.4
1000	3.8	7.0	7.1	8.3
500	4.1	7.9	8.2	7.6
250	5.9	9.2	9.4	8.4
105		11.0	11.9	
53	} 7.6	13.9	14.5	} 8.9
<53	17.2	24.8	22.2	29.7
		Crude fat (% db)		
Unsieved	2.6	3.3	3.1	2.2
2000	1.2	1.6	1.0	1.1
1000	1.2	1.6	1.3	1.0
500	1.5	1.9		1.0
			} 2.5	
250	1.8	2.1		1.1
105		2.9		
	} 2.7		} 3.9	} 1.2
53		3.0		
<53	4.4	4.9	10.2	3.0
		Crude fiber (% db)		
Unsieved	30.3	24.1	12.1	12.4
2000	41.8	37.4	15.2	10.3
1000	45.1	39.1	22.7	27.6
500	44.0	37.1		31.8
			} 22.6	
250	34.7	31.0		29.0
105		24.5		
	} 27.6		} 13.8	} 18.1
53		19.6		
<53	8.4	6.3	2.0	4.0

[a] Waste fractions are sieve size opening in microns unless otherwise indicated.

[b] Feces were collected from animals confined in metabolism crates. Manure was feces, urine, and dilution water collected from animals confined in a housed feedlot. Waste was material removed from OF during cleaning.

Table 6. Chemical characteristics of beef cattle waste as affected by ration roughage content and feedlot operation.

Waste fraction[a]	Ration roughage level			
	High	Medium	Low	Low
	- - - - - Feces[b] - - - - -			manure[b]
		Total nitrogen (% db)		
Unsieved	1.31	2.40	2.47	3.20
2000	0.83	1.14	1.54	1.82
1000	0.61	1.12	1.14	1.33
500	0.66	1.26	1.30	1.22
250	0.94	1.47	1.50	1.34
105		1.76	1.90	
	} 1.22			} 1.42
53		2.22	2.32	
<53	2.75	3.97	3.55	4.75
		Total phosphorous (% db)		
Unsieved	1.02	1.20	0.66	0.77
2000	1.13	1.59	0.56	0.55
1000	1.58	1.05	1.10	3.46
500	1.70	0.76		1.20
			} 1.69	
250	2.27	5.58		
				} 3.04
105		0.64		
	} 1.48		} 2.73	
53		1.03		2.49
<53	0.52	0.58		0.41
		Total carbon (% db)		
Unsieved	32.9	29.3	32.6	40.4
2000	43.8	50.1	43.0	43.2
1000	44.7	39.4	34.2	32.0
500	45.6	25.1		
			} 43.0	} 46.8
250	39.9	35.6		
105		41.4	24.6	35.1
	} 40.8			
53		35.7	......	42.4
<53	42.7	40.7	39.0	39.4

[a] Waste fractions are sieve size openings in microns unless otherwise indicated.

[b] Feces were collected from animals confined in metabolism crates. Manure was feces, urine, and dilution water collected from animals confined in a housed feedlot. Waste was material removed from OF during cleaning.

2. Utilization (nutrient recovery by recycling indirectly through crops or directly through animals).

3. Energy reclamation (as fuel by direct combustion or indirectly as combustible gas recovery).

4. Structurally (as nonsupport wall components or insulation, etc.).

5. Combinations of disposal and utilization (partial destruction

Table 7. Concentration of elements in beef cattle waste as affected by ration roughage content and feedlot operation.

Waste fraction[a]	Ration roughage level			
	High	Medium	Low	Low manure[b]
	- - - - - Feces[b] - - - - -			
		Potassium (% db)		
Unsieved	0.527	0.794	0.364	1.460
2000	0.117	0.371	0.066	0.259
1000	0.100	0.462	0.106	0.179
500	0.145	0.226		0.187
			} 0.069	
250	0.277	0.888		0.270
105		0.371		
	} 0.284		} 0.121	} 0.259
53		0.435		
<53	1.630	3.320	0.665	3.750
		Calcium (% db)		
Unsieved	0.467	0.507	0.367	0.543
2000	0.386	0.468	0.117	0.173
1000	0.319	0.392	0.208	0.309
500	0.217	0.276		0.318
			} 0.217	
250	0.600	1.400		0.490
105		0.441		
	} 0.457		} 0.349	} 0.662
53		0.601		
<53	0.714	1.040	0.596	0.705
		Sodium (% db)		
Unsieved	0.164	0.089	0.187	0.329
2000	0.042	0.100	0.039	0.073
1000	0.047	0.051	0.070	0.128
500	0.025	0.031		0.058
			} 0.069	
250	0.084	0.103		0.101
105		0.043		
	} 0.122		} 0.172	} 0.120
53		0.065		
<53	0.269	0.302	0.303	0.850
		Magnesium (% db)		
Unsieved	0.146	0.284	0.354	0.291
2000	0.132	0.223	0.076	0.063
1000	0.093	0.221	0.130	0.095
500	0.075	0.135		0.093
			} 0.058	
250	0.175	0.599		0.139
105		0.248		
	} 0.138		} 0.101	} 0.164
53		0.318		
<53	0.323	0.648	0.641	0.665

Table 7. Concentration of elements in beef cattle waste as affected by ration roughage content and feedlot operation (continued).

Waste fraction[a]	Ration roughage level			
	High	Medium	Low	Low manure[b]
	- - - - - Feces[b] - - - - -			
	Manganese (% db)			
Unsieved	0.027	0.009	0.017	0.012
2000	0.025	0.007	0.005	0.005
1000	0.018	0.008	0.008	0.004
500	0.013	0.004		0.007
			} 0.021	
250	0.034	0.014		0.014
105		0.008		
	} 0.019		} 0.015	} 0.017
53		0.013		
<53	0.031	0.022	0.028	0.025
	Iron (% db)			
Unsieved	0.790	0.080	0.178	0.139
2000	0.524	0.100	0.009	0.095
1000	0.369	0.062	0.191	0.231
500	0.308	0.054		0.209
			} 0.752	
250	0.940	0.227		0.462
105		0.088		
	} 0.175		} 0.687	} 0.480
53		0.149		
<53	0.103	0.149	0.201	0.220
	Zinc (% db)			
Unsieved	0.012	0.010	0.034	0.014
2000	0.005	0.010	0.012	0.005
1000	0.006	0.013	0.023	0.018
500	0.006	0.006		0.011
			} 0.011	
250	0.018	0.027		0.034
105		0.015		
53	} 0.001	0.016	} 0.020	} 0.019
<53	0.009	0.025	0.047	0.033
	Copper (% db)			
Unsieved	0.005	0.002	0.003	0.001
2000	0.005	0.004	0.002	0.015
1000	0.011	0.034	0.002	0.068
500	0.003	0.002		0.036
			} 0.013	
250	0.090	0.008		0.101
105		0.007		
	} 0.002		} 0.026	} 0.194
53		0.023		
<53	0.007	0.023	0.017	0.050

[a] Waste fractions are sieve size openings in microns unless otherwise indicated.

[b] Feces were collected from animals confined in metabolism crates. Manure was feces, urine, and dilution water collected from animals confined in a housed feedlot. Waste was material removed from OF during cleaning.

or stabilization of a fraction by biological, chemical, or mechanical treatment to enhance, release, or modify desirable components).

Biological disposal of HF manure may be accomplished by high loading rates to cropland, sanitary landfills, and water treatment techniques. Materials handling design will be dictated by climatic conditions and moisture content of the material. Water must be added if manure is pumped to cropland or treated by conventional techniques. Water must be extracted for operation of conventional loading equipment and truck hauling to the field, and for sanitary landfill disposal. An estimated 12.1 tons of dilution water must be added to HF manure to effectively pump one ton of dry solids to the field or to utilize water treatment techniques. About 2.6 tons of water must be removed (per ton dry solids) from HF manure if land application with conventional equipment or sanitary landfill techniques are used.

Land application of animal waste for nutrient recovery by plants is common. Loading rates of manure may be estimated by equating crop nutrient requirements to nutrients available in animal waste (Table 8). Assuming all nutrients are available, the quantity of N and K limits corn plant yield to less than 1 ton dry weight per ton of dry waste applied from MR and LR rations and HF operation (Table 9).

Most soils in Nebraska have sufficient quantities of K; therefore, nitrogen is the limiting nutrient. The amount of N contained in OF and HR ration waste limits corn plant production to 0.4 ton per ton of dry waste applied. Elements for crops, such as Na, may also restrict production if present in toxic quantities.

Assuming that all nutrients are available and Na will not reach toxic levels, waste from HR rations and OF may be applied at rates of 2 tons per ton of dry corn plant yield and MR and LR rations and HF manure may be applied at 1 ton dry solids per dry ton corn plant yield.

Assuming that palatability is acceptable and disease potential is not a problem, the limiting factor for cattle waste as a feed source appears to be in the quantity of digestible solids (Table 8). Digestible solids from a low roughage are four times greater than for high roughage ration waste (Table 10). The total solids for one ton of dry HR ration waste are sufficient to feed about 100 head of finishing cattle per day, but fulfill only 33% of the digestible dry matter requirement. The quantity of protein per ton of dry waste fulfills 80% to 140% of the animals' daily requirements for all waste studied except that from a HR ration. The small Mn and fat requirements may be met with a supplement. K is an element limitation for HR and LR feces and Na limits MR ration feces for refeeding.

Table 8. Estimated quantity of nutrients and energy in one ton (db) of animal waste.[a]

Material	Ration roughage level				
	High	Medium	Low	Low manure[b]	Low waste[b]
	- - - - - Feces[b] - - - - -				
	(lb/ton dry matter)				
Total solids	2000	2000	2000	2000	2000
Vol. solids	1738	1788	1878	1716	490
Dig. solids	270	344	1154	1088	....
Energy (M calories)[c]	3942	4107	4225	3944	889
Crude protein	164	300	308	400	....
Crude fat	52	66	62	44	....
Crude fiber	606	482	242	248	....
Total N	26.2	48	49.3	64	21
Total P	20.4	24	13.2	15.3	1.6
Total C	658	586	652	808	....
K	10.54	15.88	7.28	29.20	5.79
Ca	9.34	10.14	7.34	10.86	3.32
Na	3.28	1.78	3.74	6.58	2.20
Mg	2.92	5.68	7.08	5.82	1.79
Mn	0.54	0.18	0.34	0.24	0.11
Fe	15.8	1.60	3.56	2.78	2.64
Zn	0.24	0.20	0.68	0.28	0.02
Cu	0.10	0.04	0.06	0.02	0.001

[a] One ton of dry solids was estimated to be equivalent to 3.8, 5.2, 3.7, 4.6, and 2.2 tons wet weight for high, medium, and low roughage ration feces, housed feedlot manure, and outdoor feedlot waste, respectively.

[b] Feces were collected from animals confined in metabolism crates. Manure was feces, urine, and dilution water collected from animals confined in a housed feedlot. Waste was removed from outdoor, unpaved feedlots during cleaning.

[c] M calories=calories x 10^6=1 megacalorie

Depending on the ration roughage content, 2.7 to 4.2 tons of water would be present to yield one ton of dry waste. If 12 gallons per day per animal is used as an estimate of water requirements, the HF waste would supply 73.7% of the daily water requirement for finishing animals.

The wet sieved fractions (53 microns and larger) were odorless and may help justify solids separation for refeeding. The practical limit of mechanical separation is 500 microns since 35% to 40% of the total solids may be separated (Figure 1). A smaller screen size would be impractical because volume flow per unit area of screen would be greatly reduced. The nutrient content of the less than 53-micron fraction is as great as, or greater than, the other fractions including the unsieved waste for most nutrients studied; however, the wet solids are odorous and would appear unpalatable. Research is required to determine a feasible process for solids extraction.

Table 9. Potential dry corn plant yield from application of one ton of animal waste to cropland based on estimated nutrient requirements of corn.

Nutrient	Corn nutrient requirement (37) (lb/ton db)	High	Medium	Low	Low manure[a]	Low waste[a]
		- - - - - Feces[b]	- - - - -			
		- - - - - Tons corn plant yield (dry weight)				- - - - -
N (lb/ton)	52.0	0.50	0.92	0.95	1.23	0.40
P	5.0	4.08	4.80	2.64	3.06	0.32
K	36.0	0.29	0.44	0.20	0.81	0.16
Ca	8.0	1.17	1.26	0.92	1.36	0.42
Mg	4.5	0.65	1.26	1.57	1.29	0.40
Mn	0.04	13.50	4.50	8.50	6.00	2.75
Fe	0.06	263.33	26.67	59.33	46.33	44.00
Zn	0.04	5.58	4.65	15.81	6.51	0.50
Cu	0.007	14.28	5.71	8.57	2.85	0.14
Na	0.00[b]	....	....	....	....	....

[a] Feces were collected from animals confined in metabolism crates. Manure was feces, urine, and dilution water collected from animals confined in a housed feedlot. Waste was removed from outdoor, unpaved feedlots during cleaning.

[b] Sodium is a non-essential element (37) available in animal waste (3.3, 1.8, 3.7, 6.6 lb/ton dry matter in HR, MR, LR ration and HF waste, respectively).

Table 10. Estimated percent of total daily requirements for 100 head of finishing beef cattle fulfilled by one ton of dry solids.

Nutrient	Animal requirement[a]	Ration roughage level: High	Medium	Low	Low manure[b]
		- - - - - Feces[b]		- - - - -	
Total d.m.	20.4	98	98	98	98
Digestible d.m.	16.5[c]	16.3	21.4	71.4	67.3
Crude protein	2.1	79.6	145.9	149.0	194.9
Crude fat	1.0[d]	53.1	67.3	63.3	44.9
P	0.04	495.9	582.6	320.4	371.4
K	0.14	76.5	115.4	53.1	212.2
Ca	0.04	226.5	245.9	178.6	263.3
Na	0.02[e]	246.9	90.8	190.8	335.7
Mg	0.03	95.9	186.7	232.6	191.8
Mn	0.20	3.1	1.0	2.0	1.0
Fe	0.02	982.6	99.6	221.4	172.4
Zn	0.28	398.0	331.6	1128.6	464.3
Cu	0.04	1244.8	497.9	746.9	247.9

[a] Requirements are for finishing beef cattle in lb/an.-day except Zn and Cu which are in gm/hd/day 21-30).

[b] Feces were collected from animals confined in metabolism crates. Manure is feces, urine, and dilution water collected from animals confined in a housed feedlot.

[c] Assumed total solids requirement is 81% digestible for a finishing ration.

[d] Based on 5% of total solids fed.

[e] Based on the atomic weight proportion of 0.25% salt (NaCl) content of ration.

Energy reclamation requires removal of water before solids can be burned as fuel or to design a system for combustible gas recovery. The dry solids in animal wastes are 130% of the energy in lignite coal; however, limited research information indicates neither method of energy reclamation is practical (19).

Design criteria are not available for integrating system components using biological, chemical, and mechanical processing for maximizing the utilization of animal waste. Present technology dictates that the most practical solution to animal waste management is:

1. Dilute manure to a moisture content of 92 to 94% wb.
2. Separate the solids (500 micron and larger) mechanically or hydraulically (solids passing a 500-micron screen or effluent from a hydraulic settling tank may be transported through conduit without plugging valves, nozzles, etc., and the separated solids may be moved with conventional hauling or spreading equipment).
3. Transport the less than 500-micron fraction by pumping and the greater than 500-micron by conventional hauling equipment.

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