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Beef Waste Management Economics for Minnesota Farmer-Feeders

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Southwestern Minnesota farmers who feed beef cattle are evaluating their waste management systems in terms of compliance with 1971 Minnesota Pollution Control Agency regulations. Feedlots do not comply with current regulations if located or constructed in a manner which allows rainfall or snowmelt runoff to carry animal excreta to public surface or ground water supplies. A runoff control device, which usually includes diversion terraces to stop unpolluted runoff from entering the lot and a detention pond to prevent effluent runoff from leaving the lot, may be built. This may allow the farmer to use his present beef facilities and maintain the same size of operation. The direct cost (defined as cash outlays) of pollution control compliance would then be the sum of annual fixed and variable costs of the runoff control device. Fixed costs include depreciation, interest, and any taxes, insurance, or repairs for runoff control structures or equipment. Variable costs include fuel, lubrication, repairs, and hired labor needed to pump or clean the runoff control device.

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The profit maximizing farmer will want to consider alternative waste management systems and associated housing technologies. Alternative systems may constitute a better choice than runoff control devices in terms of providing: better pollution protection, the same protection for less cost, or increased farm-feedlot profits. Indirect costs of pollution control become important considerations when selecting a waste management system. For example, in Southwestern Minnesota, fall plowing and early spring planting are essential for optimum corn yields. A farmer incurs an indirect cost when he is forced to haul waste or pump a detention pond when those tasks compete for scarce plowing or planting time. Foregoing the opportunity to use scarce time in a more profitable manner reduces total business revenues.

Two situations are relevant to the Southwestern Minnesota corn-soybean farmer who feeds beef cattle. Situation I concerns currently operating feedlots where pollution control is necessary but no major change in feeding facilities or cropping program is considered. Situation II concerns feedlot operators who are beginning, expanding, remodeling, or who cannot control runoff in their current location. The existence of both direct and indirect costs emphasizes the need to study the waste management-housing system in its relation to the entire farm-feedlot business. The main thrust of the study was to develop a method to determine optimal farmer response to Minnesota regulations. It is left for others to use this model to speculate on alternative regulations and guidelines.

Objectives of this study include determining: (1) direct costs and indirect (opportunity) costs of complying with regulations, (2) net return maximizing alternative systems, (3) optimal time schedules for waste handling, (4) marginal value or cost of beef wastes, (5) effects of system choice on field crop selection and crop operation timing, and (6) effects of Set-Aside acres or rotating disposal field.

COSTS OF RUNOFF CONTROL ON ESTABLISHED FEEDLOTS

To determine direct costs of meeting pollution control regulations on open lots and conventional drylots, investment in runoff control structures, investment in pumping equipment, and operating expenses must be estimated. It is assumed in Situation I that the farmer-feeder is satisfied with his feedlot design and capacity and that the number of cattle fed and feed efficiency remain constant. Adequate labor and field time is available to haul whatever additional solid waste is collected and there is nearby cropland suitable for disposal of liquids.

One way to determine investment costs for runoff control structures would be to calculate a number of estimates for so-called "typical" lots located on "typical" topography with "typical" soil and subsoil. An engineer would systematically calculate volumes of excavation or earth fill needed for: a) a diversion terrace to keep unpolluted water off the lot; b) a settling channel or settling basin to slow runoff enough to allow solid particles to settle out of suspension; c) a detention pond with design capacity for six months runoff; and d) any lot grading needed to obtain uniform lot slopes. Engineering fees and charges for all earthwork could be added to costs for pipe or drain tile, a sump, a detention pond fence, seed, and miscellaneous items. However, actual cost is extremely farm specific, and no one type of control device with specified components will fit all lots in a given size category.

For this study, itemized runoff control structure investment costs were obtained for fourteen Southwestern Minnesota beef feedlots with one-time lot size capacities ranging from 100 to 1500 head. All these installations were in operation by fall 1971, and had been designed according to Soil Conservation Service specifications, which meet MPCA regulations. Total investment (estimated by least squares linear regression) was approximately $1120 plus $3.20 per head of capacity. The average size lot in this sample, 592 head, needed a $3018.57 runoff control device. In this small sample only 39 percent of the variation in investment cost is associated with variation in feedlot capacity. This again emphasizes the fact that while average investment costs may be suitable for a general economic study of runoff control investment, individual farm planners must obtain specific estimates. The estimated investment costs in Table 1 can probably be considered a lower bound for future installations because construction costs are increasing and newer plans are incorporating additional features.

For most Southwestern Minnesota feedlot applications, disposal alternatives for liquid runoff are limited to pumping on cropland. Evaporation rates are normally too low in Southwestern Minnesota to expect ponds to be emptied by evaporation only and, of course, design should hold seepage to a minimum. A wide range of pumping and distribution equipment could be selected for feedlot runoff control, but the most common systems are adapted from sprinkler irrigation technology. Original investment costs for one possible disposal system are listed in Table 2.

Some of the high fixed costs of spray disposal equipment may be reduced in a number of ways: (1) Used equipment is often available from other areas of the state where irrigation technology is changing to center-pivot equipment. (2) Some companies perform custom pumping, charging $15 to $20 per pumping hour depending on equipment capacity. (3) A number of farmer-feeders may buy this equipment jointly, thus spreading these fixed costs over a large number of cattle. (4) The farmer who has access to water for irrigation may use the pumping equipment mainly for that purpose and thus allocate only a portion of the fixed cost to beef waste disposal.

Operating costs--Calculations of direct costs of pollution control for Southwestern Minnesota feedlots are shown in Table 1. Operating costs of the disposal system include fuel, lubrication, and repairs on the tractor power unit at \$.03 per horsepower hour and \$.15 per hour for repair and lubrication of the pump and gun. The 100 head producer will find custom hiring at \$18 per hour costs less than owning and operating the equipment.

Assuming that there must be disposal of one-half of the 26 inches of annual precipitation (9) from the entire drainage area, total annual runoff to be pumped for each lot size can be determined. Half of this quantity will be pumped in spring and half will be pumped in late fall, according to SCS design calculations. Some operators can be expected to vary this schedule according to their particular need for supplemental irrigation. The collection basin should be emptied in late fall in order to receive all snowmelt. One will note that runoff is primarily a function of precipitation over the entire drainage area. Varying the number of animals within a given lot will not significantly alter the volume to be pumped.

The solids collected in the settling channel or settling basin will be removed annually, usually in September, when corn silage harvest provides land for spreading, or during July, if land is available for spreading. Solids removed from the settling basin are assumed to be .25 ton (33 percent dry matter) per head capacity on open lots and conventional drylots (9). The variable cost of hauling this solid waste is \$.38 per wet ton.[1]

[1]Calculated in Table 8.

Table 1. Summary of Direct Costs of Runoff Control on Beef Feedlots in Southwestern Minnesota.*

	As Constructed in Survey				Limited to 250 Square Feet per Head			
	Head Capacity				Head Capacity			
	100	500	1000	1500	100	500	1000	1500
PHYSICAL DATA								
Lot size, acres	---	---	---	---	.6[12]	2.9	5.7	8.6
Drainage area, acres	.92[1]	4.46[2]	8.08	11.69	.75[13]	3.5	6.8	10.3
Runoff, cubic feet[3]	45415	210461	381283	551634	35393	165165	320892	486057
Pumping time, hours[4]	11	53	95	138	9	42	80	122
INVESTMENT COSTS								
Runoff control device[5]	$1439	$2722	$4325	$5928	$1439	$2722	$4325	$5928
Pumping equipment[6]	---	3565	3565	3565	---	3565	3565	3565
Total investment cost	$1439	$6287	$7890	$9493	$1439	$6287	$7890	$9493
	(14.39)*	(12.57)	(7.89)	(6.33)	(14.39)	(12.57)	(7.89)	(6.33)
ANNUAL COST CALCULATIONS								
Pump operation[7,8]	$198	$ 80	$143	$207	$162	$ 63	$120	$183
Fixed cost of pump (owned)	---	428	428	428	---	428	428	428
Annual pumping & equipment cost	$198	$508	$571	$635	$162	$491	$548	$611
Labor charge, $2 per hour	---	106	190	276	---	84	160	244
Annual pumping cost incl. labor	$198	$614	$761	$911	$162	$575	$708	$855
Fixed cost, control device[9]	144	272	433	593	144	272	433	593
Annual cost of runoff handling	$342	$886	$1194	$1504	$306	$847	$1141	$1448
	(3.42)	(1.77)	(1.19)	(1.00)	(3.06)	(1.69)	(1.14)	(.96)
Solid removal variable cost[10]	9	47	95	142	9	47	95	142
Labor charge, $2 per hour	13	63	125	188	13	63	125	188
Annual cost of runoff control	$364	$996	$1414	$1834	$328	$957	$1361	$1778
	(3.64)	(1.99)	(1.41)	(1.22)	(3.28)	(1.91)	(1.36)	(1.19)
UNDER CONDITIONS WHERE WASTE HAS VALUE IN CROP OPERATION								
Manure credit[11]	45	223	445	667	45	223	445	667
Annual cost of runoff control	$319	$773	$969	$1167	$283	$734	$916	$1111
	(3.19)	(1.55)	(.97)	(.78)	(2.83)	(1.47)	(.92)	(.74)

*Values in parentheses are on a per head basis.

[1]Footnotes on following page.

[1]Estimated at 400 square feet per head total area serviced by runoff control device.

[2]Least squares linear regression estimate: Area serviced, acres = .848 + .00723 x number of head. One-time lot capacity is associated with 69 percent of the variation in area serviced by the runoff control device. Survey of systems in operation by spring 1972, Southwestern Minnesota.

[3]Assuming average of 26 inches of annual precipitation with 50 percent collected in basin. 13/12 acre ft. x 43,560 $ft.^2$/acre = 47,190 $ft.^3$/acre.

[4]At 500 gallons per minute, 30,000 gallons are pumped per hour or 4000 cubic feet per hour.

[5]Least squares linear regression estimate: cost = $1118.52 + 3.21 x number of head. No value added for land acres covered by control device.

[6]See Table 2, custom hired for 100 head capacity lots.

[7]Custom hired @ $18/hour for 100 head capacity lots.

[8]Fuel, lubrication, repairs on tractor are 45 horsepower x $.03/horsepower hour = $1.35 + $.15 pump repair = $1.50/hour for 500, 1000, 1500 head capacity lots.

[9]Twenty year payback, eight percent interest on remaining value plus taxes and maintenance.

[10]Runoff control device collects additional .25 ton of solids per head (see Table 5). Directly associated costs of removal calculated in Table 8. Four tons per hour can be hauled with conventional spreader and tractor loader. Fixed costs ignored because equipment is necessary with or without runoff control device.

[11]N = 10 lb./ton @ $.06, P_2O_5 = 7 lb./ton @ $.09 and K_2O = 11 lb./ton @ $.05. Manure credit of $1.78. Nutrients in pumped effluent account for leaching losses in the recovered solids. See Table 6 for fertilizer values.

[12]At 250 $ft.^2$/head = 175 head/acre.

[13]Area enclosed by diversion terraces. Driveways, sorting pens, etc. assumed to take 25 percent more space on 100 head lot, 20 percent more space on larger lots. See Butchbaker (3) p. 128.

Table 2. Investment in Pumping and Big Gun Spray Disposal Equipment for Runoff Control Device.

Equipment	Specifications	1972 New Cost[1]
PTO driven pump	500 gallons per minute 230-240 foot head at pump 45 continuous brake horsepower	1200
Tractor safety control	For diesel, stop if: 1) Loss of pump prime 2) Loss of oil pressure 3) Increased oil level 4) Too high coolant temperature	115[2]
Suction line	20 foot hose Suction strainer Welded wire cage	150
Big gun sprinkler	Gun mounted on wagon with pipe racks	850[3]
Pipe, aluminum	6" diameter, 1000 ft. @ $1.10/ft.	1100[4]
Fittings	Elbows, connectors, 15 foot hook-up hose	150
	Total cost	$3565
	Annual fixed cost, 15[5] year life	$ 428
	If 2500 feet of pipe, total cost	$5215
	Annual fixed cost, 15 year life	$ 626

[1]Cost information from dealer, extension engineer, Soil Conservation Service engineer, and farmer interviews. Used equipment is available as indicated for several items in following footnotes.

[2]Gas tractor safety control new cost is approximately $55.00

[3]Wagon and pipe racks simplify moving gun rig. A completely equipped traveling gun system with flexible pipe for quarter mile travel costs $6500. A new boom sprinkler capable of wetting up to four acres per setting costs approximately $2500. However, a number of used booms priced from $300 to $600 may be available in Minnesota.

[4]Pipe length of 1000 feet considered adequate for most feedlot applications.

[5]Private discussion with R. E. Machmeier, University of Minnesota Agricultural Extension Engineer.

No fixed costs for spreader and loader equipment are allocated because this equipment is normally already owned by the feedlot operation to haul wastes from the lot.

The lower portion of Table 1 shows the estimate of the fertilizer nutrient value in the recovered wastes. The calculation used N, P, and K estimates for fall spread solid beef wastes from steers fed grain rations.[1] Leaching and volatilization losses are offset by the nutrients pumped on fields in the liquid runoff. Using the nutrient value as a manure credit reduces the annual cost of runoff control to $3.19, $1.55, $.97 and $.78 per head for the 100, 500, 1000, and 1500 head capacity feedlots,respectively.

The second section of Table 1 reports calculations for less spacious lots. Investment costs are assumed to be the same as those estimated from the 1972 survey because more site preparation would be necessary when reducing the typical Southwestern Minnesota feedlot to a 250 square feet per animal size. The end result of this calculation is a substantial reduction in pumping costs for the smaller size lots. This reduces annual cost of runoff control (solid and liquid) after manure credit to $2.83, $1.47, $.92, and $.74 per head for the 100, 500, 1000, and 1500 head capacity feedlots, respectively.

ECONOMICS OF ALTERNATIVE WASTE MANAGEMENT-HOUSING SYSTEMS

To accomplish the remaining objectives, a profit maximizing linear programming model was developed for a 500 acre corn-soybean farm having one-time capacity of 500 head in alternative housing systems. Determining the most profitable farm organization requires three major steps: (1) determining

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[1]See Table 6.

the quantity of available resources; (2) budgeting resource requirements (land, labor, field days, storage space, cash costs) and expected income from each crop and cattle feeding enterprise or activity; and (3) solving for the combination of enterprises which maximize net revenue within the limits of available resources. This is accomplished by using a computer program designed to systematically solve the mathematical statements developed. [See (1, 6, 9) for theory and practical aspects of applying linear programming.]

Resources: Critical resources include cropland, feeding facilities, field time, and labor.

Feedlot facility components used in this study are summarized in Table 3. Open lots have 250 square feet of lot surface per animal including two earthen mounds with 25 square feet of mound surface per animal. Each mound is topped by a 200 foot long windbreak fence constructed of eight inch boards with one inch spacing. A ten foot wide concrete apron is constructed next to wooden fenceline feedbunks. Four row wire rope fencing surrounds the lot and divides the lot so that two groups of 250 head may be fed. The runoff control device and pumping equipment investment on the open lot corresponds to the investment reported in Table 1.

The partially-paved conventional drylot includes a pole frame barn, open to the south or east, with 17 square feet of bedded area (packed earth floor) per head. Cattle are fed from a fenceline bunk with a concrete apron similar to the open lot. Only 100 square feet of lot space per animal is subject to runoff, allowing construction of a smaller runoff control device. The conventional feedlots, for which runoff control investment costs were obtained, typically allowed as much or more lot space per head as the open lot described in the preceding paragraph. However, concrete aprons, a concrete walkway, and

Table 3. Specifications and Investment Costs for Feedlot Facility Components,[1] 1973, 500 Head Capacity Lots

Item	Open lot	Conventional Drylot	Manure scrape unit	Slotted Floor unit
		Specifications		
Building space/head (sq.ft.)	--	17 bedded	17 bedded	17
Bunk space/head (ft.)	1	1	.75	.75
Building dimensions (ft. x ft.)	--	40 x 215	40 x 375	40 x 375
Lot space/head (sq.ft.)	250	100	12 (alley)	--
Lot dimension (ft. x ft.)	250 x 500	200 x 250	--	--
Concrete dimension (ft. x ft.)	10 x 500	10 x 700	16 x 375	24 x 375(slats)
All weather driveway (ft. x ft.)	16 x 550	16 x 550	16 x 400	14 x 400
		Investment Costs		
Land	$ 1285	$ 734	$ 184	$ 184
Pole frame building @ $1.25/sq.ft.	--	10750	18750	18750
Concrete @ $.40/sq.ft.	2000	2800	2400	--
Slats @ $1.25/sq.ft.	--	--	--	11250
Pit	--	--	--	19600
Bunks, treated wood @ $5.00/ft.	2500	2500	1875	1875
Driveway @ $1.00/ft.	550	550	400	400
Mounds	1350	--	--	--
Windbreak fence @ $3.00/ft.	1200	--	--	--
Fence @ $1.30/ft. and $1.70/ft.	1625	572	204	122
Gates @ $50.00	150	150	250	150
Waterers and pipe	500	500	500	500
Electric service	100	100	200	200
Working corral	1500	1500	1500	500
Total investment	$12760	$20156	$26263	$53531
Average investment cost per head	$26	$40	$53	$107
Annual cost[2]	$1393	$2215	$2888	$5887

[1]Does not include feed storage, feed delivery, or feed processing equipment. Runoff control device is not included. See (4, 9).

[2]Twenty year life, with straight line depreciation to 10 percent salvage value, 8 percent interest, 1.3 percent tax and insurance, and 1.5 percent repairs. Land cost determined separately at 8 percent interest on purchase price of $367 per acre plus $8.13 tax per acre. Other costs adapted from (4) using Minnesota cost levels.

bedded shelter allow the cattle to avoid the muddy lot surface during wet weather. Therefore less lot space is provided in this study.

The manure scrape unit, which has no outdoor lot or runoff control device, has 17 square feet of bedded area (packed earth floor) per animal. The concrete scrape alley is 16 feet wide and bunk space is nine inches per head, allowing another 12 square feet of area per head. The fenceline feedbunk is located along the open side of the building.

In each of the above facilities, solid waste is handled with tractor front-end loaders and conventional spreaders. The concrete aprons and the manure scrape alley are cleaned every ten days. Some operators may use a two-week cleaning schedule.

The slotted floor unit is also open to the south or east. The slotted floor area is 24 feet wide and the fenceline feedbunk and driveway take the remaining 16 feet. The concrete pit is eight feet deep although some operators prefer ten foot pit depth. The pit is divided by crosswalls into 40 foot sections for effective agitation because no area of the pit should be further than 30 feet from the discharge of the manure pump during agitation. The crosswalls may also serve to brace outer walls. Sections of slats are removable to permit the pump to be lowered to a shallow sump in each smaller pit. After agitation, the liquid waste is pumped into tractor-drawn tank wagons for distribution on cropland.

Watering facilities include plumbing, waterers, and concrete bases for the waterers in each facility. The working corral facilities are similar for each unit, except in the slotted floor building where the driveway serves as a holding area and chutes are the only additional expense. Fenceline feeding, rather than auger feeding, is used in each of the facilities simply because lot size may be expanded more readily. Storage and feeding equipment is the same for all systems.

Field time is hours available for actual field operation after regular servicing and maintenance. It is the time available for productive work and ignores overhead, set-up and clean-up time. The study assumes a 12 hour field time day. Five spring time periods, April 1-June 4, and six fall time periods, September 1-November 30, are considered critical in this study. Boisvert (2) asserts that field time is a heterogeneous resource because certain field operations can be performed only during certain times of the production period. The sequence of these operations is important, for example, land must be prepared before planting can begin. Untimely operations reduce yields as will be specified in the section defining the crop enterprises. The expected amount of field time available in each period is derived from the results of Boisvert's regression analysis of rainfall and temperature effects on field days at the Lamberton, Minnesota, Experiment Station. Boisvert combined this information with probability distributions generated from rainfall and temperature data obtained for 59 years from the Bird Island, Minnesota, weather station.

The critical labor time periods coincide with critical field time periods. The operator and family labor available is assumed to be 12 hours per day during these time periods and does not include overhead labor. Hired labor is customarily available for tractor operation during silage harvesting only.

Beef feeding enterprise: Costs and returns, animal performance, and other requirements are detailed in Table 4. Caution should be used when interpreting these 1973 cost figures as both animal and feed prices have fluctuated recently.

When this study was initiated these prices seemed to be reasonable long-term planning prices. However, even if price magnitudes change, the long-run price relationships should hold for planning purposes.

Table 4. Costs, Returns, and Resources Used for Feeding Beef Cattle in Various Waste Handling-Housing Systems.

Item	Waste handling: Housing system:	Solid Open Lot	Solid Conventional Drylot	Solid Scrape Barn	Liquid Slotted Floor
430 to 1030 Pound Calf on High Grain Rations, November Purchase, One Lot per Year					
Total gain, pounds		600	600	600	600
Average daily gain, pounds		2.1	2.2	2.3	2.3
Days in lot		290	275	260	260
Gross margin per head[1]		$150.00	$150.00	$150.00	$150.00
Total cash cost per head		$ 28.59	$ 27.33	$ 26.22	$ 26.22
Return over cash cost		$121.41	$122.67	$123.78	$123.78
Raised feed	Corn, bushels	64	60	60	60
	Corn, silage, tons	2	2	2	2
Bedding, tons[2]		.4	.275	.275	-
Labor required, hours/head (350-700 head)		2.4	2.1	2.1	1.7
650 to 1100 Pound Yearling on High Grain Rations, Feedlot Kept Filled to Capacity					
Total gain, pounds		450	450	450	450
Average daily gain, pounds		2.25	2.5	2.5	2.5
Days in lot		200	180	180	180
Turnover--lots per year		1.8	2.0	2.0	2.0
Gross margin per head		$119.25	$119.25	$119.25	$119.25
Total cash cost per head		$ 22.15	$ 20.22	$ 20.22	$ 20.22
Return over cash cost		$ 97.10	$ 99.03	$ 99.03	$ 99.03
Annual return over cash cost		$174.78	$198.06	$198.06	$198.06
Raised feed	Corn, bushels	60	55	55	55
	Corn, silage, tons	1.1	1	1	1
Bedding, tons per head		.25	.2	.2	-
Labor required, hours/head (350-700 head)		1.8	1.6	1.6	1.3

[1]Gross margin calculations average $25.00 per hundredweight of gain for calves and $26.50 per hundredweight of gain for yearlings net of selling and trucking costs. Private conversations with P. R. Hasbargen and inspection of feedlot records from Southwestern Minnesota indicate this is a reasonable expectation for the next five year period. Gross margin per head is (sell weight x price) minus (buy weight x price) minus (death loss x buy weight x price) all divided by total weight gain.

When cattle reach 700-750 pounds, the proportion of corn silage to high moisture shelled corn is decreased. The amounts of feed and rates of gain are obtained from farm record information, while the differences between waste

Table 4. Costs, Returns, and Resources Used for Feeding Beef Cattle in Various Waste Handling-Housing Systems. (Continued)

Item	Waste handling: Housing system:	Solid Open Lot	Solid Conventional Drylot	Solid Scrape Barn	Liquid Slotted Floor
430 to 1080 Pound Calf on High Silage Rations, November Purchase, One Lot per Year					
Total gain, pounds		650	650	650	650
Average daily gain, pounds		1.9	2.0	2.1	2.1
Days in lot		340	320	310	310
Gross margin per head		$162.50	$162.50	$162.50	$162.50
Total cash cost per head		$ 33.70	$ 31.95	$ 31.08	$ 31.08
Return over cash cost		$128.80	$130.55	$131.42	$131.42
Raised feed	Corn, bushels	44	40	40	40
	Corn, silage, tons	4.8	4.4	4.4	4.4
Bedding, tons		.5	.35	.35	-
Labor required, hours/head (350-700 head)		2.8	2.5	2.5	2.0
650 to 1150 Pound Yearling on High Silage Rations, Feedlot Kept Filled to Capacity					
Total gain, pounds		500	500	500	500
Average daily gain, pounds		2.1	2.3	2.3	2.3
Days in lot		240	220	220	220
Turnover--lots per year		1.5	1.6	1.6	1.6
Gross margin per head		$132.50	$132.50	$132.50	$132.50
Total cash cost per head		$ 26.56	$ 24.48	$ 24.48	$ 24.48
Return over cash cost		$105.94	$108.02	$108.02	$108.02
Annual return over cash cost		$158.91	$172.83	$172.83	$172.83
Raised feed	Corn, bushels	44	40	40	40
	Corn, silage, tons	3.9	3.5	3.5	3.5
Bedding, tons		.3	.26	.26	-
Labor required, hours/head (350-700 head)		2.1	1.9	1.9	1.5

[1](cont.) Death loss has averaged 1.66 percent for long fed calves and 1.01 percent for short fed yearlings for the past six years according to Southwestern Minnesota feedlot records.

[2]Bedding is cobs on open lot and straw in other units. Yearlings in open lots are assumed to need the most bedding during winter and early spring; the estimate given averages total used per animal.

management-housing systems are estimated from experimental data. Approximately five percent reduction in average daily gain for calves and ten percent reduction for yearlings is estimated for open lots compared with lots having shelter. Daily gains were even higher for calves in covered confinement (scrape barn and slotted floor) than in the drylot during the first two years of housing trials at Morris, Minnesota. Shelter appears to be more beneficial to feeders in the finishing phase than to lighter animals. Mud and cold possibly stress the heavier animals to the point that more energy is used for body maintenance and less for fattening. Direct exposure to the hot summer sun also seems to reduce the gains of finishing cattle significantly. These research results correspond with field observations. Farmers who own both open and confinement buildings claim they obtain best results by starting calves outside and finishing heavy cattle inside.

Farm planners who are considering alternative waste handling systems want to know quantities of waste which must be removed. Precise estimates of quantity and quality of recoverable waste (feces, urine, bedding, waste feed, and waste water) are difficult to determine from the wide range of values reported in waste management literature. Rule-of-thumb estimates in the literature indicate manure produced daily is approximately six percent of body weight or 60 pounds of manure per 1000 pounds of live-weight. Farmers feeding high silage rations will probably find this figure appropriate, but recent research on high grain rations at the West Central Minnesota Experiment Station at Morris report approximately half of the manure accumulation that would be expected from feeding high silage rations. This observation is supported by other studies (5,12,13). Estimates of total and per day recoverable waste are reported in Table 5.

In the linear programming (LP) framework an accounting must be made of the amount of waste on inventory at times when land and labor are available for spreading. Assuming equal daily amounts of manure are produced throughout the feeding period simplifies the problem of manure production varying with body weight. However, the Hegg and Larson (5) research and Snapp and Neuman (12) estimates show no consistent pattern over the feeding period. Also, two-phase

Table 5. Estimated Recoverable Waste Production with Various Waste Handling-Housing Systems.

Type of cattle	Ration	Solid Open lot No runoff[1] control	Solid Open lot Runoff control	Solid Drylot No runoff control	Solid Drylot Runoff control	Solid Scrape Barn	Liquid Slotted Floor
			Total tons per feeding period				
Calves	grain[2]	.75	1.00	1.75	2.00	2.50	3.40
Calves	silage[3]	1.35	1.80	3.15	3.60	4.40	6.00
Yearlings	grain	.60	.80	1.45	1.65	2.00	3.10
Yearlings	silage[3,4]	1.05	1.40	2.55	2.90	3.50	5.50
				Pounds per day			
Calves	grain[2]	5.0	7.0	12.5	14.5	19.0	26.0
Calves	silage[3]	8.0	10.5	19.5	22.5	28.5	38.5
Yearlings	grain	6.0	8.0	16.0	18.5	22.0	34.0
Yearlings	silage[3]	8.5	11.5	23.0	26.5	32.0	50.0

[1]Approximately 25% of outside lot manure is assumed to be transported by runoff from lots without runoff control.

[2]Original information is unpublished data from West Central Minnesota Experiment Station at Morris. Adjusted by animal weights, total gain, and length of feeding period reported in table.

[3]Original information is unpublished data obtained from Roy Black, Extension Agricultural Economist, Michigan State University. Adjusted by animal weight, total gain, and length of feeding period reported in table.

[4]Silage rations assumed to produce about 1.75 times as much manure as grain rations.

feeding programs with higher proportions of roughage for light cattle and finishing on higher proportions of grain make the assumption of linearity plausible. Readers may wish to compare this with Nordstedt, et. al. (8) who used dynamic programming with waste production as a function of time.

Fertilizer elements per ton of waste vary according to time in storage, storage conditions, dry matter content, ration fed, and amount of bedding used. Availability of these nutrients to field crops depends primarily on the time of year waste is applied and how soon it is incorporated into the soil. Replacement of these nutrients by beef wastes reduces cash outlays for commercial fertilizer. Estimated analysis of wastes (as hauled) from the various waste handling systems is shown in Table 6. A ton of manure hauled in spring before

Table 6. Estimated Fertilizer Nutrients in Solid and Liquid Waste From Beef Cattle Fed Grain and Roughage Rations.

	Dry matter	Total Nitrogen as N	Phosphorus as P_2O_5	Potassium as K_2O
	Percent	Commercial fertilizer equivalent pounds per ton		
Solid Wastes	33%			
Grain rations				
Total		20.0	11.0	14.0
Spring spread		15.0	8.0	11.0
Fall spread		10.0	7.0	11.0
Silage rations				
Total		15.0	11.0	14.0
Spring spread		11.0	8.0	11.0
Fall spread		7.5	7.0	11.0
Liquid Wastes	10%			
Grain rations				
Total		16.0	6.5	6.0
Spring spread		12.0	4.3	4.5
Fall spread		8.0	4.3	4.5
Silage rations				
Total		9.0	6.5	6.0
Spring spread		6.75	4.3	4.5
Fall spread		4.5	4.3	4.5

Source: Figures derived from unpublished Minnesota and Michigan Experiment Station and Extension estimates. See (9) for documentation.

the crop is planted is assumed to make 75 percent of total N, 66 percent of P_2O_5, and 75 percent of K_2O available to the crop expressed as equivalent to nutrients in commercial fertilizer (7, 8). Fall application reduces N to 50 percent. This accounts for storage losses and the need for timely application of plant nutrients.

The model specifies that adequate unplanted or harvested land must be available to spread up to 20 tons of solid waste and up to 40 tons of liquid waste per acre. Although the application rates are above average, they are feasible for Minnesota soil conditions and the typically available farm machines. The practical farm manager would apply waste at rates indicated by soil tests or at lighter rates to cover a greater acreage and then balance nutrients with commercial fertilizer.

Table 7 shows investment and fixed costs for manure loading and hauling equipment. Butchbaker et. al. (3) indicate that for lots marketing less than 2000 head per year, the lowest average total cost system for hauling solid beef waste is the tractor mounted loader and pull-type spreader. Similarly, pull-type 1400-1500 gallon tank spreaders filled by an impeller pump constitute the lowest average total cost system for cold slotted floor barns with deep pits.

Table 7. Investment and Annual Cost for Waste Handling Equipment.

Item	1973 new cost*	Estimated life, years	Annual fixed costs
Solid wastes			
Front end loader	$1200	10	$180
Pull-type spreader, 300 bu.	2500	10	375
			$555
Liquid wastes			
Impeller pump	$1950	10	$293
Pull-type tank, 1500 gal.	2000	10	300
			$593

*Machinery dealer suggested list price adjusted for inflation and discounts. There is a wide variation in price between companies. As with other machine investments, used machine purchases may reduce the cash outlay for individual farmers.

Directly associated costs of loading, hauling and spreading beef wastes are reported in Table 8. The per ton variable cost used in this study is $.38 for solid wastes and $.12 for liquid wastes.

Table 8. Directly Associated Cost of Loading, Hauling, and Spreading Beef Waste.

	Hours per load	Fuel, lubrication repairs per hour[1]	Total per load
Solid Beef Waste (33 Percent Dry Matter)			
Loader, front end	.2	$ .32	$ .064
Loader tractor, 50 hp	.2	1.04	.208
Spreader, 2 ton	.3	.50	.150
Spreader tractor, 70 hp	.3	1.11	.333
Cost per load			$ .755
Cost per ton (33% dry matter)			$ .380
Liquid Beef Waste (10 Percent Dry Matter)			
Impeller pump	.0333	$ .25 (est.)	$ .008
Pump tractor, 70 hp	.0333	1.11	.037
Spreader, 1500 gallon	.3330	.50 (est.)	.167
Spreader tractor, 50 hp	.3330	1.04	.346
Cost per 5.8 ton load (10% dry matter)			$ .558
Cost per ton			$ .096
Agitation charge per ton[2]			.024
Total cost per ton			$ .120

[1]Unpublished data by Harsh and Milligan, Department of Agricultural Economics, Michigan State University, January, 1971.

[2]Agitation charge per ton:

24' x 40' x 8' = 7680 $ft.^3$ x 60 $lb./ft.^3$ = 460,800 lb. = 230 tons

Agitation for four hours to obtain proper mixing.

Impeller pump	4 hours @ $ .25 =	$1.00
Pump tractor, 70 hp	4 hours @ $1.11 =	4.44
Total cost		$5.44 / 230 tons = $ .024 per ton

Crop Enterprises: Realistic planning models to study beef waste handling in Southwestern Minnesota must explicitly include cropping activities as an integral part of the farm business. Land for crops: (1) provides a disposal site for beef wastes, (2) utilizes fertilizer nutrients in beef waste, (3) competes with beef feeding for labor during planting and harvesting, (4) competes with beef waste spreading for field time availability, and (5) provides feed inputs for beef feeding.

For those interested, detailed crop budgets for Southwestern Minnesota soils are reported in the author's dissertation (9). Ideally, corn grown on fall prepared land yields 120 bushels of grain or 20 tons of silage per acre and requires 170 pounds N, 80 pounds P_2O_5, and 60 pounds K_2O. Soybeans yield 40 bushels per acre and require 40 pounds P_2O_5 and 40 pounds K_2O. Reductions in these ideal yields occur whenever field operations are delayed, as can be seen in Table 9. If waste handling interferes with crop operations, reductions in

Table 9. Percentage of Ideal Yield as Dependent on Preparation, Planting, and Harvesting Time Period.[1]

Planting date	Corn fall preparation	Corn spring preparation	Soybeans
	Percent of ideal yields		
April 25 - May 5	100	85	
May 6 - May 15	93	79	100
May 16 - May 25	84	71	96
May 26 - June 6			90

Harvesting date	Corn silage	Soybeans	Corn grain
September 1 - September 15	100		
September 16 - September 30	100	100	
October 1 - October 15	95	95	100
October 16 - October 31		82	98
November 1 - November 15			96
November 16 - November 30			93

[1]Adapted from Minnesota Beef Farm Planning Model developed by University of Minnesota Extension economists in farm management.

yields reduce net income.

Model summary: Figure 1 helps conceptualize the timing involved in developing this model. The corn and soybean field operations are shown in the first two columns opposite approximate starting dates. For illustrative purposes, the calf feeding activities are shown. The income from calves purchased one year is realized in the next calendar year. A calendar income tax year and constant planning prices are used in the gross margin calculations to make the calendar year assumption plausible. If the yearling steer activity were illustrated, the feeding facility would be utilized throughout the entire year. Similarly, a farmer using an uncropped disposal field Set-Aside option would be able to haul wastes from early April to mid-November. Once land is planted, manure spreading cannot be resumed until harvest.

Although fixed costs are not considered within decision-making linear programming models, one must calculate basic fixed costs (summarized in Table 10) for the alternative systems in order to choose the most "profitable" system. Both the pump operating cost and the pump fixed costs are included as fixed costs on runoff controlled open lots and drylots. Once the control device is built, it must be pumped each year because runoff is a function of precipitation. The pumping cost calculations for large lots, as found in the survey, are used on the open lot. The pumping cost for the smaller design capacity is used on the drylot system. Labor costs for pumping are not included, as pumping takes place when it does not compete for time with other activities.

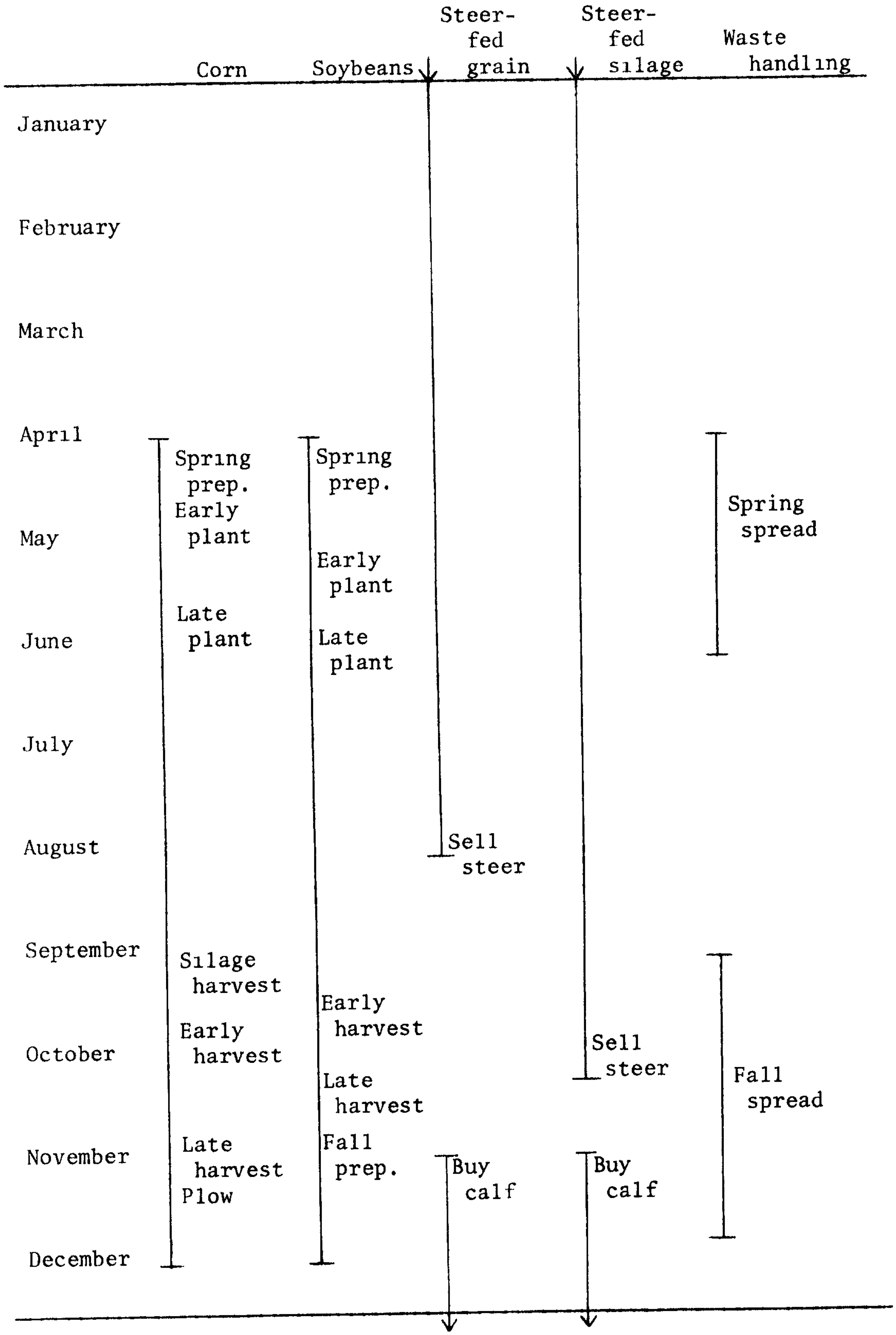

Figure 1. Illustration of Activity Cycles.

Table 10. Summary of Annual Fixed Costs, 500 Acre Farm With 500 Head Capacity Feedlot, Southwestern Minnesota.

Description	Annual costs	Comments
Items common to all systems		
Cropland	$19496	See (9)
Silos, 3 20'x70'	3120	See (9)
Silo unloaders, 2	684	See (9)
Grain storage, 25,000 bu.	875	See (9)
Grinder-mixer	360	$2400, 10-year life
Feed wagon with scale	525	$3500, 10-year life
Crop machinery	9550	See (9)
Auto, truck (farm share)	595	$3500, 8-year life, SW Minn. Farm Mgmt. Assoc.
Sub-total annual fixed cost	$35205	
Solid waste handling systems		
Open lot, no runoff control	$ 1262*	
Waste handling equipment	555	Table 7
Total annual cost	$37022	
Open lot, runoff control	$ 1262*	
Waste handling equipment	555	
Pumping runoff control device	508	Large drainage area
Runoff control device	272	Table 1
Total annual cost	$37802	
Conventional drylot, no RC	$ 2140*	
Waste handling equipment	555	
Total annual cost	$37900	
Conventional drylot, RC	$ 2140*	
Waste handling equipment	555	
Pumping runoff control device	491	Smaller drainage area
Runoff control device	272	Table 1
Total annual cost	$38663	
Manure scrape barn	$ 2869*	
Waste handling equipment	555	
Total annual cost	$38629	
Liquid waste handling system		
Slotted floor barn	$ 5868	
Waste handling equipment	595	Table 7
Total annual cost	$41668	

*All handling systems are adjusted for land cost.

PROGRAMMING RESULTS

Table 11 compares "profit maximizing" open lots before and after the use of a runoff control device. In each case, the LP model selects silage-fed calves as the optimal feeding program. However, imposing runoff control results in a $377 reduction in return over costs considered in the LP model. Thus, $377 is the <u>indirect cost</u>. This reduction may be attributed to the slight reduction in cattle numbers, to the increased quantity of waste which must be hauled, and, more importantly, to the less optimal (later) planting schedule. When the cost of owning and operating a runoff control device is included, the total cost (reduced return to all labor) is $1157.

A similar analysis is made in Table 12 for a farm-feedlot using conventional drylot facilities. Grain-fed yearlings are selected by the LP model as the optimal drylot feeding program. Runoff control reduces (indirect cost) return over variable costs by $205 in this example. This indirect cost is a result of a significant reduction in total cattle fed (910 compared to 824) and a slight increase in total waste handled, which forced a less optimal (later) harvesting schedule. When the direct costs of runoff control are subtracted, the total reduction in labor earnings is $968.

The implications of these results are more important than the actual numbers for this hypothetical farm feedlot. Costs of pollution control are often greater than the engineer's estimated cash outlays and allocated expenses. Even the operator who adjusts cattle numbers and his time schedule in an optimal fashion will bear indirect costs due to pollution control if his waste handling competes with other farm enterprises. Discussions with farmers, agricultural scientists, and engineers lead the author to believe waste handling competition with other enterprises is the rule rather than the

Table 11. Determination of Indirect and Total Cost of Controlling Runoff on Open Lot, 500 Head Capacity, Southwestern Minnesota.

Item		Prior to control		After control	
Value of the program		Return	Head[1]	Return	Head[1]
Grain fed calves		$60929	500	$61139	500
Grain fed yearlings		60433	900	60137	900
Silage fed calves		(61737	500)*	(61360	495)*
Silage fed yearlings		47266	543	57106	517
Net return calculation					
Optimum program		$61737		$61360	
Fixed cost, table 10		37022		37802	
Return to all labor		$24715		$23558	
Runoff control indirect cost				$ 377	
Runoff control total cost				$ 1157	
Scheduling of:					
Planting		Acres		Acres	
Fall corn	Apr 26	209		174	
	May 6				
	May 16				
Spring corn	Apr 26	4		39	
Soybeans	May 6	212		213	
	May 16	75		66	
	May 26			7	
Harvesting		Tons		Tons	
Silage	Sep 1	1209		1214	
	Sep 16				
	Oct 1	1254		1223	
Corn	Oct 1	Bushels		Bushels	
	Oct 16				
	Nov 1	4688		4801	
	Nov 16	5966		5483	
Soybeans	Sep 16	6071		6097	
	Oct 1	1437		1605	
	Oct 31	3796		3556	
Waste handling		Tons		Tons	
	Early	240		240	
	Apr 1				
	Apr 26				
	May 6				
	May 16	145		126	
	May 26			138	
	Sep 1				
	Sep 16				
	Oct 1				
	Oct 16	290		386	
	Nov 1				

*Optimal program

[1]Number fed during entire year.

Table 12. Determination of Indirect and Total Cost of Controlling Runoff on Conventional Drylot, 500 Head Capacity, Southwestern Minnesota.

Item		Prior to control		After control	
Value of the program		Return	Head[1]	Return	Head[1]
Grain fed calves		$65465	500	$65624	500
Grain fed yearlings		(69145	910)*	(68940	824)*
Silage fed calves		68429	478	66595	442
Silage fed yearlings		61893	505	61150	481
Net return calculation					
Optimum program		$69145		$68940	
Fixed cost, table 10		37900		38663	
Return to all labor		$31245		$30277	
Runoff control indirect cost				$ 205	
Runoff control total cost				$ 968	
Scheduling of:					
Planting		Acres		Acres	
Fall corn	Apr 26	129		224	
	May 6	72		67	
	May 16				
Spring corn	Apr 26	95			
Soybeans	May 6	134		166	
	May 16	54		27	
	May 26	16		16	
Harvesting		Tons		Tons	
Silage	Sep 1	911		823	
	Sep 16				
	Oct 1				
		Bushels		Bushels	
Corn	Oct 1	6751		4421	
	Oct 16	4396		6632	
	Nov 1	6327		7220	
	Nov 16	10285		11178	
Soybeans	Sep 16	4319		3404	
	Oct 1	3617		4797	
	Oct 16				
Waste handling		Tons		Tons	
	Early	240		240	
	Apr 1			126	
	Apr 26				
	May 6				
	May 16	152		212	
	May 26	313		314	
	Sep 1	157		192	
	Sep 16	179		26	
	Oct 1				
	Oct 16			154	
	Nov 1	279		115	

*Optimal program

[1]Number fed during entire year.

exception. One strength of this model, then, is that it facilitates detection of these indirect costs.

Farmer-feeders in Situation II (described on page 2) want to know which alternative waste handling-housing system is the most profitable. Given the assumptions used in this study, the farm-feedlot with liquid waste handling - slotted floor housing earns the highest return to all labor, $36153, among the alternatives considered in Table 13. Labor earnings for the solid waste handling systems rank as follows: conventional drylot--$30277, manure scrape barn--$27839, and open lot--$23558.

Possible reasons for the superior return to all labor in the liquid waste handling system are: (1) A greater number of cattle can be fed due to the faster turnover rate (assuming the lot is full at all times). (2) No bedding is purchased for the slotted floor facility. (3) Due to rapid waste handling, earlier timing of crop planting and harvesting can be achieved. Similar statements may be made about the higher return achieved in the drylot over the other solid waste systems. Of course, the ability to feed a greater number of cattle given a particular set of resources is most important. The scrape barn might be expected to compete more favorably with the drylot; however, the larger amounts of wastes collected indicate the scrape barn operator should feed grain rations to calves, because they generate lower volumes of waste. In the open lot facility the LP model selects silage fed calves. Performance coefficients used in the model reflect lower rates of gain and less efficient feed conversion in open lots. One would expect the operator of an open lot to be concerned with low cost gains on roughage rations and to be less concerned with length of feeding period in this low fixed cost facility.

Table 13. Optimal Organization for Farm-Feedlots with Alternative Waste Management-Housing Systems, 500 Crop Acres, 500 Head Capacity, Southwestern Minnesota.

Item		Solid waste Open lot	Solid waste Drylot	Solid waste Scrape barn	Liquid waste Slot floor
Value of program		Return Head'	Return Head'	Return Head'	Return Head'
Grain fed calf		$61139 500	$65624 500	($66468 500)*	$68735 500
Grain fed yearling		60137 900	(68940 824)*	66263 772	(77821 1000)*
Silage fed calf		(61360 495)*	66595 442	64633 398	74309 500
Silage fed yearling		57106 517	61150 481	59655 425	61941 800
Net return calculation		Return	Return	Return	Return
Optimum program		$61360	$68940	$66468	$77821
Fixed cost (table 10)		37802	38663	38629	41668
Return to all labor		$23558	$30277	$27839	$36153
Scheduling of:					
Planting		Acres	Acres	Acres	Acres
Fall corn	Apr 26	174	224	219	224
	May 6		67		113
	May 16				
Spring corn	Apr 26	39			
Soybeans	May 6	213	166	219	118
	May 16	66	27	47	45
	May 26	7	16	15	
Harvesting		Tons	Tons	Tons	Tons
Silage	Sep 1	1214	823	923	1000
	Sep 16			77	
	Oct 1	1223			
		Bushels	Bushels	Bushels	Bushels
Corn	Oct 1		4421	12114	11209
	Oct 16		6632	8136	4380
	Nov 1	4801	7222		6979
	Nov 16	5483	11178		10938
Soybeans	Sep 16	6097	3404	8185	4500
	Oct 1	1605	4797	2869	1898
	Oct 16	3556			
Waste handling		Tons	Tons	Tons	Tons
	Early	240	240	240	1000
	Apr 1		126	73	
	Apr 26				
	May 6				
	May 16	126	212	169	650
	May 26	138	314	310	
	Sep 1		192		550
	Sep 16		26		
	Oct 1			53	
	Oct 16	386	154	406	
	Nov 1		115		900
Value of waste per ton		Dollars	Dollars	Dollars	Dollars
Spread in spring		+1.20	-8.53	+ .31	+1.21
Spread in fall		-5.68	-8.53	+1.78	- .63

*Optimal program

'Number fed during entire year.

The schedule of the loading-hauling-spreading operation is given at the bottom of Table 13. The early spring period, which is suitable for waste hauling but not suitable for tillage operations, is fully utilized in each system. Once spring field preparation begins, waste handling is delayed until all the corn and most of the soybeans are planted. In the case of all three solid waste systems, enough land is left to be planted in late May to permit spreading the remaining waste at maximum rates. It is apparently more profitable to let spring spreading interfere with soybean planting than let additional fall spreading interfere with harvesting and fall plowing. Reduced yields as a penalty for late harvesting seem to postpone fall waste handling in all except the drylot system.

Crop selection seems to be affected most by type of ration and type of cattle as shown in Table 13. Interrelated to this, crop scheduling is affected by waste scheduling. More corn is planted when the optimal feeding program is grain-fed yearlings. In the lower net return calf feeding systems more cash grain soybean acres are substituted for corn acreage. The opportunity to perform profitable preparation, planting and harvesting operations may be foregone in order to handle beef feedlot wastes. Greater quantities of waste cause greater delays.

At the margin, farm-feedlots with relatively small quantities of recoverable wastes and/or relatively large hauling capacity will tend to treat manure as a valuable by-product. Conversely, at the margin, farm-feedlots with relatively large quantities of recoverable wastes and/or relatively small hauling-spreading capacity will tend to treat manure handling as a costly disposal process. The shadow price is a powerful tool for purposes of this model, because it internally calculates the value (positive shadow price) or the cost (negative shadow price) of an additional ton of beef waste at various time periods rather than imposing a manure credit. For example, the last 40 tons of waste spread from the grain-fed yearlings in the drylot with runoff control costs $8.53 per ton to spread. On the other hand, the spring-spread liquid manure was worth $1.21 per ton while the last 80 tons of fall-spread liquid manure cost $.63 per ton (negative shadow price). When waste handling operations do not interfere with timely field work, the fertilizer content of the beef waste at the time the waste is spread is the primary determinant of manure value. Negative shadow prices occur when the opportunity to do timely field work is sacrificed in order to haul beef waste. In some cases labor availability may be as critical as field time.

Post-optimal analysis (6) was performed to measure input cost and product price sensitivity of the solutions obtained. Significant to waste management interests, the solutions remain optimal for a wide variation in loading-hauling-spreading cost and for large increases in fertilizer price. Waste handling practices would not be altered if the costs of handling varied from those developed in Table 8. Similarly, during the "energy crisis" fertilizer prices could double from the prices used in the study without changing the farm plan.

Increasing resource availability (greater hauling capacity in solid waste-handling systems, additional labor, additional field time) narrowed the difference in labor returns between liquid and solid systems, but did not change the ranking of the systems. Individual operators with heavy debt loads and limited cash flow may select a drylot system because of lower investment requirements.

Set-Aside programs in recent years provided an opportunity to eliminate timing bottlenecks by allowing summer waste handling. Net returns may be increased if historical payment levels for Set-Aside are maintained; however, this is not the case during the current "food crisis." The opportunity cost of a rotating disposal field (without Set-Aside payment) would range from $20 to $40 per acre (9).

CONCLUSIONS

Direct costs of runoff control are farm specific. Per head investment and operating costs are greater for small feedlots. Indirect costs (reduction in farm business net returns) can be evaluated by using linear programming. The programming model can determine returns, optimal cattle feeding and crop enterprise combinations, and optimal waste handling and crop operations schedules for alternative systems. Pollution control consultants should consider alternative waste handling-housing systems in terms of farm-feedlot profit before recommending runoff control structures on current facilities.

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