Effectiveness of Vegetated Buffer Strips in Controlling Pollution from Feedlot Runoff[1]

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ABSTRACT

A rainulator was used to test vegetative buffer strips for their ability to control pollution from feedlot runoff. Cropped buffer strips on a 4% slope reduced runoff and total solids transported from a feedlot by 67 and 79%, respectively. Total N and P were reduced by an average of 84 and 83%, respectively. Ammonium-N and PO_4-P were similarly reduced, but average NO_3-N in the runoff increased because some NO_3-N was gained from the sorghum (*Sorghum vulgare* L.)-sudangrass (*Sorghum sudanense* L.) and the oat (*Avena sativa* L.) buffer strips. During both years, the number of coliform organisms in the runoff water was reduced after runoff passed through the vegetated buffer strips. These results indicated that nonstructural feedlot discharge control practices are a promising alternative method for controlling pollution from feedlot runoff.

Additional Index Words: **runoff filter strips, vegetated filters, livestock waste, rainulator.**

Young, R. A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. J. Environ. Qual. 9:483–487.

[1] Contribution from the North Central Soil Conserv. Res. Lab., Sci. and Educ. Admin., Agric. Res., USDA, Morris, Minn., in cooperation with the Minn. Pollut. Control Agency and the Minn. Agric. Exp. Station, Sci. Journal Series 10,851. Received 9 Oct. 1979.

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The potential of runoff from livestock feedlots for polluting receiving bodies of water has been widely documented. Runoff from livestock feedlots has long been recognized as a potential source of pollution, and available technology has indicated that the best method of controlling runoff is to install a runoff catchment basin. As these basins were put into widespread use under existing state and federal feedlot pollution-control regulations, certain problems became apparent: (i) basins are expensive, even when available cost-sharing and tax incentives are taken into account; (ii) runoff control basins often require operators to purchase or rent liquid, manure-handling equipment; (iii) because no discharge-evaluation technique had been proven, enforcement and technical-assistance agencies often require catchment basins, even if the possibility of pollutant discharge is remote; and (iv) if the catchment basin is not maintained properly, odors at various times of the year may become a nuisance for both operators and their neighbors.

Alternative pollution-control measures or land-management techniques that reduce or prevent discharge of pollutants were needed. This paper investigates the feasibility of using different management treatments to control the discharge of pollutants below active feedlots. Our specific objective was to evaluate the ability of land and cropping practices to absorb and retain pollutants in runoff from livestock feedlots.

PROCEDURE

Rainfall simulator tests were conducted for 2 successive years on six plots, 41.15 m long, up and down slope (4%), by 4.06 m wide (Fig. 1). These plots were located at the lower edge of an active feedlot so that their upper length (13.72 m) lay within the feedlot and their lower lengths (27.43 m) extended below the feedlot. During the second year, wet soil conditions at the lower end necessitated shortening the plots to 35.05 m, so that only 21.34 m extended below the feedlot. Plot width corresponded to that of many runoff plots in rainulator studies used in previous runoff and erosion research. In both years, two other plots, 13.72 m long and 4.06 m wide, were located within the feedlot so that their lower edge coincided with the feedlot boundary. The feedlots were located in Stevens County, in west central Minnesota and had been in use for 7 years. They contained about 310 head of cattle at the time of the study.

The first year, that portion of two study plots extending below the feedlot boundary was plowed, disked, harrowed, and planted across the slope to corn (*Zea mays* L.) at a population of 59,000 plants/ha ('Pioneer 3955', 95-day corn). Weeds were controlled with herbicides. The lower portion of two of the six plots was rough plowed and seeded to orchardgrass (*Dactylis glomerata* L.) at the rate of 13.55 kg/ha and the lower portions of the last two plots were plowed, disked, harrowed, and planted to a mixture of sorghum (*Sorghum vulgare* L.) and sudangrass (*Sorghum sudanense* L.) at a rate of 33.6 kg/ha. The two 13.72-m-long plots within the feedlot were not treated. Each set of two plots was considered as a replicate. The second year, only two cropping treatments, corn and oats (*Avena sativa* L., 'Froker') were tested.

Between 30 and 45 days after planting, a rainulator (Meyer, 1960), modified to simulate rainfall on plots up to 45.72 m long, was used to apply water to induce runoff and erosion. Water was applied to simulate rainfall energy of a 25-year, 24-hour rainstorm for this climatic area. We chose to simulate rainfall energy because Wischmeier (1959) showed that the most reliable indicator of the capacity of rainfall to cause soil loss was the product of rainfall energy and the maximum 30-min intensity of a storm. Energy calculations were based on rainfall-frequency data from Hershfield (1961) and on rainfall-kinetic energy values from Wischmeier and Smith (1958). A 25-year, 24-hour storm for this area has an average intensity of 0.48 cm/hour and kinetic energy of 2,109,000 kg-m/ha. Since the rainulator could not apply such low-intensity rainfall, we chose an intensity of 6.35 cm/hour. For a rainstorm of this intensity to apply the same amount of energy as the 0.48-cm/hour storm, a rainfall duration of 71 min was required. This application of 6.35 cm/hour for 71 min was applied to each plot twice—the first at existing moisture conditions (dry run) and the second, 24 hours later (wet run), when the plot area was essentially saturated.

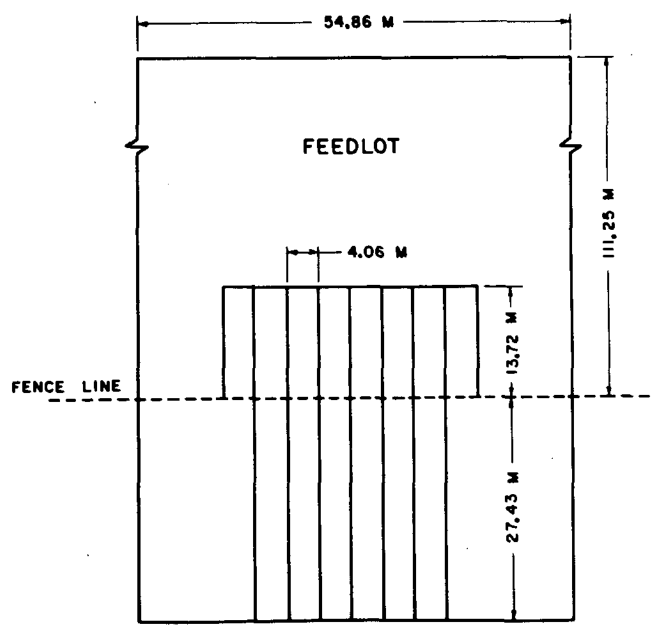

Fig. 1—Plot layout.

During each rainulator run, runoff rates were measured continuously at the bottom of each plot using a 0.37-m HS flume equipped with a Belfort water-stage recorder. During the first study year, runoff was sampled for nutrients and indicator organisms periodically at the lower end of the plots and, for the 41.14-m-long plots, at the feedlot edge and 13.72-m downslope from the feedlot edge. During the second year, we took grab samples every 15 min during rainfall simulation at 4.57-m intervals downslope from the feedlot edge.

Samples were always taken in sets of three. One sample of each set was treated with 2 ml of 10*N* sulfuric acid (H_2SO_4) for each 250 ml of sample. In the laboratory one nonacidified sample of each set was analyzed for sediment content. The other nonacidified sample was divided into two portions after the sediment had settled out; one portion was refrigerated until analyzed for total phosphorus (TP) and the other portion was filtered and frozen until analyzed for ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and soluble orthophosphate (PO_4-P). The acidified sample was refrigerated until it was analyzed for total Kjeldahl nitrogen (TKN) and chemical oxygen demand (COD). Sediment from the nonacidified samples was separated by decanting, air dried, and analyzed for TKN, NH_4-N, NO_3-N, TP, and extractable P.

We determined TKN using the macro-Kjeldahl method, modified using Kel-Paks for water (Bremner, 1965). NO_3-N and NH_4-N were analyzed by using an automated colorimetric phenate method and an automated cadmium reduction method on a two-channel Technicon Auto-Analyzer (USEPA, 1974). Total nitrogen (TN) was assumed to be approximately equal to the sum of TKN plus NO_3-N. From 5 to 60% of the NO_3-N may be converted to NH_4-N and recovered in the Kjeldahl analysis (Nelson and Sommers, 1975). However, assuming an average recovery of 30%, the error in TN would probably not exceed 4% considering the relatively low concentrations of NO_3-N in the runoff samples.

We obtained TP (inorganic plus organic) values by digesting unfiltered samples with perchloric acid, instead of ammonium persulfate, and analyzing them at 880-nm wavelength on a spectrophotometer after color development with an ammonium molybdate-ascorbic acid-antimony method. To determine PO_4-P, we used the same color development method on filtered water samples and analyzed them at 880-nm wavelength on a spectrophotometer (USEPA, 1974). To determine extractable P, we used a dilute acid-flouride procedure as described by Bray and Kurtz, 1945.

Separate water samples were collected in sterile containers to determine total coliforms (TC), fecal coliforms (FC), and fecal streptococci (FS). We counted microorganisms using the fundamental MF procedure and standard enteric indicator tests (Millipore Corp., 1973).

RESULTS

Water and Sediment Losses

Total solids and dissolved nutrients in runoff were reduced by all cropping treatments (Tables 1 and 2). As runoff and entrained solids passed through the vegetated buffer strips, they were reduced an average of 67 and 79%, respectively. Total nitrogen (TN $\cong$ TKN + NO_3-N), NH_4-N, TP, and PO_4-P in runoff were reduced by an average of 84, 63, 83, and 76%, respectively. Average NO_3-N values, in runoff, however, increased about 9%, due to the fact that some NO_3-N was picked up from the sorghum-sudangrass and oat plots.

Runoff and entrained solids and, consequently, nutrients in runoff were reduced most on the corn plots (Table 1). Runoff was reduced 82% on corn plots as compared with 81, 61, and 41% reductions on the orchardgrass, sorghum-sudangrass, and oat plots, respectively. Solids transported in runoff from corn plots were reduced 86% as compared with 66% reductions from orchardgrass, 82% reductions from sorghum-sudangrass, and 75% reductions from oats.

Table 1—Runoff and sediment transported from beef cattle feedlots and cropped buffer strips (average of two replications).

	Antecedent soil moisture content† 0–15 cm	Runoff	Sediment
	%	cm	kg/ha
	1977		
Feedlot‡			
Dry run	32	6.86	643.3
Wet run	35	7.67	1,473.5
Total		14.53	2,116.8
Corn§			
Dry run	22	0	0
Wet run	36	0.25	138.9
Total		0.25	138.9
Orchardgrass§			
Dry run	25	0.43	367.8
Wet run	31	2.39	344.1
Total		2.82	711.9
Sorghum-Sudangrass§			
Dry run	24	1.55	127.2
Wet run	34	4.06	255.9
Total		5.61	383.1
	1978		
Feedlot‡			
Dry run	68	7.11	2,412.6
Wet run	66	7.26	1,706.1
Total		14.38	4,118.7
Corn¶			
Dry run	31	1.17	279.1
Wet run	38	3.71	508.0
Total		4.88	787.1
Oats¶			
Dry run	44	3.12	392.2
Wet run	50	5.38	644.6
Total		8.51	1,036.8

† Gravimetric, dry weight basis.
‡ 13.72 m long.
§ 27.43 m long buffer strip + 13.72 m of feedlot.
¶ 21.34 m long buffer strip + 13.72 m of feedlot.

Table 2—Dissolved nutrients in runoff from beef cattle feedlots and cropped buffer strips (average of two replications).

	Total Kjeldahl nitrogen	Ammonium nitrogen	Nitrate nitrogen	Total phosphorus	Orthophosphate
	kg/ha				
		1977			
Feedlot†					
Dry run	9.71	2.50	0.34	4.76	3.36
Wet run	7.36	2.19	0.03	4.68	2.93
Total	17.08	4.69	0.37	9.45	6.29
Corn‡					
Dry run	0	0	0	0	0
Wet run	0.31	0.09	0.02	0.17	0.10
Total	0.31	0.09	0.02	0.17	0.10
Orchardgrass‡					
Dry run	1.19	0.40	0.06	0.46	0.31
Wet run	4.02	1.23	0.28	1.79	1.12
Total	5.21	1.63	0.34	2.25	1.43
Sorghum-Sudangrass‡					
Dry run	2.69	0.68	0.32	1.44	1.10
Wet run	5.88	1.79	0.35	3.47	2.57
Total	8.57	2.47	0.67	4.91	3.67
		1978			
Feedlot†					
Dry run	15.68	1.93	0.08	7.55	2.63
Wet run	9.56	1.38	0.09	5.66	1.74
Total	25.24	3.31	0.17	13.20	4.37
Corn§					
Dry run	1.53	0.24	0.21	1.03	0.79
Wet run	3.88	0.48	0.54	2.45	1.81
Total	5.41	0.72	0.75	3.48	2.60
Oats§					
Dry run	6.10	1.01	1.05	2.90	1.94
Wet run	7.69	1.22	0.87	3.65	2.58
Total	13.80	2.23	1.93	6.55	4.52

† 13.72 m long.
‡ 27.43 m long buffer strip + 13.72 m of feedlot.
§ 21.34 m long buffer strip + 13.72 m of feedlot.

The larger reductions in soil and water losses from the corn plots may have been caused by the corn rows retarding runoff since they were planted across the slope. Whenever narrow rectangular field plots are tilled and planted across slope, there is a risk of overestimating the effectiveness of the treatment in reducing soil and water losses (Young et al., 1964) as compared with treatment effects on large size fields. However, even taking this bias into consideration, these reductions are large.

Nutrient Losses

The reduction in TN and TP associated with the solids in the runoff from all treatments for the 2 years of testing averaged 93 and 92%, respectively (Table 3). Both NH_4-N and PO_4-P were reduced an average of 93%. Nitrate losses associated with solids from the feedlot were low and essentially did not change as the runoff and entrained solids passed through the vegetated buffer strips.

The 21.34-m buffer strips planted to corn reduced the concentration of solids in the runoff water by 73%. Concentrations of TN, NH_4-N, TP, and PO_4-P in solution were reduced by 67, 71, 67, and 69%, respectively. Twenty-four slope-length-increment samples taken during the second year were used to develop the following concentration-slope length relationships for corn:

$$\text{TKN} = 42.65 - 1.28\,L \qquad R^2 = 0.59$$
$$NH_4\text{-N} = 4.94 - 0.16\,L \qquad R^2 = 0.48$$
$$NO_3\text{-N} = 3.95 - 0.10\,L \qquad R^2 = 0.17$$
$$\text{TP} = 24.60 - 0.72\,L \qquad R^2 = 0.51$$
$$PO_4\text{-P} = 19.43 - 0.62\,L \qquad R^2 = 0.57$$

where the soluble nutrient concentration at a point below the feedlot is expressed in mg/liter and L is the length of the buffer strip in meters. These relationships are shown graphically in Fig. 2.

The initial nutrient concentration values of runoff at the feedlot edge, on which these equations are based, fall within the range of nutrient concentrations of feedlot runoff found in the literature (Miner et al., 1979; Manges et al., 1975; Coote and Hore, 1978; Wieneke et al., 1978). However, we must emphasize that these equations were developed for data on 4% slopes. For steeper slopes, runoff velocities may be slightly higher, which could result in smaller reductions in nutrient concentrations in the runoff because of reduced contact time of runoff with the buffer-strip vegetation. In that case longer buffer strips to increase the time of contact should be considered.

This study did not include runoff plots to determine normal background nutrient concentrations from areas not influenced by a feedlot for comparison. Data obtained from a study by Burwell et al. (1975) was used for this purpose. Burwell et al. determined nutrient losses

Table 3—Nutrients attached to sediment transported in runoff from beef cattle feedlots and cropped buffer strips (average of two replications).

	Total Kjeldahl nitrogen	Ammonium nitrogen	Nitrate nitrogen	Total phosphorus	Extractable phosphate
	kg/ha				
		1977			
Feedlot†					
Dry run	14.65	0.13	0.01	5.74	2.27
Wet run	34.83	0.45	0.01	12.50	5.22
Total	49.48	0.58	0.02	18.24	7.49
Corn‡					
Dry run	0	0	0	0	0
Wet run	0.72	0.02	T¶	0.26	0.07
Total	0.72	0.02	T	0.26	0.07
Orchardgrass‡					
Dry run	1.53	0.04	T	0.54	0.13
Wet run	1.46	0.02	T	0.50	0.15
Total	2.99	0.07	T	1.04	0.28
Sorghum-Sudangrass‡					
Dry run	0.49	0.01	T	0.17	0.04
Wet run	1.06	0.02	T	0.23	0.11
Total	1.56	0.03	T	0.40	0.15
		1978			
Feedlot†					
Dry run	42.16	0.27	0.02	12.50	6.06
Wet run	27.37	0.33	0.01	8.80	4.12
Total	69.53	0.60	0.03	21.30	10.18
Corn§					
Dry run	2.14	0.02	0.06	0.86	0.35
Wet run	3.97	0.04	0.16	1.10	0.68
Total	6.11	0.06	0.22	1.96	1.03
Oats§					
Dry run	3.83	0.01	0.02	1.43	0.60
Wet run	6.46	0.02	0.04	2.32	0.97
Total	10.30	0.03	0.06	3.76	1.56

† 13.72 m long.
‡ 27.43 m long of buffer strip + 13.72 m of feedlot.
§ 21.34 m long of buffer strip + 13.72 m of feedlot.
¶ Trace.

for various soil cover conditions on Barnes loam in west central Minnesota. The values used for comparison were measured from corn plots, conventionally tilled and with no manure applied, during the first 2 months after corn planting. This is the critical erosion period for field crops in this region and coincides with the period during which the feedlot tests were run. Average rainfall on the runoff plots during this period was 6.43 cm (Mutchler et al., 1976).

Table 4 compares the concentration of soluble nutrients in runoff from the feedlot and from the end of a 22.86-m buffer strip of corn, as calculated from the above equations, with the average nutrient

Table 4—Comparison of average nutrient concentrations in runoff from buffer strips and natural field runoff plots.

	Total Kjeldahl nitrogen	Ammonium nitrogen	Nitrate nitrogen	Total phosphorus	Orthophosphate
	mg/liter				
Feedlot	40.6	4.9	3.9	23.1	19.0
Corn					
22.86 m buffer	13.4	1.2	1.7	8.1	5.2
22.86 m runoff plot†	1.4	0.7	0.9	1.8	1.0

† Burwell et al., 1975.

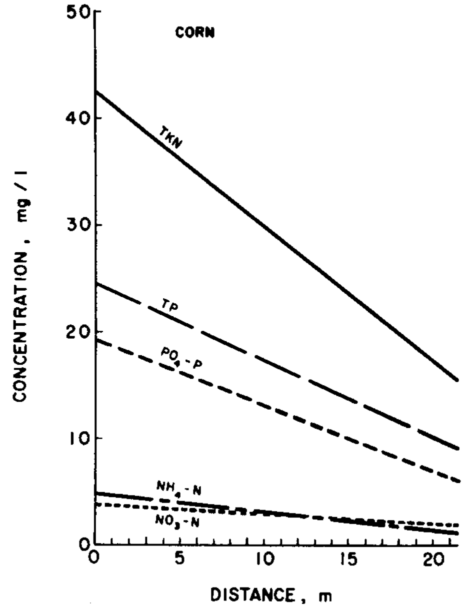

Fig. 2—Nutrient concentration vs. slope length for corn.

concentrations found in runoff from these 22.86-m-long natural rainfall runoff plots. Based on this information, a buffer strip of about 32.00 m of corn would be required to reduce the nutrient concentration in runoff from a 13.72-m-deep feedlot to the same level that might be expected from a field of corn receiving no feedlot runoff.

Bacteriological Quality

All vegetated buffer strips reduced the number of indicator organisms in runoff (Table 5). Runoff at the feedlot edge averaged 90.2 × 10^6 TC, 7.6 × 10^6 FC, and 46.3 × 10^6 FS. After runoff passed through the buffer strips, counts were reduced 69% for TC and FC, and 70% for FS. Total coliform counts varied with the length of the buffer strip, according to the following relationship:

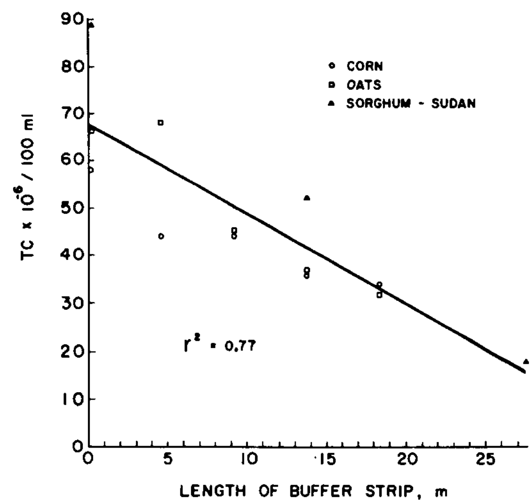

Fig. 3—Concentration of total coliform/100 ml of runoff vs. slope length.

Table 5—Microorganisms in runoff from beef cattle feedlot and cropped buffer strips (average of two replications).

	Total coliform	Fecal coliform	Fecal streptococcus
	$\times 10^6$/100 ml		
Feedlot†			
Dry run	107.071	9.916	50.183
Wet run	73.405	5.312	42.375
Avg	90.238	7.614	46.279
Corn§			
Dry run	30.167		
Wet run	23.125		
Avg	26.646		
Orchardgrass‡			
Dry run	32.000	2.640	6.000
Wet run	52.000	4.240	20.000
Avg	42.000	3.440	13.000
Sorghum-Sudangrass‡			
Dry run	5.000	0.760	3.000
Wet run	30.000	1.800	27.000
Avg	17.500	1.280	15.000
Oats§			
Dry run	26.443		
Wet run	28.125		
Avg	27.279		

† 13.72 m long.
‡ 27.43 m long of buffer strip + 13.72 m of feedlot.
§ 21.34 m long of buffer strip + 13.72 m of feedlot.

$$TC = 67.34 - 1.90L \quad R^2 = 0.77 \quad n = 15$$

where TC is expressed as organisms $\times 10^{-6}$/100 ml and L is length of buffer strip in meters (Fig. 3).

Table 6 shows the recommended bacteriological standards for surface waters for general and designated recreational water use (USDI, 1968). According to the relationship shown in Fig. 3, a 35.44-m-long buffer strip would be required to reduce the TC count from a 13.72-m-deep feedlot to $<1{,}000$/100 ml, which is the maximum recommended level for primary contact recreational use. This is about the same length of corn row required to reduce nutrient levels to values comparable to a corn field not receiving feedlot runoff. Although total amounts of nutrients and microorganisms in runoff and solids would increase as feedlot length increases because of the additional volume of runoff, concentrations of nutrients and microorganisms on a unit-area basis would remain relatively constant and, thus, not vary greatly from the measured values.

SUMMARY

Based on rainulator results from 2 years of testing, nonstructural feedlot discharge control practices are a promising alternative method for controlling pollution from feedlot runoff. Cropped buffer strips on a 4% slope reduced runoff and total solids transported from a feedlot by 67 and 79%, respectively. TN and TP were reduced by an average of 84 and 83%, respectively. NH_4-N and PO_4-N were similarly reduced but average NO_3-N in the runoff increased because NO_3-N was gained from the sorghum-sudangrass and the oat buffer strips. During both years, the number of coliform organisms in the runoff water was reduced after runoff passed through the vegetated buffer strips. Buffer strip lengths of 36 m appear to be sufficient to reduce to acceptable levels concentrations of both nutrients and microorganisms in feedlot runoff from summer rainstorms on feedlot areas of the size tested.

Table 6—Recommended bacteriological standards for surface waters.†

Surface water	Total coliform	Fecal coliform
	organisms/100 ml	
Public water supply and general recreational use	10,000	2,000
Designated recreational use:		
Secondary contact	5,000	1,000
Primary contact	1,000	200

† USDI, FWPCA. 1968.

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