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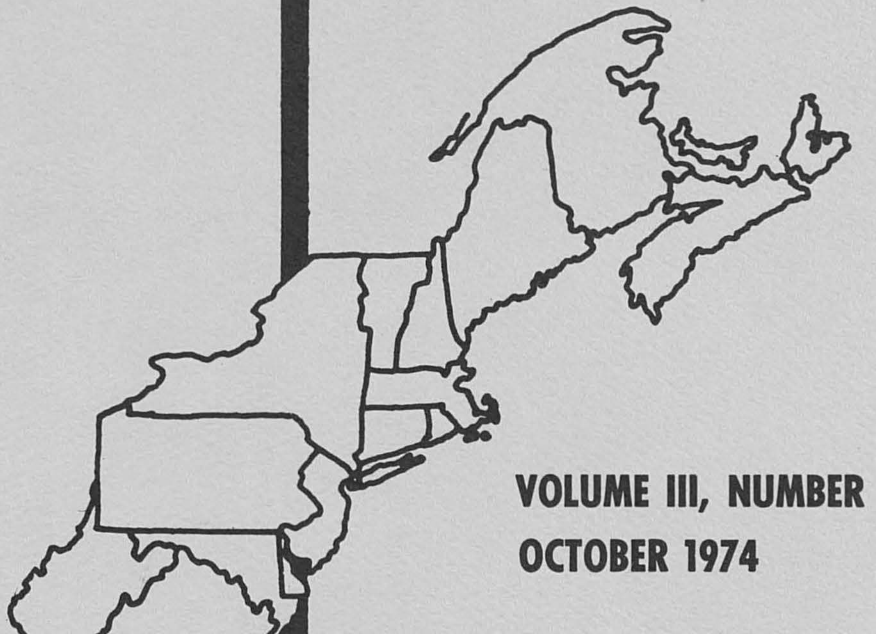

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ECONOMICS OF DAIRY MANURE STORAGE AND NUTRIENT LOSSES FROM A SMALL WATERSHED

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Until recently, nutrient losses from livestock manure have been of little concern. Manure, a valuable by-product in the past, is now regarded as a waste product to be disposed of in the cheapest manner possible [1]. The cost of manure handling frequently exceeds the value of the nutrients in it [2]. This is still true in 1974 even though the price of fertilizer has increased substantially.

For dairy farmers, the least cost means of handling manure has been daily spreading of manure. This practice has become a concern environmentally as a possible source of nutrient losses to streams and lakes via runoff. Researchers and governmental bodies have suggested that daily spreading of manure during the winter be banned or at least regulated. The rationale is that the spreading of manure daily, particularly on frozen ground, leads to increased nutrient losses compared to some alternative means of handling manure.

Limited data are available from plot experiments on runoff and nutrient losses from alternative ways of handling manure. In a three year study reported by Minshall, et.al. [5], runoff and nutrient losses were measured from plots with no manure, fresh manure applied in the winter and fermented and liquid manure applied in the spring. Their results indicate lower nutrient losses from spring spread manure. However, during the winter of 1967, 72 percent of the N and 42 percent of the P losses from winter-manure plots occurred during one 0.75 inch rainfall immediately after spreading. In a similar study at Aurora, New York, runoff and nutrient losses are being measured from plots with different rates and seasons of application [8]. These data also indicate large losses of N and P when manure was spread on frozen ground and followed by snowmelt and rainfall a few hours later. Since neither of the studies simulate daily spreading, to assert that daily manure spreading increases nutrient loading to streams and lakes seems capricious. Daily spreading of manure is being attacked with data taken from extreme circumstances and where the manner of spreading does not necessarily simulate daily spreading. Furthermore, a direct cause and effect relationship between nutrient loading of a stream and daily manure spreading can not be established because nutrients measured in a stream are the sum of a multitude of losses and the portion coming from a specific field or agricultural practice can not be identified.

Purpose

While the losses to a stream from daily spreading versus storage have not been measured, they can be estimated by simulation. This paper reports on a simulation of losses of nitrogen, phosphorus and soil from crop production to a stream for daily manure spreading and for 12 month storage with plow down within one day after spreading. These nitrogen, phosphorus and soil losses are then incorporated into a linear programming model to determine the impact on farm income of restrictions and effluent taxes on nutrient losses under both manure handling systems. Reliability of an economic analysis on the impact of controlling nutrients from manure spreading is dependent upon the accuracy of underlying physical relationships identified and quantified in the simulation model.

Physical Loss Model

Schaffer [6] developed a simulation procedure to compute the magnitude of nitrogen, phosphorus and soil losses under daily manure spreading and manure storage for a small New York watershed. The simulation model is made up of four major sub-models: (1) Soil Moisture-Temperature Model, (2) Soil Loss Model, (3) Nitrogen Loss Model and (4) Phosphorus Loss Model. 1/ This physical model estimates losses for three constituents to water generally identified as being of most concern regarding water quality - - nitrogen, phosphorus and soil.

The physical model was used to compute the residual losses to water generated by the agricultural activities in Mink Creek, a 6,900 acre watershed in east-central New York. Approximately 64 percent of the land area is in agriculture with 21 dairy and one non-dairy full time farms in the watershed. This watershed was chosen because it was predominately agricultural and much of the needed background information to evaluate the watershed was already accumulated. Kling [4] had delineated soils and land use and the Department of Environmental Conservation, New York State had measured the flow and nutrient loading of Mink Creek for the period April 1969 to April 1970 [3]. Data on crops grown, estimates of inputs, crop yields, livestock numbers, and productivity levels were collected by a survey during July 1973. With this information and weather data, the needed parameters were obtained to estimate the nitrogen, phosphorus and soil loss coefficients by cropping activities for both daily manure spreading and manure storage with direct plow down.

1/ For a more complete discussion of the physical model see Schaffer, et.al. [7]. For a detailed description of the physical model see Schaffer [6].

Economic Analysis

Once the loss coefficients were estimated for each cropping activity under the two manure handling systems, the economic model was constructed in a linear programming format. To keep the LP matrix tractable and effectively describe the Mink Creek watershed some activities were aggregated or activities, not material, were eliminated. For example, corn was raised on 25 soil types and phases in the watershed, each with a number of input-output parameters. These data were condensed to six soil types with only one productivity level of corn on each. Table 1 presents the crops by soil types used to describe the agricultural land activities in Mink Creek watershed. It also gives the computed nitrogen, phosphorus and soil losses per acre in Mink Creek. These losses are the quantity of constituents delivered to the stream, and are net of the amount redeposited, fixed or reduced by some process on their way to the mouth of the stream. The net losses were obtained by forcing the descriptive model to produce exactly the amount of N and P in the stream after deducting estimated contributions from woodland, other non-farm land, and septic tank effluent from Hetling's [3] stream measurements of N and P. The non-farm losses were estimated to be 2 percent and 38 percent of the N and P losses measured in Mink Creek, respectively.

The computed description of the watershed, under daily manure spreading, is presented in the first column of Table 2. The agricultural activities and resources were constrained to limits or combination of activities consistent with those found in Mink Creek. Given these constraints, the initial solution is representative of the kinds, amounts and intensities of agricultural practices found in the July 1973 survey of Mink Creek.

The net return of $447,272 is return over variable costs for the farm production of the entire watershed or about $20,300 per farm. Subtracting fixed costs for items such as taxes, interest and depreciation would reduce the net income per farm to less than $10,000.

The computed description of the watershed, under annual manure storage with direct plow down is presented in column five of Table 2. With no restriction on nitrogen loss, watershed income, phosphorus and soil losses were lower while nitrogen losses were higher than with daily manure spreading. Watershed income is lower because of the added cost of manure handling with annual storage. Increased hay sales and reduced cost of nitrogen and phosphorus fertilizer soften this loss of income somewhat. With annual manure storage, there is a reduction in oats and an increase in hay acres. Since the phosphorus and soil loss coefficients are larger for oats than for alfalfa, there is a decrease in phosphorus and soil losses. Also less manure phosphorus is lost in runoff because of direct plow down.

It is important to note that in the unrestricted (initial) solutions, nitrogen losses are higher (57,732 vs. 55,501 lbs.) with storage than with daily spreading. Manure ammonia volatilization losses are usually large with daily manure spreading, but they are minimal when manure is

Table 1
Computer Nitrogen, Phosphorus, and Soil Losses for Mink Creek Agricultural Activities

Crop	Year	Soil	Daily Manure Spreading Loss/Acre			Annual Storage, 2/ Direct Manure Plow Down Loss/Acre	
			N Lbs.	P Lbs.	Soil Tons	N Lbs.	P Lbs.
Corn Silage	1	Honeoye	23.9	.33	.17	27.2	.247
		Lima	22.5	.247	.11	24.4	.165
		Lansing	23.6	.33	.16	30.8	.247
		Conesus	21.1	.247	.10	24.6	.165
		Appleton	20.2	.165	.06	22.9	.165
		Farmington	26.0	.247	.10	27.2	.165
Corn Silage	2	Honeoye	26.6	.989	.51	31.9	.66
		Lansing	29.5	.907	.45	33.3	.66
		Farmington	28.4	.577	.25	29.1	.495
Potato		Lansing	63.1	.165	.18	63.1	.165
Corn Grain		Conesus	21.60	.247	.17	21.6	.247
Oats 1/		Honeoye	24.1	.33	.26	27.7	.247
		Lima	20.7	.247	.15	22.4	.165
		Lansing	22.8	.33	.21	29.8	.247
		Conesus	22.5	.247	.15	26.2	.165
		Farmington	16.8	.165	.11	17.5	.165
Alfalfa	1-3	Honeoye	10.4	.082	.01	10.4	.082
		Lima	10.1	.082	.01	10.1	.082
		Lansing	11.7	.082	.01	11.7	.082
		Conesus	10.8	.082	.01	10.8	.082
		Farmington	7.3	.082	.01	7.3	.082
Alfalfa	4-5	Honeoye	7.7	.082	.01	11.1	.082
		Lima	6.9	.082	.01	11.0	.082
		Lansing	7.4	.082	.01	11.8	.082
		Conesus	7.2	.082	.01	11.6	.082
		Farmington	5.7	.082	.01	8.0	.082
Birdsfoot Trefoil		Appleton	9.1	.082	.01	9.1	.082
Improved Pasture		Honeoye	4.4	.082	.01	4.4	.082
		Lima	3.4	.082	.01	3.4	.082
Permanent Pasture			1.6	.124	.03	1.6	.124

1/ Nutrient losses from oats for annual manure storage and direct soil incorporation were computed from the ratio of daily to direct first year corn loss rather than via the physical model.

2/ Annual manure storage and direct soil incorporation costs were computed to be $2.92 per ton per year. For daily manure spreading, the variable costs were $.16 per ton. Neither figure includes labor expense.

plowed down within 24 hours. The ammonium in stored manure is rapidly converted to nitrate after soil incorporation. Because of high nitrate inventories and little crop uptake at this time of year, nitrate loss by seepage is increased on crops receiving stored manure. 2/

Two types of policies for controlling nitrogen and phosphorus in the watershed were studied, restrictions and effluent taxes on nutrient losses. In each case, the linear programming model was allowed to select the activities that would maximize farm income subject to the policies applied.

Restrictions on Nitrogen and Phosphorus Losses

The effect of applying restrictions on losses of N on farm organization, watershed income, and phosphorus and soil losses are reported in Table 2. The data in the table indicate the least cost rearrangement of crop and livestock activities to achieve a given level of nitrogen loss.

These results for daily manure spreading show that restricting nitrogen loss to 34,536 lbs. would reduce beef production by 200, require part of the replacement heifers to be purchased, cut corn acreage nearly in half and leave 1,193 acres idle. Net farm income in the watershed would be reduced by about $58,000 or approximately $2,600 per farm. The reduction in nitrogen losses is achieved from a decrease in cropped acres. It also causes a substantial reduction in phosphorus and soil losses.

With annual manure storage and direct plow down, the 34,356 lb. restriction on nitrogen loss decreases crop acres about 1,431 acres and reduces net farm income in the watershed approximately $62,900 or about $2,860 per dairy farm. Both the decrease in crop acres and net farm income are slightly larger than with daily manure spreading. This relationship occurs for all levels of nitrogen restriction, because the nitrate losses are greater for all crops when manure is stored. As the selected levels of nitrogen losses are reduced, livestock numbers and cropland acres are decreased. This in turn further reduces farm income in the watershed as well as resulting in lower and lower losses of phosphorus and soil, for both manure handling systems.

The results of applying restrictions on the loss of phosphorus from agricultural production activities are presented in Table 3. The phosphorus restrictions also cause reductions in livestock numbers, crop acres and farm income, but smaller reductions than did the nitrogen restrictions. Losses of nitrogen and soil were also reduced by the application of phosphorus restrictions.

2/ This is not known with certainty, i.e., it has not been confirmed from field experiments. The information results from the nitrogen simulation model.

Table 2
Effect of Nitrogen Loss Restrictions on Farm Organization and Income, Mink Creek Watershed

		Daily Manure Spreading				Annual Manure Storage With Direct Plow Down			
		Restrictions on Nitrogen Loss (lbs.)				Restrictions on Nitrogen Loss (lbs.)			
	Unit	Initial	34,536	25,773	17,010	Initial	34,536	25,773	17,010
Net return	($)	447,272	388,957	347,022	266,015	401,977	339,074	295,668	214,132
Cows	No.	935	935	838	733	935	838	831	646
Heifers	"	234	53	---	---	234	---	---	---
Buy heifers	"	---	181	209	183	---	210	208	162
Beef	"	200	---	---	---	200	---	---	---
Potatoes	Acres	55	55	---	---	55	55	---	---
Corn	"	800	420	354	169	800	444	238	149
Oats	"	499	272	222	169	379	201	208	149
Hay	"	1,976	1,390	1,119	851	2,095	1,199	1,236	754
Permanent Pasture	"	970	970	970	970	970	---	---	---
Buy corn	Bu.	21,520	28,037	24,532	53,564	25,985	18,779	39,883	44,089
N purchased	Lbs.	32,736	20,569	9,801	2,529	20,800	15,458	3,566	2,239
P_2O_5 purchased	"	95,145	60,948	35,640	17,853	87,923	50,131	23,343	15,809
N loss	"	54,501	34,536	25,773	17,010	57,732	34,536	25,773	17,010
P loss		690	471	402	294	575	384	324	251
Soil loss	Tons	320	195	158	103	272	175	126	94
Buy labor	Hrs.	25,604	12,352	1,157	---	25,056	2,575	---	---
Sell hay	Tons	584	---	---	---	791	---	---	---
Idle	Acres	---	1,193	1,635	2,141	---	1,431	1,648	2,278

Table 3
Effect of Phosphorus Loss Restrictions on Farm Organization and Income, Mink Creek Watershed

		Daily Manure Spreading				Annual Manure Storage With Direct Plow Down			
		Restrictions on Phosphorus Loss (lbs.)				Restrictions on Phosphorus Loss (lbs.)			
	Unit	Initial	442	330	218	Initial	442	330	218
Net return	($)	447,272	406,216	359,830	291,016	401,977	385,213	350,760	288,149
Cows	No.	935	935	850	835	935	935	935	825
Heifers	"	234	192	---	---	234	234	96	---
Buy heifers	"	---	42	212	209	---	---	137	206
Beef	"	200	---	---	---	200	200	---	---
Potatoes	Acres	55	55	55	55	55	---	---	---
Corn	"	800	519	393	197	800	800	700	449
Oats	"	499	363	259	206	379	378	260	174
Hay	"	1,976	2,021	1,493	1,228	2,095	2,095	1,499	1,061
Permanent pasture	"	970	---	---	---	970	59	---	---
Buy corn	Bu.	21,520	28,874	23,625	79,001	25,985	25,785	29,746	54,827
N purchased	Lbs.	32,736	25,534	20,996	11,765	20,800	20,800	19,300	15,532
P_2O_5 purchased	"	95,145	75,861	59,592	39,368	87,923	85,535	70,258	46,995
N loss	"	54,501	42,944	32,759	23,519	57,732	55,755	44,370	30,599
P loss	"	690	442	330	218	575	442	330	218
Soil loss	Tons	302	192	145	84	272	232	178	111
Buy labor	Hrs.	25,604	17,387	3,974	688	25,056	23,975	13,294	---
Sell hay	Tons	584	---	---	---	791	14	---	---
Idle	Acres	---	1,342	2,100	2,614	---	913	2,259	2,559

With the same level of phosphorus restrictions for daily manure spreading and manure storage, the reduction in crop acres and farm income is slightly greater with daily manure spreading. At the 442 lb. restriction on phosphorus losses, cropland would be reduced by 1,342 acres and farm income would be decreased about $41,000 or $1,860 per farm under daily spreading. For the annual manure storage scheme, cropland would be reduced by 913 acres and farm income decreased by $16,764 or $760 per farm. This occurs because the phosphorus losses are less for all crops under the manure storage-direct plow down system. However, farm income for the watershed is greater under daily manure spreading because manure disposal is less costly.

In summarizing restrictions on either nitrogen or phosphorus, both result in a substantial reduction in crop acres and farm income in the watershed for the two manure handling systems considered. Under both nitrogen and phosphorus restrictions daily spreading results in the greatest farm income for the watershed.

Nitrogen and Phosphorus Effluent Taxes

Ideally, effluent taxes should be set equal to the level that would achieve the water quality that would maximize social welfare. Because the appropriate level of tax is unknown, several levels of tax were used.

The results of applying nitrogen effluent taxes of $2, $5 and $10 per lb. are reported in Table 4. For both daily spreading and manure storage, the tax was effective in reducing nitrogen losses. However, at the $2 tax level, the tax was much more effective in reducing nitrogen losses under the daily spreading system than under storage. In fact, the nitrogen loss at the $2 tax level was higher with storage than in the no-tax solution with daily spreading.

The N effluent tax reduced farm income for two reasons. First, the tax on nitrogen effluent must be paid and second, there is a change in farm organization when this is less costly than paying the tax.

Higher effluent taxes result in lower farm incomes. In this watershed model, manure storage not only resulted in lower income in the no-tax solution but also caused greater reductions in income for a given increase in tax than with daily spreading.

Because of the low levels of phosphorus losses (in comparison to nitrogen), much higher phosphorus effluent taxes per lb. were needed to achieve reductions in phosphorus losses (Table 5). With manure storage, phosphorus losses were lower in the initial solution and continued to be lower at each level of tax. At each level of tax, farm income was lower with storage than with daily spreading. However, the reduction in income for a given level of tax was smaller for storage than for daily spreading.

As with the restrictions policy, the tax on either nitrogen or phosphorus resulted in lower losses of the other nutrient as well as lower soil losses.

Table 4
Effect of Nitrogen Effluent Taxes on Farm Organization and Income for Mink Creek Watershed

	Unit	Daily Manure Spreading Effluent Tax on Nitrogen ($/lb.)				Annual Manure Storage With Direct Plow Down Effluent Tax on Nitrogen ($/lb.)			
		Initial	$-2.	$-5.	$-10.	Initial	$2.	$5.	$10.
Net return	($)	447,272	344,336	218,581	106,293	401,977	286,681	170,705	49,871
Cows	No.	935	935	935	844	935	935	835	835
Heifers	"	234	234	---	---	234	234	---	---
Buy heifers	"	---	---	234	211	---	---	208	208
Beef	"	200	200	---	---	200	200	---	---
Potatoes	Acres	55	55	---	---	55	55	---	---
Corn	"	800	662	397	188	800	800	356	190
Oats	"	499	401	254	188	379	378	205	191
Hay	"	1,974	2,210	1,280	950	2,095	2,095	1,220	966
Permanent pasture	"	970	970	970	970	970	970	970	970
Buy corn	Bu.	21,520	25,027	27,147	65,742	25,985	25,879	25,238	64,736
N purchased	Lbs.	32,736	38,800	11,266	2,819	20,800	20,800	5,348	2,870
P_2O_5 purchased	"	95,142	87,437	40,737	19,906	87,923	87,923	30,657	20,264
N loss	"	54,501	49,576	29,086	19,421	57,732	57,460	28,765	21,588
P loss	"	690	624	440	322	575	569	352	289
Soil loss	Tons	302	250	175	119	272	269	145	114
Buy labor	Hrs.	25,604	25,327	9,286	---	25,056	25,030	756	---
Sell hay	Tons	584	491	---	---	791	770	---	---
Idle	Acres	---	---	1,397	2,002	---	---	1,559	1,983

Table 5
Effect of Phosphorus Effluent Taxes on Farm Organization and Income for Mink Creek Watershed

		Daily Manure Spreading				Annual Manure Storage With Direct Plow Down			
		Effluent Tax on Phosphorus ($/lb.)				Effluent Tax on Phosphorus ($/lb.)			
	Unit	Initial	$200	$300	$500	Initial	$200	$300	$500
Net return	($)	447,272	325,686	276,296	195,574	401,977	297,239	254,798	193,613
Cows	No.	935	783	935	835	935	935	935	835
Heifers	"	234	234	234	---	234	234	234	---
Buy heifers	"	---	---	---	209	---	---	---	209
Beef	"	200	200	177	---	200	200	7	---
Potatoes	Acres	55	55	55	55	55	55	55	55
Corn	"	800	800	577	301	800	800	800	681
Oats	"	499	381	413	275	379	378	331	173
Hay	"	1,974	2,111	2,204	1,574	2,095	2,095	1,856	1,045
Permanent pasture	"	970	---	---	---	970	---	---	---
Buy corn	Bu.	21,520	26,917	31,419	28,517	25,985	25,597	24,096	26,304
N purchased	Lbs.	32,736	34,042	28,354	15,771	20,800	20,800	20,800	19,006
P_2O_5 purchased	"	95,142	90,484	84,312	56,411	87,923	85,602	80,799	62,008
N loss	"	54,501	49,698	47,363	31,424	57,732	55,661	52,490	36,470
P loss	"	690	516	488	309	575	435	407	266
Soil loss	Tons	302	228	207	128	272	231	222	142
Buy labor	Hrs.	25,604	24,336	23,821	2,889	25,056	23,656	18,402	1,742
Sell hay	Tons	584	---	---	---	791	---	---	---
Idle	Acres	---	1,025	1,051	2,095	---	---	1,257	2,346

Comments

Regardless of whether restrictions or effluent taxes were used as the policy instrument, reduced nutrient losses were achieved by reducing agricultural output in the watershed. At higher levels of tax or lower nutrient loss restrictions, crop production and finally livestock production in the watershed were reduced. If alternative levels of fertilization and/or conservation practices had been included in the model, perhaps nutrient losses could have been achieved with less reduction in agricultural output.

Idle acres, which increased as losses were reduced, were not charged with nutrient losses. This is not correct because there are losses from idle acres. To the extent that idle acres contributed to losses the results under-estimate losses and the cost of achieving a given reduction in losses.

Part of the reduction in N, P and soil losses is achieved by increasing losses in other watersheds. As losses in the watershed were reduced, crops and dairy replacements purchased from outside the watershed were increased. To the extent that such production creates losses in other watersheds, the net result is a transfer of nutrient residuals to other watersheds.

Summary

A watershed model was developed to incorporate both estimated losses of nitrogen, phosphorus and soil and costs to farmers of reducing such losses. All results should be considered preliminary and subject to change with further research. In particular, more reliable nutrient and soil loss data are needed, for both the daily spreading and stored manure alternatives.

Results of the modeling effort indicate that costs to farmers of reducing N, P and soil losses are substantial. In addition, it is questionable whether losses from agricultural production (particularly for phosphorus) can be reduced to the levels used in the model.

A comment could be made relative to the removal of phosphorus by the agricultural activities in the watershed. In the unrestricted solution, with daily spreading, phosphorus (P) purchased in fertilizer was 41,522 lbs. Manure production contributed 27,028 lbs. of P for a total P applied to land of 68,550 lbs. The estimated loss from farming was 690 lbs. Therefore, farm production activities removed approximately 99% of the phosphorus input, a considerably higher removal than that achieved by most tertiary sewage treatment plants. This does not say that the farmers in Mink Creek could not decrease phosphorus losses, but indicates that such reductions would make substantial changes in agricultural activities. It also suggests that losses from agricultural activities, particularly phosphorus, are much smaller than some people believe.

Finally, the research presented in this paper casts doubt on whether a restriction on winter spreading of manure would produce positive environmental benefits. While storage and direct plow down would likely result in somewhat less phosphorus losses to water, there is the possibility that nitrogen seepage losses would be increased. Therefore, it seems questionable to force farmers to pay the additional costs required by storage systems.

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