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ECONOMICS OF SIZE IN DAIRY FARM ADJUSTMENT TO WATER QUALITY CONSTRAINTS

by

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Abstract

Adjustment of small, medium, and large Vermont dairy farms to successively tighter constraints on phosphorus loss was modeled using linear programming. Aggregate response to phosphorus control was estimated for an area from farm marginal costs. Medium and large farms have lower costs than small farms and could achieve higher levels of phosphorus reduction at the same proportional loss of income.

Key words: Dairy, manure management, phosphorus, economics of size, water quality.

ECONOMICS OF SIZE IN DAIRY FARM ADJUSTMENT TO WATER QUALITY CONSTRAINTS

Agricultural nonpoint sources of water pollution have been a national concern since 1972 (Holmes, 1979). As industrial and municipal point sources are brought under control, nonpoint sources become relatively more important (Council on Environmental Quality, 1979). Policy response has been of two kinds. A variety of Federal programs have been developed or modified to provide subsidies to farmers for agricultural practices designed to reduce pollution. On the other hand, state and local regulatory programs have been enacted to enforce control of agricultural runoff. Economic analysis of control measures is needed for both approaches, to determine appropriate cost share rates that recognize on-site and off-site benefits and to balance environmental goals against the economics of the farm sector. Both subsidy and regulatory programs currently ignore farm size as a variable in water quality programs.

This research was conducted as part of the Vermont Agricultural Runoff Study, funded by the U.S. Department of Agriculture as a Cooperative River Basin Study. Watersheds draining Vermont's principal dairy areas contribute significant phosphorus loads to Lakes Champlain and Memphremagog, accelerating nuisance algae growth and eutrophication. The objective of the research was to investigate tradeoffs between farm income and reductions in phosphorus runoff from agricultural practices. Different herd sizes were studied to determine if income effects due to phosphorus control practices would be borne equitably. If income effects between herd sizes are unequal, subsidy and regulatory policy should take that fact into account.

Description of the Model

A linear programming format was chosen to represent the profit maximizing behavior of farm operators constrained by technical operating requirements and the goal of phosphorus loss reduction.

Operating constraints are represented in four components. Dairy operations encompass herd management, replacement, feeding, and milk production. Milk production is directly related to feeding requirements through a milk response function. Feeds are grown or purchased and yields are translated into nutritional equivalents, accounting for harvest, storage and feeding losses. Manure management systems include nine liquid and solid manure storage systems and three daily spreading systems based on Safley (1977). The financial structure of the farm is reflected by long- and medium-term debt and annual debt service requirements. Federal taxes on current income are computed taking account of deductions for expenses and depreciation, investment tax credits, and special tax provisions for pollution control facilities (Moore, et. al., 1979). All prices, rates, and costs reflect 1979 price levels.

Phosphorus losses are associated with two aspects of the crop activities: soil erosion and manure spreading. Phosphorus adsorbed to soil particles is estimated by the following loading function (McElroy, et. al., 1976):

$$P_a = 20.0\ edcr$$

where P_a = phosphorus adsorbed to soil particles (lb./acre);
e = gross soil erosion estimated using the Universal Soil Loss Equation (tons/acre/yr.);
d = a sediment delivery ratio based on watershed drainage area;

c = soil phosphorus concentration (g/100g);
r = an enrichment ratio varying by sediment load;
20.0 = a dimensional constant.

Dissolved phosphorus losses are calculated using the following equation and literature values compiled in Gilbertson, et. al., (1979):

$$P_d = 0.226\ (0.95\ R_r C_r + 0.8\ R_s C_s)$$

where P_d = phosphorus dissolved in runoff (lb./acre);
R_r, R_s = runoff from rainfall and snowmelt (inches);
C_r, C_s = runoff phosphorus concentration in rainfall and snowmelt under varying management (ppm);
0.226 = conversion factor with units of lb./acre-inch;
0.95,0.80 = factors reflecting decrease in runoff from rainfall and snowmelt with surface applied manure.

Erosion and adsorbed losses vary with the crop, soil group, conservation practices, and tillage method. Dissolved losses vary with the crop, season in which manure is applied, and whether manure is incorporated into the soil or surface applied. Dissolved losses were adjusted for higher manure application rates based on Klausner, et. al., (1976). Crop inputs, outputs, and phosphorus losses are averaged over the stand life for hay crops. Example phosphorus loss estimates are shown in Table 1. The very high loads for manure spread in winter reflect higher runoff for this season, higher runoff concentrations for cover conditions at this time, and lack of incorporation.

The model was run for small (35 cow), medium (54 cow), and large (116 cow) dairy farms with herds, machinery complements and soil resources typical of Vermont dairy farms. Economic aspects of the model were validated by comparison with published averages of Vermont

Table 1 — Phosphorus Loss Estimates for Some Sample Crop Activities, Soil Resource Group 8

Crop	Corn Silage		Alfalfa-Grass[1]	Clover-Grass[2]
Tillage	Conventional	No-till	Conventional	Conventional
Manure Rate (tons/acre/year)	15.00	15.00	15.00	15.00
Erosion (tons/acre/year)	17.80	8.05	0.85	1.29
Phosphorus Loss (lbs./acre/year)				
Adsorbed	5.11	2.71	0.45	0.63
Dissolved[3]				
Spring	0.19	0.19	0.25	0.25
Summer	N/A	N/A	0.20	0.20
Fall	0.03*	0.11	0.14	0.14
Winter	1.50	1.50	3.95	3.95

[1] Annual average over five-year stand life.
[2] Annual average over three-year stand life.
[3] By season in which manure is applied.
*Indicates manure incorporated into soil; otherwise surface applied.

farms participating in the Cooperative Extension's Electronic Farm Accounting (ELFAC) system (Tremblay, 1979). Operating receipts and operating expenses were within 10 percent of ELFAC figures for all farm sizes, and operating income was within 20 percent. Results also compare favorably with average results for SIC 024 farms in the 1978 Agricultural Census for Vermont. No validation of the environmental results of the model has been attempted.

Results and Discussion

The LP model was used to simulate a farm operator's profit-maximizing response to constraints on bioavailable phosphorus loss. A base solution was run for each farm size with no constraint on phosphorus loss, erosion, or choice of manure handling system. Phosphorus losses were then parametrically reduced from the base level in increments of 10 percent of the base level.

The most important difference in the base solutions for different farm sizes is that both medium and large herds turn to some manure storage even in the absence of phosphorus constraints. The finding that at least some manure storage is profitable is at variance with conclusions of other studies (Schaffer, Jacobs, and Casler, 1974; Ashraf, Christensen and Frick, 1974; Haith and Atkinson, 1977). Previous studies concluded that neither labor savings nor nutrient retention justify the added cost of storage systems. The difference here is partly caused by allowing combinations of systems. If the medium farm, for example, were constrained to choose between the daily spread (68 percent of manure) and storage (32 percent of manure) systems, it is likely that all manure would be daily spread. However, there are no such constraints in reality, and many farmers do use multiple systems, especially when the operation is expanded. Most studies of manure system economics take a partial budget approach that abstracts the investment in manure handling system from other aspects of the farm. Here the manure handling decision is integrated with other farm decisions and solved simultaneously with dairy, crop, and financial decisions. As an example, the large farm base solution was compared to a similar base solution constrained to use a daily spreading system, and the results are shown in Table 2. Savings on labor and fertilizer amount to only 50 percent of changes in income with the storage system. Operating costs, tax advantages and related changes in crop production account for the rest.

As an example of the parametric analysis, changes in the small farm with successively lower allowable phosphorus loss are summarized in Table 3. Reductions in phosphorus loss are initially achieved through costless shifts in manure spreading between crops and seasons. Additional reductions up to 20 percent require control of soil erosion through contour plowing. The 30 percent reduction requires some manure storage to increase manure spreading and soil incorporation at fall plowing. Additional soil erosion control through contour plowing and minimum tillage on corn is needed. Contour strip-cropping is required to achieve a 40 percent phosphorus reduction, as well as more manure storage, contour plowing, and minimum tillage. Reductions in phosphorus between 50 and 80 percent are attained by substituting manure storage and contour strip-cropping for contour plowing and minimum tillage. To achieve the most extreme reduction in phosphorus loss, almost all manure is stored and spread in spring and fall so that it can be incorporated. Soil erosion is reduced to 24 percent of the base level, income is decreased 19.3 percent, and debt increased 15.6 percent.

Table 2 -- Costs of Manure Systems, Large Farm

Category	Daily System	Storage System	Savings
Operating Costs[1]	$ 8,948	$ 5,677	$3,271
Labor[2]	3,756	2,210	1,546
Debt Service	5,662	9,384	-3,722
Plant Nutrients[3]	-4,136	-4,974	838
Tax Deductions[4]	-2,643	-6,120	3,477
Net System Cost	$11,587	$ 6,177	$5,410
Farm Income	$14,194	$18,960	$4,766

[1] Includes taxes, insurance, repairs, bedding material, electricity, and diesel fuel.

[2] Total annual labor is 1,192 hours for the daily system and 704 hours for the storage system.

[3] Nutrients required for crop production less those supplied by commercial fertilizers, valued at $.13/lb. N, .22/lb. P_2O_5, and .04/lb. K_2O.

[4] Tax deductions for operating costs, interest and depreciation valued at marginal tax rates.

Table 3 — Summary of Parametric Reduction in Bioavailable P, Small Farm, Cluster 5

	Units	Base	Phosphorus Reduction								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
Milk cows	NR.	35	35	35	35	35	35	35	35	35	35
Bioavailable P	Lbs./yr.	111.1	100.0	88.9	77.8	66.7	55.6	44.5	33.4	22.3	11.2
Soil erosion	Tons/yr.	723	675	454	345	293	293	285	262	241	172
Net income	Dols./yr.	8,929	8,923	8,892	8,903	8,402	8,322	8,199	7,920	7,577	7,203
Total debt	Dols.	67,953	67,953	67,953	67,953	70,767	74,163	75,161	76,970	77,590	78,575
Debt service	Dols./yr.	9,180	9,180	9,180	9,180	9,569	10,054	10,171	10,418	10,464	10,610
Crops											
Corn	Acres	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	41.8
Hay	Acres	57.0	57.0	57.0	53.2	53.2	53.2	53.2	53.2	53.2	55.0
Oats	Acres	3.0	3.0	3.0	6.8	6.8	6.8	6.8	6.8	6.8	3.1
Total	Acres	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Practice											
Spring tillage	Acres	3.0	3.0	3.0	6.8	6.8	6.8	6.8	6.8	6.8	78.7
Fall tillage	Acres	97.0	97.0	97.0	69.1	56.0	56.6	61.2	74.4	88.2	7.3
Contour	Acres	0.0	5.4	32.6	39.9	37.2	36.6	32.0	18.8	5.0	0.0
Contour strip	Acres	0.0	0.0	0.0	0.0	5.6	6.8	15.9	42.3	69.9	80.0
Terrace/diversion	Acres	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
Winter cover	Acres	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minimum till	Acres	0.0	0.0	0.0	24.1	37.2	36.6	32.0	18.8	5.0	0.0
Manure Handling System[1]	N/A	Q11-100%	Q11-100%	Q11-100%	Q11-94% B10-6%	Q11-80% B10-20%	Q11-61% B10-39%	Q11-47% B10-53%	Q11-33% B10-67%	Q11-15% B10-85%	Q11-10% B10-90%
Spreading											
Spring	%	25%	25%	25%	23%	19%	17%	20%	30%	45%	50%
Summer	%	25%	25%	25%	23%	19%	14%	10%	6%	2%	0%
Fall	%	25%	25%	25%	30%	42%	54%	60%	57%	52%	50%
Winter	%	25%	25%	25%	23%	19%	14%	10%	6%	2%	0%

[1] Manure handling systems are: Q-11 = tractor scraper - solid spreader, spread daily;
B10 = tractor scraper - stack - solid spreader; 180 day storage.

The medium and large farms follow relatively similar patterns in terms of the order and succession of practices, but there are differences. First, because manure storage is profitable in the base solution, these farms have more flexibility to meet phosphorus goals by shifting manure between crops and seasons. Income is maintained at the base level up to the 30 percent reductions on the medium and large farms. Second, the more expensive practices (minimum tillage and terrace/diversion) are not required to control erosion. Decreases in income are larger in absolute terms than for the small farm — $1,202 and $2,016 for the largest reduction on medium and large farms, respectively. However, these decreases are a smaller percent of base income -- only 8.9 and 10.6 percent, respectively.

Marginal Costs of Phosphorus Control

A product of the parametric analysis is the marginal cost of the required phosphorus reductions at each increment. These are graphed for each farm size in Figure 1. The larger the farm, the cheaper are reductions in phosphorus loss. For the small farm, beyond a reduction of about 75 pounds, phosphorus reduction response is almost totally inelastic.

An aggregate marginal cost (supply) curve for phosphorus reduction can be derived by weighting the individual farm curves in Figure 1 by the number of farms in that size class in a particular watershed and summing over farm sizes. Such a curve was constructed for a watershed with 20 small, 46 medium, and 44 large farms.

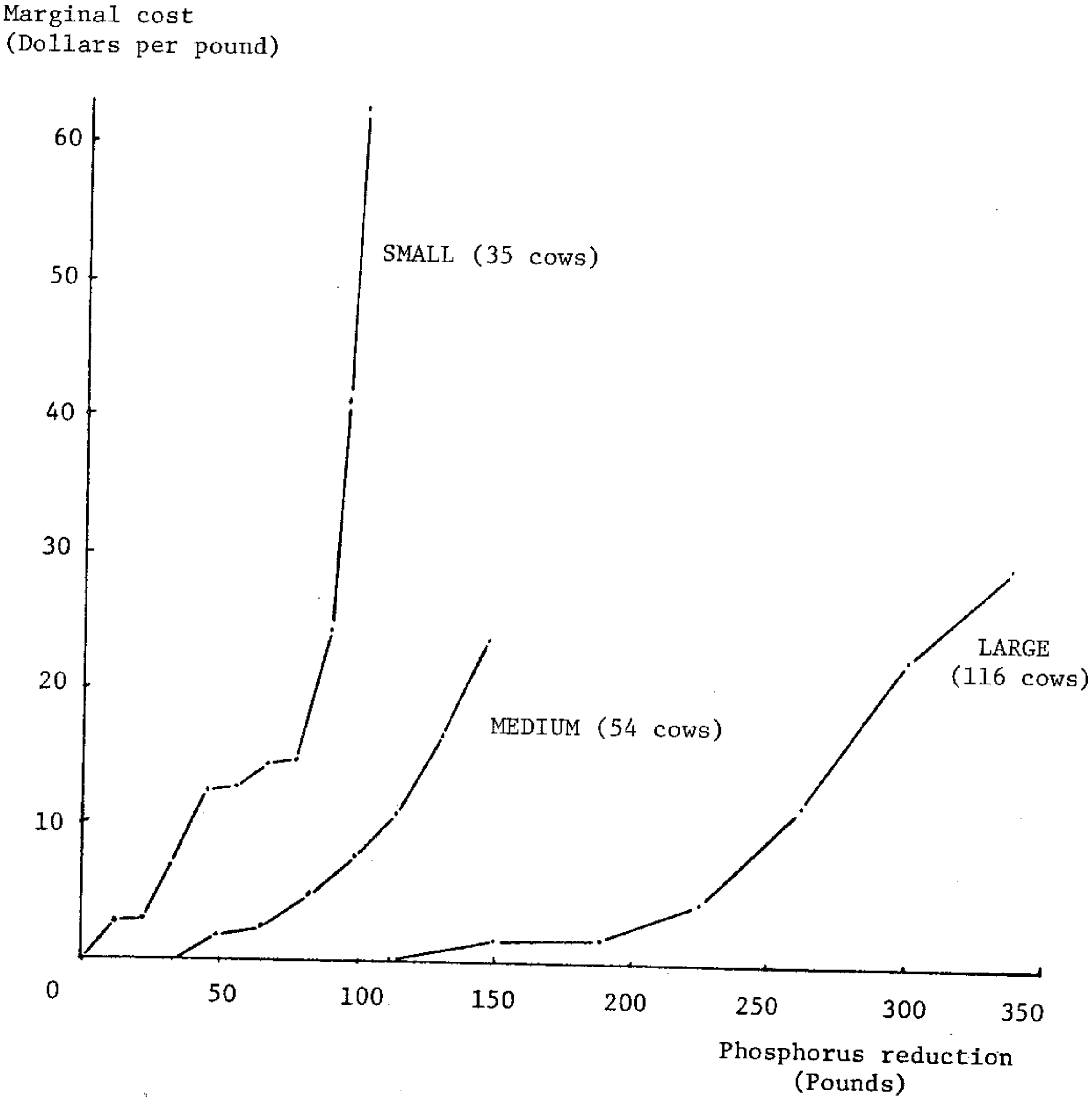

Figure 1. Marginal cost of phosphorus reduction by farm size

Ideally, a curve showing the marginal benefits per unit of phosphorus reduction would be developed and the point at which marginal benefits equaled marginal costs chosen as the optimal control level. As a practical matter, there are several sources of uncertainty in choosing an optimal goal for phosphorus reduction. First, the link between practices on the land and phosphorus delivery to receiving waters is not well understood. Second, the relationships between phosphorus export levels and water quality problems such as algae blooms, fish kills, odors, and other effects are also not well understood. Third, the monetary benefits resulting from an improvement in water quality are difficult to measure. Finally, nonmonetary benefits from water quality improvement probably exist but cannot be directly incorporated in the calculation of benefits.

Despite these problems with estimation of benefits, displaying the aggregate marginal cost curve alone can be useful. Policy makers can subjectively estimate benefits of phosphorus reduction to choose an optimal control level. The aggregate and individual marginal cost curves can then be used to estimate the overall and individual economic impacts and the optimal amount and kind of practices required.

For the example watershed, contrast two policies designed to achieve a reduction of 17,500 pounds of phosphorus (70 percent). Requiring all farms to achieve a 70 percent reduction would cost small farmers \$14.72 per pound and reduce their income 11.3 percent. Medium and large farmers would sacrifice only 5.2 and 3.5 percent of farm income, respectively. Total farm income drops \$81,932. On the other hand, requiring reductions at equal marginal cost for the three farm sizes means a reduction of 56 percent for small farms, 70 percent for medium farms, and 72 percent for large farms. The income reductions are 7.6, 5.2 and 4.0 for small, medium and large farms, and total farm income drops $78,714. Such a solution achieves the same level of phosphorus reduction at roughly the same cost to farm income but distributes the burden more equitably across farm sizes.

Conclusions

Simulation of phosphorus control under profit maximization on typical Vermont dairy farms can help design programs with the optimal combination of soil conservation and manure management practices at each level of control and on each size farm. Control programs and cost sharing policies should be based on these practices and take economic differences due to farm size into account. Larger farms can bear larger phosphorus reductions than small farms, many of which may not be worth considering. Since the income effect is different for different herd sizes, an equitable policy would offer different subsidies for the same phosphorus reduction level or set different reduction levels for the same subsidy. Marginal costs of phosphorus reduction, by farm size, can be aggregated for watershed analysis and provide a better guide for designing control programs than costs which do not recognize farm size.

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