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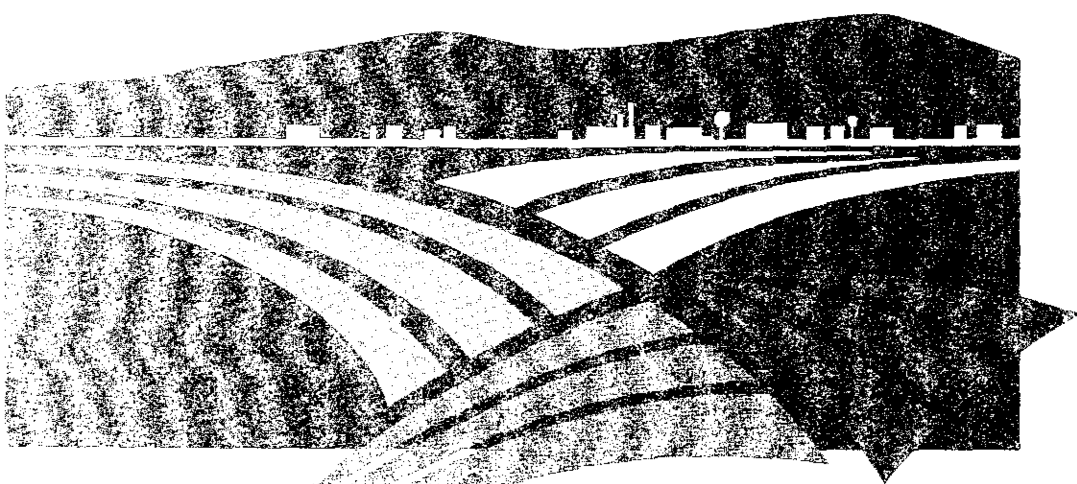

Virginia's
Rural Economic Analysis Program

Department of Agricultural Economics
College of Agriculture and Life Sciences
Virginia Tech

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In order to protect water quality, Virginia farmers with concentrated livestock operations may be required to limit manure applications on crop and pasture land to amounts consistent with agronomic recommendations. This study examined the short-term farm adjustments and financial impacts of such restrictions on representative model Rockingham County dairy farms. Data representative of dairy farms with the capacity to milk 80 cows were assembled from surveys and from other sources. Farm A had medium acreage (241 acres) and Farm B had small acreage (154 acres). Farm C was identical to Farm A except that it had three broiler houses, a common supplementary enterprise on Rockingham County dairy farms. Farm D and Farm B were also identical except for a broiler enterprise on Farm D.

Three policies were evaluated. Policy 1 was the baseline policy, under which no restrictions were placed on the amount of nutrients that could be applied to crops or pasture land. Policy 2 represented a more restrictive policy under which nutrient applications from commercial fertilizer or manure were limited to nitrogen recommendations for crops or pasture. Policy 3 was even more limiting, restricting nutrient applications to the most limiting of either nitrogen or phosphorus recommendations. In some instances, Policies 2 and 3 may limit the ability to replace commercial fertilizer with manure nutrients, thus adding to production expenses. It was assumed that all poultry litter could be exported from the farm without cost, if necessary, and that all dairy manure was applied to the farm's crop and pasture land. If excess manure nutrients were produced, crop and hay acreages could be altered to plant more nutrient-utilizing crops. If no other adjustment was possible, cow numbers were reduced in order to produce no more than the amount of nutrients that could be applied under the policy.

Dairy farms without poultry are not affected by Policy 2 restrictions. Farms with broiler operations, however, see net returns reduced by a small amount (about 1 percent) from the Policy 1 baseline, because operators must lower manure applications and purchase commercial potassium.

Income effects of Policy 3 (limiting manure applications to the more restrictive of nitrogen or phosphorus requirements) are much more severe for all farms. Dairy cow numbers fall below two-thirds of milking capacity for all farms. Profits are wiped out on farms without poultry enterprises. Net returns on medium-sized and small-sized farms with poultry enterprises fall 40 percent and 38 percent, respectively. It is questionable whether farms with characteristics similar to the representative farms could continue to operate under such a policy if affordable alternative manure disposal procedures were not available.

Policies that restrict manure applications according to crop phosphorus requirements (such as Policy 3) would impose large costs and seriously affect the competitiveness of Rockingham County dairy farms. If such policies were imposed, farmers would attempt to adjust by exporting more manure and litter. Although poultry litter is already exported from many farms, additional research is needed to determine whether it is economically feasible to export dairy manure. High storage, handling, and transport costs would be incurred to export dairy manure to farms or other entities that desire additional nutrients.

Additional research should be conducted to evaluate both the water quality benefits and the farm costs of compliance with a broader range of nutrient-restriction policies. Such estimates could help policymakers evaluate alternative policies that achieve water quality objectives and permit farms to be profitable and competitive. Efforts should also be made to investigate how animal wastes can be processed to improve their market acceptability and value for a wider range of nutrient needs. Government-sponsored programs to increase the demand for processed manure nutrients may simultaneously improve farm profitability and water quality.

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INTRODUCTION

Problem Description

Spreading manure from confined livestock facilities on small acreages can endanger surface water and groundwater quality. Dairy farms produce large quantities of manure that is usually spread on crop or pastureland. A survey of 46 Rockingham County, Virginia, dairy farmers indicated that one-half the farms had 3 acres or less per dairy cow (Bosch *et al.*). In addition, more than one-fourth of the farms had supplementary poultry enterprises, which also produce large amounts of nutrients in animal waste. By satisfying some or all of their crop nutrient requirements with animal wastes, farmers save money on commercial fertilizer purchases. Because of uncertainty about manure nutrient content, availability to crops, and spreading rates, commercial fertilizer and animal wastes are far from perfectly substitutable. Because of such uncertainty, or simply because of high livestock per acre intensity, manure nutrients—particularly nitrogen (N) and phosphorus (P)—are often applied at higher rates than required by crops. Nutrients not taken up by crops are susceptible to leaching into groundwater or running off into surface water.

Most Virginia farmers are under no obligation to limit manure applications to amounts consistent with agronomic recommendations for N or P, and no policies have been proposed to limit applications in this manner.[1] Instead, government efforts to reduce the potential for nutrient contamination of water supplies from confined animal production have relied heavily on education and cost-share programs, through which farmers may voluntarily adopt practices that reduce pollution potential. Such practices include improved storage, more accurate spreading, and nutrient-management planning. With improved storage, manure may be applied to crops closer to the time of rapid nutrient uptake, thus reducing the potential for runoff or leaching. Nutrient-management plans, combined with accurate spreading, more closely match manure applications to plant nutrient requirements.

In some cases, federal, state, or local regulations affect manure disposal. The federal Coastal Zone Act Reauthorization Amendments of 1990 require that farmers located in the coastal zone have nutrient-management plans for the use of commercial fertilizer, animal manure, and other nutrient sources (U.S. Environmental Protection Agency). States in the coastal zone are to develop and implement such plans subject to approval by the U.S. Environmental Protection Agency. In Virginia, all farmers who operate livestock confinement facilities that are classified as "concentrated" operations must have nutrient-management plans for the disposal of animal waste. Concentrated operations include farms with capacity for 700 dairy cows, 1,000 feeder cattle, 2,500 hogs, or 100,000 broilers (Virginia State Water Control Board). In Rockingham County, a local ordinance requires poultry producers to file nutrient-management plans for manure disposal in order to obtain a building permit for poultry house construction. The plan must provide for "..land application at approved locations and agronomic rates, as established by the Virginia Cooperative Extension Service and other appropriate agencies" (Rockingham County Zoning Ordinance, Division 9, Section 17-178). All poultry producers in the county will be required to file such nutrient-management plans by 1994.

If additional public efforts are made to reduce nutrient loadings to water supplies from non-point sources such as intensive livestock operations, policies may be adopted to limit livestock capacity per farm to numbers consistent with land resources and allowable manure export. As a simple example, consider that a dairy cow and her replacements

[1]Throughout this report, we assume that applying nutrients in amounts consistent with standard agronomic recommendations will not result in excess nutrients that may leach to groundwater or run off in surface water.

produce approximately the plant-available N required for 1.2 acres of corn silage on high productivity soil.[2] A farm of 100 acres, all planted to corn silage and with no opportunity for manure export, could then milk no more than 83 cows. Limiting manure applications in this way would impose on farmers the costs of planting more nutrient-using crops, exporting manure, or reducing livestock numbers.

Study Description

This study focused on dairy and dairy/poultry farming in Rockingham County, the leading producer of livestock and poultry in the state. The geological characteristics of the county (its karst hydrogeologic structure) and the county's location in the Chesapeake Bay drainage area present a potential for nutrient contamination of surface water and groundwater, and the economic importance of agriculture increases the significance of nutrient-management policies to the county.

According to estimates of county nutrient applications (Bosch, *et al.*), Rockingham County farmers, on average, apply nitrogen from commercial fertilizers and manure to crop and pasture land in amounts below standard agronomic recommendations, but they apply phosphate (primarily from dairy manure and poultry litter) in amounts considerably above recommended levels. Phosphate applications average 50 pounds above recommended levels for all crop and soil-productivity groups. Phosphate over-applications are more frequent on dairy farms, particularly those with relatively low land area per cow and those with supplementary poultry enterprises. This study evaluated the potential costs to dairy farmers of alternative manure management policies. As discussed below, survey results (Bosch, *et al.*) were used to analyze dairy farms with moderate and low land resources and with poultry enterprises, because such farms are likely to incur higher costs of compliance with manure management policies.

Representative farms were constructed to examine the effects of poultry enterprises and cropland acreage (see "What is a 'Representative Farm'?" page 3 and Appendix for details). Three policies were examined (see "What is a 'Policy'?" page 3 for details): Policy 1—no limitations on manure applications; Policy 2—manure applications limited to the recommended amount of N for the crop or pasture; and Policy 3—manure applications limited to the recommended amount of either N or P for the crop, whichever is most restrictive. It was assumed that nutrient applications greater than recommended amounts would give no greater yield, and that the operator of each representative farm would select livestock numbers and crop acreages so as to obtain the highest possible net returns, given resource and manure-application constraints on resources and any constraints on manure applications. Each representative farm was described by a set of accounting equations, and the mathematical technique of linear programming determined the most profitable farm organization.

Under each policy, farms could export off the farm all unneeded poultry litter at no cost. In effect, we assumed that other farmers clean out poultry houses, taking the litter in exchange. It was assumed that dairy manure, however, could not be exported. The relatively high nutrient density of poultry litter—averaging about 65 pounds of N, 26 pounds of P, and 19 pounds of K per ton of fresh litter—makes export of such litter economically viable (Bosch and Napit). By contrast, dairy manure is commonly stored as a liquid, and it averages only about 21 pounds of N, 5 pounds of P, and 15 pounds of K per 1,000 gallons. Because of its low nutrient content by weight, dairy manure is expensive to transport long distances.

[2] A cow and her share of the replacement herd produce about 3.35 tons of manure dry matter per year. After adjusting for losses (see Appendix), this manure contains approximately 160 pounds of plant-available N. Corn silage on high fertility soil requires about 135 pounds of N per acre.

What is a "Representative Farm"?

It's not practical to analyze potential policy impacts on every dairy farm in Rockingham county. Instead, we used survey results (Bosch et al. and Bosch and Napit), current budgets (Virginia Farm Management Crop and Livestock Enterprise Budgets), cost of production information (Mountain States Management Service), and information from other sources to estimate resources, capacity, and typical costs of certain types of dairy farms. We assembled data representative of two 80-cow capacity dairy farms, the average capacity in the county. Based on survey results, one representative farm had medium acreage (241 acres) and one had small acreage (154 acres). The medium-sized farm had as many acres as the smallest one-half of dairy farms in the county (the 50th percentile). The small-sized farm had the acreage of the smallest one-fourth of dairy farms in the county (the 25th percentile). About one-fourth of dairy farms in Rockingham county have poultry enterprises, so we constructed two additional representative farms identical to the dairy-only farms except that they each had three broiler houses. The table shows the characteristics of these four representative farms:

	Medium Acreage	Small Acreage
Dairy only	**Farm A** 80-cow capacity 241 total acres •93 high-productivity acres •40 low-productivity acres •96 pasture acres	**Farm B** 80-cow capacity 154 total acres •60 high-productivity acres •25 low-productivity acres •61 pasture acres
Dairy & Poultry	**Farm C** 80-cow capacity 241 total acres •93 high-productivity acres •40 low-productivity acres •96 pasture acres 3 broiler houses •458,400 bird/yr capacity	**Farm D** 80-cow capacity 154 total acres •60 high-productivity acres •25 low-productivity acres •61 pasture acres 3 broiler houses •458,400 bird/yr capacity

What is a "Policy"?

The purpose of this study was to examine the production and financial impacts of possible nutrient-management policies on Rockingham County dairy farms. It was assumed under all policies that manure nutrients would be used to replace as much commercial fertilizer as possible.

Policy 1 was the baseline policy, under which there were no restrictions on the amount of nutrients that can be applied to crops or pasture land.

Under **Policy 2**, the total of nutrient applications from commercial fertilizer or manure had to be limited to amounts consistent with nitrogen recommendations for the crop or pasture. Farms that annually produce more plant-available nitrogen in manure than required by crops or pasture were restricted from applying some manure.

Under **Policy 3**, nutrient applications were restricted to the most limiting of either nitrogen or phosphorus recommendations. Replacement of commercial fertilizer by manure nutrients and disposal of excess manure were most restricted under Policy 3.

Policies 2 and 3 are possible policies that could evolve from voluntary nutrient management plans currently in place. Real managers would undoubtedly devise innovative ways to comply with such requirements, but alternatives available to the representative farms in this study included only costless export of poultry litter, selection of nutrient-intensive crops, and reductions in livestock numbers.

Farm A: Medium Acreage, No Poultry

Policy 1—Unlimited Manure Application (current policy). Farm A produces sufficient feed for 80 milk cows, and net annual returns are $15,080 (Table 1). The crop mix includes 85.3 acres of rye- corn silage, 135.8 acres of pasture, 5.3 acres of alfalfa, and 2.6 acres of corn grain. In addition to all farm-produced manure, 13,058 pounds of commercial fertilizer N, 1,083 pounds of commercial P, and 7,621 pounds of commercial K are purchased and applied to crop and pasture land. N applications do not exceed recommendations, but P applications from dairy manure exceed recommendations by 4,467 pounds.[3]

TABLE 1. Model results for Farm A (medium acreage and no poultry enterprise).

Item	Policy 1: No restriction	Policy 2: N restriction	Policy 3: N or P restriction
Net returns($)	15,080	15,080	2,847
Cows	80	80	51
Corn grain (ac)	2.6	2.6	13.4
Rye-corn sil (ac)	85.3	85.3	53.5
Alfalfa (ac)	5.3	5.3	27.3
Other hay (ac)	0	0	38.7
Pasture (ac)	135.8	135.8	96.0
Excess N[a] (lbs)	0	0	0
Excess P (lbs)	4,467	4,446	0
Comm. N[b] (lbs)	13,058	12,594	18,372
Comm. P (lbs)	1,083	1,062	0
Comm. K (lbs)	7,621	8,018	9,283
Dairy manure shadow price[c] ($/ton)	17.36	17.36	-121.31

[a] Excess N and P are amounts that manure N or P applications exceed total crop recommendations.
[b] Commercial N, P, and K are commercial fertilizers applied on the farm.
[c] Manure shadow prices are the amounts by which net farm income would change if there were one more ton of manure (dry matter basis) requiring disposal.

Additional manure on these farms would have replaced some of these purchases and raised net returns. In this case, the shadow price on dairy manure indicates the farm could afford to pay $17.36 per ton of dry matter for additional manure to replace commercial fertilizer nutrients (see "What is a 'Shadow Price'?" page 5).

Policy 2—Manure Applications Limited to N Recommendations. Farm A has enough cropland that cow numbers, crop acreages, and net annual returns are unaffected by the policy that limits manure applications according to crop N recommendations.[4] Manure applications are shifted between some crops, but excess P applications and commercial fertilizer purchases are roughly equal to those under Policy 1.

[3] Commercial P is purchased even though the farm applies some excess P from manure. This occurs because N and K requirements of rye-corn silage and fescue pasture result in overapplication of P from manure. However, there is insufficient manure for all crops and some commercial fertilizer is required for a portion of the rye- corn silage acreage.

[4] It should be noted that total N production from Farm A's dairy herd greatly exceeds crop requirements, but plant-available N does not. We assume that liquid dairy manure applied to crop or pasture land is not incorporated, so a large proportion of the N, as ammonia, evaporates into the atmosphere (for more detail on this assumption, see the Appendix).

What is a "Shadow Price"?

The linear programming procedure used here to examine representative farms determines the highest possible net farm returns, subject to resource constraints such as limited farm land, livestock capacity, and manure for application to crops or pasture. In addition to the best net farm returns, the results indicate the **shadow prices** of limiting resources. The shadow price of dairy manure indicates how much farm income has changed because of the last ton of manure produced. If the shadow price is positive, all dairy manure has been applied and there are still more cost-saving opportunities to substitute dairy manure nutrients for commercial fertilizer nutrients. If the dairy manure shadow price is negative, the farm has surplus manure under the policy scenario, and the last ton of manure produced has decreased net income by the amount of the shadow price.

Policy 3—Manure Applications Limited to N or P Recommendations. Corn grain, alfalfa, and other hay (orchard grass) production increase on Farm A under Policy 3, while pasture and rye-corn silage production decrease. Most orchard grass hay is sold. The decrease in feed crop production and constraints on manure spreading cause cow numbers to fall from 80 to 51. Net returns decline by nearly 80 percent compared to the baseline policy. Manure is spread at lower rates, so more commercial N and K are purchased and applied to meet crop recommendations. The shadow price of dairy manure indicates that net farm income is reduced $121.31 by the last ton of manure dry matter.

Farm B: Small Acreage, No Poultry

Policy 1—Unlimited Manure Application (current policy). The crop mix for Farm B includes 60.6 acres of rye-corn silage and 85.4 acres of pasture (Table 2). Because it has smaller total acreage, Farm B produces fewer acres of feed crops than farm A, and feed production can support only 69 cows. Legume hay could be purchased as supplemental feed, but at the milk and feed prices assumed in this study, purchasing feed is not profitable. Despite an 80-cow capacity, therefore, only 69 cows can actually be maintained.

TABLE 2. Model results for Farm B (small acreage and no poultry enterprise).

Item	Policy 1: No restriction	Policy 2: N restriction	Policy 3: N or P restriction
Net returns($)	10,960	10,960	-4,619
Cows	69	69	33
Corn grain (ac)	0	0	8.5
Rye-corn sil (ac)	60.6	60.6	33.9
Alfalfa (ac)	0	0	17.2
Other hay (ac)	0	0	25.4
Pasture (ac)	85.4	85.4	61.0
Excess N[a] (lbs)	0	0	0
Excess P (lbs)	4,100	4,100	0
Comm. N[b] (lbs)	6,336	6,336	11,822
Comm. P (lbs)	525	525	0
Comm. K (lbs)	3,698	3,698	5,912
Dairy manure shadow price[c] ($/ton)	17.36	17.36	-252.00

[a] Excess N and P are amounts that manure N or P applications exceed total crop recommendations.
[b] Commercial N, P, and K are commercial fertilizers applied on the farm.
[c] Manure shadow prices are the amounts by which net farm income would change if there were one more ton of manure (dry matter basis) requiring disposal.

Fewer cows mean lower milk production, and net returns for Farm B are $10,960, less than three-fourths of Farm A net returns. In addition to all farm-produced manure, commercial fertilizer purchased and used includes 6,336 pounds of N, 525 pounds of P, and 3,698 pounds of K. Nitrogen applications do not exceed recommendations, but P applications from dairy manure exceed recommendations by 4,100 pounds. The manure shadow price is the same as for Farm A, indicating that another ton of available manure would increase farm net returns by $17.36 by reducing commercial fertilizer costs.

Policy 2—Manure Applications Limited to N Recommendations. Like Farm A, Farm B is unaffected by policies that restrict manure applications according to crop and pasture N recommendations. The principal restriction on this farm's income-generating activities is that it cannot grow or afford to purchase sufficient feed for its cow capacity. However, even if milk or feed prices were favorable and additional cows could be added to the herd, it is likely that the farm could not maintain 80 cows because they would produce more N than allowed under Policy 2.

Policy 3—Manure Applications Limited to N or P Recommendations. On Farm B, crop production is altered to use as much manure as possible while attempting to maintain cow numbers. Rye-corn silage production falls to 33.9 acres and pasture falls to 61 acres. Corn grain (8.5 acres), alfalfa (17.2 acres), and other hay (25.4 acres) are introduced to the crop mix. Commercial N and K fertilizer purchases increase by 87 percent and 60 percent, respectively, over the baseline.

Feed production is insufficient for the number of cows fed under the baseline policy, and cow numbers fall to 33, less than one-half the baseline number. Farm B suffers a net loss of $4,619 under Policy 3. It is difficult to see how a real-life farm with these characteristics could continue to operate under such a manure-restriction policy, unless a cost-effective method of exporting dairy manure were available.

Farm C: Medium Acreage With Poultry Enterprise

Policy 1—Unlimited Manure Application (current policy). Farm C's crop and pasture acreage is identical to Farm A, with dairy and poultry production at capacity (Table 3). The broiler enterprise does not affect the crop mix because all broiler feed is purchased. With poultry litter available, all crop and pasture nutrient requirements can be satisfied by dairy manure and poultry litter applications, and no commercial fertilizer is purchased. For the farm, excess N applications total 3,584 pounds and excess P applications total 12,822 pounds. In addition, 66 tons of poultry litter are exported off the farm.

Broiler production is very profitable for this farm, which in the baseline scenario has net returns of $43,859. The dairy manure shadow price indicates that net farm income is reduced $2.04 by the last ton of manure dry matter.

Policy 2—Manure Applications Limited to N Recommendations. Crop acreages and livestock production are unaffected by the policy limiting manure applications to crop and pasture nitrogen requirements. N and P requirements are satisfied with dairy manure and poultry litter applications. Some supplemental commercial K (1,660 pounds) must be purchased to meet crop recommendations for that nutrient; consequently, net returns decline by $635 (1 percent) under this policy.

Poultry litter export increases to 106 tons. The dairy manure shadow price indicates that net farm income is reduced very little ($0.50) by the last ton of manure dry matter.

TABLE 3. Model results for Farm C (medium acreage with poultry enterprise).

Item	Policy 1: No restriction	Policy 2: N restriction	Policy 3: N or P restriction
Net returns($)	43,859	43,224	26,482
Cows	80	80	47
Broilers (1,000s)	458.4	458.4	458.4
Corn grain (ac)	2.6	2.6	16.9
Rye-corn sil (ac)	85.3	85.3	44.6
Alfalfa (ac)	5.3	5.3	34.3
Other hay (ac)	0	0	0
Pasture (ac)	135.8	135.8	133.2
Excess N[a] (lbs)	3,584	0	0
Excess P (lbs)	12,822	11,334	0
Comm. N[b] (lbs)	0	0	11,805
Comm. P (lbs)	0	0	0
Comm. K (lbs)	0	1,660	7,550
Poultry litter export (tons)	66	106	325
Dairy manure shadow price[c] ($/ton)	-2.04	-0.50	-96.89

[a] Excess N and P are amounts that manure N or P applications exceed total crop recommendations.
[b] Commercial N, P, and K are commercial fertilizers applied on the farm.
[c] Manure shadow prices are the amounts by which net farm income would change if there were one more ton of manure (dry matter basis) requiring disposal.

Policy 3—Manure Applications Limited to N or P Recommendations. Total corn acres fall by 30 percent from the baseline, and alfalfa acres increase from 5.3 acres to 34.3 acres as Farm C reduces livestock production and increases production of alfalfa hay for sale. All poultry litter (325 tons) is exported, but additional N (11,805 pounds) and K (7,550) must be purchased to satisfy crop and pasture requirements.

Feed production is sufficient for only 47 cows, a 41 percent decline from the baseline. Although poultry production is maintained at capacity, higher expenses and lower milk sales cause net returns to fall by 40 percent from the baseline. The dairy manure shadow price of $96.89 indicates that net farm income is reduced considerably by the last ton of manure dry matter.

Farm D: Small Acreage With Poultry Enterprise

Policy 1—Unlimited Manure Application (current policy). Farm D raises 67.7 acres of rye-corn silage and 78.3 acres of fescue pasture under the baseline policy (Table 4). Similarly to Farm B, this farm can raise and purchase enough feed for only 69 cows. Nutrient applications from dairy manure and poultry litter exceed recommendations by 2,591 pounds of N and 9,293 pounds of P. One hundred forty-nine tons of poultry litter not needed for crops or pasture are exported.

Net returns are $37,541, more than three times the returns of Farm B, an identical farm except for the broiler enterprise. The dairy manure shadow price of -$2.04 indicates that net farm income is reduced slightly by the last ton of manure dry matter that must be applied.

TABLE 4. Model results for Farm D (small acreage with poultry enterprise).

Item	Policy 1: No restriction	Policy 2: N restriction	Policy 3: N or P restriction
Net returns($)	37,541	37,207	23,269
Cows	69	69	31
Broilers (1,000s)	458.4	458.4	458.4
Corn grain (ac)	0	0	12.6
Rye-corn sil (ac)	67.7	67.7	34.5
Alfalfa (ac)	0	0	25.6
Other hay (ac)	0	0	0
Pasture (ac)	78.3	78.3	73.3
Excess N[a] (lbs)	2,591	0	0
Excess P (lbs)	9,293	7,824	0
Comm. N[b] (lbs)	0	0	7,681
Comm. P (lbs)	0	0	0
Comm. K (lbs)	0	1,085	5,728
Poultry litter export (tons)	149	189	325
Dairy manure shadow price[c] ($/ton)	-2.04	-0.50	-117.32

[a] Excess N and P are amounts that manure N or P applications exceed total crop recommendations.
[b] Commercial N, P, and K are commercial fertilizers applied on the farm.
[c] Manure shadow prices are the amounts by which net farm income would change if there were one more ton of manure (dry matter basis) requiring disposal.

Policy 2—Manure Applications Limited to N Recommendations. Crop acreage and livestock production on Farm D are not affected by this policy. Some poultry litter applications are replaced by dairy manure, and 1,085 pounds of commercial K nutrients are purchased. As a result, net returns fall $334 (1 percent) from the baseline.

Excess P applications decrease 16 percent from the baseline. Poultry litter exports increase by 27 percent to 189 tons. The dairy manure shadow price of -$0.50 again indicates that net farm income is slightly decreased by the last ton of manure.

Policy 3—Manure Applications Limited to N or P Recommendations. Farm D is seriously affected by this policy. Total corn acres fall by 30 percent and pasture acres decrease by 6 percent from the baseline, with alfalfa acres increasing so that more manure P is used. To complete crop nutrient requirements, the farm must purchase 7,681 pounds of N and 5,728 pounds of K. Even with these adjustments, feed production and purchase can support only 31 cows, a 55 percent decline from the baseline. Net returns fall to $14,272, a 38 percent decline from Policy 1.

All poultry litter produced on the farm is exported. The dairy manure shadow price of -$117.32 is considerably more negative than that under Policies 1 or 2, indicating that dairy manure applications under Policy 3 require costly adjustments.

SUMMARY and IMPLICATIONS

This study examined least-cost, short-term adjustments of dairy farms to policies that limit manure applications to amounts consistent with nutrient recommendations for crops and pasture. Figure 1 indicates the net returns for each representative farm under the three policy scenarios. There are two key features to these results.

1. Policies based on nitrogen recommendations are not very costly to most dairy farmers. Net returns for dairy farms with poultry enterprises decrease about 1 percent, but farms without poultry are unaffected.

2. Policies based upon the most limiting of nitrogen or phosphorus recommendations are devastating for the majority of dairy farms, whether or not they have a poultry enterprise. Income decreases from the baseline policy of no restrictions by $12,233 (81 percent) for medium-sized farms without broilers, $15,579 (142 percent) for small-sized farms without broilers, $17,377 (40 percent) for medium-sized farms with broilers, and $14,272 (38 percent) for small-sized farms with broilers. The majority of Rockingham dairy farms would experience extreme difficulty in staying afloat financially if this type of policy were put in place.

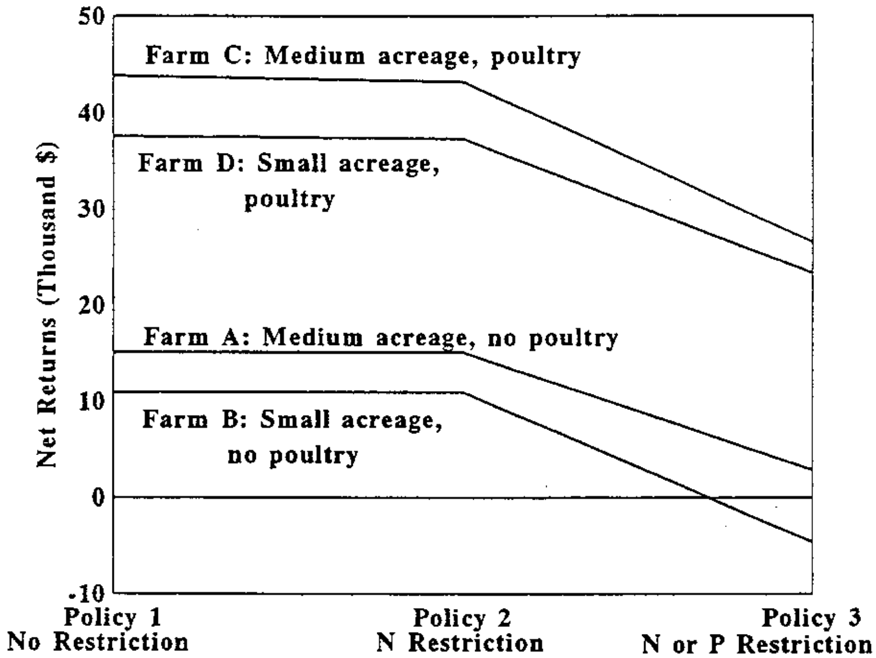

FIGURE 1. Net farm returns on four representative farms under three manure-restriction policies.

High negative shadow prices indicate strong economic incentives that would be presented to many dairy farmers if nutrient restrictions were enacted. Shadow prices estimate forgone returns due to compliance with manure application restrictions. The linear programming model utilized here has indicated the least cost of compliance with nutrient restrictions, with the assumption that poultry litter, but not dairy manure, can be exported. Spreading on neighbors' land, purchase or rental of additional land for manure disposal, and payments to contractors for hauling away excess manure are all costly but effective adjustments that dairy farmers may make but that were not considered in this analysis.

The results turn on two critical assumptions. First, *poultry litter export from the farm is assumed to be costless.* More accurately, the relative results for different policies will hold as long as the cost of export is less than the cost of spreading. Survey results indicate, however, that many poultry producers apply litter to crops or pasture in larger quantities than predicted by the cost-optimization model described here (Bosch, *et al.*). Either litter export is more costly than own-farm application, or farmers feel that crops and pasture need more nutrients from litter than recommended. Bosch and Napit suggest that exporting poultry litter as fertilizer for crop applications is economically feasible. However, additional research is needed to determine whether dairy manure storage, processing, handling, and transportation could make export feasible.

Second, *it is assumed that incorporation of litter or manure immediately after spreading on crop or pasture land will not be required under policies such as those examined above.* Standard estimates for inorganic nitrogen losses, due to evaporation plus runoff, from manure that is not incorporated immediately after application are 25 percent for poultry litter and 75 percent for dairy manure. Policies requiring incorporation in order to reduce atmospheric pollution or surface runoff have the paradoxical result of increasing the potential for nitrogen leaching into groundwater. If dairy farmers incorporated manure, many could replace some commercial N purchases with manure N previously lost to evaporation or runoff. However, manure storage and application procedures may have to be changed, and increased costs could be expected. Some farms with very high cow/land ratios might be seriously constrained by incorporation requirements combined with nutrient application restrictions. For farms with poultry, policies limiting applications to N recommendations and requiring incorporation of litter would stimulate more litter export. If export costs more than spreading, then farm returns will decrease much more than the small decrease estimated here for Farms C and D.

These research results have implications for farmers, farm researchers and educators, and local and state government policymakers.

Farmers

Farmers should follow nutrient recommendations in order to reduce the potential for water quality damage. Many farmers do not have sufficient land to apply animal wastes at rates that protect water quality. Farmers must realize that unsafe disposal of animal wastes may contribute to environmental problems and finally result in costly regulations imposed on all the farming community. Farmers should carefully follow policy debates concerning animal waste disposal and water quality protection. The results of this study show that regulations could potentially impose unsustainable costs on farmers, and the possibility of such regulations must be considered when making new investments or planning expansion of livestock operations.

Farm Researchers and Educators

Research and educational efforts should focus on soils, crops, and farming practices that minimize the potential for runoff and leaching of manure nutrients. Further research is needed to evaluate a broader range of alternative nutrient-management policies. Such research should assess the costs and benefits of water quality protection for farmers, local economies, and consumers.

More research is needed to evaluate and promote the effectiveness of manure as a crop fertilizer. Livestock farmers need to know more about the factors affecting nitrogen mineralization rates, so that overapplications can be avoided. Educators should continue to demonstrate the cost-effectiveness of manure applications to crop farmers in order to increase the demand for manure export from livestock-intensive regions.

Efforts should also be made to investigate how animal wastes can be economically stored, processed, and transported in order to maximize market acceptability and value for a wide range of nutrient needs. If an effective market system could link purchasers of plant nutrients with producers who have a surplus of animal waste producers, manure "disposal" might become a farm profit center while it also satisfies water quality objectives.

Policymakers

Policymakers need to consider the costs to farmers as well as the water-quality benefits of manure-management restrictions. In areas where limits on animal manure spreading impose severe financial burdens to farmers, policymakers should consider other options. In some cases, point sources of nutrient pollution such as sewage treatment plants may be able to reduce nutrient pollution more cheaply than nonpoint sources such as farms. Some watersheds may also be able to achieve reductions more cheaply than others. Regional or watershed standards may be set based upon the local cost of nutrient reductions. The Chesapeake Bay Program appears to be following this option with its "tributary strategy" (Permenter).

Policymakers should also encourage the formation of manure markets to facilitate movement of manure to other farms or other users. State and local governments in livestock regions could stimulate markets for manure—and help protect their tax bases—by purchasing composted manure for use on parks, roadways, or other areas. Golf courses, lawn-care firms, and turfgrass farms could receive incentives to use locally composted animal manure. These and other innovative, public and private efforts could transform the problem of excess animal waste production into opportunities for economic development *and* water quality protection.

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APPENDIX: DESCRIPTION of REPRESENTATIVE FARMS

Data describing the representative farms and model assumptions are described in this appendix. For each farm, net returns are equal to total receipts from crop and livestock sales minus fixed costs and variable crop and livestock costs. A linear programming routine was used to maximize net returns to farm land, labor, and management resources subject to various resource constraints.

Total farm output and sales are limited by available land for growing crops and pasture and by the capacity of dairy and broiler facilities. All four farms have milking facilities for 80 cows, the median number of cows milked by a sample of dairy farms in the study area (Bosch *et al.*). Farms C and D have three broiler houses, each with 21,000 square feet of floor area and with the capacity to produce 458,400 broilers per year (Covey).[5]

Farm livestock enterprises are shown in Table A-1. Milk sale price is $12 per hundred-weight, steer sales price is $100 per hundred-weight for 500-pound steers, and broiler sales price is $1.07 per bird. Variable costs of production do not include costs for corn grain, forage, or pasture. Purchasing or raising such feeds are included as separate enterprises in the linear programming model, and their total costs depend upon the level of feed production or purchase selected. Feed costs are then deducted directly from farm net returns. Enterprise cost and resource requirement data were taken from Cooperative Extension budgets (Virginia Cooperative Extension) and DAIRYLP, a dairy linear programming model (Groover and Allen).[6]

TABLE A-1. Production and variable costs for representative farm livestock enterprises.

Type	Enterprise description	Production per unit[a]	Variable cost per unit($)[b]
Milk cow	Corn silage ration	18,000 lbs	972
Milk cow	Hay ration	18,000 lbs	906
Market livestock	Steer	500 lbs	267
Replacement heifer	Heifer: birth to wean	N/A	104
Replacement heifer	Heifer: wean to breed on pasture	N/A	57
Replacement heifer	Heifer: breed to fresh on pasture	N/A	33
Replacement heifer	Heifer: wean to breed on silage	N/A	97
Replacement heifer	Heifer: breed to fresh on silage	N/A	33
Poultry	Broiler house	152,800 birds/year	7,108

[a] All livestock production and costs are per animal, except for broilers which are per broiler house.
[b] Variable dairy livestock expenses include minerals, milk replacer, calf grower, feed grinding and mixing, breeding, veterinary expenses, supplies, DHIA fees, milk hauling and assessment, market and cull livestock hauling and marketing, building and fence repair, variable machinery expense, utilities, and operating interest. Variable broiler expenses include electricity, fuel, repairs, taxes, and insurance.

Total manure production for one dairy cow and her share of the replacement herd is 3.36 tons of dry matter per year (Midwest Plan Service). Broiler manure production (dry matter) from hatching to market weight is 0.71 ton per 1,000 birds (Roller). Nutrient percentages in manure are averages reported by the Virginia Tech Manure Testing Laboratory. Nutrients in litter dry matter are 4.57 percent N, 1.82 percent P, and 1.34 percent K.

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[5]Broiler production capacity is based on survey results in Bosch *et al.*

[6]Additional details are available from the authors.

Nutrients in dairy manure dry matter are 4.62 percent N, 1.14 percent P, and 3.38 percent K. Not all manure N is available to plants. If the manure is not completely incorporated, a portion of the inorganic nitrogen evaporates as ammonia in a process known as volatilization. Survey results (Bosch *et al.*) indicate that most farmers in the area do not incorporate manure, and non-incorporation is assumed in the model. In calculating plant-available N, 75 percent of inorganic N in dairy manure and 25 percent of inorganic N in litter is assumed lost by volatilization and surface runoff. Organic N is slowly mineralized and 69 percent becomes plant-available over a four-year period (Virginia Division of Soil and Water Conservation). Net N, defined as gross N minus losses to volatilization and incomplete mineralization, is thus 2.36 percent of dairy manure dry matter and 3.2 percent of litter dry matter.

Land resources of each representative farm are shown in Table A-2. Farms A and C have crop and pasture acreages equal to the median value of dairies in the Bosch *et al.* survey (241 acres). Farms B and D have small acreages equal to the 25th percentile value in the survey (154 acres). Cropland was divided into high- and low-productivity land by grouping soil types found in Rockingham County according to expected corn yields for each soil type.

TABLE A-2. Land and livestock resources on representative farms.

Item	Farm A: medium acreage, no poultry	Farm B: small acreage, no poultry	Farm C: medium acreage, poultry	Farm D: small acreage, poultry
Total land (acres)	241	154	241	154
Low productivity cropland (acres)	39.8	25.4	39.8	25.4
High productivity cropland (acres)	93.2	59.6	93.2	59.6
Pasture (acres)	96	61	96	61
Other land[a] (acres)	12	8	12	8
Milk cow capacity	80	80	80	80
Acres per cow	3.01	1.93	3.01	1.93
Broiler sales capacity (1,000 birds)	0	0	458.4	458.4

[a] Other land includes land in roadways, farmstead, and ponds.

Expected yields by crop are the planning yields from the Virginia Agricultural Land Use and Evaluation System (VALUES).[7] The specific yields for high- and low-productivity groups were obtained by weighting VALUES yield estimates for each soil type by the number of acres of that soil type found in Rockingham County.

Estimated crop and pasture nutrient recommendations for high- and low-productivity soils are shown in Table A-3. Weighted average nutrient recommendations for the low- and high-productivity groups, respectively, are based on recommendations for individual soil types and the proportion of total Rockingham County cropland represented by each soil type. Since P and K recommendations are based on soil test values, estimated P and K recommendations for each soil and crop type are calculated as weighted averages of county soil test results.[8] The alfalfa/corn silage and alfalfa/corn grain rotations refer to four years of alfalfa followed by two years of corn. For the first year of corn following alfalfa, 90 pounds carryover N is estimated (as recommended by VALUES). Bacteria associated with alfalfa fix their own nitrogen, so no additional nitrogen application to alfalfa is needed. In Policies

[7]VALUES was developed by the Crop and Soil Environmental Sciences Department at Virginia Tech.

[8]Soil sample results of the Virginia Tech Soil Testing Laboratory from Rockingham County in 1986 and 1987 were used.

2 and 3, however, where nitrogen application was not allowed to exceed the crop's nitrogen recommendation, nitrogen applications to alfalfa are allowed up to the amount of nitrogen removed in the harvested crop (50 pounds per ton of hay). In such cases, it is assumed that external nitrogen application simply replaces nitrogen fixation and no environmentally excessive nitrogen results (Serotkin).

TABLE A-3. Recommended nutrient application rates, yields, and variable expenses for representative farm enterprises.

Enterprise description	Recommended application rate (lbs/acre) N	P	K	Yield per acre	Variable cost per acre ($)
Corn grain, HP[a]	119	12	35	119 bu.	202
Corn grain, LP	69	12	35	69 bu.	175
Alfalfa/corn grain, HP[b]	0/74	15/12	163/35	5.4 T/119 bu	174/202
Alfalfa/corn silage, HP[b]	0/92	15/10	163/107	5.4 T/16.6 T	174/166
Corn silage/rye, HP	237	20	138	16.6/4.0 T[c]	180
Corn silage/rye, LP	79	20	138	10.2/3.4 T	161
Corn silage, HP	137	10	107	16.6 T	166
Corn silage, LP	79	10	107	10.2 T	148
Orchard grass hay, HP	244	20	107	3.7 T	74
Orchard grass hay, LP	195	20	73	2.2 T	45
Fescue hay/pasture	60	13	28	1.5 T/2.7 AUM[d]	34
Unfertilized natural pasture	0	0	0	1.1 AUM	8
Fertilized natural pasture	50	20	39	1.7 AUM	19

[a] HP and LP are high- and low-productivity soils, respectively. Variable crop expenses include seed, lime, pesticides, pesticide applications, variable machinery costs, hauling, drying, and operating interest. Labor, commercial fertilizer purchases, and fertilizer or manure application costs are not included in these expenses.
[b] The rotation is four years of alfalfa followed by two years of corn. The first values for nutrients, yields, and costs refer to an acre of alfalfa, the second to corn.
[c] For corn silage/rye, the first yield refers to corn silage, the second to ryelage.
[d] For fescue hay/pasture, the first yield refers to fescue hay yield, the second to Animal Unit Months of pasture.

Cost of fertilizer purchase and application, or of manure application depend upon the crop combination chosen by the model. The variable costs of dairy manure spreading (fuel, repairs, and lubrication) for dairy manure are $3.21 per ton of manure dry matter plus 0.55 hour of labor. Litter spreading costs are $2.16 per ton of dry matter and 0.35 hour of labor (Bosch and Napit). Manure is spread in the fall on ryelage and in the spring on all other crops and pasture. Custom fertilizer application costs, including operating interest, are $5.78 per acre. Commercial N, P, and K purchase costs, including operating loan interest, are $0.28, $0.60, and $0.20 per pound, respectively.

Each farm has two full-time workers including the owner-operator. Each worker works a maximum of 2,400 hours per year. Additional part-time hired labor can be hired at $5.50 per hour. Fixed costs for each farm are shown in Table A-4.[9] Farm C has higher fixed costs than Farm D because it is larger and has higher rent expenses and more depreciation, interest, tax, and insurance expenses for machinery. Farm C has higher fixed costs than Farms A and B because of additional depreciation and interest expenses incurred for its poultry facilities.

[9] Fixed costs were based on average costs reported by Virginia dairies subscribing to the Mountain States Management Service in 1988-1990 (Edgar *et al.*). Costs were adjusted to reflect differences in land area and herd size between average Virginia dairies and the representative farms in this study.

TABLE A-4. Representative farm fixed costs.

Item	Farm A: medium acreage, no poultry ($)	Farm B: small acreage, no poultry ($)	Farm C: medium acreage, poultry ($)	Farm D: small acreage, poultry ($)
Depreciation	9,863	7,769	30,138	28,044
Interest	8,209	6,768	11,810	10,369
Taxes	1,082	740	1,082	740
Insurance	4,029	3,856	4,029	3,856
Rent	8,364	5,345	8,364	5,345
Full-time labor	20,000	20,000	20,000	20,000
Total	**51,547**	**44,478**	**75,423**	**68,354**

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