# Evaluation of phosphorus-based nutrient management strategies in Pennsylvania

**Article** *in* Journal of Soil and Water Conservation · November 2002

Source: OAI



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**ABSTRACT:** Farm management and financial impacts of three phosphorus (P) nutrient management strategies outlined in the U.S. Department of Agriculture (USDA) and U.S. Environmental Protection Agency (USEPA) (1999) Unified Strategy for Animal Feeding Operations—soil test crop response (STCR), environmental soil P threshold (ESPT), and P Index (PI)—were evaluated on ten Pennsylvania farms. For each farm, a nutrient management plan (NMP) writer and project economist developed one nitrogen-based and three P-based NMPs and associated partial budgets. Greater management and financial restrictions occurred on high animal density (> 2 animal equivalent units $ac^{-1}$) and multiple production enterprise farms. Although NMPs for the PI were more expensive to develop, writers and farmers found it the most flexible and practical strategy. Variable P-based NMP impacts indicated the need for a strategy such as the PI that accounted for multiple farm management factors. First-year total NMP implementation costs (across all ten farms) were $61,690 for the STCR, $47,862 for the ESPT, and $45,380 for the PI.

**Keywords:** Eutrophication, farm economic analysis, nonpoint source pollution, nutrient management planning, phosphorus, phosphorus index, soil phosphorus

**Optimal soil phosphorus (P) levels must be maintained to maximize crop production.** However, when P moves from the site of application into surface and groundwater flow, it can accelerate eutrophication of receiving fresh water bodies (Carpenter et al. 1998). Recently, the U.S. Environmental Protection Agency (USEPA 1996) and the U.S. Geological Survey (USGS 1999) identified eutrophication as the most ubiquitous water quality impairment in the United States. Eutrophication restricts water use for fisheries, recreation, and industry due to the increased growth of undesirable algae and aquatic weeds and oxygen shortages caused by their death and decomposition. An increasing number of surface waters have experienced periodic and massive harmful algal blooms (e.g., *cyanobacteria* and *Pfiesteria*) that contribute to summer fish kills, unpalatability of drinking water, formation of carcinogens during water chlorination, and that are linked to neurological impairment in humans.

Surface waters receive P from point and nonpoint sources. Since the late 1960s, the relative contributions of P to water bodies from point and nonpoint sources have changed dramatically. On the one hand, great strides have been made in the control of point source discharges of P, such as the reduction of P in sewage treatment plant effluent. These improvements have been due in part to the ease of identifying point sources. On the other hand, less attention has been directed to controlling nonpoint sources of P, mainly because of the difficulty in their identification and control (Carpenter et al. 1998). Control of nonpoint sources of P remains a major hurdle in the protection of fresh surface waters from eutrophication.

Nonpoint nutrient sources contribute 84% of all P entering U.S. surface waters (USEPA 1996) and 74% of P entering the Chesapeake Bay (Alliance for the Chesapeake Bay 1998). These P sources have variable discharge locations that pose unique challenges in identifying, regulating, and remediating these sources. Nonpoint losses originate from both agricultural and urban areas; however, agriculture has been identified as contributing more nonpoint P than urban areas (Carpenter et al. 1998). Ten percent of the nonpoint P entering the Chesapeake Bay originates from urban areas, while 56% originates from agricultural areas (Alliance for the Chesapeake Bay 1998).

In response to these nonpoint P contributions and water quality impairment, the USDA and USEPA in 1999 jointly issued the Unified Strategy for Animal Feeding Operations. This Unified Strategy outlined three P-based nutrient management approaches: (1) the soil test crop response (STCR) approach, managing P based on agronomic soil P thresholds so that P applications are based on crop needs; (2) the environmental soil P threshold (ESPT) approach, managing P based on ESPTs by identifying a critical soil P concentration above which runoff P enrichment is unacceptable; and (3) the phosphorus index (PI) approach, managing P applications on fields at greatest risk for P loss (USDA and USEPA 1999). One or more of these strategies has been incorporated into each state's USDA-Natural Resource Conservation Service (USDA-NRCS) 590 nutrient management practice standard and are being considered by many states, including Pennsylvania, as a basis for nutrient management planning. While the P management strategies have been outlined, there is no accompanying farm management and financial impact assessment.

McDowell et al. (2001) compared the three P-based nutrient management strategies, STCR, ESPT, and PI, on a watershed basis in a central Pennsylvania research watershed and showed that each P-based nutrient management option resulted in different nutrient management recommendations. However, to examine the feasibility of P-based nutrient management implementation and the related

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farm management implications on specific types of agricultural operations across Pennsylvania, it was necessary to compare the P-based nutrient management options at the farm level. Additionally, the farm level financial impact of implementing each of the three P-based strategies needed to be assessed.

This study examined the farm management and financial impacts of the three outlined P-based management strategies on ten Pennsylvania farms. The relative management and economic impacts of P-based nutrient management plan (NMP) implementation were assessed by comparing (1) the three P-based NMPs, (2) each of the three P-based NMPs to a nitrogen (N)-based NMP, and (3) how each P-based strategy influenced Pennsylvania's NMP development process. The objective of the economic analysis was to provide estimates of the farm level cost of meeting the nutrient application recommendations under the three P-based management strategies: STCR, ESPT, and PI.

**Table 1. Animal Feeding Operation guidance for the Soil Test Crop Response P-based nutrient management strategy (USDA and USEPA 1999).**

| Soil test crop response strategy | |
|---|---|
| Soil Test Category | Guidance for manure rates |
| Low | N-based management |
| Optimum | 1.5 x P removal |
| High | P removal |
| Excessive | No manure |

## Methods and Materials

*Nutrient management plan development.* Nutrient management plan writers were selected for the project in a cooperative effort between Pennsylvania State Conservation Commission (SCC) staff and project coordinators. Of the ten participating NMP writers, seven were commercial plan writers, two were Pennsylvania Conservation District employees, and one was a part-time farmer NMP writer. The set of plans developed for each farm included: a N-based NMP written to meet the regulatory requirements of Pennsylvania's Nutrient Management Act, (Act 6; SCC 1993), a P-based NMP using the STCR strategy, a P-based NMP using the ESPT strategy, and a P-based NMP using the Pennsylvania PI.

The NMP writers participating in the project were trained by project coordinators to modify an Act 6 N-based plan using the three P-based management strategies. The plans for all three strategies were developed on a field-by-field basis, using the criteria and management recommendations outlined in the Unified Strategy on Animal Feeding Operations (USDA and USEPA 1999).

The cooperating NMP writers were involved in the selection of the cooperating farms. Each farmer worked with a NMP planner to develop N and P-based NMPs. The project involved ten farms located across Pennsylvania and represented varied farm management systems, including five multiple production enterprises and four concentrated animal operations (CAOs) (Table 5). Concentrated animal operations had an animal density of greater than 2250 kg live weight/ha (2000 lb live weight/ac) and were required under Act 6 regulations to have a N-based NMP prior to the project participation (SCC 1993).

The crop acreage ranged from 18 to 344 ha (45 to 850 ac). Average farm size was 109 ha (270 ac), reflecting several larger cooperating farms (Table 5). Corn (*Zea mays*) was the predominate crop grown followed by alfalfa (*Medicago sativa* L.) or grass hay. Soybeans (*Glycine max*) were grown on 4 farms, but not on any of the dairy farms. Other crops included oats (*Avena sativa* L.), wheat (*Triticum aestivum* L.), spelt (*Triticum spelta*), barley (*Hordeum vulgare*) silage, and rye (*Secale cereale* L.) silage.

All of the farms utilized manure as a primary nutrient source; fertilizer purchases were minimal. The farmers in this study used manure to first meet corn N requirements and then applied it to hay fields. Manure was generally not applied to legumes such as alfalfa and soybeans. All the dairy and swine operators collected and stored manure in liquid form, including waste water from the milk house, milking parlor, pen areas, and surface runoff. The liquid dairy and swine manure tended to be low in relative nutrient value; poultry manure was generally drier with a greater nutrient density. Under current N-based nutrient management, six of the ten farms exported manure and three farms imported manure (Table 5).

*Phosphorus-based nutrient management strategies.* The first approach, the STCR strategy, used the agronomic soil test level to guide nutrient applications (Table 1). Soil test P categories were from Pennsylvania's soil testing program (Beegle 1999). Once the soil test reached the optimum level for crop production, the nutrient application to the field was based on P to prevent future accumulation of soil test P (Table 1). This approach only used the soil test P level to evaluate the potential P loss from a field.

The second approach, the ESPT strategy, used an environmentally established soil P threshold level of 200 ppm P (400 lb P/ac), above which there was a significant potential for an unacceptable P loss from soil to surface runoff (Table 2). This environmental soil P threshold is based on field research in Pennsylvania watersheds by McDowell and Sharpley (2001). These researchers found that above a Mehlich-3 concentration of 200 ppm P (400 lb P/ac; based on a 0 - 13 cm (0 - 5 in) sampling depth) the potential for P enrichment of surface runoff was significantly ($p>0.01$) greater than below this soil P concentration.

The third strategy used a PI to define areas within the landscape vulnerable to P losses, which allowed for targeting of management and/or remedial efforts. The premise of the PI is that all areas of a landscape do not contribute equally to P losses. In fact, a majority of losses come from a small area in most watersheds and result from only a few storm events (Gburek et al. 2000). The PI was originally developed by USDA-NRCS in cooperation with several research scientists as a screening tool for use by field staff, watershed planners, and farmers to rank the vulnerability of fields as sources of P loss in runoff (Lemunyon and Gilbert 1993). The PI

**Table 2. Animal Feeding Operation guidance for the Environmental Soil P Threshold P-based nutrient management strategy (USDA and USEPA 1999).**

| Environmental soil P threshold strategy | |
|---|---|
| Soil Test P Level | Guidance for manure rates |
| < 150 ppm P | N-based management |
| 150 - 300 ppm P | P removal |
| 300 - 400 ppm P | 0.5 x P removal |
| > 400 ppm P | No manure P |

**Table 3. Pennsylvania P Index version used for nutrient management plan development and evaluations.**

| Transport Factors | | | | | | Field value |
|---|---|---|---|---|---|---|
| Erosion | Soil Loss (t /ac) | | | | | |
| Runoff Class | 0 -Very Low | 1-Low | 2-Medium | 4-High | 8-Very High | |
| Leaching | 0 - Low | | 1[†] - Medium | | 2[‡] - High | |
| Contributing Distance | 0<br>> 500 ft. | 1<br>500 to 350 ft | 2<br>350 to 250 ft | 4<br>250 to 150 ft | 8<br>< 150 ft | |
| Source Factors | | | | Transport Factors / 22 | | |
| Soil Test | Soil Test P (ppm P) | | | | | |
| | Soil Test Rating = 0.2 x Soil Test P (ppm P) | | | | | |
| Fertilizer Rate | Fertilizer P (lb $P_2O_5$ /ac) | | | | | |
| Fertilizer Application Method | 0.2<br>Injected | 0.4<br>Incorporated<br>< 1 wk. | 0.6<br>Not incorporated<br>May to October | 0.8<br>Not incorporated<br>Nov. to April | 1.0<br>Frozen or<br>snow covered | |
| | Fertilizer Rating = Rate x Method | | | | | |
| Manure Rate | Manure P (lb $P_2O_5$ /ac) | | | | | |
| Manure Application Method | 0.2<br>Injected | 0.4<br>Incorporated<br>< 1 wk. | 0.6<br>Not incorporated<br>May to October | 0.8<br>Not incorporated<br>Nov. to April | 1.0<br>Frozen or<br>snow covered | |
| Manure P Availability | 0.8<br>Low - Dairy | | 0.9<br>Medium - Swine | | 1.0<br>High - Poultry | |
| | Manure Rating = Rate x Method x Availability | | | | | |
| | | | | Source Factor | | |
| | | | | PI = Source x Transport | | |

**[*†]Some artificial drainage**
**[‡]Patterned artificial drainage**

accounts for and ranks source and transport factors controlling P loss in runoff and identifies sites where the risk of P movement is expected to be higher than that of others.

In the project, an assessment of site vulnerability to P loss was made by selecting rating values for individual transport and site management factors from the Pennsylvania PI (Table 3). The soil erosion factor for each site was calculated using the Revised Universal Soil Loss Equation (RUSLE) and published soil survey information. The soil loss value was generally included in the farm operation soil conservation plan developed by USDA-NRCS in Pennsylvania, and therefore was calculated across cropping rotations, based on the values for the predominate soil in the field and uniform slope across a field. Surface runoff class was assigned from the relationship between soil permeability class and slope detailed in the Soil Survey Manual (Soil Survey Staff 1993). Initially, the NMP writers assigned a qualitative distance class as a part of the PI evaluations. Then, as the PI and its quantitative distance categories developed during the study, the initial distance assessments were interpreted by the project coordinators and placed in the representative distance category listed in Table 3. Typically, the distance was determined using a topographic map or field measurement. A PI value was obtained by multiplying summed transport, source, and management factors (Table 3). The Animal Feeding Operation recommendations based on PI rankings are given in Table 4 (USDA and USEPA 1999).

*Feedback collection*. Feedback surveys developed with the assistance of a cooperative extension program evaluator were sent to cooperating NMP writers and farmers. The intent of the surveys was to assess the opinions of both NMP writers and farmers regarding P-based management strategies and the NMP development process as a whole. Additionally, a feedback session in October 2000 was held to review project results to date with NMP writers, SCC staff, and Pennsylvania USDA-NRCS staff.

*Economic analysis.* Cooperating farms provided year 2000 financial records for an in-depth financial analysis that provided the basis for estimating the costs of adjusting to nutrient applications recommendations under each of the three P-based nutrient management strategies, as compared to N-based nutrient management. Each farm was visited to collect receipts, and records for expenses, capital purchases, crop production, animal production, and nutrient application. The data was analyzed with FINPACK® to produce a beginning and ending balance sheet, an accrual income statement, and an enterprise analysis (CFFM 2000).

After completion of the base financial analysis, the nutrient management writer for each participating farm was contacted and asked to provide crop nutrient recommendations for each of the three P-based nutrient management strategies. The nutrient recommendations were compared to actual applications reported by the farmer. If the recommended rates were less than the actual nutrient application rates, the farmer was asked what his management adjustments would involve. These management adjustments were then incorporated with the base

**Table 4. Animal Feeding Operation guidance for the P Index P-based nutrient management strategy (USDA and USEPA 1999).**

| Phosphorus index strategy; Version as of May 2001 | | |
|---|---|---|
| PI values | PI rating | Guidance for manure rates |
| < 60 | Low | N-based management |
| 60 - 80 | Medium | N-based management |
| 80 - 100 | High | Limited to P removal |
| > 100 | Very High | No manure applied |

analysis to estimate the farm's financial performance under each of the P-based strategies. The estimated, adjusted net farm income was then compared with the net farm income under N-based nutrient management to assess the overall financial impact of each P management strategy. Accrual net farm income was used as the basis for comparison because it shows true income with adjustments for changes in inventories, accounts payable and receivable, and depreciation.

## Results and Discussion

All NMPs submitted for cooperating farms met the requirements of Act 6 nutrient management regulations (SCC 1993) and were developed according to Animal Feeding Operation guidance and specifications for nutrient application rates outlined in the USDA and USEPA Unified Strategy (1999; Tables 1-4). In the evaluation of the field-by field P-based NMP development process, NMP writers identified the following areas as requiring clarification: (1) definition of a field; (2) averaging manure applications across the rotation; (3) availability of soil test P values; (4) accounting for pasture areas; and (5) development of manure application summaries for the farm operator. These areas were not clearly defined in writer training and should be better defined in future NMP training and implementation efforts.

*Farm management impacts.* Farm management changes required to comply with the three P-based NMP recommendations were farm-specific, but the following summarizes P-based nutrient recommendations for each strategy across all cooperating farms. Considering recommendations for P-based nutrient application rates, the STCR strategy impacted 14 to 100% of evaluated acreage, ESPT impacted 0 to 95%, and PI impacted 0 to 81% (Table 6). The STCR strategy had the greatest and most consistent impacts on a percentage basis across all acreage, regardless of farm location, size, or animal enterprise; however, the available land base for manure redistribution was more limited in the southeastern and central regions (Farms 1 to 7; Table 6). For example, on Farm 8 (northeast PA) the STCR strategy impacted 58% (82 of 142 ha (203 of 351 ac)) of land, while on Farm 4 (central PA) it impacted 52% (40 of 76 ha (99 of 189 ac)) of land. On a percentage basis, the impact seemed similar between farms, but Farm 8 had 60 ha (148 ac) of remaining available land base and Farm 4 had 36 ha (90 ac) of remaining available land base for on-farm redistribution of manure. This indicates the importance of examining the management impacts on an individual farm basis. For the ESPT and PI, Farms 1 to 7 located in the southeastern and central regions of Pennsylvania (Tables 5 and 6) and five of which were CAOs (Table 5) had a higher percentage of acreage impacted than Farms 8 to 10 (Table 6).

To examine the variable impact of the nutrient management practices on the farming operations, total manure production and manure available for on-farm use were compared for each farm (Table 7). This comparison reflected the characteristics of individual farming operations by considering farm acreage, crop production, and farm management. Farms 1 to 5 had management changes that necessitated exporting either part or all of the manure off-farm, while management changes on Farms 6 to 10 would require the redistribution of manure on-farm (Table 7). The STCR was the most restrictive, allowing no manure application on 2 farms, reduced P-based manure applications on 3 farms, and N-based manure applications on 5 farms (Table 7). Both the ESPT and PI strategies allowed manure application on all farms, but the EPST restricted manure application on a P-basis on 5 farms and the PI on 4 farms.

While it was clear that the STCR management requirements were the most restrictive across all farms, the relative impact of the ESPT and PI strategies varied more on a farm-by-farm basis. On Farms 3 and 5, the PI required more manure to be exported than

**Table 5. Summary of farm management information.**

| Farm | Location | Production Type | Acreage (A) | CAO† | Imports Manure | Exports Manure |
|---|---|---|---|---|---|---|
| 1 | Southeast | Beef/Swine | 63 | x | | x |
| 2 | Southeast | Dairy/Broiler | 154 | | | x |
| 3 | Southeast | Layers/Swine | 394 | x | | x |
| 4 | Central | Heifer/Turkey | 189 | x | x | x |
| 5 | Central | Broiler | 215 | | x | |
| 6 | Central | Beef/Broiler | 45 | x | | x |
| 7 | Central | Dairy | 457 | | | |
| 8 | Northeast | Dairy | 351 | | x | |
| 9 | Northwest | Dairy | 445 | | | |
| 10 | Southwest | Dairy | 850 | | | |

**† CAO = Concentrated Animal Operation; CAO > 2000 lb live weight/A and regulated under Pennsylvania's Nutrient Management Act (Act 6; SCC 1993).**

**Table 6. Summary of farm acreage requiring P-based nutrient application rates under each P-based nutrient management planning.**

| Farm | Location | STCR† Acreage (A) | ESPT† Acreage (A) | PI† Acreage (A) |
|---|---|---|---|---|
| 1 | Southeast | 60 of 63 | 34 of 63 | 15 of 63 |
| 2 | Southeast | 146 of 154 | 147 of 154 | 0 of 154 |
| 3 | Southeast | 394 of 394 | 153 of 394 | 275 of 394 |
| 4 | Central | 99 of 189 | 41 of 189 | 154 of 189 |
| 5 | Central | 170 of 215 | 0 of 215 | 48 of 215 |
| 6 | Central | 6 of 45 | 2 of 45 | 18 of 45 |
| 7 | Central | 299 of 457 | 0 of 457 | 0 of 457 |
| 8 | Northeast | 203 of 351 | 8.5 of 351 | 0 of 351 |
| 9 | Northwest | 388 of 445 | 30 of 445 | 0 of 445‡ |
| 10 | Southwest | 309 of 850 | 7 of 850 | 0 of 850‡ |

**† Evaluated phosphorus nutrient management planning strategies:**

**STCR = Soil Test Crop Response strategy**

**ESPT = Environmental Soil P Threshold strategy**

**PI = Phosphorus Index strategy**

**‡ These farms were not included or only partially included in the revised PI evaluation because of incomplete information.**

**Table 7. Summary of relative differences between total manure production and on-farm manure utilization under N and P-based nutrient management planning.**

| | | Manure Production | On-farm manure use as a percentage of total manure production | | | |
|---|---|---|---|---|---|---|
| Farm | Livestock | Total Manure | N-Basis | STCR† | ESPT† | PI† |
| 1 | Swine<br>Beef | 287,000 gal<br>643 t | 88%<br>100% | 0 %<br>19% | 9%<br>100% | 59%<br>82% |
| 2 | Dairy<br>Broilers | 1,113,000 gal; 140 t<br>430 t | 100%; 100%<br>46% | 0%; 0%<br>0% | 100%; 100%<br>0% | 100%; 100%<br>100% |
| 3 | Layers<br>Swine | 12,000 t<br>1,095,000 gal | 21%<br>34% | 0%<br>0% | 10%<br>30% | 5%<br>23% |
| 4 | Dairy Heifers<br>Turkeys | 1188 t<br>623 t | 100%<br>60% | 43%<br>0% | 81%<br>54% | 8%<br>0% |
| 5 | Broilers | 470 t | 98% | 56% | 98% | 88% |
| 6 | Beef<br>Broilers | 180 t<br>18 t | 100%<br>100% | 100%<br>100% | 100%<br>100% | 100%<br>100% |
| 7 | Dairy | 826,000 gal | 100% | 100% | 100% | 100% |
| 8 | Dairy | 800,000 gal | 100% | 100% | 100% | 100% |
| 9 | Dairy | 3,000,000 gal | 100% | 100% | 100% | 100% |
| 10 | Dairy | 2,000,000 gal | 100% | 100% | 100% | 100% |

**† Evaluated phosphorus nutrient management planning strategies:**

**STCR = Soil Test Crop Response strategy**

**ESPT = Environmental Soil P Threshold strategy**

**PI = Phosphorus Index strategy**

**Table 8. Farm financial impact based on comparisons of N-based to P-based nutrient management planning using 2000 financial information.**

| | Net Farm Income Impact | | |
|---|---|---|---|
| Farm | STCR† | ESPT† | PI† |
| 1 | - $3385<br>- 6.8% | - $1659<br>- 3.3% | - $1071<br>- 2.1% |
| 2 | - $6919<br>- 5.6% | - $1201<br>- 1.0% | — |
| 3 | - $42,973<br>- 45.4% | -$34,525<br>- 36.5% | - $38,809<br>- 41.0% |
| 4 | - $4870<br>- 5.0% | - $1102<br>- 1.1% | - $6220<br>- 6.4% |
| 5 | + $874<br>+ 3.1% | — | + $287<br>+ 1.0% |
| 6 | + $521<br>+ 13.5% | + $342<br>+ 8.8% | + $433<br>+ 11.2% |
| 7 | - $27<br>- 0.07% | — | — |
| 8 | — | — | — |
| 9 | - $5235<br>- 4.5% | — | — |
| 10 | — | — | — |

**† Evaluated P-based nutrient management planning strategies:**

**STCR = Soil Test Crop Response strategy**

**ESPT = Environmental Soil P Threshold strategy**

**PI = Phosphorus Index strategy**

under the ESPT strategy; under that strategy, Farms 1, 2, and 4 would have to export more manure. However, the PI strategy offered more management flexibility, as it considered several farm management factors including soil erosion and manure application method. These factors, which are not addressed in the STCR and ESPT strategies, may present additional options for meeting NMP implementation (Table 3). For example, when PI evaluations on Farms 3 and 5 were examined, it was determined that changing the manure application method could increase the amount of manure applied on-farm. Unlike the ESPT strategy, which is based only on the soil test P level, the PI strategy can offer farm management options including, but not limited to exporting manure. As a result, the PI strategy was the only strategy that offered the farm operator options and flexibility in making management decisions.

Farms 6 to 10 required no export of manure under N or P-based nutrient management strategies (Table 7). With the exception of Farm 6, this indicated the importance of farm size, location, production enterprise, and animal density in evaluating the relative nutrient management impacts. Farms 7 to 10 were land extensive dairy operations, had animal densities below the Pennsylvania regulatory limit of 2250 kg live weight/ha (2000 lb live weight/ac) (Table 5), and were located outside of southeastern and central PA.

*Economic analysis.* 1. Dairy farms (Farms 7-10). By livestock group, the dairy farms faced fewer restrictions than dairy/poultry, poultry, or the beef/swine farms, and were generally more land extensive with adequate acreage to distribute manure. All of the farms faced potential management changes under the STCR strategy, three under the ESPT strategy, and none under the PI. None of the farms had to export manure (Table 7); however, Farm 9 had to redistribute more than 3.78 million L (1 million gal) of manure on-farm. There were no related financial costs to restrictions on Farms 8 and 10. Farm 7's compliance cost was $27 and Farm 9's was $5235 under the STCR strategy (Table 8). Farm 8 complied with the PI NMP by moving manure from an impacted field to an adjoining field that did not receive any manure, and Farm 7 combined manure redistribution with the purchase of a small amount of N fertilizer.

Farm 9 faced restrictions under the STCR strategy that limited manure application on many fields close to the dairy facilities. As a result, 4.16 million L (1.1 million gal) of manure were transferred to distant rented cropland at cost of $5235 (Table 8). The situation on Farm 9 was characteristic of growing dairy farms in Pennsylvania. Many dairy farms continue to attempt to raise most of their forage; therefore, crop acreage tends to increase as cow numbers increase. This helps

to provide adequate acreage for manure application, but it is common for the additional cropland to be located at a distance of 16 km (10 mi) or more from the dairy facilities, making manure transfer an economic burden. Hauling by farm tractor becomes prohibitively time consuming and contracting with custom spreaders can be expensive, often costing more than the value of the manure. Therefore, land extensive farms may incur a cost due to redistributing the manure to distant cropland.

2. Dairy/poultry farms (Farms 2 and 4). The addition of a poultry operation to a dairy farm adds a new dimension to manure management practices. The economics are simple: adding broilers or turkeys can increase farm income. Equipment from the dairy operation can be used for the poultry operation, and the use of the poultry manure can offset the cost of fertilizer. But after years of applying dairy and poultry manure, field P levels continue to rise, and complying with P-based nutrient management becomes more difficult.

The dairy/broiler farm (Farm 2) participating in this study faced restrictions under the STCR and ESPT strategies. Under the STCR strategy, the farm exported all dairy and broiler manure (Table 7). Exporting manure 8 km (5 mi) resulted in a compliance cost of $6919, representing a reduction in the farm's profitability (Table 8). Under the ESPT strategy, the farm would have to export all broiler litter (Table 7) and purchase N fertilizer for a compliance cost of $1201 (Table 8).

Farm 4, which raises dairy heifers and turkeys, faced restrictions under all three P-based strategies. Varying amounts of manure had to be exported under each P-based nutrient management strategy, resulting in a range of compliance from $1102 to $6220. The PI was the most restrictive strategy with the ESPT strategy being the least restrictive (Table 8). For Farms 2 and 4, the ability to sell their poultry manure was an integral factor in the economic impact of P-based NMP implementation.

3. Poultry farm (Farm 5). Farm 5 was subject to restrictions under the STCR and PI strategies, but compliance with both strategies increased net farm income (Table 8). The farm was located in an area with limited livestock production, which permitted the sale of all produced poultry litter. In compliance with P-based NMPs, broiler litter was sold and replaced with less expensive N fertilizer. This situation was desirable for both parties. The key was the farm location in an area where markets to readily sell manure were available.

4. Poultry/swine farm (Farm 3). This farm represented the potential nutrient management impacts of cooperative manure export agreements with other farming operations. The layer operation produced 10,884 MT (12,000 t) of manure per year, and the farm had a swine finishing operation that produced an additional 4.14 million L (1,095,000 gal) of manure per year (Table 7). Through two unique agreements with neighboring crop farmers, 8617 MT (9500 t) layer manure and 2.74 million L (725,000 gal) of swine manure were exported.

Layer manure not spread on Farm 3 was exported to a neighboring crop farmer for resale and on-farm use. In exchange for the manure, the crop farmer provided the following services to Farm 3: collection of the manure at the layer houses, application of manure to cropped fields, tillage, planting, harvesting, and payment for all chemicals. Swine manure was exported to another neighboring crop farmer who supplied the labor for export. Farm 3 supplied the equipment.

Despite existing agreements, additional manure would have to be exported under all three P-based management strategies (Table 7). The financial impacts for Farm 3 were calculated under the assumption that the cooperating crop farmers could continue to import manure (Table 8). However, if these cooperating crop farms were also subject to management changes under P-based nutrient management and could not import the manure, the financial impacts for Farm 3 could potentially increase.

Using year 2000 farm financial information, an analysis was performed to estimate the potential impacts if the current manure export agreement were to be changed because of P-based manure management requirements on the cooperating crop farms. The following assumptions were made in the analysis:

a) The crop farmers would no longer import the layer or swine manure.

b) Farm 3 could sell 4535 MT (5000 t) of layer manure locally for $2.75/MT ($2.50/t) and export the remaining manure to a farm an average of 32 km (20 mi) away, with the importing farm paying for the transportation costs.

c) Farm 4 must pay to haul the swine manure 8 km (5 mi) to neighboring farms.

d) Farm 3 must now pay for additional labor to collect, load, and spread the layer and swine manure.

The net farm income under this management scenario decreased by an additional 15% (STCR), 16% (ESPT), and 14% (PI) when compared to the financial impacts determined using the existing farm management, manure export agreement, and year 2000 financial information (Table 8).

5. Beef/swine farm (Farm 1). The restrictions faced by Farm 1 were caused by having concentrated livestock production on limited acreage. Farm 1 faced restrictions under all three strategies, with the STCR strategy being the most restrictive (Tables 6 and 7).

*Survey feedback*. Survey feedback showed that cooperating farmers thought Pennsylvania contributed to environmental problems associated with P, and that P-based NMPs would help in addressing environmental concerns. Despite these opinions, they still had greater concerns about N loss to groundwater.

Through surveys and a feedback session, NMP writers stated that PI NMPs took twice as much or more time, and were more expensive to develop than STCR or ESTP NMPs. The additional time associated with the PI assessments was due to information collection. However, writers did note that as more assessments were completed and NMPs developed, they became more efficient at using the PI. Additionally, writers favored the development of computerized information tools to facilitate the PI NMP development process and noted that using a current farm conservation plan helped determine soil loss, soil type, field slope values, and tillage methods.

In comparing the three P-based management strategies, NMP writers preferred the PI strategy because it incorporated transport processes, made sense, and was more likely to be implemented by their clients. Generally, the STCR approach was thought to be too restrictive to current farm management practices. The obstacles to the acceptance of the ESTP strategy included difficulty in explaining the determination of the environmental P threshold level and the difference between agronomic and environmental threshold levels.

## Summary and Conclusion

The evaluation of the ten cooperating farms using the STCR, ESPT, and PI nutrient management planning strategies resulted in not only management and economic analyses, but

also information about the NMP development process and P-based nutrient management. This information will be important for NMP writer training and implementation of a P-based nutrient management program.

Feedback on the acceptability of P-based nutrient management planning demonstrated the recognition by Pennsylvania farmers of the environmental impacts of P loss, but also emphasized the greater concern about N loss to groundwater. Cooperating NMP writers preferred the PI strategy because it accounted for sources and transport of phosphorus as well as farm management characteristics.

Using a field-by-field NMP development process raised several issues demonstrating that P-based nutrient management planning will require additional NMP writer training, clearer definitions of land use and fields on farms, and the need for consistency between NMPs and other farm management plans, such as the farm conservation plan.

In examining the impact on farm management, the ESPT strategy restricted manure application on less area than the STCR strategy, and the PI strategy was the most flexible in terms of nutrient management. The southeast and central regions, both high animal density areas in Pennsylvania, were most impacted by P-based nutrient management. Indicators of potential management impacts due to P-based nutrient management included: high animal densities, limited off-farm manure options, limited land base, and combined animal enterprises.

Financially, the STCR strategy proved to be the most costly for the ten farms. Two farms did not incur any costs while two other farms realized financial benefits. The other strategies were not as conclusive. Of the four farms financially impacted by both the ESPT and the PI strategies, two had higher compliance costs under the PI and two under the ESPT strategy. However, in these cases, only manure export was examined as a management option. The PI strategy offers other potential management options such as erosion control and manure incorporation. Use of these options may have increased on-farm manure utilization and reduced compliance costs. These management options were not available under the STCR or the ESPT strategies. In total costs across all ten cooperating farms, the STCR strategy was the most expensive option, costing $61,690 for compliance. The ESPT and PI strategies resulted in a cost of $47,862 and $45,380, respectively.

The variable economic and management impact of the P-based NMPs indicated the need for a dynamic management tool that accounts for multiple aspects of farm management. Of the three P-based nutrient management strategies outlined by USDA and USEPA (1999), only the P Index accounts for multiple source and transport factors. This indicates that for states such as Pennsylvania with diversified agricultural operations the PI may offer the most flexible nutrient management approach by accounting for multiple source and transport factors that reflect farm management. Yet there is still a need to examine the potential impacts beyond the individual farm scale.

## Acknowledgements

Funding provided by the Pennsylvania State Conservation Commission. Contribution from The Pennsylvania State University Department of Crop and Soil Sciences with cooperation from USDA-Agricultural Research Service (ARS) Pasture Systems and Watershed Management Research Unit, University Park, Pennsylvania.

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