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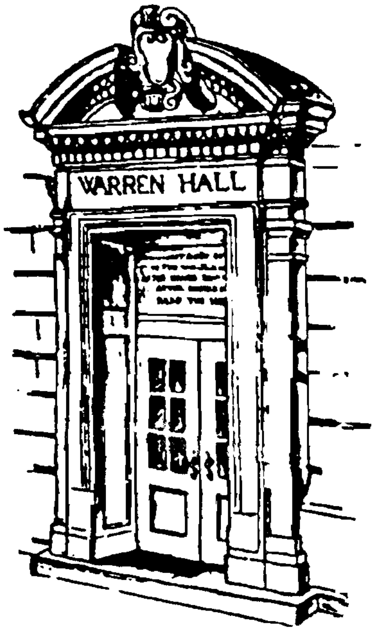

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Department of Agricultural, Resource, and Managerial Economics
Cornell University, Ithaca, New York 14853-7801 USA

Constraining Phosphorus in Surface Water: Dairy Farm Resource Use and Profitability*

John J. Hanchar, Wayne A. Knoblauch and Robert A. Milligan

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CONSTRAINING PHOSPHORUS IN SURFACE WATER: DAIRY FARM RESOURCE USE AND PROFITABILITY

Abstract

The New York City Watershed Agricultural Program (NYCWAP) seeks to reduce the potential for phosphorus movement from farms to surface waters. Toward this objective, a "Phosphorus Index for Site Evaluation" (P-Index) provides planners in the NYCWAP with a tool for identifying problems and evaluating solutions. A linear programming model was used to examine dairy farm resource use and profitability given resource constraints and constraints on the values of the P-Index. Results indicate dramatic differences in expected effects on resource use and returns above variable costs between less restrictive targets in the upper end of the "medium" (for example, 24 and 17) and more restrictive targets in the lower end of the range (for example, 13 through 10). The differences have implications for choosing a target to guide planning on farms – regarding expected effects on profitability, the target within the "medium" range matters.

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Introduction

Society is increasingly looking to nonpoint sources of water pollution for opportunities to obtain incremental improvements in water quality and, or to protect water supplies from future declines in quality. As attention on pollution of water supplies from nonpoint sources increases, society is increasingly examining agriculture as a source of nonpoint source pollution. In the New York City (NYC) watershed, the Watershed Agricultural Program through its whole farm planning effort seeks to address dairy farming's potential to adversely affect water quality (Hanchar, Milligan, Knoblauch 1997). Dairy farms are potential sources of pathogens, nutrients, sediment, and other pollutants.

The eutrophication of reservoirs is the major pollution problem associated with nutrients for NYC's water supply (New York City Watershed Agricultural Program 1998). To address eutrophication in NYC reservoirs, the NYC Watershed Agricultural Program (NYCWAP) seeks to reduce the potential for phosphorus movement from dairy farms to surface waters. The program faced a major challenge in identifying workable tools that planning teams (farmers and watershed planning staff) could use to measure, quantify, potential phosphorus movement for the purposes of identifying problems and evaluating alternative solutions.

Adapting the "Phosphorus Index" described by Lemunyon and Gilbert (1993) to reflect special conditions in the NYC watershed, Klausner (1997) developed a "Phosphorus Index for Site Evaluation" (P-Index). P-Index values reflect the potential for phosphorus movement from a site to surface waters. The P-Index provides planners in the NYCWAP with a tool for identifying problems and evaluating solutions. Since a variety transport and source factors affect the index, a variety of possible ways to reduce potential phosphorus movement and, or achieve desired targets for the P-Index might exist. Changes in the farm business that affect transport include runoff and erosion controls. Changes in the farm business that affect sources of phosphorus on the farm include changes in the amounts, timings, forms, locations and methods of P applications to land (Sharpley, Daniel and Edwards, 1993). No research looks at resource use, adaptations in resource use and profitability associated with reducing the potential for phosphorus movement from farms as measured by the P-Index.

Information regarding the possible effects on dairy farm resource use and profitability associated with reducing potential phosphorus movement and, or meeting P-Index targets would be useful to policymakers within the NYCWAP as they work to refine the program to better meet objectives and goals. This research contributes to a better understanding of the possible changes in resource use and tradeoffs associated with meeting P-Index targets by identifying optimal allocations of resources on dairy farms that maximize profit subject to resource constraints. Planners will benefit from information that helps to identify optimal means for achieving various P-Index targets. We begin by describing Klausner's (1997) P-Index. We then describe the linear programming model and representative farm data used to study resource use and profitability associated with constraining the potential for phosphorus movement from dairy farms. Empirical results follow. Summary and conclusions end the paper.

Measuring the Potential for Phosphorus Movement Using the P-Index

Context

Under a variety of agronomic, climatic and hydrogeologic conditions, runoff and subsurface movement of water have the potential to transport phosphorus from land on farms to surface and ground water resources in amounts that may be unacceptable. To address eutrophication in NYC reservoirs for the purpose of protecting water quality, the NYCWAP seeks to reduce the potential for phosphorus movement from farms to surface waters. A key to achieving this objective is the ability to measure the potential for phosphorus movement from farms using workable tools by planning teams on farms. Armed with workable tools for measuring potential, planning teams are better able to identify problems, examine underlying causes, identify alternatives, evaluate alternatives, and select the best or set of best solutions.

A Phosphorus Index for Site Evaluation

To address the need for a workable tool, Klausner (1997) adapted the "Phosphorus Index" described by Lemunyon and Gilbert (1993) to reflect special conditions in the NYC watershed. Let PI equal the value of the P-Index for a site. Then

(1) $PI = \alpha K$,

where α is a (1 by 7) vector of weights equal to (1.5,1.5,1,0.75,0.5,1,0.75) and K is a (7 by 1) vector of variables, factors, (k_1, k_2, ... k_7). The variables represented by the column vector K are calculated as follows.

(2) $k_1 = 0.5*SL$ for $0 \leq SL \leq 15$, and $k_1 = 7.5$ for $SL > 15$,

where SL is the average soil loss for the site in tons per acre per year estimated using the Revised Universal Soil Loss Equation (Renard, Foster, Weesies, McCool, and Yoder 1997).

(3) $k_2 = 1$, if HS = 1; 2 if HS = 2; and 4, if HS = 3 ,

where HS is the WAP's measure of hydrologic sensitivity (Klausner, 1995).

(4) $k_3 = 0.1*\text{SPT}$ for $0 \leq \text{SPT} \leq 80$, and $k_3 = 8$ for $\text{SPT} > 80$,

where SPT is the value of the Cornell University Soil Phosphorus Test Result in pounds per acre per year.

(5) $k_4 = 0.1*\text{PFERT}$ for $0 \leq \text{PFERT} \leq 90$, and $k_4 = 9$ for $\text{PFERT} > 90$,

where PFERT is the pounds of P_2O_5 applied as fertilizer per acre.

(6) $k_5 = 0$, if no P_2O_5 is applied as fertilizer;

1, if phosphorus (P) fertilizer is band placed at planting deeper than 1 inch;

2, if P fertilizer is topdressed April 1 through August 31, or incorporated just before planting;

4, if P fertilizer is applied September 1 through October 31;

8, if P fertilizer is applied November 1 through March 31.

(7) $k_6 = 0.05*\text{PMANURE}$ for $0 \leq \text{PMANURE} \leq 150$, $k_6 = 7.5$ for $\text{PMANURE} > 150$,

where PMANURE is the organic P application rate in pounds of P_2O_5 applied per acre.

(8) $k_7 = 0$, if no P is applied via manure applications;

1, if manure is incorporated deeper than 4 inches;

2, if manure is topdressed from April 1 through August 31 or incorporated just before planting;

4, if manure is applied from September 1 through October 31;

8, if manure is applied from November 1 to March 31.

The P-Index is meant to be a unit less measure. Therefore, planners can use the index to measure the potential for phosphorus movement from fields and, or areas within fields that have similar site characteristics. Planners obtain weighted measures by computing the product of a site's, field's or set of field's area and the calculated P-Index.

Suppose a site, field, had the following characteristics:

SL = 3 tons/acre/year; HS = 1; SPT = 25 lb/acre; PFERT = 20 lb P_2O_5/acre; P fertilizer is band placed at planting deeper than 1 inch, PMANURE = 90 lb P_2O_5/acre; organic P application is in June. Using equations (1) through (8), the P-Index value would be 14.3. Klausner (1997) provides some guidelines for site interpretations (table 1). If a planner calculated a P-Index value of 14.3 for a site, then the planner would associate a medium potential for P movement with the site.

Discussions in the watershed suggest a desire to obtain "medium" ratings on fields. If a farm has fields that exceed the medium rating, then planners must identify the allocation of resources among competing uses that will achieve desired results, while meeting profitability, and other objectives and goals of the farm business (Hanchar, Milligan, Knoblauch 1997). The number of transport and source factors that affect the P-Index, combined with the relationships among these, and other output and input choices that farmers must make hint at the potential complexity of the problem.

Model

To simultaneously evaluate the many possible allocations of available resources among competing uses on dairy farms for their ability to achieve P-Index targets while maximizing economic performance, we developed and solved a linear programming model. Key choices examined given the context of the P-Index include: cow numbers and ration selection; allocations of land, human and capital resources to production, including choices regarding fertilizer and manure amounts, timings, locations, and methods among crops. The latter are key factors in measuring potential phosphorus movement from a site using the P-Index.

The general form of the linear programming model is

(9) Maximize $f(X) = cX$

subject to

$AX \leq b$

$X \geq 0$

where c is a (1 by n) row vector, X is a (n by 1) column vector, A is a (m by n) matrix and b is a (m by 1) column vector. Schmit and Knoblauch (1995) provide the basis for the linear programming model used to examine dairy farm resource use and profitability given resource constraints and constraints on the values of the P-Index. The linear objective function, f(X), represents returns above variable costs. X is a column vector representing levels of possible farm activities, c is a row vector of estimated gross margins corresponding to the vector of activities. An individual gross margin is a price, return, or cost per unit of the corresponding activity. The column vector b represents the right hand sides for the model's constraint set.

Three prominent differences between the set of activities of the linear programming model used here and the set of Schmit and Knoblauch (SK) (1995) exist. First, the current model does not contain cow and replacement activities for SK's predominantly orchardgrass forage-based TMR. Second, the crop activities included here allow for a rotation of corn silage and alfalfa, where four years of corn silage follow four years of alfalfa, and continuous alfalfa with a four year stand life. Activities for manure and fertilizer applications of phosphorus by crop, by land group, by time period in the current model represent prominent differences relative to the SK model.

Two important differences between the set of constraints of the linear programming model used here and the constraint set of SK exist. First, constraints that specify restrictions on the values of the P-Index for each land group replace SK's limitations on P lost. Second, a constraint that accounts for the tons of N unaccounted for using the approach for estimating nutrient balances of Klausner (1995) replaces SK's limitations on the N lost.

A prominent difference reflected in the activities and constraints of the current model relative to SK relates to the way each describes the land resource. Twelve groups of tillable land, reflecting three levels of hydrologic sensitivity and four "Soil Test P" categories describe the land resource examined in the current model. Recall, that these attributes are two of the seven site characteristics used to compute the P-Index for a site.

Optimal solutions that maximize returns above variable costs were obtained for unrestricted and restricted cases. The latter included targets for the P-Index between 24 and 10, where 24 represents the upper boundary of Klausner's (1997) "medium" range for purposes of site interpretations and recommendations. P-index restrictions were imposed on each of the twelve land groups. Using the P-Index target of 24 as an example, the constraint for a given land group, takes the following form:

(10) $aX \leq 24 * \text{the number of acres in the land group}$,

where ‘a’ is a (1 by n) row vector of coefficients. The row vector ‘a’ represents contributions to the P-Index corresponding to the activities of the model.

Representative Farm Description

To represent dairy farms in the NYC watershed we utilized a single description of a representative farm. The 60 cow dairy of Schmit and Knoblauch (1995) provided data, and technical coefficients for the model.

To describe the land resource of the representative farm, we began by deriving a distribution of tillable cropland acres by level of hydrologic sensitivity by soil test P category (table 2). We used the methods and approaches described by Klausner (1995), Klausner (1997) and field level data from a farm in the NYC watershed. The information in table 1 combined with the description of the representative farm that specifies 185 acres of tillable cropland yielded a distribution for the tillable cropland acres (table 3).

Equations (1) through (8) describe the factors for calculating the P-Index. In the model, three sets of activities have non-zero technical coefficients for the P-Index constraints. First, are the crop by land group activities. The coefficients for the crop by land group activities reflect the partial effects on the P-Index associated with the following factors: average soil loss, soil test P category, hydrologic sensitivity risk level, P fertilizer applied as starter, and P fertilizer application method (table 4). For example, the value of 13.1 for corn silage on hydrologic sensitivity risk level 2 land with a soil test P category of low equals

(11) $(1.5,1.5,1,0.75,0.5)$ 📫 (k_1,k_2,k_3,k_4,k_5) ,

where $k_1 = 0.5 * SL$, for $SL = 10.0$;

$k_2 = 2$, that is, $HS = 2$;

$k_3 = 0.1 * SPT$, for $SPT = 6.0$;

$k_4 = 0.1 * PFERT$, for $PFERT = 20$;

$k_5 = 1$, that is, P fertilizer is band placed at planting deeper than 1 inch.

The values for SL and SPT represent weighted averages for the land group using field level data and acres by field. Since the activity in the example is a corn silage activity, the value for SL is calculated using the RUSLE and necessary factors for four years of corn silage in an eight year rotation with alfalfa. The crop by land group activities incorporate recommendations for amounts, timings and methods of P fertilizer applications following Klausner (1995).

A second set of activities associated with non-zero technical coefficients for the P-Index constraints is the set of manure application activities. Manure application activities are defined as: apply a ton of manure by crop by land group by time period. All organic P applications are topdressed. The treatment of organic P applications in calculating the P-Index was an issue in specifying the model.

Consider the possibility of topdressing 30 pounds of P via manure to an acre of alfalfa grown on hydrologic sensitivity risk level 2, low soil test P category land during the April through August period; and 60 pounds to an acre in the September through October period. Using equations (7) and (8) to calculate the portion of the P-Index attributed to organic P applications yields the following:

$$(12) \quad 1(0.05*30) + 0.75((30/90)*2) + 1(0.05*60) + 0.75((60/90)*4),$$

where 90 is the total amount of P applied via manure, the sum of the two applications. Amounts and timings of organic P applications among crop by land group activities are important choice variables for the current study. To specify the model with respect to manure applications and to maintain the assumptions of the general linear programming model, we estimated a linear function of the following form.

(13) $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$,

where y = the portion of the P-Index attributed to organic P applications (amount and method), x_1 is the pounds of P applied in manure from April through August, x_2 is the pounds of P applied in manure from September through October, and x_3 is the pounds of P applied in manure from November through March, and β_0 was restricted to equal 0. A hypothetical data set was created to estimate the function. The estimated parameters $\beta_{1,}$, β_2, and β_3 multiplied by the pounds of P per ton of manure yielded the technical coefficients for the manure application activities. A result of this approach is that the P-Index constraints in the model represent estimates of the relationships between the true P-Index and the activities.

The third set of activities associated with a set of non-zero technical coefficients for the P-Index constraints is a set of P fertilizer purchase and application activities. These activities by themselves, or in combination with manure application activities meet nutrient requirements net of the amount recommended at planting. We specify the model to reflect the recommendation that such applications would occur at planting for corn silage, and would be top dressed from April through August for alfalfa (Klausner 1995).

Using representative farm data, the model was solved assuming the distribution of tillable cropland represented in table 3 with no restrictions on the value of the P-Index; and then with the following restrictions on the value of the P-Index: 24, 17, 16, ... 10. We also solved the model using alternative distributions of tillable cropland. Alternative distributions reflect different distributions of tillable cropland among the levels of hydrologic sensitivity.

Results

With no constraints on the P-Index, returns above variable costs were maximum at $76,835 for the 60 cow farm (table 5). The optimal number of cows was 60 and all 185 acres of available tillable cropland were in corn silage or alfalfa production. Restrictions on the P-Index of 24, 17, and 16 had virtually no effect on profitability, cow numbers, animal rations, and overall crop selection. However, adaptations in resource use did occur with respect to crop selection by land group, and the amounts and timings of manure applications among the crop by land group activities (table 6).

An important result is that the potential exists for dairy farmers to achieve P-Index targets in the middle of the medium range without sacrificing returns above variable costs. Results suggest that farmers might achieve P-Index targets in the middle of the medium range by allocating hydrologic sensitivity risk level 2 land from continuous alfalfa to the rotation of corn silage and alfalfa, and allocating hydrologic sensitivity risk level 3 land from the rotation of corn silage and alfalfa to continuous alfalfa, while maintaining the overall crop selection reported in table 6. Results also suggest that farmers might adapt the amounts and, or timings of manure applications among crop by land group activities in response to P-Index restrictions. A notable adaptation reflected in the results is that the P-Index restriction of 16 is achieved in part by allocating a relatively large amount of manure away from corn silage production on hydrologically sensitive risk level 3 land during the November to March period, while allocating considerably more manure to alfalfa production on hydrologically sensitive risk level 3 land during the November through March period.

Imposition of P-Index restrictions of 15 and 14 reduced returns above variable costs by 3 and 7 percent, respectively compared to the unrestricted case (table 5). Moves from a corn silage based ration to an alfalfa based ration for the cows and greater alfalfa acres relative to corn silage characterized this set of results (table 7). The profitability effects for the P-Index restrictions of 15 and 14 combined with the results describing adaptations in the rations fed suggest that there is a fairly narrow range in which farmers might use these types of changes to achieve the P-Index targets without experiencing relatively large decreases in returns above variable costs.

Restrictions on the P-Index in the range 13 to 10 yielded substantial reductions in optimal returns above variable costs and changes in resource use compared to the unrestricted case (table 5). Optimal returns above variable costs declined by 21 percent relative to the unrestricted case for the P-Index restriction of 13. Optimal returns above variable costs declined by 68 percent relative to the unrestricted case for the P-Index restriction of 10. Dramatic declines in optimal cow numbers and crop acres characterized this set of results (tables 5 and 8).

A shadow price associated with a land group constraint represents the value of having an additional acre of land in the given land group providing the same variables remain in the optimal basis (table 9). Results indicate that the value to a dairy producer of an additional unit of land decreases for all available land groups as constraints on the value of the P-Index require lower and lower potentials for phosphorus movement from lands to surface waters. The value of an additional unit of land decreases dramatically for all available land groups for constraints at the bottom of the medium range (P-Index less than or equal to 10), when compared to results for the P-Index less than or equal to 16. Shadow prices for all available land groups indicate that an additional unit of land can not be expected to increase the optimal value of the objective function when the P-Index target is less than or equal to 10.

Shadow prices on the P-Index by land group constraints represent the values of unit increases in the right hand sides of the constraints (table 10). Recall that the right hand side of such a constraint is the P-Index target, for example 24, times the acres in the land group. See equation (10). For a given P-Index target, some relatively substantial differences in shadow prices among the P-Index by land group constraints exist. For example, note the shadow prices of $266 and $938 for the P-Index restrictions on HS3, STPM and HS3, STPH lands, respectively, for the P-Index target of 13. These shadow prices suggest relatively high values are associated with unit increases in the right hand sides of these constraints. A unit increase can be viewed as relaxation of the P-Index target given that acres in land group remain the same.

Results differed quite markedly as we used different distributions of tillable cropland acres among levels of hydrologic sensitivity. For example, using a uniform distribution of acres among all three levels of hydrologic sensitivity resulted in maximum returns above variable costs of approximately $74,300 and $68,400 for P-Index targets of 13 and 10, respectively. Using a distribution where 65 percent of the tillable cropland acres were described as hydrologic sensitivity risk level 3 and the remainder level 2, yielded maximum returns above variable costs of approximately $56,000 and $19,900 for P-Index targets of 13 and 10, respectively. Compare these results to the results in table 5 -- $60,420 and $24,493 for P-Index targets of 13 and 10, respectively. Clearly, results are sensitive to the availability of land by level of hydrologic sensitivity. The availability of land that is less hydrologically sensitive allows for achieving P-Index targets in the lower end of the medium range with less adverse effects on dairy farm resource use and profitability.

For the uniform distribution, shadow prices associated with the land group constraints were notable. Shadow prices increased substantially for hydrologic sensitivity risk level 1 land for all soil test P categories as P-Index targets moved from less than or equal to 17, to less than or equal to 13 and finally to less than or equal to 10. For example, the shadow price associated with the hydrologic sensitivity risk level 1, soil test P low land constraint, increased from $98, to $118, and then to $195, for P-Index targets of 17, 13, and 10 respectively. Land described as hydrologic sensitivity risk level 1, soil test P low increased in value to the dairy producer as P-Index constraints became more restrictive.

Summary and Conclusions

The purpose of this paper is to examine resource use and profitability on dairy farms given resource constraints and constraints on phosphorus movement from land as measured by the P-Index (Klausner 1997). Results suggest dramatic differences in expected effects on resource use and returns above variable costs between restrictions at the upper end of the "medium" range for the P-Index (for example, 24, 17, and 16) and restrictions at the lower end of the range (for example, 13 through 10). Results suggest that farmers might achieve P-Index targets over the range of 24 to 16 with little or no adverse effects on returns above variable costs. Results suggest that farmers might achieve the targets in this range by altering crop selection by land group, and by altering amounts, timings and locations of manure applications. The results also suggest that expected incremental improvements in water quality associated with achieving lower P-Index targets over the range 17 to 12 are obtained at increasingly greater costs measured by expected declines in returns above variable costs.

The sensitivity of resource use and profitability to variation in the P-Index target within the "medium" range has implications for choosing a target to guide planning on farms – the target within the "medium" range matters relative to expected effects on profitability. The choice of a P-Index target or desired reduction in the potential for phosphorus movement from land should also reflect that incremental improvements in the P-Index over the range or 24 to 12 are obtained at increasingly greater costs as measured by declines in returns above variable costs.

Results suggest that adaptations in resource use with respect to crop selection by land group, and the amounts, locations and timings of manure applications among the crop by land group activities might play a prominent role in achieving P-Index targets in the middle of the medium range, while not adversely affecting returns above variable costs. Planning efforts that seek to achieve reductions in potential phosphorus movements from land will benefit from such information. The results should point planning efforts to changes in the farm business that address water quality issues related to phosphorus, while allowing farmers to achieve other business objectives and goals.

Results associated with the analyses that assumed a uniform distribution of tillable acres among the three hydrologic sensitivity risk levels suggest that other types of changes in the farm business could play roles in achieving P-Index targets. For example, changes in the farm business designed to make less hydrologically sensitive land more available could help to achieve P-Index targets in the lower end of the medium range. Making less hydrologically sensitive land more available may or may not be the preferred solution for achieving P-Index targets in the lower end of the medium range depending upon the incremental costs and benefits associated with the changes.

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Table 1. Guidelines for interpreting values of the P-Index

P-Index Value	Site Interpretation
less than 10	Low potential for P movement from site. If farming practices are maintained at the current level, then there is a low probability of an adverse impact to surface waters from P loss.
10 to 24	Medium potential for P movement from site. Chance for an adverse impact to surface water exists. Some remedial action should be taken to lessen the probability of P loss.
25 to 42	High potential for P movement from site and for an adverse impact on surface water to occur unless remedial action is taken. Soil and water conservation as well as P management practices are necessary to reduce the risk of P movement and water quality degradation.
greater than 42	Very High potential for P movement from site and for an adverse impact on surface waters. Remedial action is required to reduce the risk of P movement. Soil and water conservation practices, plus a P management plan must be put in place to reduce potential for water quality degradation.

Source: Klausner (1997).

Table 2. Portion of tillable cropland acres by hydrologic sensitivity by soil test P category

		Hydrologic Sensitivity	
Soil Test P Category	Risk Level 1	Risk Level 2	Risk Level 3
< 9 pounds per acre (Low)		0.037	0.172
9 to 39 pounds per acre (Medium)		0.213	0.228
40 to 80 pounds per acre (High)		0.173	0.145
> 80 pounds per acre (Very High)		0.020	0.011
Total		0.443	0.556

Table 3. Tillable Cropland Acres by Soil Test P Category by Level of Hydrologic Sensitivity -- 60 cow dairy

		Hydrologic Sensitivity Rating	
Soil Test P Category	Risk Level 1	Risk Level 2	Risk Level 3
< 9 pounds per acre (Low)		6.8	31.8
9 to 39 pounds per acre (Medium)		39.4	42.2
40 to 80 pounds per acre (High)		32.0	26.8
> 80 pounds per acre (Very High)		3.7	2.0
Total		81.9	102.8

Table 4. Partial Values for the P-Index by Crop by Land Group[a]

Land Group[b]	Corn Silage[c]	Alfalfa[d]
HS1, STPL	13.7	6.35
HS1, STPM	15.2	6.2
HS1, STPH	16.3	7.7
HS1, STPVH	19.2	10.6
HS2, STPL	13.1	7.7
HS2, STPM	12.7	7.1
HS2, STPH	16.5	8.9
HS2, STPVH	20	12
HS3, STPL	19.3	10.8
HS3, STPM	20.8	10.8
HS3, STPH	22.5	12.7
HS3, STPVH	23.4	15.0

[a] Partial values reflect fixed effects(for purposes of the model) associated with: the level of hydrologic sensitivity; soil test P category; soil loss; amount of P fertilizer applied as starter; and P fertilizer application method.

[b] HS1, HS2, HS3 denote hydrologic sensitivity risk level 1, 2 and 3 land, respectively, while STPL, STPM, STPH, STPVH denote soil test P category low, medium, high, and very high land, respectively.

[c] Reflects four years of corn silage in an eight year rotation with alfalfa.

[d] Reflects a four year stand life.

Table 5. Returns above Variable Costs and Cow Numbers by P-Index Restriction – 60 Cow Farm

P-Index Restriction	Returns above Variable Costs	Number of Cows
Unrestricted	$76,835	60
≤ 24	76,835	60
≤ 17	76,826	60
≤ 16	76,795	60
≤ 15	74,917	60
≤ 14	71,639	58
≤ 13	60,420	46
≤ 12	36,063	27
≤ 11	29,973	21
≤ 10	24,493	14

Table 6. Acres by Level of Hydrologic Sensitivity by Crop and Tons of Manure Applied by Level of Hydrologic Sensitivity by Time Period by Crop, by P-Index Restriction

		P-Index Restriction		
	Unrestricted:		< or = 16:	
Level of Hydrologic Sensitivity/ Time Period	Corn Silage	Alfalfa	Corn Silage	Alfalfa
HS Risk Level 2:	21.3 acres	60.6 acres	33.6 acres	48.3 acres
HS Risk Level 3:	33	69.8	20.7	82.1
Total	54.3 acres	130.4 acres	54.3 acres	130.4 acres
HS Risk Level 2:				
APR to MAY	103 tons	23 tons	217 tons	--- tons
JUN to AUG		302		279
SEP to OCT	49	56	229	58
NOV to MAR	197		295	
HS Risk Level 3:				
APR to MAY	161		70	
JUN to AUG		129		151
SEP to OCT		182		
NOV to MAR	398	121		421

Table 7. Animals by Rations, by P-Index Restrictions -- 60 Cow Farm

Restriction on P-Index	Cows, Alfalfa Based Ration	Cows, Corn Silage Based Ration	Replacements, Alfalfa Based Ration	Replacements, Corn Silage Based Ration
Unrestricted		60		43
≤ 24		60		43
≤ 17		60		43
≤ 16		60		43
≤ 15	26	34		43
≤ 14	58			42
≤ 13	46		21	12
≤ 12	27		19	
≤ 11	21		15	
≤ 10	14		10	

Table 8. Tillable Crop Acreage Use by P-Index Restriction – 60 Cow Farm

P-Index Restriction	Corn Silage	Alfalfa	Idle
Unrestricted	54.3	130.4	
≤ 24	54.3	130.4	
≤ 17	54.3	130.4	
≤ 16	54.3	130.4	
≤ 15	36.3	148.5	
≤ 14	12.3	170.4	2.0
≤ 13	3.4	152.5	28.8
≤ 12		81.9	102.8
≤ 11		78.2	106.5
≤ 10		38.8	145.9

Table 9. Land Use and Shadow Prices by Land Group by P-Index Restriction -- 60 Cow Farm

Land Group[a]	Corn Silage (Acres)	Alfalfa (Acres)	Idle (Acres)	Shadow Price ($)
Unrestricted:				
HS2, STPL	3.4	3.4	0	98
HS2, STPM	0	39.4	0	101
HS2, STPH	16.0	16.0	0	104
HS2, STPVH	1.8	1.8	0	104
HS3, STPL	15.9	15.9	0	98
HS3, STPM	2.7	39.4	0	101
HS3, STPH	13.4	13.4	0	104
HS3, STPVH	1.0	1.0	0	104
P-Index ≤ 24:				
HS2, STPL	3.4	3.4	0	98
HS2, STPM	2.7	36.7	0	101
HS2, STPH	16.0	16.0	0	104
HS2, STPVH	1.8	1.8	0	104
HS3, STPL	15.9	15.9	0	98
HS3, STPM	0	42.2	0	101
HS3, STPH	13.4	13.4	0	104
HS3, STPVH	1.0	1.0	0	104
P-Index ≤ 16:				
HS2, STPL	3.4	3.4	0	94
HS2, STPM	12.9	26.5	0	97
HS2, STPH	16.0	16.0	0	97
HS2, STPVH	1.3	2.4	0	96
HS3, STPL	12.3	19.5	0	83
HS3, STPM	0	42,8	0	94
HS3, STPH	8.2	18.6	0	94
HS3, STPVH	0.2	1.8	0	92
P-Index ≤ 10:				
HS2, STPL	0	6.8	0	< 0
HS2, STPM	0	39.4	0	< 0
HS2, STPH	0	32.0	0	< 0
HS2, STPVH	0	0	3.7	< 0
HS3, STPL	0	0	31.8	< 0
HS3, STPM	0	0	42.2	< 0
HS3, STPH	0	0	26.8	< 0
HS3, STPVH	0	0	2.0	< 0

[a] See Table 4, footnote b. Note that no HS1 land is available for this repesentative farm.

Note: Negative shadow prices possible given that land group constraints are equality constraints in the model.

Table 10. Shadow Prices For P-Index by Land Group Constraints by P-Index Restrictions – 60 Cow Farm

	P-Index Constraint for:							
P-Index Restriction	HS 2, Soil Test P Low	HS 2, Soil Test P Medium	HS 2, Soil Test P High	HS 2, Soil Test P Very High	HS 3, Soil Test P Low	HS 3, Soil Test P Medium	HS 3, Soil Test P High	HS 3, Soil Test P Very High
≤ 24	$0	$0	$0	$0	$0	$0	$0	$0
≤ 17	0	0	0	0	0	0	0	0
≤ 16	1	1	1	1	1	1	1	1
≤ 15	13	13	13	13	13	13	13	13
≤ 14	30	30	30	30	30	30	30	103
≤ 13	42	42	42	42	42	266	938	26
≤ 12	70	70	70	70	385	316	171	68
≤ 11	70	70	70	165	169	159	91	70
≤ 10	70	70	70	83	108	106	70	61

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