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**THE ECONOMIC IMPACTS OF  
PHOSPHORUS-BASED MANURE  
MANAGEMENT POLICIES ON A  
REPRESENTATIVE NORTH CENTRAL  
INDIANA HOG-GRAIN FARM**

by

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Staff Paper #01-3

May 2001

**Dept. of Agricultural Economics**

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# **THE ECONOMIC IMPACTS OF PHOSPHORUS-BASED MANURE MANAGEMENT POLICIES ON A REPRESENTATIVE NORTH CENTRAL INDIANA HOG-GRAIN FARM**

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## Abstract

Federal and State regulatory agencies are considering switching from a nitrogen-based manure disposal policy to one that is phosphorus-based. This analysis estimates the compliance costs of this policy change for a representative hog-grain farm in Wabash County, Indiana. The representative farm includes 1,500 acres of cropland and has the capacity to raise 11,970 grow-finish hogs annually. The farm model also has the potential to produce four different crops on six different land types. A non-linear math-programming model was developed for this study to determine the optimal mix of management activities for a phosphorus-based regulation. The model maximizes farm returns above variable costs, subject to resource and regulatory constraints. The model allows mitigation of compliance costs via the choice between four different pig diets, three alternative methods of disposing manure, changes in timing of manure application, and crop pattern adjustments. This analysis concludes that the new regulation will result in a decrease in whole-farm returns above variable costs, use of alternative pig diets, and an increase in wheat acres planted. The model also reveals that it is optimal for the farmer to hire a custom hauler to assist in application of manure in an effort to reduce the degree to which available field days constrains farming activities. The estimated cost to the farmer, as a result of the policy change, ranges between \$0.56 to \$21.74 per pig capacity. The range of this estimate depends on the performance of markets for custom manure disposal, new feed ingredients, and off-farm spreading contracts. Thin markets for these factors reduce the flexibility the farmer has in mitigating the compliance costs via changes in diet, application method, cropping systems, and land activities.

Keywords: Environmental Regulation, Hog Production, Phytase

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## Introduction

The current regulation for manure disposal within most states, requires that the manure nutrient, nitrogen, cannot exceed the nitrogen needs of crops grown on land where manure will be applied. As a result of this policy, phosphorus levels in the soil have increased leading to water quality problems. As a result, state and federal lawmakers have considered requiring livestock producers to apply manure based on the phosphorus needs of crops. It is the objective of this paper to determine the cost of this policy change on a representative hog-crop farm in North Central Indiana. In addition this paper will also address those management decisions the farmer will make in order to mitigate potential increased costs that are a result of the policy change.

## Background

Over the past 30 years the pork industry has experienced profound structural changes. For instance, Indiana has recently experienced an increase in the swine industry, mirroring most other regions in the U.S. (Figure 1). For example, since the 1970s more than 4.3 million hogs have been in inventory in Indiana, but the number of hog operations has steadily decreased, from 27,000 in 1976 to only 9,600 in 1995 (Sims, Simmard, Joern, 1998).

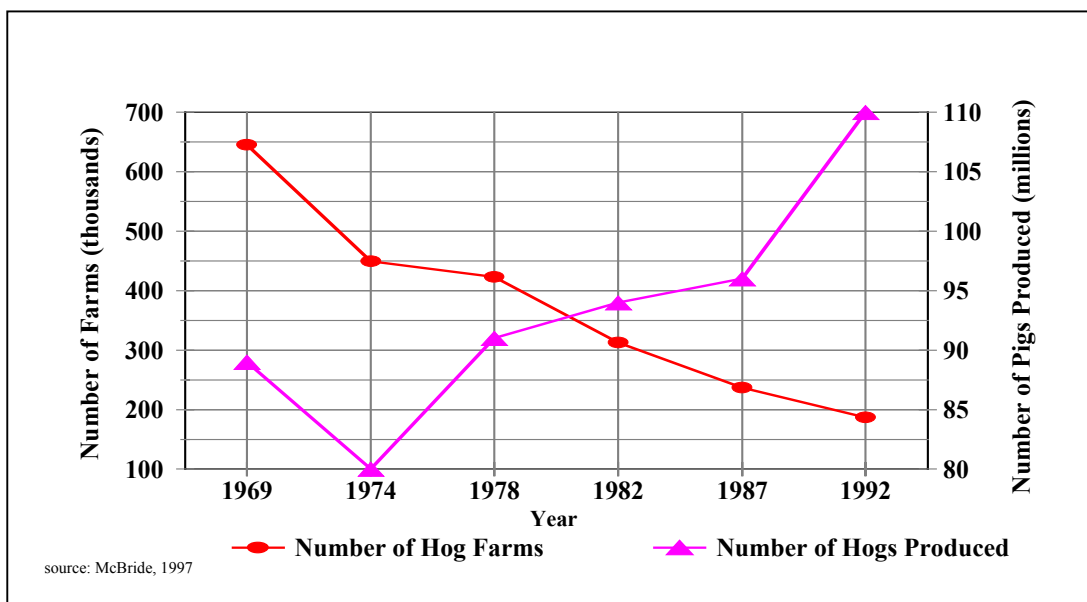


Figure 1 The Number of Hog Farms and Hog Production in the U.S.

Indiana's hog industry has expanded by gradually building larger confinement facilities (confined feeding operations), which have resulted in an increase in the number of hogs per acre. The increases in animal density have presented new challenges in the collection, storage, and land application of manure. The intensification of animal production has created areas where nutrients produced in animal wastes greatly exceed crop nutrient requirements. Even if swine manures are applied at rates that match crop nitrogen (N) needs, phosphorus (P) applications usually exceed crop P removal by 300 to 500%. (Sims, Simmard, Joern, 1998)

With the overapplication of P on cropland, a variety of environmental problems have occurred. Excessive P supplied to water bodies has been found to result in eutrophication, hypoxia, and algal blooms. With our nation's water quality in jeopardy under current manure land application policies, federal and state lawmakers have moved towards implementing alternative manure disposal methods. For instance in Indiana, the Indiana Department of Environmental Management (IDEM) has proposed a rule, which could require hog operators in the state to begin applying manure at an agronomic rate. To apply manure at an agronomic rate means that all the nutrients supplied by manure must not exceed those same nutrients required for plant growth. These nutrients are nitrogen, phosphorus, and potassium. In most cases, this will mean that manure is disposed of at a phosphorus rate as opposed to a nitrogen rate.

With these proposed new regulations it is not clear to policy makers how it will impact existing farmers. This paper estimates the economic impacts of a phosphorus-based manure application regulation on a representative hog-grain farm in North Central Indiana. Additionally, this analysis will estimate the sensitivity of the costs under alternative market environments. The impacts will be identified through changes in farm returns above variable costs, cropping patterns, pig rations, manure disposal methods, and manure disposal locations.

To estimate the impact of a phosphorus-based manure application policy, a math-programming model is developed. This model employs a representative hog-crop operation located in north central Indiana. The North central region of Indiana is where the majority of hog production occurs. The data used in the model is taken from agricultural information from this area.

The model will be solved based on current regulations, then solved again based on additional constraints reflecting the new phosphorus-based policy. A comparison of results will indicate the potential impacts the representative farm will face as a result of changes in manure management regulations.

In this analysis the on-farm cost of manure disposal by the farmer was found to be non-linear, therefore the math programming model will be non-linear. This model has the objective of maximizing farm returns above variable costs, subject to on-farm resource and environmental constraints. The environmental constraints represent new and current regulations. The model was programmed in the GAMS (Brooke, Kendrick, and Meeraus, 1988) language.

### **Previous Research**

In the few studies that have been done to determine the effects of a phosphorus-based manure disposal policy, all found that it would decrease profits due to an increase in manure disposal costs (Fleming et al., 1998; Pratt, et al., 1997; Massey and Krishna, 1995a; Schnitky and

Miranda, 1993). According to Massey and Krishna (1995a) there are three adverse effects on the costs of applying manure based on a Phosphorus Standard<sup>1</sup>. First, the distance traveled to haul the manure will increase, which will cause transportation costs to rise. Secondly, the adjusted application rates are much lower than under the Nitrogen Standard<sup>2</sup>, therefore nitrogen will be under-applied. The farmer will then need to pass over the field again with commercial fertilizer in order to supply the remaining nitrogen needed by crops. This will cause the farmer to bear both a manure and commercial fertilizer application cost for the same land area. Thirdly, the time needed to apply the manure is increased. All of these factors will cause the cost of manure disposal to rise and reduce farmer profit.

Additionally, Schnitkey and Miranda (1993) found that a Phosphorus Standard would lead to a decrease in the optimal number of hogs raised. Thus, in order for the farmer to remain competitive, fewer pigs are raised than under the Nitrogen Standard regulatory environment.

### **Diet Manipulation**

One method that farmers can use to alter the amount of nutrients excreted from pigs is through diet manipulation. This would include alternative ingredients in the pigs' diet, which would result in a reduced amount of nutrients excreted. Alternative ingredients used in the diets for this study includes the enzyme phytase, and reduced crude protein supplemented with synthetic amino acids.

Phytase is an enzyme, which breaks down phytate so phosphorus and other nutrients are released. Pigs have virtually no phytase activity of their own. This means that the pigs are unable to digest phosphorus, therefore it is excreted instead of absorbed by the body. (McKnight, 1996)

Phytase is available commercially and can be used as a dietary supplement for pigs. This synthetic version of phytase has been found to be an effective means of reducing P excretions from pigs (Knabe and O'Quinn, 1996).

Phosphorus excretion has been shown to be reduced with estimates ranging from 25-50 percent due to adding synthetic phytase to pig diets (Simons et al., 1990; Jongbloed et al., 1992; Cromwell et al., 1993a,b; Lei et al., 1993; Kornegay, 1996). The manure produced using phytase will have lower phosphorus levels, which is beneficial for the farmer, because manure can be applied at a higher rate than under manure produced from the original diet. With higher application rates, manure disposal costs are reduced. However, the incentive for the farmer to use phytase for assisting the pigs in absorbing P will depend on whether the cost of the enzyme is less than the reduced costs of manure application. These will all be factors in a farmer's decision to use phytase.

An additional method that farmers can use to further reduce phosphorus in manure is to use a reduced crude protein diet supplemented with synthetic amino acids and phytase. With this alternative diet, the nitrogen excreted in manure has been known to decrease by 28-45 percent

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<sup>1</sup> Phosphorus Standard refers to the policy that manure must be spread based on the phosphorus needs of crops.

<sup>2</sup> Nitrogen Standard refers to the policy that manure must be spread based on the nitrogen needs of crops.

and phosphorus was further reduced (**from the phytase only diet**) by 14 percent (Sutton et al., 1998a; Sutton et al., 1998b).

Diet manipulation methods are used to reduce the amount of nutrients excreted by pigs. If the amount of nutrients excreted is reduced, then the farmer can apply manure at a higher rate under a Phosphorus Standard than with manure produced from the industry standard diet. Land application costs are reduced because the farmer can apply more manure per acre with the alternative diets. Such diet manipulations include the addition of phytase, which significantly reduces the amount of phosphorus excreted. In addition, the farmer can use a reduced crude protein diet supplemented with both synthetic amino acids and phytase. This diet will achieve an even greater reduction in nutrients excreted. These diet manipulation strategies can be costly, but become economical under varying regulatory environments.

### **Data and Assumptions**

As mentioned earlier, the representative farm for this model is designed based on information from typical crop-livestock farms in north central Indiana. Within the model the farmer will be constrained by time, regulations, and resource constraints. The model was developed in order to determine the short-run impact on returns above variable costs and farm procedures due to policy changes. The crop area consists of 1,500 acres and the farm operator manages 11,970 grow-finish hogs annually.

The cropland is endowed with a typical combination of soil types, their distribution is commonly found in north central Indiana. Three soil types are used and include Miami, Crosby, and Brookston. Differences in crop yields are only a result of different soil types. In aggregate, these soils represent areas on a farm that produce low yields (Miami), average yields (Crosby), and high yields (Brookston). It was determined that the soil type distribution would be 25 percent of the farm in low yielding soils, 40 percent in average yielding soils, and 35 percent in high yielding soils (Howard, 1999).

In this model, the farmer is given the choice to grow four different crops. Crop choices include continuous corn (CC), rotation corn (RC), rotation beans (RB), and wheat (W). Continuous corn represents an area of the farm where year after year corn is grown. Rotation corn is an area of the farm where the first year corn is grown, then the following year beans (soybeans) are grown in the same area. Rotation beans is an area of the farm, where in the first year beans are grown, then the following year corn is grown in the same place.

### **Farm Configuration**

For manure application practices it is important to consider the distance traveled to the various sections within the farm. The farm was also divided into Near and Far land, thus creating six different land types. For the representative farm, Near land consists of 40 percent of the farm, and Far land consists of 60 percent. In Figure 2, the breakdown of the representative farm is illustrated with the number of acres in each plot and the distances in miles shown respectively. The soil types are distributed randomly throughout the farm. The Near and Far characteristic is used for each soil type. For instance, the average yield area that is closest to the hog barn is considered to be, average yield near. The average yield area that is furthest from the hog barn is referred to as, average yield far.

The arrows in Figure 2 represent the assumed routes the farmer would follow to reach the field and apply manure. These distances are used to estimate the travel costs of disposing manure. The distances were measured using the concept of sections, where 640 acres equals one square mile. Therefore, the length of the farm is approximately 2.34 miles long and the width is assumed to be one (1) mile. Figure 2 also illustrates the location of the grow-finish barn. The location of the barn was based on the assumption that the farmer would locate the hog facility on low yielding soil (Howard, 1999). Therefore, it is assumed that if the hog barn is located near low yielding soil, it is also built on low yielding soil.

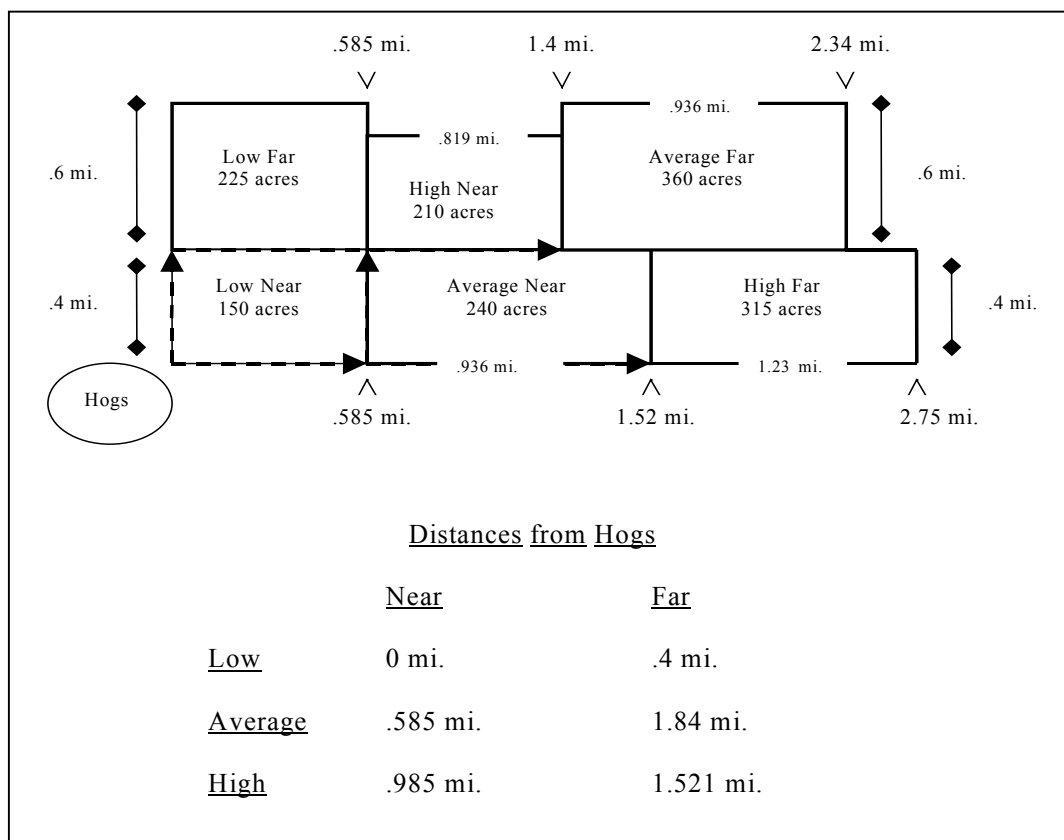


Figure 2 Configuration of the Representative Farm

As mentioned before, a typical farm in north central Indiana, finishes 11,970 hogs annually. For each grow-finish cycle the farmer has the capacity to support 3,990 grow-finish hogs (Foster, Hurt, and Hale, 1995). This model looks only at the waste management concerns for manure produced by the grow-finish operation. Manure is stored in a deep pit beneath the hog barn, and the pit can hold 120 days worth of storage.

To estimate the application rate for manure disposal on cropland, the farmer should consider the nutrient losses based on the diet fed to pigs, method of manure storage, method of application, and yield of crops. Once all the nutrient losses are considered the final nutrient content is used to determine the actual application rate (gallons per acre). The most common method of manure application in Indian is subsurface injection. Thus, the math-programming model employs this method.

### **Alternative Diets**

The model chooses between four different diets. All diets are assumed to result in the same volume of manure produced, and each diet is fed in four phases over a four-month period. Each diet contains different additives that alter the nutrients excreted by the pigs. These additives reduce the amount of nutrients excreted, but also increase the cost of the diets. The Brill Corporation Diet Sequence Program generated the diet information.

Diet 1 represents the industry standard sequence, or the diet most farmers are currently feeding their grow-finish pigs. This diet does not contain nutrient reducing additives. Diet 2 includes phytase, an enzyme that reduces the amount of phosphorus excreted by 30 percent from Diet 1. Diet 3 has a decreased amount of crude protein, which reduces the amount of nitrogen excreted by 35 percent from Diet 1. Diet 3 is also supplemented with synthetic amino acids and phytase, as a result phosphorus is reduced by an additional 14 percent from Diet 2 (a 40 percent reduction from Diet 1). Diet 3 can result in thicker back fat, which could reduce the market value of the pig by approximately 2 percent. Diet 4 is essentially the same as Diet 3, except the farmer supplements fiber in order to maintain the market value of the pig achieved from Diet 1 and Diet 2. It is also assumed that the farmer currently has a bin to store the fiber and add it to the diet sequence. The importance of these various diets is the affect they have on the nutrient content of manure and in the case of Diet 3, the effect they have on hog revenues.

### **Days Available for Work**

The time horizon in the model is over one year. The year is divided into six periods, and each period is two months in duration. Table 1 displays the time periods where planting and harvesting occurs for crops, when manure disposal can occur by crop, and when the growth and sell of pigs occurs.

TABLE 1 Time Table for When Farm Activities Occur

<b>PERIOD</b>	<b>PLANTING</b>	<b>HARVESTING</b>	<b>SPREAD MANURE</b>	<b>PIGS</b>
1. Dec. – Jan				Raise
2. Feb. – Mar.			Bean & Corn Land	Sell
3. April – May	Beans & Corn		Bean & Corn Land	Raise
4. June – July		Wheat	Bean & Corn Land	Sell
5. Aug. – Sept.			Wheat	Raise
6. Oct. – Nov.	Wheat	Beans & Corn	Bean & Corn Land	Sell

The activities chosen by the farmer are constrained by the number of good field days available in each period. Such activities include the decision of what land type each crop will be grown on, how much of the crop to grow, and when and where manure application will take place. The total field days available for work are listed in Table 2.

TABLE 2 Total Good Field Days Available for Work in Each Period

PERIOD	# OF DAYS AVAILABLE
1	9
2	8
3	27
4	21.3
5	43
6	37
Source: Doster et al., 1997; & Purdue University Cooperative Extension, 1994.	

The good field days available for planting and harvesting plus the good field days available for spreading commercial fertilizer and manure must be less than or equal to the total number of good field days available. The good field days available for planting and harvesting are shown in Table 3. The availability of field days is determined primarily by historical data on weather conditions.

TABLE 3 Good Field Days Available for Planting and Harvesting

CROP	PER. 1	PER. 2	PER. 3	PER. 4	PER. 5	PER. 6
CC	0	0	16.1	0	0	30
RC	0	0	16.1	0	0	30
RB	0	0	16.1	0	0	30
W	0	0	0	7	0	20.8
Source: Doster, 1997.						

The model assumes timely planting and harvesting. This means that the farmer will begin planting beans and corn sometime after April 26 and finish planting before mid May. Harvesting of these crops will occur during the month of October. Timely planting and harvesting is also assumed for the production of wheat. These assumptions assure that soil type, and not the timing of planting and harvesting will affect crop yields.

The model also includes good field days available for disposing of manure and spreading commercial fertilizer. Table 4 shows the good field days available in each time period and on which crop it can occur.

TABLE 4 Good Field Days Available for Spreading Manure and Commercial Fertilizer

CROP	PER. 1	PER. 2	PER. 3	PER. 4	PER. 5	PER. 6
CC	9	8	27	10	0	0
RC	9	8	27	10	0	0
RB	9	8	27	10	0	0
W	0	0	0	0	43	0
Source: Purdue University Cooperative Extension Service, ID-205, 1994.						

The good field days available for spreading during winter are based on the assumption that the farmer has the proper best management practices, such as filter strips, to ensure minimal environmental impact. The good field days available in Period 4 are based on the assumption that the farmer is able to inject manure until the corn is two inches high, which is assumed to be in the first part of June (Purdue University Cooperative Extension Service, 1994).

### **Fertilizer Requirements**

All crops require fertilizer for growth. Fertilizer requirements are based on the nitrogen, phosphorus, and potassium needs of crops. For this model, the farmer has three sources of fertilizer; commercial fertilizer, hog manure spread by the farmer, and hog manure spread by a custom hauler. The model also balances fertilizer requirements with the need for disposing of manure.

The model chooses the most economical application method by comparing the cost of manure disposal on the farm by either the farmer or the custom applicator. In addition, the farmer has the choice to hire the custom applicator to haul manure off the farm. It is assumed for this scenario that the custom applicator can find cropland available for manure application.

The cost of manure application by the farmer is different from the cost of hiring a custom hauler. For custom applicator use, the cost of disposal was based on rates charged by a north central Indiana custom applicator corporation (Merrell Brothers Corporation, Kokomo, Indiana). This company bases their rates on a per gallon basis, which is dependant on the distance required to travel to the field where the manure is to be disposed. The cost of manure disposal by a custom hauler ranges between \$0.01 - \$0.021 per gallon depending on how far the custom applicator has to travel.

This model considers a non-linear cost function for manure disposal by the farmer. For this study the operating costs (variable costs) of manure disposal were considered. In order to estimate the total variable costs of manure disposal for a variety of application rates, distances traveled, and number of acres the manure would be spread on, the following equation was estimated<sup>3</sup> (Equation 1).

$$TC = a_0RA + a_1R^2A + a_2A + a_3A^2R + a_4DRA + a_5SRA \quad (1)$$

For this equation  $TC$ , is the total variable cost of manure disposal.  $R$  represents the application rate,  $A$  is the number of acres in the field where the manure is disposed,  $D$  is the distance traveled to the field, and  $S$  is the assumed total acres the farmer will use annually to spread manure. This nonlinear cost function provides flexibility in the model for estimating the cost of disposal. With this cost curve the model is able to estimate the cost of manure disposal for all combinations of crops, yields, number of acres applied to, and distances traveled.

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<sup>3</sup> This cost curve was estimated using OLS based on data extracted from the “Manure Distribution Cost Analyzer” developed by Raymond E. Massey, Crops Economist, University of Missouri.

## The Model

The model used to estimate the impact on a farmer's returns above variable costs due to a change in manure application policies is based on a non-linear program, which considers both cropping and livestock decisions made by the farmer. This model maximizes farmer returns above variable costs, subject to resource and regulatory constraints. The profit maximization point will be found where the combination of time and resources results in the maximum profit attainable. The model was constructed and solved by the General Algebraic Modeling System (GAMS).

The hypothetical Indian farmer is faced with a limited supply of land, days for work, and capital. Therefore, the farmer must choose the production bundle of crops and livestock that will maximize profits subject to the limits in factors of production and regulatory constraints. The use of mathematical programming is the general means by which such a constrained problem is solved. Constrained optimization is defined as maximizing an objective function, such as profit, subject to certain limits and conditions that must be met. Therefore, a constrained optimization problem finds the optimal point within the boundaries set by the constraints.

The constrained optimization problem can be written mathematically as:

$$\text{Objective} \quad \text{Maximize TRVC}(\mathbf{q}, A, R, D, S) \quad (2)$$

$$\text{subject to:} \quad g_i(\mathbf{q}) \leq b_i \quad (3)$$

$$\mathbf{q} \geq 0. \quad (4)$$

Where TRVC is the total returns above variable costs, and  $\mathbf{q}$  is a vector of outputs, such as crops and livestock. The  $g_j$ -constraints represent restrictions from regulations, the availability of inputs, and technical feasibility. The final constraint represents non-negativity (equation 4).

Since the farmer is constrained by the days available for work. Planting and harvesting have to be completed within a certain window of time. As a consequence, the farmer must balance the time needed to spread manure, plant, and harvest the crops. In addition, other constraints represent public policies, which limit the amount of nutrients that can be supplied to the land from manure. Both of these types of constraints can be represented mathematically by Equation (3). These constraints are generally defined by inequalities and affect the amount of  $\mathbf{q}$  that can be produced.

## Results

The impact of manure application policy changes was measured by calculating the differences in returns above variable cost levels between the results of alternative runs of the model. The first run represents the management decisions the farmer would be expected to make based on applying manure the nitrogen rate (N-RATE). The second run represents the management decisions made by the farmer where land application of manure is based on meeting the phosphorus needs of the crops (P-RATE).

Both runs of the model were based on the data and assumptions presented in this paper. The only difference between N-RATE and P-RATE are the nutrient requirements. N-RATE

allows for nitrogen from manure to meet but not exceed the nitrogen needs of crops. This would then allow for manure phosphorus to be greater than the phosphorus needs of crops. Thus, N-RATE represents the current regulatory environment. In addition, the model constrains the amount of manure nitrogen to be no more than 150 pounds per acre per year, as dictated by current Indiana Department of Environmental Management guidelines.

Alternatively, P-RATE does not allow for manure phosphorus to exceed the phosphorus needs of crops. Thus P-RATE represents the proposed regulatory environment. Through comparing the results between N-RATE and P-RATE it would illustrate what actions the representative farmer would take in order to mitigate the costs of the new phosphorus based regulations.

### **Crop Selection**

For each scenario the entire 1,500 acres were used for crop production. For the N-RATE scenario, a total of 697.32 acres were grown in rotation corn, 697.32 acres were grown in rotation beans, and 125.36 acres of wheat were produced. The crop mix under the P-RATE scenario resulted in 664.36 acres of rotation corn, 664.36 acres of rotation beans, and 171.18 acres in wheat. The most significant change came from an increase of 45.82 acres of wheat on Average Yield Far land for the P-RATE scenario (Table 5).

TABLE 5 Crop Mix for Both N-RATE and P-RATE

Crop	Low Yield		Average Yield		High Yield	
	Near	Far	Near	Far	Near	Far
<b>N-RATE CROP DISTRIBUTION</b>						
CC	0	0	0	0	0	0
RC	50	75	119.82	180	105	157.5
RB	50	75	119.82	180	105	157.5
W	50	75	0.36	0	0	0
<b>P-RATE CROP DISTRIBUTION</b>						
CC	0	0	0	0	0	0
RC	50	75	120	156.86	105	157.5
RB	50	75	120	156.86	105	157.5
W	50	75	0	46.18	0	0

### **Number of Pigs Raised and Diet Selection**

It takes two periods for the pigs to complete the grow-finish stage, thus a new diet mix can be chosen every other period (1, 3, and 5). For the N-RATE scenario it is optimal for the representative farmer to raise the maximum number of pigs (11,970), and feed them all Diet 1 (industry standard). For the P-RATE scenario the number of pigs per period and in total did not change, but the type of diet chosen to feed the pigs was modified. In total 11,970 pigs were raised during the year, but 5,968 pigs were fed Diet 1, and 6,002 were fed Diet 2. Diet 2 contains the enzyme phytase, which reduces the phosphorus excreted by the pigs. Table 6 shows the number of pigs raised in each period as well as the number of pigs chosen to eat a particular diet for each scenario.

TABLE 6      Number of Pigs Fed Each Diet by Period for Each Scenario

Period	Diet 1	Diet 2	Diet 3	Diet 4
<b>N-RATE</b>				
1	3,990	0	0	0
3	3,990	0	0	0
5	3,990	0	0	0
<b>P-RATE</b>				
1	3,247	743	0	0
3	2,490	1,500	0	0
5	231	3,759	0	0

### **Manure Application**

One of the interesting outcomes from the change in manure disposal policies, is the change in land application practices. This includes the timing of when the manure is applied, how it is applied, and on what part of the farm it is applied. The most significant change from the N-RATE scenario to the P-RATE scenario is that the farmer chooses to hire a custom hauler to dispose of manure on soybean fields. It was determined that under the P-RATE scenario the farmer became time constrained, thus hiring a custom hauler.

### **The Estimated Cost of the Regulation Change**

The representative farm returns above variable costs were reduced as a result of the regulation change. For the N-RATE scenario the returns above variable costs were \$849,382, and the returns above variable costs for the P-RATE scenario was \$842,693. The change in policy therefore decreased returns above variable costs by \$6,689. This was mainly a result of an increase in manure disposal costs, and a reduction in revenue received from crops and hogs.

It is useful to estimate the cost per pig capacity as a result of a farmer complying with the new P-RATE policy. The cost per pig capacity is estimated based on the change in returns above variable costs between the N-RATE and P-RATE scenarios. This is then divided by the total capacity of pigs (11,970). The estimated cost, in dollars, from this model is \$0.56 per pig capacity.

### **Sensitivity Analysis**

Other scenarios were also considered in order to reflect alternative market environments. Each scenario assumes a phosphorus-base manure application policy and the results are compared to those of the P-RATE scenario. The results of these scenarios also show the benefits from having a choice between alternative diets and methods of manure disposal. Six alternative scenarios were modeled.

The first scenario assumes that the farmer can choose between four possible diets. In addition, he can hire a custom hauler to apply manure on or off the farm. This market environment represents a situation where a farmer has a variety of options to choose from in

order to adjust to regulatory change. This scenario is the same P-RATE discussed earlier in the paper.

In the second scenario, the farmer may still choose between four different diets, but the market for custom application is extremely thin or non-existent. The extreme case where there is no supply of custom application is modeled. In addition, there is no nearby land available for manure application off-farm. Liabilities associated with environmental accidents and odor discourage landowners from entering into manure spreading contracts; therefore the farmer cannot hire a custom applicator to dispose of manure off the farm.

The third scenario allows for the custom hauler to apply manure on and off the farm, but the farmer can only feed pigs Diet 1. This alternative represents a situation where the farmer does not have the means to supply the pigs with different diets in the short run. Handling specialized ingredients like phytase, synthetic amino acids, and fiber requires additional feed storage facilities. These storage facilities may not always be available in the short run. For the representative farm in this thesis, it was assumed the farmer had additional bins available to store the alternative ingredients (phytase, synthetic amino acids, and fiber). This scenario represents a situation where the farmer does not have additional bins, thus in the short-run the farmer is unable to feed Diets 2, 3, and 4. Alternatively, this scenario may reflect a market failure in the phytase market whereby insufficient supply of this ingredient exists in the short-run. In all circumstances listed above, the farmer is only able to feed pigs Diet 1.

For the fourth scenario, the custom applicator can apply manure off-farm but not on-farm. In addition, the farmer can only feed pigs Diet 1, due to the same reasons listed from Scenario 3. This alternative illustrates a situation where the only custom applicator available is a neighboring farmer, and this farmer is only willing to apply manure on his own land. In addition, there is no commercial custom applicator in the market of transporting manure off-farm.

Scenario 5 does not allow the custom applicator to apply manure on or off the farm, but the farmer can choose between the four different diets. This scenario can represent a situation where a custom applicator is not available to the farmer. Such a situation is not unlikely in some areas where there are not many other hog farms. On the other hand, the farmer has the means to feed alternative diets to the pigs.

The last scenario is the most restrictive. The farmer is unable to use a custom applicator or feed alternative diets to the pigs. This scenario can represent a market situation where a farmer is unable or unwilling to adjust to the new regulatory environment. Table 7 lists and defines each scenario.

TABLE 7      Alternative Scenarios Defined

SCENARIO	DEFINITION
1	The P-RATE scenario discussed earlier allows for the farmer to choose different diets, and the use of a custom hauler to apply on the farm or to take it off the farm.
2	Allows for the farmer to choose any of the four diets. He can hire a custom applicator to apply manure on the farm but not off the farm.
3	Allows for the farmer to have a custom hauler apply manure on cropland or take it off the farm, but he can only feed the pigs Diet 1.
4	Allows the farmer to have a custom hauler take the manure off-farm but not on-farm. In addition, the farmer can only feed Diet 1.
5	Allows for the farmer to choose any of the four diets, but he cannot hire a custom hauler to apply on the farm or take the manure off the farm.
6	Does not allow for the farmer to hire a custom hauler to apply on the farm or off the farm, and can only feed Diet 1.

The results of the scenarios are illustrated in Tables 8-9. Table 8 shows how the returns above variable costs, for each scenario, compare to the N-RATE results. In addition, this table shows how the number of hogs raised changes under each possible market environment. According to these results, Scenarios 5 and 6 are the only instances where it is optimal for the farmer to reduce the number of pigs raised.

Table 8 also illustrates the estimated cost of the phosphorus-based regulation. This cost is in dollars per pig capacity. These results show the potential costs the representative farm could face depending on the market environment. For Scenario 1 the phosphorus-based regulation can cost a farmer \$0.56 per pig capacity. Alternatively, if the farmer has no options for adjustment, as in Scenario 6, the phosphorus-based regulation can cost up to \$21.74 per pig capacity.

TABLE 8      Estimated Cost Per Pig Capacity Due to Regulation Change

SCENARIO	RETURNS ABOVE VARIABLE COSTS	TOTAL NUMBER OF PIGS	CHANGE IN RETURNS FROM N-RATE*	COST OF REGULATION (\$/PIG)**
1	842,693	11,970	\$6,689	\$0.56
2	842,693	11,970	\$6,689	\$0.56
3	841,185	11,970	\$8,197	\$0.68
4	814,712	11,970	\$34,670	\$2.90
5	715,833	9,450	\$133,549	\$11.16
6	589,104	6,922	\$260,278	\$21.74
<b>N-RATE</b>	<b>849,382</b>	<b>11,970</b>		

\* The change in returns above variable costs is calculated; N-Rate returns above variable costs minus SCENARIO returns above variable costs. Also refers to the total cost of the regulation change.

\*\* Cost per pig capacity = change in returns above variable costs/11,970. The cost per pig is referred to as the cost per pig capacity as a result of the regulation change.

It is evident from these results that it is useful for the farmer to have an option for different diets and methods of manure disposal. These results also indicate that the benefit of having options for manure disposal is greater than the benefit of alternative diets. This can be seen by comparing the costs from Scenario 1 and Scenario 5, where the use of a custom hauler is available for scenario 1 but not available for scenario 5. The results show that the benefit from being able to use a custom applicator is \$10.60 per pig capacity. By comparing Scenario 1 and Scenario 3 the benefit from using alternative diets can be measured. The results show here that the benefit from phytase diets is \$0.12 per pig capacity. It is evident from this analysis that the farmer benefits more from the custom applicator, although it is better to have both options for feed and manure disposal.

Table 9 explains what changed on the farm under the conditions given in the alternative scenarios. The first scenario lists the results from P-RATE. The details listed next to Scenario 1 are the adjustments made by the representative farm as a result of the phosphorus-based regulation. For the other scenarios, the phosphorus-based manure regulation is also assumed to be the regulatory environment. These results are then compared with the details from Scenario 1. It is apparent that most of the adjustments occur in cropping patterns, manure disposal procedures, and diet manipulation.

TABLE 9 Changes from Other Scenarios Compared to Scenario 1

SCENARIO	WHAT IS HAPPENING
1	<ul style="list-style-type: none"> <li>- returns above variable costs decreased by \$6,689</li> <li>- wheat increased by 46 acres</li> <li>- custom applicator disposes of manure on cropland</li> <li>- the custom hauler is not applying manure off-farm</li> <li>- 50% of the pigs are fed Diet 1, 50% of the pigs are fed Diet 2</li> </ul>
<b>CHANGES FROM SCENARIO 1</b>	
2	<ul style="list-style-type: none"> <li>- there was no change from the P-Rate scenario. The effects of this option would be seen under a situation where the pig capacity was greater, and where the number of days available for spreading were reduced like in 'A' and 'D'.</li> </ul>
3	<ul style="list-style-type: none"> <li>- custom applicator use increases</li> <li>- all pigs are fed Diet 1</li> <li>- wheat increases by 64.71 acres</li> </ul>
4	<ul style="list-style-type: none"> <li>- the farmer is having 936,000 gallons of manure taken off the farm</li> <li>- wheat acres increase by 64.71.</li> </ul>
5	<ul style="list-style-type: none"> <li>- the farmer raises 2,520 less pigs</li> <li>- wheat production increases by 130.29 acres</li> <li>- the farmer feeds 5,425 pigs Diet 4, and 3,990 pigs Diet 2.</li> </ul>
6	<ul style="list-style-type: none"> <li>- the farmer raises 5,048 less pigs</li> <li>- increases wheat production by 118.72 acres.</li> </ul>

### Conclusion

For the representative farm, which consisted of 1,500 acres of cropland, and the capacity to manage 11,970 grow-finish hogs annually, the manure disposal policy change resulted in a decrease in the farmer returns above variable costs. This result is consistent with the findings of studies discussed in the literature review. These studies also looked at the impact on farmer profit (returns above variable costs in this study) due to the implementation of a phosphorus-based application standard (Schnitkey and Miranda, 1993; Schmit and Knoblauch, 1995; Massey and Krishna, 1995; Pratt et al., 1997). Under the conditions available in this model, it became more profitable to hire a custom hauler to apply manure as opposed to decreasing the number of pigs raised. Previous research found that the optimal number of animals decreases with a phosphorus-standard (Schnitkey and Miranda, 1993; Schmit and Knoblauch, 1995). These studies only provided one option of manure application, where as the model for this study allowed for three options of manure disposal. These include disposing of manure on the farm by the farmer, disposing of manure on the farm by a custom hauler, and having a custom hauler take the manure off the farm. The number of pigs did not decrease when the farmer had these choices. Another reason why the number of pigs raised did not decrease is because the farmer had alternative diets to choose from. Diet 2, which includes the enzyme phytase, was fed to approximately half of the pigs in the P-RATE scenario.

Another change that occurred due to a phosphorus-based manure disposal regulation, was the farmer chose to apply manure on soybean fields. This was also found to be beneficial in the

Fleming et al. (1998) study. The farmer needed more land to dispose of the same amount of manure; thus manure was applied to soybean fields.

The previous research reviewed for this study does not appear to have looked at the effects of the limits of time available for the farmer to perform various activities. In this study, it is clear that the farmer became time constrained. As a result, he hired a custom hauler to apply manure on his fields. It was more beneficial to feed the pigs a phosphorus-reducing diet in addition to hiring a custom hauler in order to reduce the cost of the regulation.

The cropping patterns were also affected due to the policy change. In the P-RATE analysis, the number of wheat acres increased by about 46 acres. It was also found in Schmit and Knoblauch (1995), that the cropping patterns were affected. In both cases, secondary crop acres such as wheat in our model, and orchardgrass in their model increased. Wheat acres may have also increased to provide a place for manure to be spread during period 5.

As a result of the sensitivity analysis, it is evident that if the farmer has the option to use a custom hauler, and feed the pigs nutrient reducing diets, that the farmer can reduce the cost of manure disposal policy changes. A phosphorus-standard would require that less manure be disposed per acre. Thus, the farmer would need more land and more time to dispose of the same amount of manure. With nutrient reducing diets, manure can be disposed of at a greater rate under the phosphorus-standard, which can reduce the manure disposal costs to the farmer. The results from the sensitivity analysis also revealed that the cost of the regulation would vary depending on the market environment. Results showed that the cost per pig capacity, due to the policy change, could be considerably reduced if the farmer is able to utilize a custom hauler and different diets for the pigs. The cost per pig capacity ranges between \$0.56 - \$21.74 depending on the market environment.

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