# Economic Analysis of Phosphorus-Reducing Technologies in Pork Production

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Soil phosphorus levels have increased as pork production has become concentrated. Phosphorus-based manure management regulations for land application have been proposed by policy makers. The objective of this study is to determine benefits/costs of adopting two alternatives for reducing phosphorus: synthetic amino acids or phytase. An optimization model is constructed to determine optimal excreted nitrogen and phosphorus from alternative feed ingredients. Results are derived using different manure storage and application systems. While the two alternatives are not least-cost ingredients, they become profitable when producers are constrained by land. An important result is that the net cost of manure is negative.

*Key words:* cost-benefit analysis, manure management, pork production, swine

## Introduction

The term "industrialization of agriculture" has been used to describe the shift from diversified farms with livestock and crops to specialized livestock or crop enterprises with larger numbers of crop acres or animals. Pig numbers in the U.S. have *not* dramatically increased, but technological advances have significantly reduced the number of production operations (Hurt, Boehlje, and Hale). While large confinement facilities have significantly increased production efficiency, they also have presented new management challenges in the collection, storage, and treatment of larger manure quantities. The 95 million hogs marketed in 1995 excreted approximately 17,000 billion pounds of manure which contained over 1 billion pounds of nitrogen and .33 billion pounds of phosphorus (Sutton et al. 1996). Although the number of production operations has decreased, the quantity of manure and manure nutrients generated on a per acre basis has increased dramatically due to an increase in the number of hogs per operation that has not been matched by a proportional increase in the crop land acres associated with those operations (Schmitt, Schmidt, and Jacobson).

The challenge of properly managing and distributing the manure has raised concerns about air and water quality in rural communities. A recent national water quality assessment conducted by the U.S. Geological Service reported that animal manure

nutrients (phosphorus and nitrogen) were the primary cause of water impairment in 114 watersheds (U.S. General Accounting Office). Palmquist, Roka, and Vukina found significant declines (9%) in housing values when pork production enterprises were constructed or expanded in the vicinity of existing homes in North Carolina. The European Union has recognized manure problems by imposing a tax on excreted phosphorus which corresponds to the number of animals per farm.

Most regulations for livestock and poultry operations are specifically targeted to protect water resources from nonpoint source pollution (Jones and Sutton). The nutrients of greatest concern from a water quality perspective are nitrogen and phosphorus. Because nitrate contamination of drinking water is a potential health concern for people and animals that use groundwater for their water supply, most state guidelines and regulations for land application of manure are based on nitrogen crop requirements. Jones and Sutton also found that states regulate minimum storage capacity requirements for livestock enterprises including location, manure management plans, and other issues related to animal wastes.

Phosphorus does not generally pose a direct threat to human health, but excessive levels can degrade surface water quality by causing algae blooms in surface water drinking supplies. Such events increase the cost of water treatment for local municipalities. Because phosphorus is not subject to dissipation between excretion and land application, low nitrogen-to-phosphorus requirements in manure and high nitrogen-to-phosphorus requirements in plants make the land area required to distribute manure based on crop phosphorus needs two to four times as great as the land area required to distribute manure based on crop nitrogen needs. Schmidt, Jacobson, and Schmitt found that less than 25% of producers surveyed had ever analyzed their manure for nutrient content, and that less than 20% of producers had ever calibrated their manure spreaders. Thus, even where manure is applied, these results suggest that nearly half of the producers still apply their standard rate of inorganic fertilizer nutrients based on nitrogen and thus further increase soil phosphorus levels.[1]

Animal manure, biosolids, and inorganic fertilizer phosphorus applications that exceed crop needs increase soil phosphorus levels beyond those required for optimum crop production. Sharpley reported that when soil phosphorus levels increase, the potential for movement also increases. Barker and Zublena found that 18 (3) of the 100 counties in North Carolina had enough nutrients to exceed the phosphorus (nitrogen) requirements for crops in those counties.

Corn and soybean meal, which are the primary ingredients in swine diets, contain phytic acid as the predominant form of phosphorus. Phytic acid constitutes approximately 65% to 75% of total phosphorus in a typical swine diet. However, because nonruminant animals cannot utilize phytic acid, it is not nutritionally available to swine, and thus is excreted by the animal. To meet the nutritional requirements for phosphorus in swine diets, producers add inorganic phosphorus. The excess phytic acid phosphorus is excreted, thereby contributing to the phosphorus problem.

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[1] In states like Indiana, where the majority of pork producers have been in business for extended periods of time, phosphorus overapplication from manure and inorganic fertilizer has resulted in soil test levels that often exceed 500 mg phosphorus per kg in fields that regularly receive manure. As a point of reference, fertilizer recommendations are 0 lbs./acre for all field crops in Indiana, Ohio, and Michigan when soil levels exceed 50 mg phosphorus per kg (Vitosh, Johnson, and Mengel).

Four methods have been proposed to reduce phosphorus application in excess of crop needs. One method is to apply manure over more acres at the phosphorus rate of uptake by the crop. The second is to use synthetic amino acids as a replacement for soybean meal to reduce phosphorus intake because soybean meal is composed of 1% phosphorus. Synthetic amino acids are expensive, and only lysine is commonly used in the U.S. Phytase and low-phytic acid corn are two methods which increase phytic acid phosphorus availability and reduce phosphorus excretion and inorganic phosphorus intake. Enzyme microbial phytase was approved for use in the U.S. in 1996, while low-phytic acid corn has not been commercially released (Ertl, Young, and Raboy). Thus, in the short run, the use of synthetic amino acids and phytase are the two alternatives available for producers who may be constrained by land.

The objective of this research is to determine benefits and costs of adopting synthetic amino acids or phytase for a profit-maximizing feeder pig finishing pork producer. In doing so, we model alternative manure storage and application methods. Benefits include a reduction in land requirements for application of manure based on phosphorus soil tests, less inorganic phosphorus being fed as an ingredient, and potential changes in storage and application technologies. The use of synthetic amino acids and phytase increases cost. An optimization model is constructed to determine the optimal excreted nitrogen and phosphorus from alternative feed nutrients and ingredients. Land requirements are identified for manure application, and alternative policy regulations are analyzed.

## Methodology

Manure nutrient modeling requires information on the following: (*a*) feed nutrient and ingredient relationships, (*b*) feed nutrient conversion, (*c*) types of storage and application systems, (*d*) fertilizer nutrient conversion, and (*e*) regulations on storage and application. We describe these in greater detail in the following sections. To avoid confusion with the term "nutrient" in the following discussion, "feed nutrients" refers to animal nutrient requirements, while "fertilizer nutrients" are nutrients used in crop production.

*Feed Nutrient and Ingredient Relationships*

The methods used to solve for the optimal levels of nutrient $j$ ( $j$ = protein, lysine, etc.) from $i$ ($i$ = corn; soybean meal; synthetic lysine, methionine, threonine, and tryptophan; etc.) feed ingredients follow previous work by Boland, Foster, and Preckel (BFP). The following analysis adds a manure value component to their optimization models. Equations (1)–(4) are restated from BFP. A relationship between nutrients and ingredients restricts the nutritional content of the feed to be equal to the sum of the nutritional content of the ingredients (on a per pound of feed basis):

(1)
$$z_j = \sum_i x_i h_{ji} \quad \forall j,$$

where $z_j$ is the amount of nutrient $j$ per pound of feed, $x_i$ is pounds of feed ingredient $i$ per pound of feed, and $h_{ji}$ is pounds of feed nutrient $j$ from one pound of feed ingredient

$i$ (a proportion). The sum of all ingredients is equal to 98% of the feed, with the remainder being made up of fixed feed additives:

$$(2) \qquad\qquad \sum_i x_i = 0.98.$$

The nutrient content of the feed must be within bounds of the animal's requirements, or:

$$(3) \qquad\qquad l_j \le z_j \le u_j \quad \forall j,$$

where $l_j$ $(u_j)$ is the lower (upper) limit on the proportion of feed nutrient $j$ in a pound of feed. The animal's ration must be within the bounds on energy, or:

$$(4) \qquad\qquad \sum_i x_i e_i \le E,$$

where $E$ is the bound on total energy in the ration that comes from the sum of energy $e_i$ obtained from the individual feed ingredients.

### Feed Nutrient Conversion

The fertilizer nutrient levels from the excreted manure are required in order to analyze the value of those nutrients. The relationship between protein and amino acid intake, and excreted nitrogen and phosphorus production is determined using Cromwell and Coffey's research:

$$(5) \qquad\qquad w_g = a_g - c_g,$$

where $w_g$ is the amount of the $g$th ($g$ = nitrogen, phosphorus) fertilizer nutrient excreted in the feces and urine, $a_g$ is the animal's intake of the $g$th feed nutrient, and $c_g$ is the quantity of the $g$th feed nutrient retained for growth. The quantity of excreted fertilizer nutrients is a function of the animal's live weight growth and the feed consumed by that animal. The quantity of the $g$th fertilizer nutrient excreted is estimated using the cumulative feed intake function, $f(t)$.[2] For this analysis, it is assumed that the rations are composed primarily of corn and soybean meal. The amount of excreted phosphorus is specified as

$$(6) \qquad\qquad w_{phosphorus} = \sum_i x_i h_{phosphorus\,i} * f(t) * (1 - \phi_{phosphorus}),$$

where $\phi_{phosphorus}$ is a constant equal to 25% (Cromwell and Coffey), representing the percentage of non-phytic acid phosphorus that is retained by the animal ($c_{phosphorus}$). Phytase

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[2] Additional information on modeling a multiple-ration phase feeding program is presented in BFP. To ease the notation in the following equations, we do not use their $p$ subscript denoting the number of rations in the diet. Also, we consider only the two-ration case here.

is modeled by dividing total phosphorus into "unavailable" (phytic acid) and "available" (non-phytic acid) phosphorus within $h_{ji}$. The addition of phytase lowers the National Research Council (NRC) requirement for total phosphorus from 60% to 49% of total phosphorus requirements. Parr suggests that the minimum requirement for available phosphorus is 23% of total phosphorus requirements.

Protein is the primary source of nitrogen in the diet. In order to obtain the percentage of nitrogen in an ingredient, the amount of protein is converted into nitrogen using the conversion factor of 6.25 ($\tau$) recommended by the NRC. The amount of excreted nitrogen in the ration is calculated as

$$(7) \qquad w_{nitrogen} = \sum_i x_i \frac{h_{protein\ i}}{\tau} * f(t) * (1 - \phi_{protein}),$$

where $\phi_{protein}$ and $\tau$ are constants. Cromwell and Coffey (in their tables 4 and 5) report that $\phi_{protein}$ (the amount of nitrogen retained in the animal) is 40% in corn and soybean meal diets. An analysis of potassium is not included in our research. While potassium is an important fertilizer nutrient compound, data on the percentage absorbed or excreted in the urine or feces are not currently available. Thus, only pounds of excreted nitrogen and phosphorus are determined here.

*Types of Storage and Application Systems*

Three alternative manure storage systems ($k$) are considered in this analysis (deep pits, liquid slurry tanks, and lagoons). There are three application systems ($l$) used to move and apply manure (broadcast with soil incorporation within two hours, injection, and irrigation with incorporation within 24 hours). A deep pit system requires tank wagons with a vacuum pump to haul and apply manure. For a slurry tank or lagoon system, tank wagons without vacuum pumps are used. Application using any of these three systems typically is accomplished through use of a tank wagon which injects (below-ground application into the soil) or broadcasts (above-ground application on the soil) the manure. Irrigation systems represent another option available to producers regardless of the storage option chosen, but are used most commonly with lagoon storage. For this latter system, there is no hauling and the application is done using an irrigation gun.

Detailed information on the modeling of these systems and their respective capacities can be found in Boland et al. All of these manure storage and application systems have nutrient losses associated with them due to external factors such as sunlight and air movement. Table 1 presents the figures used for each element in the system (taken from Sutton et al. 1994).

In order to properly model manure management systems, a method is needed to provide a cost for storing the nutrients if the amount being produced is greater than the amount needed for crop production. Possible solutions include giving or selling the nitrogen and phosphorus to neighboring producers, renting additional land, leasing manure rights from neighboring farms, or building additional facilities to store the nutrients as a resource to be used as a fertilizer in a later period. Let $N$ be the market herd inventory, $t$ is the number of production days for the inventory, $\delta_k$ is pounds of total manure per pound of feed consumed for the $k$th system (a proportion), $Q$ is the pounds

**Table 1. Manure Storage and Application Losses, by Fertilizer Nutrient (percent of total animal production)**

| Nutrient | Manure Storage System | | | Manure Application System | | |
|---|---|---|---|---|---|---|
| | Pits | Liquid Tanks | Lagoon | Broadcast | Injection | Irrigation |
| $NH_4$ | .225 | .150 | .775 | .225 | .025 | .350 |
| $P_2O_5$ | .100 | .100 | .675 | .000 | .000 | .000 |

Source: Sutton et al. (1994).
Note: $NH_4$ and $P_2O_5$ are crop available nitrogen and phosphorus, respectively.

of manure spread on crop land, and $\gamma_k$ is capacity (annual basis) of the manure storage system. Because we assume producers are constrained by land, we use the opportunity cost of constructing another storage system or disposal (including land) for the manure, such that

$$(8) \qquad \frac{365N}{t} \delta_k f(t) \leq Q + \gamma_k.$$

The total amount of manure produced in one year cannot exceed the amount which is used for crop production plus the storage capacity. The factor $\delta_k$ converts feed intake to manure volume per hog ($\delta$ is estimated using data from Sutton et al. 1994), and the $N$ scales volume to the market herd inventory. The factor $365/t$ converts manure over the market herd inventory to an annual basis (i.e., it converts from manure per market herd inventory to manure per year by multiplying by the number of animals in the market herd inventory per year).

*Fertilizer Nutrient Conversion*

The value of the excreted nutrients in the manure is determined by their value as a fertilizer input for crop production. Because animals excrete nitrogen and phosphorus rather than the fertilizer nutrient equivalent, conversion factors are required. The mineralization factors for swine manure from Sutton et al. (1994) are used because not all nitrogen is available the first year as a crop nutrient. The amount of crop available nitrogen (ammonia and organic nitrogen) in the first year is assumed to be 38%, 59%, and 89%, respectively, of total nitrogen for deep pits, liquid tanks, and lagoon storage systems. Excreted phosphorus multiplied by 2.29 yields crop available phosphorus ($P_2O_5$). An equation is needed to convert the feed nutrients into fertilizer nutrient quantities in the manure (on a per pound of feed basis), where $\lambda_{jlm}$ is pounds of excreted fertilizer nutrient $m$ from feed nutrient $j$ for the $l$th system (a proportion). The subscript $m$ ($m = NH_4$, $P_2O_5$) is used to denote the excreted fertilizer nutrients ($q$) in the following manner:

$$(9) \qquad q_m = \sum_j \lambda_{jlm} z_j.$$

*Regulations on Storage and Application*

State regulatory agencies have imposed minimum manure storage capacities. Jones and Sutton found a range of 120 to 360 days storage capacity. For this analysis we use a minimum storage capacity of 120 days worth of manure, based on the current (1998) Indiana Department of Environmental Management (IDEM) regulation requirement and modeled as:

$$(10) \qquad\qquad \frac{120N}{t} \delta_k f(t) \leq \gamma_k.$$

A second regulation is that the fertilizer nutrient (pounds per acre), $s_m$, applied as fertilizer must be limited by the acres, $A$, of crop land available for manure application multiplied by the maximum rate at which the nutrient can be applied to the land, or:

$$(11) \qquad\qquad \frac{q_m}{\delta_k} Q \leq A s_m.$$

With the exception of legumes such as alfalfa hay or Bermuda grass, the maximum rate allowed by IDEM is equal to the requirements for crop production (Boland et al.). These constraints must be satisfied if pigs are to be produced.

## Data

The nutrient management plan used in this study employs several assumptions, drawn from Doster et al., for a typical Indiana producer. The crop grown by these producers is assumed to be continuous corn (which is used as a source of feed ingredients) produced on average Indiana Crosby soils with a yield of 112.5 bushels per acre and adjusted for a producer who disks or cultivates during the spring. Crop fertilizer requirements for this type of continuous corn are 140 pounds of $NH_4$ and 45 pounds of $P_2O_5$. Producer returns are assumed to be a return to management and operator labor. We use the economic data (average of 1985–95 Indiana prices) from Foster, Hurt, and Hale's 300-sow farrow-to-finish high technology system. This operation corresponds to an average large system. We have adapted these costs for a producer who is finishing the pigs which are assumed to have been purchased from another producer with 300 sows. The number of market hogs on feed amounts to 2,851 animals ($N$) per market herd inventory, with approximately three inventory turns per year.

The parameters for the live weight growth function per animal, $g(z_j, t)$, are reported in BFP; $p_{live}$ is the price of live weight per pound (adjusted for premiums and discounts on live weight and percentage of lean as described in Boland); $\alpha_{mk}$ is the proportion of handling losses for nutrient $m$ under the $k$th manure storage system (table 1); $\beta_{ml}$ is the proportion of handling losses for nutrient $m$ under the $l$th manure application system (table 1); $C_{kl}$ is capital and variable costs of manure storage and application system per unit (from Boland et al.); $p_m$ is opportunity cost of fertilizer nutrient $m$ (cost of replacement with inorganic fertilizer); $w_i$ is the cost (\$/pound) of feed ingredient $i$; $p_{pig}$ is the fixed price of a new feeder pig from the producer with 300 sows; and $p_v$ is the price of variable costs per pound of live weight (from Foster, Hurt, and Hale).

Hansen, and Roka and Hoag used mixed integer programming to analyze the manure storage and application problem, while Fleming, Babcock, and Wang considered only manure costs and value.[3] Here we solve a continuous variable problem for each combination of manure storage and application system by adding a manure component to BFP's model. For each system with given capacity ($\gamma_k$), the joint production problem is solved for different combinations of land and pigs:

$$
(12) \qquad \max_{Q,t,x_i,z_j,q_m} \frac{365Nf(t)}{t} \left[ \left( p_{live}g(z_j,t) + \sum_m q_m p_m (1 - \alpha_{mk} - \beta_{ml}) - \sum_i x_i w_i \right) \right.
$$
$$
\left. - p_{pig} - C_{kl} - p_v g(z_j,t) \right],
$$

subject to equations (1)–(4) and (6)–(11). In addition, nutrition and ingredient usage and manure applications are restricted to be nonnegative:

$$
(13) \qquad\qquad\qquad\qquad x_i, z_j, Q \geq 0 \quad \forall\, i,j.
$$

Other variables will automatically be nonnegative by nonnegativity of these variables or, in the case of $t$ and $f(t)$, by choice of the functional form.

The objective equation (12) maximizes the total value of an animal converted to the $N$ inventory that moves through the system multiplied by the number of annual cycles ($365/t$) plus the fertilizer value of the manure (adjusted for handling losses), less the costs of feed, manure storage and application, and variable inputs subject to the previously identified equations. Note that the animal's live weight value—including premiums and discounts, manure value, and costs—is a function of live weight, which is a function of cumulative feed intake. The model is formulated in GAMS 2.25 (Brooke, Kendrick, and Meeraus) and solved in GAMS/MINOS 5.3 (Murtagh and Saunders).

## Results

Using Boland et al.'s model, the $C_{kl}$ costs per animal are presented in table 2 for different $(k,l)$ combinations with a fixed capacity $\gamma_k$ corresponding to 2,851 pigs annually. Note that these are considered fixed constants for each type of system. Producers were assumed to empty their manure systems twice a year; therefore, $\gamma_k$ is measured at one-half of their annual capacity. Figures 1 and 2 illustrate the land requirements for nitrogen and phosphorus application in the first year for different storage and application systems. As expected, given the losses shown in table 1, slurry tanks (lagoons) and injection (irrigation) yielded the highest (lowest) land requirements for either nitrogen or phosphorus application. Under a phosphorus-based scenario, this producer would require 2.02 (tank storage and injection application) to 5.03 (pit storage and irrigation application) times as much land relative to a nitrogen-based scenario.

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[3] Note that modeling nutrient excretion using the feed intake function rather than as a fixed proportion of live weight enables us to discern how changes in nutrient intake through alternative ingredients affect the composition of manure.

**Table 2. Manure Storage and Application System Costs ($C_{kl}$) ($/animal/year)**

| Application System | Manure Storage System | | |
| --- | --- | --- | --- |
| | Pits | Liquid Tanks | Lagoons |
| Broadcast | 0.7622 | 1.0480 | 0.7536 |
| Injection | 0.7994 | 1.0854 | 0.7910 |
| Irrigation | 1.1542 | 1.3036 | 1.0717 |

Notes: These costs were obtained from the integer programming model in Boland et al. Costs assume a fixed capacity ($\gamma_k$) corresponding to 2,851 pigs annually.

Figures 3, 4, and 5 present the net returns (varied by the animal inventory number) for broadcast, injection, and irrigation application methods, respectively. The results are reported by storage method (deep pits, slurry tanks, and lagoons) holding land acreage constant (100 acres).

Several important results should be noted. First, in all cases, the total returns per animal are less than the results reported by BFP (BFP did not include a manure component, and estimated returns of $22.48 for this scenario)—indicating that the *cost of manure storage and application is greater than the value of the manure as a nutrient in crop production for the production enterprise modeled in this analysis.*[4] This result agrees with those of Hansen, and Roka and Hoag. Boland et al. suggest that because the value of manure is negative after all economic costs and benefits are included, adopting a best management practices approach for manure management may not be feasible without additional economic incentives for producers.

A second result is that despite the cost of phytase being higher ($.195 per pound of di-calcium phosphorus replaced) than the cost of di-calcium phosphorus ($.12 per pound), a small proportion of phytase was an optimal ingredient when there was not enough land to utilize the nitrogen and phosphorus nutrients in crop production. The addition of phytase permitted more low-phytic acid phosphorus in the corn to be available for the animal, and corn is inexpensive relative to other ingredients containing phosphorus. This finding suggests that phytase is an alternative producers might consider for reducing phosphorus excretion if their state regulatory agency institutes a phosphorus-based application requirement and if producers are constrained by land.

A similar result was found for the use of synthetic lysine (cost is $1.65/lb.) and synthetic methionine ($1.23/lb.). The cost of obtaining lysine (methionine) from other ingredients such as soybean meal is $.40/lb. ($.07/lb.). Synthetic lysine was optimal in all cases, while extremely small amounts of methionine were required only when phytase was also a least-cost ingredient. This finding implies that the additional cost of manure storage is high enough so that producers could consider using a combination of technologies such as synthetic amino acids and phytase, even though their unit cost is

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[4] Hansen reported the net value of manure as –$3.79 to –$2.14 depending upon the choice of technologies, while Roka and Hoag reported that the value of manure was approximately –$3.50 per head. Both studies used different costs and prices. Our analysis is different in that we modeled feed intake using an exponential function for a particular genotype (rather than using constants from other studies or a linear feed function from another study); we optimized feed nutrients and the excreted nutrients available for crop production; and we used current industry genetics which yielded approximately 3.45 inventory turns per year (rather than using a previously reported growth function which yielded slightly less than two turns per year).
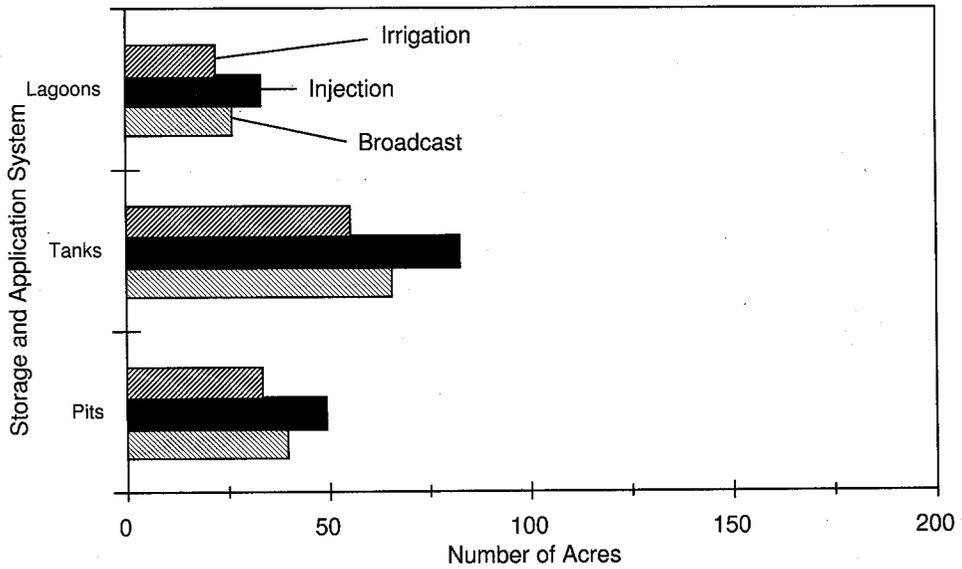
**Figure 1.  Land requirements for a nitrogen-based land application requirement, by storage and application system**
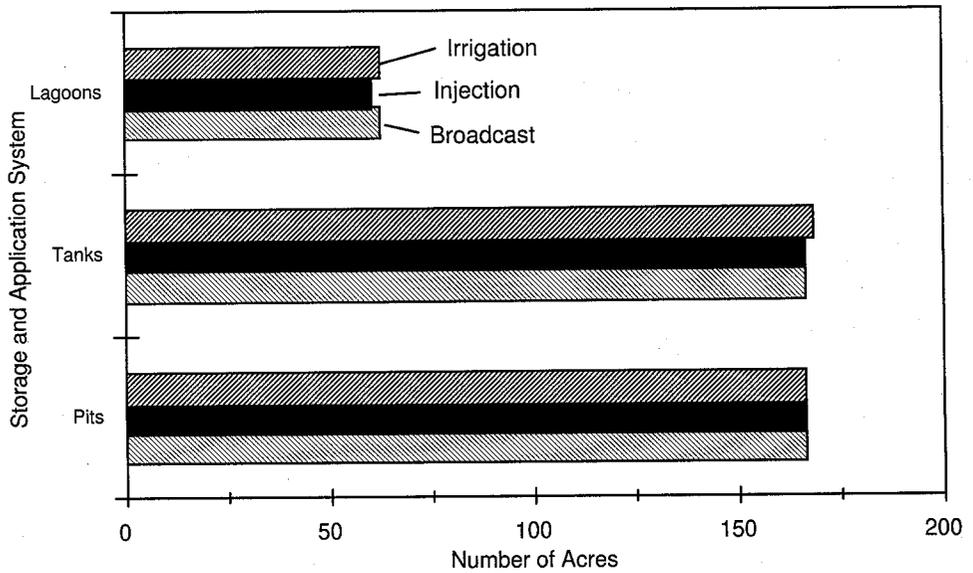


**Figure 2. Land requirements for a phosphorus-based land application requirement, by storage and application system**
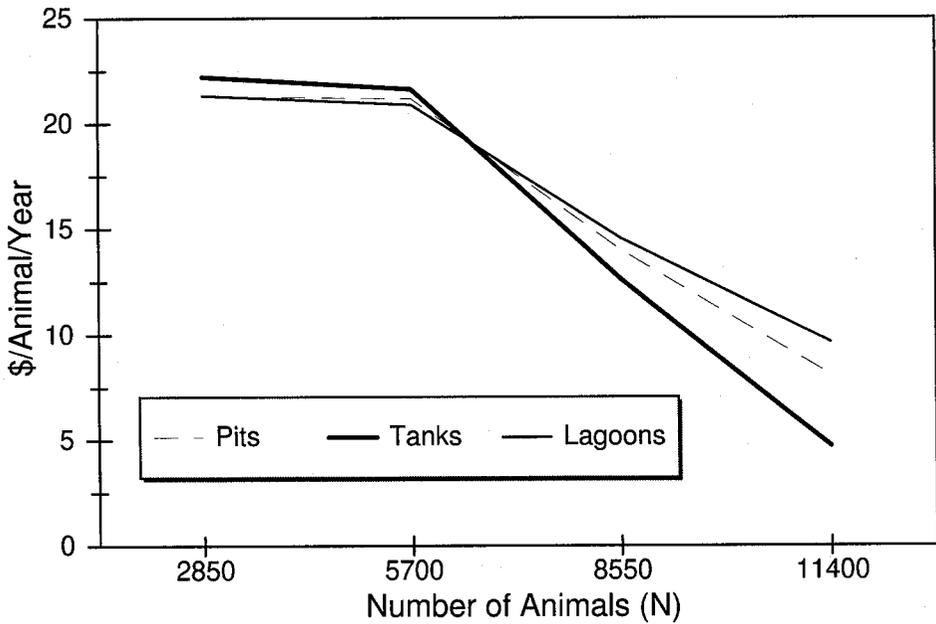
**Figure 3.  Returns per animal per year for broadcast application, by market herd inventory and storage system**
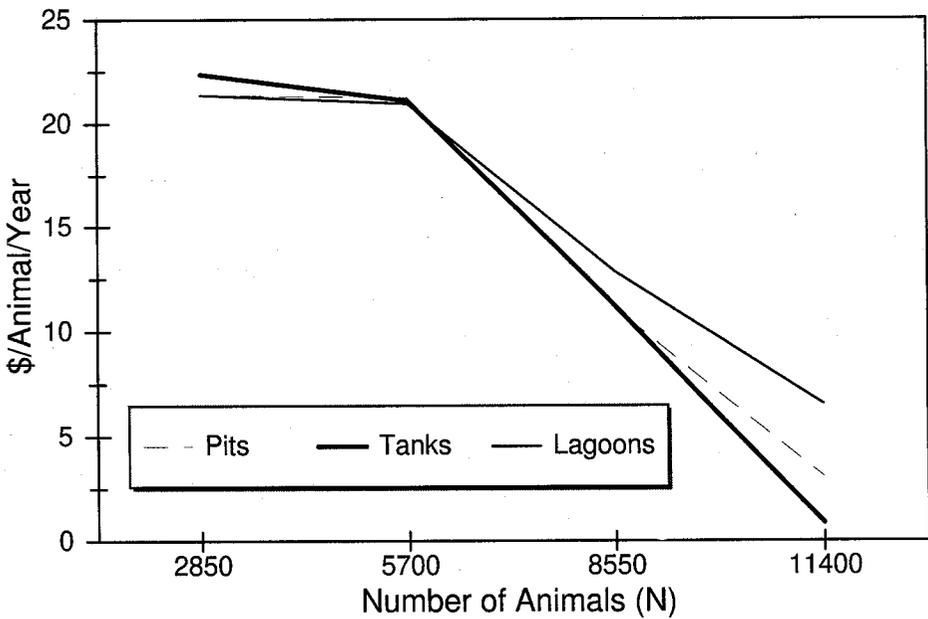


**Figure 4.  Returns per animal per year for injection application, by market herd inventory and storage system**
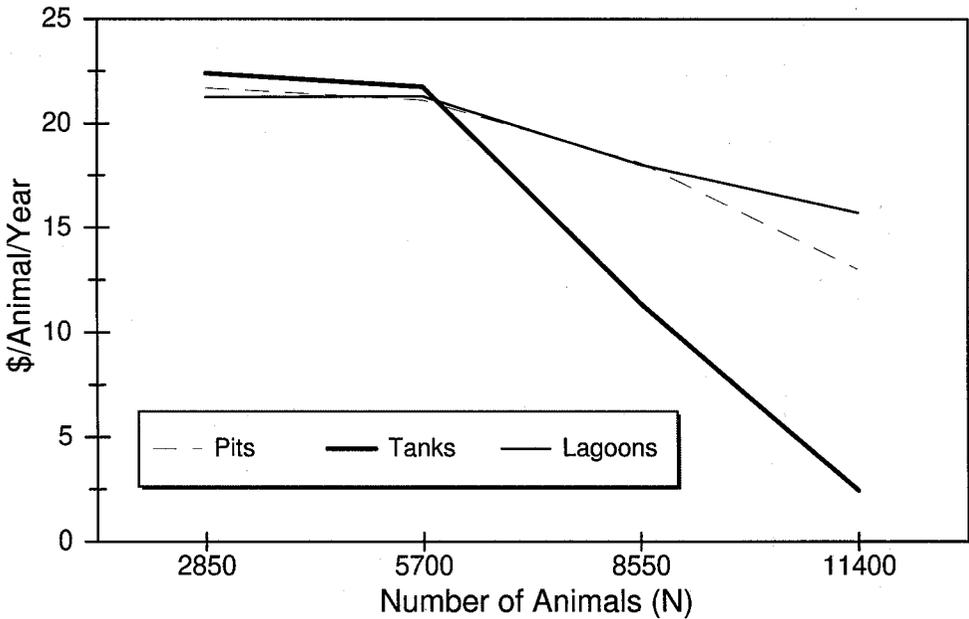
**Figure 5.  Returns per animal per year for irrigation application, by market herd inventory and storage system**

greater than the ingredients they are replacing, if constrained by land. However, for producers who have excess land, phytase and synthetic methionine are not economically practical at these prices.

The optimal levels of ingredients were the same in the first ration, but corn increased by approximately 2% in the second ration, replacing small amounts of di-calcium phosphorus and soybean meal. When phytase entered as an ingredient, the amount of phosphorus (converted to $P_2O_5$) declined 17% compared to the results of BFP, who did not use phytase as an ingredient. One unanticipated finding, although positive, was that excreted nitrogen (converted to $NH_4$) declined slightly due to the decrease in soybean meal.

A final result was that as an additional inventory of animals was added (corresponding to an additional 2,850 pigs per market herd inventory) holding land acreage constant, net returns decreased dramatically due to the increased costs of constructing manure storage facilities. The optimal number of marketing days per market herd inventory was 105 days, corresponding to approximately 3.5 inventory turns per year. In this example, producers would rapidly suffer economic losses without expanding the amount of land due to the high cost of storage (returns would be less than $10 per year, as shown in figures 3–5). While additional storage is not a viable long-term strategy, it does indicate that producers will be forced to find additional land for purchase or rent (average costs would decline more slowly), lease manure application rights from surrounding producers, hire custom manure disposal, or simply not increase the number of animals. This information can be used by policy makers to demonstrate to producers why simply increasing the size of a storage facility is not economically feasible when considering expansion without accounting for possible changes in land requirements.

Furthermore, policy makers should note that as the number of animals increases beyond the amount required for the market inventory, the combination of lagoon storage and irrigation application becomes the least-cost method to manage manure. Under this scenario, producers use a technology that maximizes losses to the environment rather than minimizing losses to ensure maximum use as a fertilizer nutrient. Policy makers in the National Environmental Dialogue on Pork Production mediation process have strongly supported requiring producers to use storage methods that minimize environmental losses such as tank storage or injection application (National Pork Producers Council). Extension specialists and extension educators and financial lenders, who require a business plan with a manure management component, can use these results to show producers who are considering expansion that their projected returns should account for these potential policy considerations.

A sensitivity analysis was conducted on the assumed pounds of manure from a pound of feed ($\delta_k$) and the price of crop nutrients ($p_m$). For the remaining economic costs, arc elasticities are presented in BFP and do not change in this analysis. In all cases the values were zero.

## Implications

One key policy issue in the industrialization of the pork industry is manure—specifically, the excess nitrogen and phosphorus present in the manure. While state regulations are based on a nitrogen basis (with the exception of Maryland), phosphorus is rapidly becoming an environmental issue because of the potential for increased water treatment costs. Twelve regulatory agencies in the 18 states participating in Jones and Sutton's survey stated that phosphorus-based application requirements will be considered in the next five years. Such a requirement likely would compel many producers to seek additional land for manure application.

The use of synthetic amino acids or phytase has great promise for reducing the amount of excreted phosphorus. This analysis suggests that small amounts of synthetic amino acids and phytase are optimal by reducing storage costs when producers are constrained by land. As regulatory agencies begin to investigate whether to base manure management regulations on phosphorus rather than nitrogen (as suggested by the National Environmental Dialogue on Pork Production), synthetic amino acids and phytase may become more attractive to pork producers.

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