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*Working Paper 97-WP 178*

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# ABSTRACT

In Iowa, the release of confinement swine odors and manure nutrients into the environment has become an important issue. The impact of policies to address these issues depends, in part, on the cost of manure delivery, which depends on how manure is stored and the distance it must be hauled. This investigation considers the cost of delivering manure nutrients for two forms of manure storage, two target nutrients, two crop rotations, and two levels of field incorporation. Many studies have found that manure applications based on phosphorous (rather than nitrogen) increase delivery costs. This investigation shows that applications based on phosphorous can better match crop nutrient need, and thereby can lead to higher profits.

# RESOURCE OR WASTE?
# THE ECONOMICS OF SWINE MANURE STORAGE AND MANAGEMENT

Is swine manure a valuable resource that farmers can use to reduce the cost of crop production or a waste byproduct that should be disposed of at minimum cost? The answer to this question has assumed a central role as many states face increased demand for regulations covering the large confinement livestock production facilities that now dominate the swine industry.

While opponents of the large confinement facilities cite many negative impacts of increased geographic concentration of manure stocks and manure odor, the perceived health hazards and environmental degradation are common themes (Hoag and Roka, 1994; Letson and Gollehon, 1996; Taff, et al., 1996; Abeles-Allison and Connor, 1990; Palmquist et al., 1997; Hurley et al., 1996). Should regulators treat manure as a waste byproduct, similar to urban sewage? If so, then the regulatory focus should be to encourage farmers to adopt waste management techniques that reduce the nutrient content of applied manure, which can then minimize environmental damage. But, if manure is a valuable resource, then regulators should encourage nutrient recycling through integration of swine and crop production.

The objective of this paper is to measure the net benefit of swine manure for alternative production systems in Iowa. Net benefit is calculated for two storage technologies (anaerobic lagoon and slurry basin), for two levels of field incorporation after application (immediate and none), and for two different target nutrients (nitrogen and phosphorous). We also consider the impact of applying manure to acreage planted only to corn rather than to corn and soybeans, the typical crop rotation in Iowa. This investigation addresses three major questions concerning swine manure management in Iowa and elsewhere: (1) Should manure nutrients be conserved and applied to crops? (2) What is the impact of a policy requiring all manure applications to be incorporated? And (3) what is the impact of a policy requiring manure applications to be based on phosphorous?

It is well accepted that swine manure can substitute for commercial fertilizer. An additional benefit of manure is that long-run soil productivity can be enhanced because manure is a rich source of organic material (Cassman et al., 1995). And many argue that integrated crop and livestock systems are good examples of economically and environmentally sustainable systems. But what must be remembered is that delivering manure to a field at the right time and in the right amount can be costly. If delivery costs are low enough, then profits from crop production can be increased by substituting manure for fertilizer. If the costs are too high, then only a portion of the delivery cost can be recovered by lower fertilizer cost, and farmers will not have a strong incentive to adopt technologies that are most consistent with maximizing the value of nutrients in crop production.

The two most important factors that determine the net benefit of swine manure in crop production are the distance the manure has to be hauled and the nutrient content of the manure. Net benefit is defined as the value of manure as a replacement source of nutrients less the cost of delivering the manure. The farther a given amount of manure must be hauled, the higher the cost. And, up to a point, the more nutrients that are delivered to a field, the greater the value. Animal manure contains varying amounts of nitrogen, potassium, and phosphorous. Exact proportions of the different nutrients depend upon the type of animal grown, the feed ration, and how manure is stored.

While other studies have considered the impact of manure management on the environment, they have either been more conceptual in nature than this study (Innes, 1996) or they tend to focus only on one method of manure storage (usually lagoon storage), one nutrient (usually nitrogen), and (or) one crop to which manure is applied. Exceptions include Pratt et al. (1997) and Govindasamy et al. (1994), who consider farm level policy changes. Specifically, Pratt et al. (1997) measured surface water quality changes and farm revenue changes for a variety of policies concerning dairy manure management in the Upper North Bosque watershed in north central Texas. Like that study, we consider a change in the target nutrient and different crop rotations. However, this work improves upon the Pratt et al. study by relaxing the assumption that marginal delivery cost is constant. We recognize that acreage for manure spreading is limited and we account for different levels of manure incorporation (i.e., tillage of manure into soil).

Net manure benefit depends critically on the cost of transporting manure to surrounding crop fields, which, in turn, depends on how manure is stored and the distance manure must be hauled. An innovative aspect of this manure delivery cost model is that physical data are used to determine the (statistical) average distance manure must be hauled. Hence, with appropriate re-parameterization, our model is directly applicable elsewhere. In this paper we consider a feeder pig finishing operation where hogs are brought to market weight in multisite units on an "all in, all out" basis. We assume that manure is applied to crops such that the quantity of manure nutrient provided just equals the nutrient need of the crop.

## A Model of Net Manure Benefit

### Delivery Cost

Firms that deliver swine manure to a field have a fee structure composed of two parts. The first is the base charge, which covers the cost to agitate (mix), load manure out of storage, and unload it in a field. The second component covers the cost of moving a quantity of manure a given distance. For delivery systems where manure is hauled, this cost represents the time "on the road" between the farm gate and the entrance to a field. For delivery systems where manure is pumped directly to a field, this cost represents the added equipment and assembly cost (time and labor) needed to deliver manure over a distance.

The total cost of delivering manure, *DC*, is given by equation (1) where *BC* is the base charge and *AMC* is the additional mileage charge. The base charge is a function of the unit cost of hauling manure ($r_B$ in dollars per gallon) multiplied by the quantity of manure hauled per finished hog (*Q* in gallons) and the number of hogs finished (*H*). The additional mileage charge is a function of the unit mileage charge ($r_A$ in dollars per gallon per mile) multiplied by *Q*, *H*, and the total number of miles that quantity of manure is hauled (*Mileage*):

$$\begin{aligned} DC &= BC + AMC \\ &= r_B QH + r_A QH\, Mileage \\ &= QH\left(r_B + r_A\; Mileage\right). \end{aligned} \tag{1}$$

Calculating mileage is difficult because of the infinite number of variations in field configuration surrounding a livestock facility. However, some generalizations can be made. The key is determining the amount of area that one must search over to find land available for manure spreading and then translating this area into an average distance hauled. The area needed for manure spreading depends on the quantity of a nutrient in manure and the quantity of that nutrient required by the crop to which manure is applied. Equation (2) shows that required acreage (*RA*) is equal to the nutrient content of manure ($N_M$ in pounds per gallon) multiplied by *Q* and *H*, and all divided by the need of a specific crop for that nutrient, $N_C$, which is measured in pounds per acre:

$$RA = \frac{N_M QH}{N_C}. \tag{2}$$

Clearly, *RA* depends on the target nutrient (either nitrogen or phosphorous) and the crop to which this nutrient is applied. *RA* also depends on the nutrient content of manure, which is a function of how manure is stored and how quickly manure is incorporated. Finally, note that both $N_M$ and $N_C$ can vary over time and by location.

While it is straightforward to calculate *RA*, this acreage rarely translates into acreage immediately available at the site where hogs are produced. If the acreage is adjacent to the production site, then $AMC = 0$. Typically, though, an area much larger than *RA* must be searched over to locate crop acreage available for manure spreading. This larger acreage, in which *RA* is a subset, will be denoted as search acreage, *SA*.

Divergence between *RA* and *SA* exists when at least one of the following occurs: (1) cropland makes up less than 100 percent of total land use in the immediate vicinity of the production site; (2) the percentage of cropland surrounding a production site that is agronomically (or legally) suited for receiving manure is less than 100 percent; or (3) the percentage of suitable land that is actually available for receiving manure is less than 100 percent.

This third factor can be important because many farmers simply do not want manure on their land. A number of reasons are cited for this reluctance. Manure is often available for land application at a time when farmers are conducting other field operations. Some farmers believe that manure applicators compact their soils and some do not believe that the nitrogen content of manure is consistent enough for them to reduce their commercial fertilizer applications. While the first two factors can be measured, this third factor is more difficult to ascertain.

Equation (3) shows that *SA* equals *RA* divided by a suitability coefficient that is the product of the proportion of cropland, α, the proportion of suitable cropland, β, and the proportion of crop acres where manure is accepted, γ:

$$SA = \frac{RA}{\alpha\beta\gamma} = \frac{N_M QH}{\alpha\beta\gamma N_C}. \tag{3}$$

The suitability coefficient will vary by location and may vary over time. Clearly, if a swine producer owns crop acreage that is suitable for manure and the producer is not opposed to putting manure on this acreage, the suitability coefficient is 1.0 and *SA* equals *RA*. If this is not the case, then the suitability coefficient will likely be less than 1.0 and *SA* will be greater than *RA*.

*SA* can be used to predict mileage traveled to spread manure. This is done by making an assumption concerning the distribution of distances to fields where manure can be spread in the area. If *SA* is assumed to be a contiguous block, the shortest and longest distances traveled (the endpoints of the mileage distribution) can be calculated. Clearly, the shortest distance is zero miles if required acreage is next to the manure source. The greatest distance from the source will occur where the entrance to a field is on the perimeter of the block opposite the source. Here, maximum one-way mileage is two times the square root of $SA$ divided by 640 acres in a square mile $\left( MAX\ Miles = 2\sqrt{\frac{SA}{640}} \right)$.

As required acreage is divided into more fields and (or) the block defined by available acreage becomes larger, the distribution of mileage to fields converges from gamma to normal. Unfortunately, only the two endpoints of this distribution are readily available. Hence, while mean travel distance is desired, only the median distance can be calculated. Specifically, the median distance traveled (in miles) is the sum of the minimum and maximum distance traveled divided by two (or half of the maximum distance). While not the statistic desired, median distance serves as a good approximation to the variable *Mileage* in equation (1) because, as the distribution of distances converges to normal, the median converges to the mean.

Finally, note that delivery cost depends on how manure is transported to fields. Using the convention that slurry manure is hauled while lagoon gray water is pumped, mileage when hauled will be twice that when pumped because a return trip is necessary. Utilizing median mileage for *Mileage*, equation (4) is found by substituting (2) and (3) into (1) :

$$DC = QH\left[ r_B + Z\, r_A \left( \frac{N_M QH}{640\alpha\beta\gamma N_C} \right)^{\frac{1}{2}} \right] , \tag{4}$$

where $Z$ represents trips; $Z = 1$ with lagoon manure storage (no return trip required); and $Z = 2$ with slurry manure storage.

## Manure Nutrient Benefit

While important, delivery cost is only half of the net benefit equation. Manure nutrients have value if their application results in reduced use of commercial fertilizer. Calculation of this value is straightforward if the ratios of N, P, and K in the applied manure are exactly equal to the corresponding ratios in the commercial fertilizer being replaced. In this case the value of the manure would equal the price per unit of each nutrient multiplied by the quantity of nutrient applied summed over the three nutrients. In addition, the crop farmer would save on the cost of applying the commercial fertilizer.

However, corn and soybeans—the two principal crops in Iowa—use nutrients in different ratios than the ratios in manure. Corn requires relatively more N than manure supplies, whereas soybeans do not require any N. Thus, if the N requirements of corn are met, then excess P and K are being applied. The value of the excess P and K is zero, which implies that not all the nutrients being applied on corn have value. Similarly, if the P requirements of soybeans are met with manure, then the marginal value of the manure N is zero.

A further complication arises when a P standard on corn is enforced. In this case, the N requirements of the crop would not be met, and farmers would find it profitable to apply additional commercial N. In this case, the farmer would not save a fertilizer application charge.

The total benefit from manure, *TB*, is given by equation

$$\begin{aligned} &TB = \Big( \sum_{i=n,p,k} P_{M,i} N_{M,i} + A \Big) QH \\ &N_{M,i} \le \frac{N_{M,T}}{N_{C,T}} N_{C,i} = \frac{N_{C,i}}{AR_T} \text{ for } T = n \text{ or } p \text{ and } i = n,p,k. \end{aligned} \tag{5}$$

where $P_{M,i}$ is the commercial price of fertilizer ($/lb) for nitrogen (N), phosphorous (P) or potassium (K); $AR_T$ is the application rate for manure (gallons per acre) based on the target nutrient (*T*) and $A$ is the application cost (expressed in $ per gallon of manure) of commercial fertilizer,

$$\begin{aligned} A &= \frac{AppFee}{AR_T} \text{ if } N_{M,i} AR_T \ge N_{c,i} \text{ for all } i,\ i = N, P, K \\ &= 0 \text{ otherwise} \end{aligned} \tag{6}$$

where *AppFee* is a fixed application fee ($5.75 per acre), which represents the cost of secondary fertilizer applications. Note that in (5) the quantity of a nutrient in manure ($N_M$ in lb per gallon) and the quantity of that nutrient required by a crop ($N_C$ in lb per acre) are also designated by *i* and *T* subscripts. The *T* subscript identifies the target nutrient, which is the nutrient on which manure applications are based, typically nitrogen or phosphorous. Hence, according to equation (5), a swine producer will receive benefit for the nutrients in swine manure, but only for the quantity of that nutrient actually used by the crop. Excess quantities of phosphorous or potassium as a result of applying manure to meet crop nitrogen need do not contribute to total benefit (Hoag and Roka, 1994).

## Efficient Manure Nutrient Application

If a swine producer is basing production decisions solely on manure nutrients, then profits are maximized where the difference between nutrient benefit and delivery cost is greatest. Hence, profits are maximized where marginal benefit is equal to marginal delivery cost. Differentiating equations (4) and (5) with respect to $H$ and setting the difference to zero results in

$$\left[\left(\sum_{i=n,p,k} P_{M,i} N_{M,i}\right) + A - r_B - \frac{3Zr_A}{2}\left(\frac{N_{M,T}\,QH}{640\alpha\beta\gamma\,N_{C,T}}\right)^{\frac{1}{2}}\right]Q = 0. \tag{7}$$

Optimal herd size is determined by solving (7). Given the solution to (7), denoted by $H^*$, maximum profit is found by substituting $H^*$ into equations (4) and (5) and then subtracting (4) from (5).

Optimal herd size and profit will depend on the manure storage system, the target nutrient, crop rotation, and whether manure is incorporated into soil when applied to a field. Manure storage impacts the parameters $Z$, $r_B$, and $r_A$ in equation (7) directly and it influences $N_M$ and $A$. The chosen target nutrient also influences $N_M$ as well as A and $N_C$. Crop rotation determines $N_C$ and A directly and may influence β. Specifically, crop nutrient requirements for corn following soybeans are not the same as for corn following corn. Furthermore, with soybeans in rotation, this acreage may not be available when nitrogen is the target nutrient. In this case β decreases. Finally, whether or not manure is field incorporated affects $r_B$, $N_M$, and $A$.

## An Application to Iowa

The two manure storage technologies considered in this investigation (slurry basin and anaerobic lagoon) capture the essential tradeoff between conserving or eliminating manure nutrients. Here, slurry storage includes both open outdoor storage basins and deep pits beneath the finishing house. In Iowa, the nutrient content and handling of manure is essentially the same for these two forms of slurry storage relative to, for example, lagoon storage. Note that closed (formed or covered) slurry storage is not considered here. Because less nitrogen is released to the atmosphere, the nitrogen content of closed storage is greater than of uncovered slurry storage systems.

A finishing hog produces 1.2 gallons of raw manure a day on average while on feed (ISU Extension, 1995a; 1996b). Assuming 20 percent water wastage in the finishing building (Bundy, 1996) and that a finished hog is on feed 114 days (ISU Extension, 1996c), each market hog produces 164 gallons of slurry manure. At the end of storage (one year), each gallon of swine slurry manure will contain on average 0.05 pounds of nitrogen, 0.035 pounds of phosphorous, and 0.025 pounds of potassium (ISU Extension, 1996b). These quantities represent storage losses of 25 to 30 percent for nitrogen and 10 to 20 percent for both phosphorous and potassium (USDA SCS, 1992). Note that nitrogen is being released to the atmosphere while phosphorous and potassium are precipitating and collecting on the bottom of the storage structure.

With lagoon storage and treatment, manure is diluted in water and, in the anaerobic environment that results, a large proportion of the nutrients in manure are released to the atmosphere (the nitrogen) or precipitate to the bottom of the lagoon (the phosphorus). With a lagoon system, the daily production of 1.2 gallons of raw manure is diluted in approximately 12 gallons of water. Of this quantity, 4.1 gallons daily or 467.4 gallons yearly are eventually delivered to a field per finished hog (ISU Extension, 1995a; 1996b). Manure delivered to a field after a year of storage in a lagoon will contain on average 0.004 pounds of nitrogen, 0.003 pounds of phosphorous and 0.004 pounds of potassium per gallon of manure delivered (ISU Extension, 1996b). These quantities represent a storage loss of 70 to 80 percent for nitrogen, 50 to 65 percent for phosphorous, and 40 to 50 percent for potassium (USDA SCS, 1992).

Again, after a year of storage, a gallon of slurry manure will contain on average 0.05, 0.035, and 0.025 pounds of nitrogen, phosphorous, and potassium while a gallon of lagoon gray water will contain 0.004, 0.003, and 0.004 pounds of the same nutrients. While these quantities of phosphorous and potassium in slurry and gray water will not usually depend upon whether manure is incorporated (assuming no wind or water erosion), this is not the case for nitrogen. If manure is not incorporated, nitrogen will be lost to the atmosphere, which reduces the quantity of this nutrient available for plant use. Specifically, 95 percent (0.0475 and 0.0038 pounds) of slurry and gray water nitrogen will be available for plant use if manure is incorporated. If manure is not incorporated, then only 70 percent (0.035 pounds) of the nitrogen in slurry and 75 percent (0.003 pounds) of the nitrogen in gray water will be available for plant use (ISU Extension, 1996b; USDA SCS, 1992). In equation (6), these nutrient values for basin and lagoon storage, with and without incorporation, are represented by the parameter $N_M$.

The value of nutrients in swine manure depends on the cost of equivalent nutrients in commercial fertilizer. In 1995 N, P, and K cost Iowa farmers an average of $.15, $.29 and $.13 per pound, respectively (ISU Extension, 1996a). If excess P and K are applied, then the total value of nutrients will be less than that suggested by these per pound values (see equation [5]).

The unit cost of delivering manure to a field ($r_B$ and $r_A$) depends upon the type of transportation used and whether or not manure is incorporated. In Iowa, manure in a slurry basin is typically hauled in large tank wagons while lagoon gray water is pumped through flexible hoses or through standard irrigation pipes. Because a return trip is not necessary when pumping materials, the distance traveled is half that traveled with tank wagons. The distance manure can be delivered is generally limited to less than three miles when pumped. Once manure is delivered to a field, it can simply be spread on the surface of soil and left or it can be tilled (or in some other way incorporated) into the soil. Incorporation is more expensive because it requires more equipment, time, and labor than broadcasting.

A survey of Iowa custom manure applicators shows the average unit charge, $r_B$, to be \$0.0079 and \$0.0057 per gallon for hauling and pumping with no field incorporation (Lorimor, 1996). If manure is incorporated, then the average unit charge is \$0.0088 and \$0.0071 per gallon for hauling and pumping. It is customary for Iowa manure applicators to include up to one mile or hauling in the base charge. IN the subsequent analysis, we adopt this custom. The unit mileage charge, $r_A$, does not depend upon incorporation. The unit mileage charge is \$0.0034 per gallon per mile when manure is hauled and \$0.0028 per gallon per when it is pumped.

Crop rotation determines the quantity of a nutrient required by a crop. Continuous corn (120 bushel per acre yield) utilizes 144 pounds of nitrogen, 45 pounds of phosphorous (phosphate), and 36 pounds of potassium (potash) per acre (ISU Extension, 1996a). Corn planted after soybeans requires only 98 pounds of nitrogen, 43 pounds of phosphate, and 35 pounds of potash per acre. Soybeans in a corn-soybean rotation (40 bushel per acre yield goal) require no nitrogen, 32 pounds of phosphate, and 60 pounds of potash per acre. Here, steady state conditions are assumed in terms of the nutrients in manure that potentially become available (it can take up to three years for manure nutrients to be available for crop use). Specifically, the quantity of a nutrient that becomes available in any given year is exactly equal to crop need. Hence, excess nutrients in manure are not "stored" for eventual use by a crop.

Should a swine producer locate a feeder pig finishing unit in a typical central Iowa swine producing county, the producer would find that 84 percent of all acreage is in crops ($\alpha$) and that this acreage is split evenly between corn and soybeans (USDOC, 1994). Whether $\beta$ is 50 percent or 100 percent will depend upon the target nutrient and the crop grown. Soybeans do not require nitrogen, hence nitrogen is not generally applied to soybeans if nitrogen is the target nutrient. In this case, $\beta$ is 50 percent and the parameter $N_c$ assumes the values for corn in a corn-soybean rotation. For illustration purposes, the proportion of crop acres where manure is accepted ($\gamma$) is set to 50 percent.

## Estimating Net Manure Benefit in Iowa

This investigation addresses three major questions concerning swine manure management in Iowa and elsewhere. Each question is addressed for two cropping systems: (1) a typical corn-soybean rotation and (2) a system of intensive manure management utilizing continuous corn. The first question is, should manure nutrients be conserved and applied to crops? Here we are trying to determine which manure storage system earns a greater return. If a lagoon system earns a greater return, then producers have an incentive to eliminate rather than conserve manure nutrients. Note that this analysis does not include storage and other costs that might differ with storage systems. We only consider the cost of delivering nutrients and weigh this against the maximum return these nutrients can receive.

The second question considers the impact of a policy requiring all applied manure to be incorporated in the soil. Swine manure odors can be unpleasant, particularly in warmer months. One way to minimize manure odor (improve air quality) is to require incorporation. A problem with incorporation is that manure cannot be applied to standing crops. This further restricts the area to which manure can be applied and this limits the time a producer has available to spread manure stocks. Increasing costs associated with tighter time constraints are not considered.

The third question concerns the impact of a policy requiring manure applications to be based on phosphorous. In Iowa, producers with large facilities are required to file a manure management plan with the Iowa Department of Natural Resources. The purpose of this plan is to ensure that manure is not applied near sensitive areas and that the target nutrient is not excessively applied. While nitrogen is the current target nutrient, there is concern that targeting this nutrient leads to excessive applications of phosphorous. Using the figures reported in this study, up to 99 pounds of excess phosphorous can be applied following a nitrogen standard. Because of this, both a nitrogen and a phosphorous target are considered.

Given two storage systems, two levels, of incorporation and two target nutrients, eight different scenarios are considered for each of the two crop systems. Table 1 reports results for the eight scenarios assuming a typical corn-soybean rotation and Table 2 reports the eight scenarios assuming intensive manure management utilizing a rotation of continuous corn. Each table records relevant parameter values for each scenario as well as net return, average manure delivery costs at seven levels of production, optimal herd size, and profitability at the optimal (with respect to manure benefits and delivery costs) herd size. Reported results are annual and unique to Iowa (or locations with parameter values similar to Iowa), and assume an optimal rate of gain for a finished hog on feed a total of 114 days.

Concerning the first question, whether manure nutrients be conserved and applied to crops, the answer is clear. As shown in Tables 1 and 2, the cost of delivering manure nutrients out of lagoon storage is always greater than the value of the delivered nutrients. The maximum value of the delivered nutrients is $.90 per hog when following a P standard in a corn-soybean rotation. The minimum marginal cost of delivering nutrients is $2.66 per hog when the manure is not soil-incorporated. Thus, producers

Table 1. Parameter values, the market value of delivered nutrients, and the average cost of delivering nutrients in Iowa swine manure to corn and soybeans

| Form of manure storage | Slurry Basin | | | | Anaerobic Lagoon | | | |
|---|---|---|---|---|---|---|---|---|
| Is manure tilled into soil? | Yes | | No | | Yes | | No | |
| Target nutrient[a] | N | P | N | P | N | P | N | P |
| Parameter Values | | | | | | | | |
| $r_B$ - Unit hauling cost (cents/gal) | 0.88 | 0.88 | 0.79 | 0.79 | 0.71 | 0.71 | 0.57 | 0.57 |
| $Q$ - Gallons of manure per head | 164 | 164 | 164 | 164 | 467 | 467 | 467 | 467 |
| $r_A$ - Unit mileage charge (cents/gal-mile) | 0.34 | 0.34 | 0.34 | 0.34 | 0.28 | 0.28 | 0.28 | 0.28 |
| $N_M$ - Nutrient content (lb. / 1000 gal) | 47.5 | 35.0 | 35.0 | 35.0 | 3.8 | 3.0 | 3.0 | 3.0 |
| $\alpha$ - Cropland availability | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 |
| $\beta$ - Suitable cropland | 0.50 | 1.00 | 0.50 | 1.00 | 0.50 | 1.00 | 0.50 | 1.00 |
| $\gamma$ - Manured cropland | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| $N_C$ - Crop nutrient need (lb./acre) | 98 | 37.5 | 98 | 37.5 | 98 | 37.5 | 98 | 37.5 |
| Economic Results | | | | | | | | |
| Gross value of delivered nutrients ($/hog)[b] | 2.98 | 3.37 | 2.20 | 3.06 | 0.68 | 0.90 | 0.54 | 0.85 |
| Average cost ($/hog) at: | | | | | | | | |
| the intercept | 1.44 | 1.44 | 1.30 | 1.30 | 3.32 | 3.32 | 2.66 | 2.66 |
| 3,300 head[c] | 1.89 | 1.86 | 1.52 | 1.71 | 4.19 | 4.20 | 3.44 | 3.55 |
| 6,600 head | 2.53 | 2.49 | 2.07 | 2.34 | 4.55 | 4.57 | 3.76 | 3.91 |
| 9,900 head | 3.03 | 2.98 | 2.50 | 2.83 | 4.83 | 4.85 | 4.00 | 4.20 |
| 13,200 head | 3.44 | 3.39 | 2.86 | 3.24 | 5.06 | 5.09 | 4.21 | 4.43 |
| 16,500 head | 3.81 | 3.75 | 3.17 | 3.60 | 5.27 | 5.30 | 4.39 | 4.64 |
| 19,800 head | 4.14 | 4.07 | 3.46 | 3.93 | 5.45 | 5.48 | 4.56 | 4.83 |
| Optimal herd size (head)[d] | 4000 | 5800 | 3300 | 5000 | NA | NA | NA | NA |
| Profit at the optimum ($) | 3751 | 5870 | 2240 | 4986 | 0 | 0 | 0 | 0 |

NOTE: Assuming a corn soybean rotation. Annual swine production and manure generation.

[a] The target nutrient (N or P) is the nutrient on which manure applications are based.

[b] Value of delivered nutrients less application costs ($5.75 per acre) if a nutrient is under applied.

[c] 3,300 head represents three turns of a 1,100 head finishing house.

[d] Optimal heard size is based on returns to manure nutrients. Specifically, this is the level of swine production where the marginal cost of delivering nutrients equals the marginal benefit received from manure nutrients.

Table 2. Parameter values, the market value of delivered nutrients and the average cost of delivering nutrients in Iowa swine manure to corn.

| Form of manure storage | Slurry Basin | | | | Anaerobic Lagoon | | | |
|---|---|---|---|---|---|---|---|---|
| Is manure tilled into soil? | Yes | | No | | Yes | | No | |
| Target nutrient[a] | N | P | N | P | N | P | N | P |
| Parameter Values | | | | | | | | |
| $r_B$ - Unit hauling cost (cents/gal) | 0.88 | 0.88 | 0.79 | 0.79 | 0.71 | 0.71 | 0.57 | 0.57 |
| $Q$ - Gallons of manure per head | 164 | 164 | 164 | 164 | 467 | 467 | 467 | 467 |
| $r_A$ - Unit mileage charge (cents/gal-mile) | 0.34 | 0.34 | 0.34 | 0.34 | 0.28 | 0.28 | 0.28 | 0.28 |
| $N_M$ - Nutrient content (lb / 1000 gal) | 47.5 | 35.0 | 35.0 | 35.0 | 3.8 | 3.0 | 3.0 | 3.0 |
| $\alpha$ - Cropland availability | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 |
| $\beta$ - Suitable cropland | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| $\gamma$ - Manured cropland | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| $N_C$ - Crop nutrient need (lb/ac) | 144 | 45 | 144 | 45 | 144 | 45 | 45 | 144 |
| Economic Results | | | | | | | | |
| Gross value of delivered nutrients ($/hog)[b] | 2.44 | 3.37 | 1.80 | 3.06 | 0.56 | 0.82 | 0.44 | 0.76 |
| Average cost ($/hog) at | | | | | | | | |
| the intercept | 1.44 | 1.44 | 1.30 | 1.30 | 3.32 | 3.32 | 2.66 | 2.66 |
| 3,300 head[c] | 1.44 | 1.72 | 1.30 | 1.58 | 3.82 | 4.12 | 3.11 | 3.47 |
| 6,600 head | 1.61 | 2.30 | 1.30 | 2.15 | 4.03 | 4.46 | 3.30 | 3.81 |
| 9,900 head | 1.90 | 2.75 | 1.53 | 2.60 | 4.20 | 4.72 | 3.44 | 4.06 |
| 13,200 head | 2.15 | 3.12 | 1.74 | 2.97 | 4.33 | 4.93 | 3.57 | 4.28 |
| 16,500 head | 2.36 | 3.45 | 1.92 | 3.30 | 4.45 | 5.12 | 3.67 | 4.47 |
| 19,800 head | 2.55 | 3.75 | 2.09 | 3.60 | 4.56 | 5.30 | 3.77 | 4.64 |
| Optimal herd size (head)[d] | 8000 | 6900 | 6300 | 6200 | NA | NA | NA | NA |
| Profit at the optimum ($) | 5565 | 7039 | 3393 | 5985 | 0 | 0 | 0 | 0 |

NOTE: Assuming a corn soybean rotation. Annual swine production and manure generation.

[a] The target nutrient (N or P) is the nutrient on which manure applications are based.

[b] Value of delivered nutrients less application costs ($5.75 per acre) if a nutrient is under applied.

[c] 3,300 head represents three turns of a 1,100 head finishing house.

[d] Optimal heard size is based on returns to manure nutrients. Specifically, this is the level of swine production where the marginal cost of delivering nutrients equals the marginal benefit received from manure nutrients.

with lagoons always lose money (from their manure operation) from having to land-apply nutrients. At a herd size of 9,900 hogs, the loss ranges from a minimum of $3.139 per hog on continuous corn with no incorporation following an N standard to a maximum of $4.15 per hog in a corn-soybean rotation with soil incorporation, following an N standard.

Conversely, there is always a herd size where the cost of delivering manure nutrients is less than the value of the nutrients when a slurry basin is used for storage. Not surprisingly, however, as herd size increases, marginal delivery costs eventually become greater than marginal benefits. The herd size where marginal cost equals marginal benefits is the herd size that would maximize profits from manure nutrients (not hog production). The optimal herd size, and the resulting profits, are shown in the last two rows of Tables 1 and 2. The herd size where total benefits equals total costs (profits equal zero) can be found by equating the average cost of delivery to the gross value of nutrients. This "break-even" herd size will always be greater than the profit-maximizing herd size reported.

Our finding that conserving nutrients for delivery to crop fields is the optimal decision in typical Corn Belt conditions is consistent with USDA data which show that 50 percent of Corn Belt swine producers stored slurry manure in pits, basins, or storage tanks in 1992 (USDA/ERS, 1996). Only 11 percent of producers used lagoons. In Iowa, the proportion of slurry basins to lagoons may be even greater. Since 1987, the Iowa Department of Natural Resources has issued 415 permits for slurry basins (not including deep pits) and 180 permits for lagoons. The close proximity of high-value, high-nutrient-using crops favors nutrient conserving, slurry storage.

The largest profit from slurry storage ($7,039) is earned for a herd size of 6,900 hogs, locating the facility in an area where only corn is grown, basing manure applications on a P-standard, and incorporating the manure into the soil. Using a P-standard instead of an N-standard forces the producer to apply manure to more acres, but more of the potential value of the manure is captured because fewer excess nutrients are applied. And, the benefits from conserving N through soil incorporation outweigh the additional costs in this scenario. As herd size grows, however, costs of following a P-standard rise faster than the costs of following an N-standard; thus, net losses would eventually be minimized by following an N-standard on continuous corn. These findings are now considered in greater detail.

Requiring all applied manure to be soil-incorporated (the second question) has the joint effect of increasing both average benefits and average delivery costs regardless of crop choice, storage technology, and target nutrient. The $0.05 to $0.78 increase in average benefit results because about 25 percent of the broadcast N is lost to the atmosphere. Average delivery costs are also increased, by between $0.14 and $0.89 at 19,800 head. This increase is due to higher machinery and labor costs and the fact that retaining more nutrients in the soil increases the area required to spread manure, so it increases mileage. The net impact is that the increase in benefits exceed the increase in costs, resulting in greater profit being earned (with slurry basin storage) when manure is incorporated.

The results in Tables 1 and 2 show that incorporating slurry manure is the optimal manure management decision in Iowa because producer profit is higher with incorporation than without it. Furthermore, incorporating manure has the added benefit of improving air quality. So why is incorporation not a common practice in Iowa and the Corn Belt? First, manure cannot be incorporated into standing crops. This places a tighter constraint on when manure stocks can be moved to crop fields, making management decisions less flexible. Second, there is evidence that manure nutrients are "given away" to find acreage for spreading that might not be available if the owner of that cropland were required to pay for manure nutrients. Not all landowners are willing to accept manure, so the nutrient credit may reflect the price for access to nearby crop acreage. Access to nearby crop acreage reduces delivery cost, which offsets the forgone benefits of soil incorporation. In this case, the producer will want to minimize cost and will avoid incorporating manure. In summary, a policy requiring producers to incorporate manure is beneficial to Iowa swine producers only if they receive full credit for manure nutrients and if the costs associated with tighter scheduling are minimal.

Requiring manure applications to be based on phosphorous (the third question) has a more varied impact across the scenarios. In all cases, following a phosphorous target increased manure benefits because all the potential value of applied nutrients are captured. However, the effects on delivery cost of following a P-standard are not uniform. Generally, marginal delivery cost increases because more acreage is needed to apply the same quantity of manure (mileage increases). This result has been well documented (Pratt et al., 1997) and is observed here when manure is applied to continuous corn. However, when slurry manure is applied to corn and soybeans with incorporation, marginal delivery cost is lower. In this case, having more suitable crop acreage (soybean land) reduces mileage; hence, marginal costs are decreased. It is interesting that this result is not noted with the remaining corn-soybean scenarios; suitable acreage is always increased when following a P-standard. Slurry manure in conjunction with incorporation appears to be necessary for a P-standard to lower costs on a corn-soybean rotation.

It is surprising that following a P-standard always increases profit with slurry storage yet producer groups are always at the forefront for fighting regulations that would force them to follow a P-standard. One explanation for this paradox is that crop farmers typically capture the benefits of manure nutrients and hog producers pay the delivery costs. With few exceptions, delivery costs from a P-standard are greater than delivery costs following an N-standard. Producers who have an objective of minimizing cost would, therefore, resist a P-standard policy. A P-standard is beneficial to Iowa swine producers only if they receive full credit for delivered manure nutrients.

If the results of this report are correct, and slurry basins are the optimal manure storage method for Iowa conditions, why, then, do some swine producers still want to use lagoon storage? There are at least two possible explanations. The first is that if the amount of land available for spreading manure is much more limited than that assumed here, then eventually, the profits from manure operations become negative and the cost minimizing method of disposing of manure nutrients is to use an anaerobic lagoon. The second explanation is that certain types of swine operations operate more efficiently on lagoon storage systems than on slurry storage. In particular, modern farrowing facilities typically use lagoon effluent for flush water instead of fresh water. The production cost advantages of lagoon storage in these facilities likely outweigh the disadvantages of higher manure delivery costs.

In summary, based on a consideration of manure benefits and delivery costs, slurry manure storage is optimal in Iowa. Under current requirements (applications based on nitrogen and no incorporation), the greatest possible return is earned by supplying manure to continuous corn. Changing state regulations to include incorporation and manure applications based on phosphorous will actually benefit swine producers (result in higher manure profits) if these changes are accompanied by a change in cropping pattern to corn-soybeans from continuous corn and if swine producers capture the benefits from the manure nutrients.

## Conclusions

In Iowa, the release of confinement swine odors and manure nutrients into the environment has become an important issue. A policy to control odor might include a requirement to incorporate swine manure into soil after spreading. Likewise, a policy to reduce manure nutrient releases into surface water and groundwater might include a change from nitrogen to phosphorous as the nutrient upon which manure applications are based. The relevant question here is, what are the potential impacts of such policy changes on confinement feeder pig finishing in Iowa?

Potential policy impacts depend on the benefits and costs of delivering manure to crop fields. The two most important factors that determine the net benefit of swine manure on a field are the distance the manure has to be hauled and the nutrient content of the manure. The farther a given amount of manure must be hauled, the higher the cost. And, up to a point, the more nutrients that are delivered to a field, the greater the value. This study develops an economic model of manure delivery cost that is useful as a tool to analyze policy changes and their impacts. Using this model we have addressed three major questions concerning swine manure management in Iowa and elsewhere: (1) Should manure nutrients be conserved and applied to crops? (2) What is the impact of a policy requiring all manure applications to be incorporated? And (3) what is the impact of a policy requiring manure applications to be based on phosphorous?

With respect to the first question, manure nutrient returns are maximized where high-nutrient-using crops are grown close to a medium-sized swine finishing facility that stores manure using nutrient-conserving methods. In this situation the fertilizer cost savings would be significant; the swine facility would not produce an excess quantity of nutrients that would have to be hauled a long distance; and the manure delivered to a field would be rich in nutrients. Indeed, in Iowa, this is the common practice.

The value of manure is greatly reduced if it has been treated in an anaerobic lagoon because much of the nitrogen is lost to the atmosphere and much of the phosphorous precipitates to the bottom of the lagoon. Hence, with anaerobic lagoons, the cost of delivering nutrients is always greater than the value of nutrients. This help explains why lagoon storage at feeder pig finishing sites is the exception rather than the rule in Iowa. Nevertheless, lagoons are utilized. As the number of hogs on a site increases, the cost disadvantage of lagoons decreases. Hence, producers with large concentrations of hogs at a finishing site may choose an anaerobic lagoon in order to minimize the profit loss from manure handling.

With respect to the second question concerning incorporation, the value of manure decreases when it is surface-applied (not incorporated) because a portion of the nitrogen is lost to the atmosphere. Furthermore, this loss of nitrogen and other gasses can impair air quality. On the other hand, it costs less to surface apply manure because less equipment is involved and the producer has greater flexibility with respect to timing of applications and finding suitable acreage. The net result is that incorporating manure increases production returns while improving air quality. However, this result depends on the value actually received for manure nutrients.

Basing manure applications on phosphorous levels rather than on nitrogen increases the value of manure nutrients because applied nutrients better match crop requirements. This also increases the cost of delivering hogs because application rates on corn are reduced; hence, more acres must be used for application. However, the profit-maximizing number of hogs and the profit levels under a P-standard are both greater than under an N-standard. The reason for this surprising result is that, if the number of hogs on a site is small enough, the increased value of manure under a P-standard on corn is greater than the additional cost of delivering the manure. So although costs are clearly higher under a P-standard, the net value of manure for low hog numbers is enhanced by adoption of a P-standard. As expected, the enhanced value disappears as the number of hogs on a site increases.

Policy impacts can depend on the assumed crop rotation. This is largely due to our assumption that manure can only be applied to corn when following an N-standard. Crop rotation also determines crop nutrient need. The most striking result is that when manure is incorporated, manure application costs actually decrease under a P-standard when manure is applied to both corn and soybeans. Furthermore, there is only a small cost increase from adopting a P-standard when manure is surface-applied. The reason for this result is that the benefits of having more acres available for spreading manure are greater than the additional costs.

The sale of manure nutrients can be beneficial to a swine producer. Note, however, that while a finished hog may earn $3.37 or less for its manure nutrients, it earns $115 or more as a consumer product. Hence, it is the market value of the hog that will drive swine production decisions, not the value of manure nutrients that a hog produces. This finding supports the conclusions drawn by Roka and Hoag (1994) that, while the value of manure nutrients is nonzero, this value is small compared to the value of the primary product, pork. In this situation, a swine producer will minimize the cost of manure storage and delivery and simply accept what value there is in the manure nutrients generated. Even so, the results of this investigation are meaningful because they indicate when it is possible to offset manure delivery cost. In Iowa, for the conditions imposed, that strategy is to store manure as a slurry, apply manure to continuous corn, base applications on phosphorous, and immediately incorporate manure when applied.

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