MANURE VALUE, PRICING SYSTEMS, AND SWINE PRODUCTION DECISIONS[1]

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Abstract: Based on a swine producer's profit maximization model in which manure value and packers' live market weight pricing systems are considered, the optimal farm inventory and optimal hog market weight are simultaneously solved for scenarios generated from the combination of two crop rotations, two forms of manure storage, two levels of manure incorporation, and two nutrient application standards. First, our results suggest that manure value has a significant impact on the optimal farm inventory as well as on the profitability of an operation. The optimal size of operation identified is quite large and varies considerably among the scenarios. Our results indicate that shallow pit buildings with lagoons can support a larger operation scale and require less acreage for manure dispersion than systems with slurry basins. For slurry basin systems, manure applications with immediate incorporation are more profitable than applications with no incorporation. Second, our results show that the optimal hog market weight is insensitive to benefits and costs of manure handling and application, reflecting a dominant influence of the pricing system on a producer's hog marketing decision. Finally, our results show that though more acres are needed for manure application when a P standard is applied in a corn-soybean rotation, still a P standard is economically advantageous to swine farmers and this standard also makes better use of manure nutrients.

Keywords: swine production, manure value, pricing system, optimal herd size, optimal live market weight.

JEL Codes: Q12, Q19, D24.

Introduction

As a joint product of hog production, manure is regarded as an organic source of crop nutrients on one hand and as a potential source of environmental pollution on the other. If the delivery costs are low enough, manure as a valuable resource can increase profits from crop production by substituting for fertilizer and the nutrients of manure are often conserved for this practice. If application costs are too high, then only a portion of the delivery cost can be recovered by the application of manure and farmers will not have incentives to use technologies that maximize the manure nutrients in crop production. The value of manure is determined by the nutrient content of manure. This value is offset by the costs to haul and apply. As herd size increases, producers must devote greater resources to manure handling activities to ensure that manure nutrients are utilized not only efficiently but also in accordance with environmental standards. In practice, manure handling can become a bottleneck of livestock production expansion.

Production decisions such as herd size and market weight are dependent on manure handling decisions (Fleming et al. 1998; Roka and Hoag, 1996). Herd size has a direct and obvious effect on manure stocks. Market or replacement age also has an effect, though the effect is not as obvious and is often neglected. As an animal matures, daily manure excretion increases. Increasing the duration of a production cycle to produce heavier animals implies younger animals replace older stock less frequently. Thus, average daily manure excretion per pig increases. Likewise, decreasing the duration of a production cycle results in lower average per pig daily manure excretion. Given the importance of manure value in production decision making, the optimal herd size and market weight decisions should be jointly made because they both contribute to the amount of manure produced. However, previous studies that analyze livestock production decisions determine the optimal herd size and the optimal market weight separately (Fleming et al., 1998; Roka and Hoag, 1996; Schnitkey and Miranda; 1993; Boland et al., 1993).

Pricing systems for hogs have an impact on the optimal slaughter (market) weight (Boland et al., 1993). In general, packers pay producers using either a liveweight pricing system or a carcass merit pricing system for hogs. Under the liveweight pricing system, revenue received from a hog depends mainly on the weight of the hog, while under the carcass merit pricing system, revenue from a hog is determined by the weight of the carcass plus components such as leanness. Since different genders and genotypes have different production responses and carcass components, their optimal market weights also differ under different pricing systems. Profit maximizing production decisions on herd size and market weight (or carcass weight) reflect the influence of pricing systems.

The purpose of this research is to simultaneously determine the optimal herd size and the optimal slaughter weights when manure value and a live market weight pricing system are taken into account. Manure value is defined as the replacement value of nutrients (cost savings of inorganic fertilizer) less the costs of storing and delivering the manure. Given that there is no cropland restriction for manure application, the optimal herd size and live market weights under various scenarios are derived by jointly solving the first order conditions of a swine finishing operation's profit maximization problem. The profit of production consists of net returns from hog sales and net manure value. A two-output (finishing hogs and manure), multi-input (feed and other inputs) production problem in continuous time is modeled in this analysis. Producers are assumed to make production decisions to maximize their annual profits. Nutrient requirements for crop production are based on a corn-soybean rotation, and manure nutrient components analyzed include nitrogen, phosphorus (phosphate), and potassium (potash). Both the nitrogen and the phosphorus standard for manure land application are considered. Two widely used types of manure storage (anaerobic lagoons and slurry basins) and two levels of field incorporation after application (immediate and none) are examined. Swine finishing production data in the Midwestern region are used (Department of Economics, 1996; Department of Agricultural and Biosystems Engineering, 1996; Lattz et al., 2002). Numerical methods are employed to solve the nonlinear multi-variable optimization problem using SAS/ETS (SAS Institute Inc., 2003).

This study distinguishes itself from previous studies. First, the optimal herd size and live market weight are jointly determined. As already noted, since herd size and live market weight both exert an effect on the volume of manure produced, production decisions on herd size and live market weight separately made can be inaccurate and even misleading (Roka and Hoag, 1996). Second, net returns from hog production, manure value, and the influence of pricing systems are incorporated into the producer's profit maximization problem while extant studies were usually focused on only one aspect of the production decision problem. Third, in our study, manure application is not limited by cropland availability and hence the value of manure as a substitute for commercial fertilizer is fully utilized. Therefore, the optimal solution to the producer's profit maximization problem indeed reflects socially optimal production. The results of our study identify not only the optimal herd size and the optimal live market weight but also the influence of manure storage and application technologies as well as manure nutrient application standards on these decision variables.

A swine production model including manure values

Consider a swine finishing farm. Barns are managed all-in-all-out. Assume there are no land restrictions for manure dispersion. Revenues of the swine farm are from two sources: hog sales and cost savings of commercial fertilizer resulting from manure land application. Let H be the barn inventory of feeder pigs, P_l be the base live market weight price ($ per pound), t be the days of a feeder pig on feed during the finishing period, G(t) be the liveweight (pounds) of a hog after t days on feed, and MB be the manure benefit from cost savings of inorganic fertilizer. The total annual revenue (TR) of the farm is:

$$TR = \frac{365}{t} P_l G(t) H + MB \qquad (1)$$

where 365/t is the number of times in a year the barn inventory turns over.

According to Fleming et al. (1998), the total benefit from manure can be calculated by

$$MB = \frac{365}{t} \Big(\sum_{i=n,p,k} P_{M,i} Nu_{M,i} + A \Big) QH \qquad (2)$$

where Q is the quantity of manure hauled per finished hog (gallons) and Q = $\int_0^t mG(s)ds$,

where m is manure generation coefficient (gallon per pound liveweight per day); $P_{M,i}$ is the commercial price of fertilizer ($/lb) for nitrogen (N), phosphorous (P) or potassium (K); and $Nu_{M,i}$ is the nutrient content of manure for N, P or K and subject to

$$Nu_{M,i} \le \frac{Nu_{M,T}}{Nu_{C,T}} Nu_{C,i} = \frac{Nu_{C,i}}{R_T} \quad \text{for T = N or P and } i = \text{N, P, K} \qquad (3)$$

where $Nu_{C,i}$ is the need of a specific crop for nutrient *i* and T is the target nutrient (N or P); R_T is the application rate for manure (gallon per acre) based on the target nutrient T and A is the land application fee (in terms of $ per gallon of manure) of inorganic fertilizer. Let AppFee be a fixed cost ($ per acre) of the secondary fertilizer applications, then

$$A = \frac{AppFee}{R_T} \text{ if } Nu_{M,i}R_T \geq Nu_{C,i} \text{ for all } i,\ i = \text{N, P, K} \qquad (4)$$

$$= 0, \text{ otherwise.}$$

We categorize production costs of a swine finishing operation into five items: the cost of feeder pigs, nonfeed costs, feed costs, manure land application costs, and the potential cost arising from packers' pig live market weight discount. Nonfeed costs include building depreciations, interest and premiums, labor costs, veterinary medical costs, transportation/marketing costs, mortality losses, and other costs that are not accounted for in the other above-mentioned cost items. For simplicity, nonfeed costs are measured in terms of $ per pound of live market weight, which is assumed to be independent of operation scale. Following Fleming et al. (1998), manure land application costs consist of two parts: a base charge (costs of mixing, loading manure out of storage, and applying it to a field) and an additional mileage charge (costs of hauling manure a given distance). The base charge is a function of the unit cost of hauling manure (r_b, $ per gallon) times the quantity of manure hauled while the additional mileage charge is a function of the unit mileage charge (r_a, $ per gallon per mile) times the quantity of manure and the number of miles that the manure is hauled. Assuming that required acreage for manure application (Ac) is a square, continuous block next to the farm, the average mileage (D, miles) of manure hauling can be approximated by (Fleming et al., 1998)

$$D = \left(\frac{Ac}{640\alpha\beta\gamma} \right)^{\frac{1}{2}} \tag{5}$$

where α, β, and γ are coefficients representing the proportion of cropland, the proportion of suitable cropland of α, and the proportion of crop acres of β where manure is accepted, respectively. Ac is determined by

$$Ac = \frac{Nu_{M,T}}{Nu_{C,T}} \frac{365}{t} QH \tag{6}$$

Hence, the cost of manure land application (CM) can be expressed as

$$CM = \int_0^t mG(s)ds \left[r_b + r_a \left(\frac{Nu_{M,T} \int_0^t mG(s)ds \frac{365}{t} H}{640\alpha\beta\gamma Nu_{C,T}} \right)^{\frac{1}{2}} \right] \frac{365}{t} H \tag{7}$$

If a pig at finishing is not within the packer's preferred live market weight range, the base price will be discounted and the loss from liveweight discounts is treated as a potential cost of production in our analysis. Typically, discounts are applied to hogs under 221 or over 289 pounds on a live market weight pricing system (Table 1). Since such a step discount schedule substantially complicates the analysis, we use a quadratic function to fit the discount schedule for live market weight:

$$CD = 173.913 - 1.347G(t) + 0.00259[G(t)]^2 \tag{8}$$

where CD is the potential cost of live market weight price discount, $ per pound of live market weight.

Combining the five cost items, we obtain the total cost of production (TC):

$$TC = P_p \frac{365}{t} H + C_n G(t) \frac{365}{t} H + P_f F(t) \frac{365}{t} H$$
$$+ \int_0^t mG(s)ds \left[r_b + r_a \left(\frac{Nu_{M,T} \int_0^t mG(s)ds \frac{365}{t} H}{640\alpha\beta\gamma Nu_{C,T}} \right)^{\frac{1}{2}} \right] \frac{365}{t} H \tag{9}$$
$$+ \left[173.913 - 1.347G(t) + 0.00259[G(t)]^2 \right] \frac{365}{t} H$$

where P_p is the price of a feeder pig, \$ per head; C_n is the nonfeed cost, \$ per pound of live market weight; P_f is the feed cost, \$ per pound of feed; and F(t) is the cumulative feed intake of a pig after t days on feed, pounds.

Subtracting equation (9) from (1), the annual profit of the swine farm (π) is

$$\pi = TR(H, t) - TC(H, t) \tag{10}$$

Differentiating equation (10) with respect to H and t, rearranging, and simplifying, we obtain the following optimality conditions for the swine farm profit maximizing problem:

$\frac{\partial \pi}{\partial H} = 0$ if and only if

$$(P_l - C_n)G(t) + \left(\sum_{i=n,p,k} P_{M,i} Nu_{M,i} + A \right) \int_0^t mG(s)ds - P_p - P_f F(t)$$
$$- \int_0^t mG(s)ds \left[r_b + \frac{3}{2} r_a \left(\frac{Nu_{M,T} \int_0^t mG(s)ds \frac{365}{t} H}{640\alpha\beta\gamma Nu_{C,T}} \right)^{\frac{1}{2}} \right] \tag{11}$$
$$-173.913 + 1.347G(t) - 0.00259[G(t)]^2 = 0$$

and $\frac{\partial \pi}{\partial t} = 0$ if and only if

$$
\begin{aligned}
&(P_l - C_n)(G'(t) - G(t)/t) + m(\sum_{i=n,p,k} P_{M,i} Nu_{M,i} + A)(G(t) - \frac{1}{t}\int_0^t G(s)ds) \\
&+ P_p / t - P_f (F'(t) - F(t)/t) - m(G(t) - \frac{1}{t}\int_0^t G(s)ds) \times \\
&\left[r_b + \frac{3}{2} r_a \left(\frac{Nu_{M,T} \int_0^t mG(s)ds \frac{365}{t} H}{640\alpha\beta\gamma Nu_{C,T}} \right)^{\frac{1}{2}} \right] + G'(t)(1.347 - 0.00518G(t)) \\
&- \frac{1}{t}\left[-173.913 + 1.347G(t) - 0.00259[G(t)]^2 \right] = 0
\end{aligned} \quad (12)
$$

Equation (11) states that the optimal herd size for an operation is where the combined value of hog sales and manure of an additional hog is exactly offset by the marginal cost to produce the last hog and dispose of the incremental increase in manure. Likewise, equation (12) states that the optimal days of a hog on feed is where the combined value of live market weight and manure of a hog staying an additional day on feed is exactly equal to the marginal cost to produce the incremental increase in live market weight and dispose of the incremental increase in manure during the last day on feed. Given a pig's growth and feed intake functions as well as other parameters such as manure nutrients, prices, and costs in equations (11) and (12), optimal herd size (H^*) and days on feed (t^*) are simultaneously determined by solving this nonlinear equations system. It should be noted that though it is not explicitly solved for in our system, the optimal live market weight of a hog at replacement is also obtained once the days on feed is determined. In fact, given the liveweight growth function of a hog, the optimal days on feed are calculated for the hog to reach the optimal live market weight in this profit maximization problem. Since it is difficult to derive an analytical solution to this nonlinear system, we use Newton's method to compute the optimal H^* and t^*. The computation was carried out by means of SAS/ETS (version 8.2).

Data

The growth function G(t) and cumulative feed intake function F(t) for finishing pigs are obtained from Andersen and Pedersen (1996). Assuming that gilts and castrated barrows are each half of the herd population and that feeder pigs enter the finishing barn at a weight of 66 lbs (30 kg), the following polynomials can be used to estimate a pig's liveweight (G(t), in pounds) and cumulative feed intake (F(t), in pounds) after t days on feed:

$$G(t) = 67.3653 + 1.4085t + 0.0275t^2 - 0.000352t^3 + 1.41\times10^{-6}t^4 \quad (13)$$

and $$F(t) = 1.3436 + 2.8336t + 0.0498t^2 - 0.000193t^3 \quad (14)$$

Based on the American Society of Agricultural Engineers Standard (ASAE, 1999), pigs in the finishing stage produce about 0.01 gallons of raw manure per pound of liveweight per day. Assuming that water wastage adds 20% to the fecal accumulation in the finishing barn (Fleming et al., 1998), each pound of animal liveweight then produces 0.012 gallons of slurry manure per day. According to the Department of Agricultural and Biosystems Engineering, Iowa State University (1996), at the end of storage (one year), each gallon of slurry manure contains on average 0.05 pounds of nitrogen (N), 0.035 pounds of phosphorus (P), and 0.025 pounds of potassium (K). However, with lagoon storage and treatment, each gallon of raw manure is diluted in about 10 gallons of water and about 3.4 gallons of this lagoon liquid are eventually applied to cropland (Department of Agricultural and Biosystems Engineering, 1995 and 1996), implying that for a facility with lagoons each pound of animal liveweight produces 0.035 gallons of lagoon manure per day for final land application. Nutrient content of manure applied to a field after a year of storage in a lagoon is 0.004 pounds per gallon for N, 0.003 pounds per gallon for P, and 0.004 pounds per gallon for K (Department of Agricultural and Biosystems Engineering, 1996). Extant research also shows that the effective N content of manure is dependent on the methods of land applications. If manure is incorporated, only 5% of the nitrogen will be lost to the atmosphere and 95% (i.e., 0.0475 and 0.0038 pounds per gallon in slurry and lagoon manure, respectively) will be available for crop use. If manure is not incorporated, nitrogen loss to the atmosphere will increase. If manure is not incorporated, only 70% (0.035 pounds per gallon) of the nitrogen in slurry and 75% (0.003 pounds per gallon) of the nitrogen in lagoon liquid will be available for crop use (Department of Agricultural and Biosystems Engineering, 1996; USDA SCS, 1992).

Crop nutrient requirements depend on the type and rotation of crop production. Corn in a continuous corn rotation (120 bushel per acre yield) requires 144 pounds of N, 45 pounds of P, and 36 pounds of K per acre while nutrient needs for corn in a soybean-corn rotation are reduced to 98, 43, and 35, respectively (Department of Economics, 1996). Soybeans in a soybean-corn rotation (40 bushel per acre yield) need no N, 32 pounds of P, and 60 pounds of K per acre. Following Fleming et al. (1998), we assume that the quantity of a nutrient that becomes available in any given year is exactly equal to the crop requirement and no excess nutrients in land will be retained for a future use. The prices of commercial fertilizer of N, P, and K are based on Iowa averages in 1995, which were $0.15, $29, and $0.13 per pound, respectively (Department of Economics, 1996).

The fixed application fee of commercial fertilizer (AppFee in equation (4)) is assumed to be $5.75 per acre (Fleming et al., 1998).

Based on our communication with custom applicators and swine farmers in Illinois, manure land application costs are about $0.01 per gallon for slurry manure incorporation and $0.0025 per gallon for lagoon liquid irrigation. Using the data from a survey of Iowa custom manure applicators (Lorimor, 1996), we decomposed the above custom rates into a base charge (r_b) and an additional mileage charge (r_a) with field incorporation or with no field corporation. These r_b and r_a estimates in different application cases are shown in tables 2 and 3.

Manure land application suitability coefficients α, β, and γ (Fleming et al., 1998) are assumed (see tables 2 and 3). The proportion of cropland 0.84 (α) represents the case in a typical Iowa swine producing county where 84% of the land is in crops and the crop fields are assumed to be split evenly between corn and soybeans. The proportion of suitable cropland (β) is 50% or 100% depending on the nutrient standard used in land application and crop types. The proportion of acres accepting manure is set to 50% for illustration purposes.

Hog carcass base price and the price of a feeder pig are assumed to be $60 per cwt and $50 per head, respectively (Li et al., 2003). This carcass weight base price is converted into a liveweight base price (i.e., $0.444 per pound of live market weight) based on a relationship between carcass weight and liveweight provided in Miller et al. (2001). The price of feed and the nonfeed cost are based on data obtained from farm business records on Illinois farms. The average feed price from 1996 to 2000 is reported to be \$0.06 per pound while the average nonfeed cost over the same period is \$16.35 per cwt, or \$0.121 per pound of liveweight (Lattz et al., 2002).

Optimization results

For comparison, the swine producer's profit maximization problem is solved for all the scenarios examined in Fleming et al. (1998). Specifically, these scenarios include two crop rotations (continuous corn vs. corn-soybean), two forms of manure storage (slurry basin vs. anaerobic lagoon), two levels of field incorporation after application (immediate vs. none), and two manure application standards (nitrogen vs. phosphorus). The optimization parameters and results are reported separately by crop rotation for all the scenarios (tables 2 and 3).

Our results show that the optimal days on feed for a pig entering a finishing barn at 66 pounds is 103 in all scenarios, implying that the optimal live market weight of a pig is 278 pounds. Since the scenarios differ mainly in benefits from and costs of manure land applications, this result suggests that the optimal live market weight is insensitive to economic parameters relating to manure storage and application and that the hog pricing system may dominate a producer's hog marketing decisions. This result is not surprising. According to Roka and Hoag (1996), profit-maximizing producers tend to raise a hog to the upper bound of the liveweight in the base price range when daily gains in pork value are greater than daily costs of production and manure handling.

The optimal hog farm inventory (H^*) varies significantly among the scenarios examined though all farm inventories are quite large. The largest inventory, 94,549 head, is found in the scenario featuring a continuous corn rotation, lagoon storage, no manure incorporation, and manure application based on an N standard, while the smallest inventory, 12,268 head, is found in the case where crop production follows a corn-soybean rotation and manure is applied under an N standard but not incorporated into the soil. Under the same nutrient application standard (N or P) and at the same level of field incorporation (immediate or none), our results show that H^* of an operation with lagoon storage is larger than that with a slurry basin, suggesting that systems with anaerobic lagoons can support larger scales of production than slurry basin systems. However, this does not imply that systems with lagoons are always more profitable than slurry basin systems. Our results show that if manure is incorporated, the maximum profits of lagoon systems are lower than that of slurry basin systems because of the low manure nutrient values and relatively high field incorporation costs of lagoon liquids. Lagoon systems are more profitable if manure is not incorporated, suggesting that producers with lagoon systems have no economic incentive to incorporate lagoon liquid into the soil and this is also consistent with the current practice in the swine industry of spray application of lagoon liquid. For slurry manure, our results confirm the findings of Fleming et al. (1998), that is, manure incorporation is the optimal strategy of manure management because profits are higher with incorporation than without it no matter what nutrient standard is employed.

Our results regarding acres needed for manure application agree with common perceptions of industry practice. First, lagoon systems require much fewer acres for manure dispersion than slurry basin systems, suggesting that if land availability for manure application is limited, lagoon systems are a better alternative of manure management. Second, compared with an N standard, a P standard will lead to a significant increase in acres needed for manure dispersion. However, our results also show that when crop production follows a corn-soybean rotation, a P standard can help swine farmers achieve higher profits because manure application based on a P standard makes better use of manure nutrients and hence manure value increases.

Conclusions

Based on a swine farm profit maximization model, we show that manure value and pricing systems have an important influence on producer's hog marketing and operation scale decisions. Specifically, pricing systems have a dominant impact on a producer's choice of optimal hog market weight while the optimal size of operation is significantly affected by benefits and costs of manure storage and application. Our results also show that incorporating slurry manure into a field can be profitable but incorporating lagoon liquid will lead to substantial economic loss. Another interesting finding of our study is that though more acres are required for manure dispersion, when crop production follows a corn-soybean rotation, swine farmers increase profits by applying manure based on a P standard since manure nutrients are better utilized.

Our results help to explain the observed trend in swine production concentration. Optimal herd size identified is quite large in all the scenarios examined in our study. Our results also show that the optimal herd inventory of swine farms using shallow pit buildings with lagoons is much larger than farms using deep pit manure storage and this is also consistent with the current practice in the swine industry.

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Table 1. Premiums and discounts for Carcass Weight and Liveweight

Hot carcass weight range, lb	Liveweight Range, lbs	Discount, $/cwt
140-147	190-200	-8.00
148-154	201-209	-4.00
155-162	210-220	-2.00
163-213	221-289	0.00 (base price)
214-220	290-299	-0.75
221-228	300-310	-1.50
229-235	311-319	-3.00

Source: Boland, M.A. (1996). Economic Optimization of Animal Replacement, Ration Consumption, and Nutrient Management: An Application to Pork Industry. Unpublished Dissertation, Purdue University.

Table 2. Optimization Parameters and Results for a Continuous Corn Rotation

Manure Storage	Slurry Basin				Anaerobic Lagoon			
Manure Incorporation	Yes		No		Yes		No	
Application Standard	N	P	N	P	N	P	N	P
Optimization Parameters								
Nu_M: Nutrient content, lb/gal	0.0475	0.035	0.035	0.035	0.0038	0.003	0.003	0.003
Nu_C: Crop nutrient requirement, lb/acre	144	45	144	45	144	45	144	45
r_a: Unit mileage charge, $/gal-mile	0.0031	0.0031	0.0031	0.0031	0.0008	0.0008	0.0008	0.0008
r_b: Unit hauling base charge, $/gal	0.0069	0.0069	0.006	0.006	0.0031	0.0031	0.0017	0.0017
α: Cropland availability	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
β: Cropland suitability	1	1	1	1	1	1	1	1
γ: Cropland acceptability	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P_l: Liveweight base price, $/pound	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444
P_p: Feeder pig price, $/head	50	50	50	50	50	50	50	50
P_f: feed price, $/pound	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_n: Nonfeed cost, $/lb of live market weight	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Optimization Results								
t^*: Opt. Days on feed, days	103	103	103	103	103	103	103	103
$G(t^*)$: Opt. Live market weight, lb	278	278	278	278	278	278	278	278
H^*: Opt. Barn inventory, head	27904	18132	28881	16935	43121	22748	94549	38710
$F(t^*)$: Feed intake, lb/hog	611	611	611	611	611	611	611	611
Ac: Acres needed for manure dispersion, acres	7045	10795	5373	10082	2476	3300	4286	5615
Manure benefit, $/hog	3.21	4.43	2.37	4.03	0.73	1.08	0.50	1.00
Annual profit at optimum, $	174618	139569	158575	126265	123576	74468	325123	162647
Scenario Abbreviation	ccsnt	ccspt	ccsn	ccsp	cclnt	cclpt	ccln	cclp

Table 3. Optimization Parameters and Results for a Corn-Soybean Rotation

Manure Storage	Slurry Basin				Anaerobic Lagoon			
Manure Incorporation	Yes		No		Yes		No	
Application Standard	N	P	N	P	N	P	N	P
Optimization Parameters								
Nu_M: Nutrient content, lb/gal	0.0475	0.035	0.035	0.035	0.0038	0.003	0.003	0.003
Nu_C: Crop nutrient requirement, lb/acre	98	37.5	98	37.5	98	37.5	98	37.5
r_a: Unit mileage charge, $/gal-mile	0.0031	0.0031	0.0031	0.0031	0.0008	0.0008	0.0008	0.0008
r_b: Unit hauling base charge, $/gal	0.0069	0.0069	0.006	0.006	0.0031	0.0031	0.0017	0.0017
α: Cropland availability	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
β: Cropland suitability	0.5	1	0.5	1	0.5	1	0.5	1
γ: Cropland acceptability	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P_l: Liveweight base price, $/pound	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444
P_p: Feeder pig price, $/head	50	50	50	50	50	50	50	50
P_f: feed price, $/pound	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_n: Nonfeed cost, $/lb of live market weight	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Optimization Results								
t^*: Opt. Days on feed, days	103	103	103	103	103	103	103	103
$G(t^*)$: Opt. Live market weight, lb	278	278	278	278	278	278	278	278
H^*: Opt. Barn inventory, head	12319	15110	12268	14125	16882	20634	35308	34435
$F(t^*)$: Feed intake, lb/hog	611	611	611	611	611	611	611	611
Ac: Acres needed for manure dispersion, acres	4570	10795	3354	10091	1424	3592	2352	5994
Manure benefit, $/hog	3.93	4.43	2.89	4.03	0.89	1.19	0.60	1.11
Annual profit at optimum, $	87455	116307	74969	105223	51617	70269	121454	149229
Scenario Abbreviation	cssnt	csspt	cssn	cssp	cslnt	cslpt	csln	cslp