Economic–Environmental Tradeoffs in Swine Finishing Operations

Greg W. de Vos, Alfons Weersink and D. Peter Stonehouse

Department of Agricultural Economics and Business,
University of Guelph, Guelph, Ontario, N1G 2W1.

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This study examines the cost effectiveness of 81 alternative manure management systems for a swine finishing operation in reducing three pollutants associated with livestock waste: ammonia, nitrogen and phosphorus. The results are presented in terms of the tradeoff between the levels of these pollutants (environmental indicator) and the economic returns to the producer. The levels of the three manure residuals cannot be reduced by more than half from the present levels under the profit-maximizing system for each farm size. Further reduction would require changes in hog numbers to reduce the volume of manure and consequently residual levels. However, the feasible reductions in residuals can be achieved at relatively low cost. Larger farms tend to have lower abatement costs as the percentage reduction in residuals increase. The attempt to reduce more than one of the residuals simultaneously is complicated by the conflicting effects of alternative manure management systems on ammonia and nitrogen levels.

INTRODUCTION

The process of raising livestock on farms incurs with it the inevitable production of manure. This manure is most often applied to farmland soils as a replacement for inorganic fertilizers in field crops, thereby providing a benefit to the farmer net of the costs of handling and applying the manure. However, manure can also impose significant off-farm costs as it can also be a major cause of both air and water pollution when handled and applied under the wrong circumstances (Westenbarger and Letson 1995). The main pollutants of concern in these cases include nitrate and phosphate contamination of ground and surface waters and gaseous...
ammonia losses contributing to odor complaints (and to a lesser extent, air, land and water pollution). These pollution problems have become much more of a growing concern in today’s society for two main reasons. The first is that the manure is concentrated on fewer farms leading to potentially larger problems associated with a spill or complaint. The second reason is that there are likely to be more complaints as the number of nonfarm rural residents continues to grow at such a rate that they have a majority voice over rural issues and pollution concerns in many municipalities. Thus, producers and policy makers are looking for economically efficient means to reduce the environmental impact of livestock waste.

There is an increasing need to provide better information on how induced changes in manure management systems and practices on livestock farms can achieve pressing environmental objectives while balancing the concerns for the economic welfare of both farmers and society at large. Existing literature on manure management has tended to employ a “partial-farm approach” that focuses on only one aspect of the problem such as manure value for use in crop production (Stonehouse and Narayanan 1984; Fleming et al 1988; Roka and Hoag 1996), or cost implications of installing different manure handling systems on farms (Narayanan and Stonehouse 1981; Kelland and Stonehouse 1984; Landreville 1987; Lazenby 1995; Fleming and Stoner 1982; Boland et al 1998; Boland et al 1999). Very few studies have tried to incorporate a whole-farm approach whereby all of livestock production decisions, cropping decisions, manure disposal decisions and environmental implications are evaluated simultaneously.

The purpose of this paper is to evaluate the economic–environmental tradeoffs stemming from manure management decisions for a swine finishing operation. A whole-farm approach is used here because decisions on the manure waste can have repercussions on the remaining aspects of the operation. The impacts of alternative management systems are presented in terms of tradeoff curves that illustrate the economic impacts to producers in monetary terms and the health impacts to the environment in physical indicator terms. The tradeoffs between the various dimensions of sustainability for livestock farmers are thus transparent and decision makers can place alternative weights on those dimensions in determining the appropriate balance between the health of the environment and the farm economy. The environmental indicators are gaseous ammonia, excess nitrogen and excess phosphorus, and the economic indicator is net returns. The study also attempts to ascertain the extent to which key economic variables affect the optimal choice of farm production and manure disposal activities on the model swine farm.

CONCEPTUAL MODEL

The optimal social level of a good such as livestock manure occurs where its marginal social costs are equated with the marginal social benefits of an additional unit of production. The use of a benefit–cost framework to determine the optimal level of manure and associated management system requires the use of nonmarket valuation techniques for each specific locational issue that may not be feasible with the human capital and budget resources of a given research team (Weersink et al 2001).

An alternative to the benefit–cost framework in quantifying the impact of agricultural production on the environment is the use of tradeoff frontiers. Quantifying tradeoffs is an essential ingredient in setting research priorities, and tradeoff assessment provides an organizing principle and conceptual model for the design and organization of multidisciplinary research projects to quantify and assess the sustainability of agricultural production systems.
(Crissman et al 1998). Antle and Heidbriak (1995) argue that plotting economic indicators (in monetary terms) against environmental indicators (in physical terms) for alternative productions systems is a preferred method for presenting information to policy makers on the economic problems related to the sustainability of farming systems. Systems on the frontier of the tradeoff curve represent the management choices that are “efficient” in producing a given level of environmental health for the greatest farm returns. The slope of the curve indicates the extent of the opportunity costs on one indicator when the other dimension of sustainability is increased. The tradeoffs between the various dimensions of sustainability are transparent, and decision makers can place alternative weights on those dimensions in determining the appropriate balance between the health of the environment and the farm economy.

**EMPIRICAL MODEL**

The tradeoffs evaluated in this study are between environmental quality in the form of manure nutrient residuals (gaseous ammonia, excess nitrogen applied to cropland, excess phosphorus applied to cropland) emitted into the environment and net returns for a hog finishing operation stemming from alternative manure management systems. Thus, the tradeoff curves in this analysis are positively sloped because total emitted manure residuals is measured rather than environmental quality.

Data for the tradeoff analysis are generated through an optimization model that identifies the farm return-maximizing solutions for a model farm while varying the type of manure management practices in place. The model farm to which the optimization technique is applied is assumed to be a hog finishing operation in Ontario. Four different enterprise sizes are modeled based on swine accommodation capacities of 200 (small), 500 (medium), 1,000 (large) and 5,000 (extra large) per 100-day hog finishing cycle. Total manure produced per annum is the product of daily manure output/pig, number of pigs/enterprise, and number of cycles/year. Composition of manure is a function of the feed ration, as well as starting and finishing weights of the pig. Excretion rates of N, P and K in the manure for different pig weights are predicted using de Lange (1999).

In addition to hog numbers finished, another choice variable in the model is the manure handling system. There are 27 possible handling systems based on a combination of each of three possible alternatives for collection, storage and application of liquid manure. The three collection methods for manure are:

- by gravity through fully slatted floors or
- through partially slatted floors to below-floor temporary storage (flush gutter) or
- by scraping of solid concrete floors to storage.

The distribution of Ontario hog farms using these collection systems was 52% for gravity, 29% for flush gutter and 19% for mechanical scraper (Bradshaw 2000). The three storage choices are:

- an earthen pit (lagoon) or
- an above-ground, open-topped concrete tank or
- an above-ground, covered concrete tank, which could include an under-barn pit.

About 12% of Ontario hog farmers use the earthen pits, 48% use an open concrete tank, and 40% use an under-barn pit or covered concrete tank (Bradshaw 2000). Each storage option is assumed to be large enough to hold the annual volume of manure produced. The field application of manure is either by:

- application of manure to cropland (gaseous ammonia emissions are neglected)
- application of manure to pasture
- application of manure to waste water treatment ponds
- application of manure to lagoons
- application of manure to ponds for anaerobic digestion
- application of manure to nutrient management programs
- application of manure to crops that are not grown
- application of manure to other agricultural fields
- application of manure to waste water treatment ponds
- application of manure to lagoons
- an irrigation gun
- a tanker broadcaster
- a tanker injector.

The distribution of Ontario hog farmers with liquid manure using an irrigation gun is 30%, 57% for a spreader and 9% for a tank injection (Bradshaw 2000).

The operating and fixed costs for each of these nine alternative handling components are a function of hog enterprise size, which also determines manure volume. Fixed costs are a function only of enterprise size. Ammonia (NH₄), nitrogen (N), and phosphorus (P) loss rates for each handling component are dependent upon manure volume and composition. Gaseous nitrogen losses in the form of NH₄ from volatilization, nitrate leaching and phosphate runoff are predicted for alternative manure composition and handling systems using MCONE4¹ (Manure Systems Research Group 1999). For each of the 27 manure-handling alternatives, costs and residual levels are additive across handling components.

The other choice variable related to manure management system in addition to handling is the hog feeding strategy. A corn–soybean meal is a typical ration for hog finishing farms in Ontario. Two variations of this base ration are also assumed available. One includes the use of lysine, which can replace some of the crude protein in the ration and subsequently reduce the level of nitrogen in the manure.² The other variation adds phytase, which reduces phosphorus emissions in hog manure. While total amount of feed required to get the hog to the desired weight along with manure composition do vary between the rations, carcass quality is not affected. These three hog feeding alternatives are combined with the nine manure handling alternative components (three collection, three storage and three application methods) to result in 81 possible manure management systems from which the farmer can choose. These activities are included in the optimization model as integer variables.

The remaining choice variables in the model are specified as real number activities. In addition to hog numbers, the farmer must chose what crops to grow and whether the nutrient needs for these crops are provided from the manure and/or synthetic fertilizers. Manure application rates are assumed to be set so as not to exceed a maximum cubic metre per hectare loading rate as specified in provincial guidelines (OMAFRA 1999). Where nutrient deficits occur, supplementary synthetic fertilizer can be purchased at market cost. When excess N results, supplementary cropland can be rented in at market cost.³ Crop nutrient needs and potential excesses associated with each system are calculated using MCLONE4 (Manure Systems Research Group 1999). The amount of land for manure disposal and feed crop production purposes was assumed equal to an average of 62% of the hog feed corn requirements. Land is available only in the spring for planting and manure application. Tillable land can be used to grow corn and/or soybeans, each of which can be sold at market prices or retained for feeding the hogs. Soybeans used for feed are crushed into meal first. Any necessary supplemental feed purchases are at market prices.

The objective function is to maximize the return of the hog operation net of the costs and values of handling and utilizing the manure produced through the selection of the choice variables just described above related to manure management system, hog production levels, fertilizer purchases, land rentals, crop production and sales, and feed purchases. Constraints on the model limit the number of hogs and land base. In addition, the constraints account for all manure produced and the level of residuals lost through the production and application of manure. Full details on the parameters of the model and the base solution are provided in Stonehouse et al (2002).
Ammonia–Farm Return Tradeoff

The manure management systems forming the tradeoff frontier between ammonia losses and farm net returns are listed in Table 1 for large and very large farms. Since the same pattern of manure management system points is observed for the other two hog operation sizes, only the large and extra large farm scenarios are reported. While 81 possible manure management systems are considered, only those on the tradeoff frontier are listed in Table 1. Other systems not listed are considered inferior to the manure systems on the frontier because they have lower net farm return levels for similar quantities of ammonia emitted. The individual components making up the 11 and 9 manure management systems in the large and very large farm size categories, respectively, along with their associated farm return and total ammonia loss levels and overall rankings are shown in Table 1. In each case, the manure management systems are shown in order of least to most ammonia losses.

<table>
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<th>Farm size</th>
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<th>Storage</th>
<th>Application</th>
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<th>Ammonia loss (kg)</th>
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<td>I</td>
<td>615.07</td>
<td>23456.72</td>
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<td>64</td>
</tr>
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Feed: 1 — corn–soy base ration, 2 — lysine added, 3 — phytase added.
Housing: SF — solid floors, PS — partially slatted floors, FS — fully slatted floors.
Application: I — irrigation gun, TB — tanker broadcaster, TI — tanker injector.

RESULTS

Ammonia–Farm Return Tradeoff

The manure management systems forming the tradeoff frontier between ammonia losses and farm net returns are listed in Table 1 for large and very large farms. Since the same pattern of manure management system points is observed for the other two hog operation sizes, only the large and extra large farm scenarios are reported. While 81 possible manure management systems are considered, only those on the tradeoff frontier are listed in Table 1. Other systems not listed are considered inferior to the manure systems on the frontier because they have lower net farm return levels for similar quantities of ammonia emitted. The individual components making up the 11 and 9 manure management systems in the large and very large farm size categories, respectively, along with their associated farm return and total ammonia loss levels and overall rankings are shown in Table 1. In each case, the manure management systems are shown in order of least to most ammonia losses.
All manure management systems on the tradeoff frontier use synthetic lysine in the ration because it simultaneously increases farm profitability through enhancing feed efficiency while reducing ammonia levels. Farm returns are maximized through the use of an earthen pit storage and irrigation gun for field application. Solid floors are the preferred housing system on large farms while it is partially slatted floors on the largest farm size. These profit-maximizing systems ranked 74 and 64 in terms of the lowest level of ammonia for large and very large farms, respectively. Regardless of farm size, ammonia levels are lowest in a manure management system consisting of fully slatted floors, a concrete-sealed storage, and a tanker injector for application. The sealed storage prevents the volatilization of nitrogen in the form of ammonia. Such a system ranks 52 and 46 among the 81 choices in terms of net farm returns for large and very large farms, respectively. Thus, there is a tradeoff between farm returns and attempts to reduce ammonia levels.

Using these extreme points on the tradeoff frontier, a large hog farm can cut back its total ammonia emissions for the year by approximately 2,808 kilograms (5,143 to 2,335) at a cost to annual farm returns of approximately $7,980 ($123,600 to $115,620). This difference works out to a hypothetical average abatement cost of $2.84 in net farm returns per kilogram of ammonia contained. In the case of a very large hog finishing operation, the difference between the tradeoff frontier extreme points is 11,782 kilograms of ammonia emitted (23,457 to 11,675) and $29,340 in annual net farm returns ($615,070 to $585,730). Therefore, a switch from the profit-maximizing manure system to the one that minimizes ammonia levels would do so at an average cost of $2.49 in farm returns per kilogram contained, which is slightly lower than the same cost for a large farm. The average cost in reduced returns per hog marketed over the year from the switch in systems is $2.66 for the large farm and $1.96 for the very large farm. The reduction of ammonia under these extreme alterations in manure management systems will lessen the likelihood of odour complaints from neighbors. In addition, such changes will also keep more of the initial nitrogen content in manure thereby increasing its potential value as a fertilizer for crops.

The hog farmer, however, is not restricted to one of these two extreme optimal manure management systems under each farm size scenario. The second and third ranked profit-maximizing systems alter the top-ranked system by switching only the application method from an irrigation gun to tanker broadcast to tanker injection, respectively. The reductions in net farm returns of less than 1% between these systems results in a reduction in ammonia levels of approximately 5%. Relatively small abatement costs are also involved in further reducing ammonia levels through changes in the type of flooring system used. However, abatement costs increase significantly as further decreases in ammonia are achieved through a change in costly manure storage facilities.

**Excess Nitrogen–Farm Return Tradeoff**

Economic–environmental tradeoffs can also be depicted for other nutrient losses emanating from manure use. The management systems on the frontier of this tradeoff curve for excess applied nitrogen (the amount applied over-and-above total corn needs) are listed in Table 2 for large and very large farms. The profit-maximizing system for both farm sizes remains the same but the systems that minimize excess N are significantly different from the one that minimizes ammonia losses. Using a ration with lysine and manure handling system of a solid floor barn with a concrete sealed storage and irrigation application of the manure minimizes
the amount of excess N. While ranking first among the 81 systems in terms of the least amount of excess N, it ranks 58th in terms of ammonia losses. The result illustrates the difficulty in addressing the level of manure residuals. Approaches, such as spreading manure on the field through an irrigation gun, minimize excess N by reducing the N content of the manure but also subsequently increase the level of ammonia emitted.

There are only three management systems along the tradeoff frontier for large farms and four systems for very large farms. The changes between these systems generally involve changing storage facilities. The solid floor barns and irrigation application method release the most ammonia and thus serve to reduce the amount of N in the manure that could be in excess. The profit-maximizing system for large farms generates the fourth least amount of excess N. Moving from this system that generates the greatest net farm returns to the one that minimizes excess N (ranks 25th in profitability), reduces the amount of excess N applied to corn by approximately 357 total kilograms (8.9 kilograms per hectare) at a cost to net farm returns of $4,995 per year. The difference between these two systems is equivalent to a hypothetical average cost of $13.99/kg of excess nitrogen no longer applied (or $1.67 per hog marketed annually). In the case of a very large hog farmer, moving from the system-maximizing net farm returns to the one minimizing excess N reduces the residual by 3,143 kilograms (15.7 kilograms per hectare). This environmental improvement is associated with a reduction in net farm returns of $24,214 or an average cost of $7.70/kg of excess nitrogen no longer applied ($1.61 per hog). This average cost is smaller than that incurred on a large hog finishing operation because there are economies of size in switching between the capital-intensive storage facilities required to abate excess N.

**Excess Phosphorus–Farm Return Tradeoff**

There are only three different excess phosphorus application amounts realized in each hog operation size across the 81 different manure management systems. The choice of feed ration

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Table 2. Optimal manure management systems located along the farm return: Excess nitrogen application tradeoff frontier for large and very large hog finishing farms

<table>
<thead>
<tr>
<th>Farm size</th>
<th>Feed</th>
<th>Housing</th>
<th>Storage</th>
<th>Application</th>
<th>Net farm returns ($000)</th>
<th>Excess N applied (kg)</th>
<th>Farm return ranking</th>
<th>Excess N ranking</th>
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</thead>
<tbody>
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</table>

Feed: 1 — corn–soy base ration, 2 — lysine added, 3 — phytase added.
Housing: SF — solid floors, PS — partially slatted floors, FS — fully slatted floors.
Application: I — irrigation gun, TB — tanker broadcaster, TI — tanker injector.
is the only component that affects excess P levels because there are no assumed aerial or water losses of P throughout the manure handling system. The two manure management systems on the frontier for large and very large hog farms along with their associated farm return and excess applied P levels and rankings are shown in Table 3. The two systems on the frontier use the same manure handling components for the profit-maximizing systems discussed earlier and either a ration with lysine or phytase. Changing between these two rations reduces excess P applied to corn by approximately 550 total kilograms for large hog farms. The cost to net farm return for this adjustment in feed ration is $3,934, implying an average cost of $7.15/kg of excess phosphate (or $1.31 per hog). A similar change in hog feed ration would reduce total excess P applied by 2,748 kilograms at a cost to annual net farm returns of $19,668 on very large farms. The associated average abatement cost of $7.16/kg of excess P applied (or $1.32 per hog) is only slightly larger than the same cost on a large operation.

Comparison of Abatement Costs
The preceding analysis identified optimal manure management systems for each of the two-dimensional operation goals of maximizing farm return levels and minimizing one of the negative manure residuals of ammonia emissions, excess N applied, or excess P applied to cropland. The differences in abatement costs between the systems on the frontier for each of the three manure residuals are illustrated in Figure 1 for large hog farms. The general pattern of abatement costs across residuals is similar between large and very large farms but the bigger farms do tend have lower abatement costs particularly for small reductions in emission levels.

There are several points to note by comparing the abatement costs in Figure 1. First, the residuals cannot generally be reduced by more than approximately 50% from the levels generated under the profit-maximizing system. Excess N can only be lowered by around 30% at a maximum on large farms. Further reductions would require changes in hog numbers to reduce the volume of manure and consequently residual levels. Second, phosphorus is the least expensive manure residual to reduce through manure management system changes. The approximate 50% reduction in excess P can be achieved by including phytase in the ration at cost of around 3% of net farm returns. Third, the relatively steep abatement curve for reduc-

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Table 3. Optimal manure management systems located along the farm return: Excess phosphorus application tradeoff frontier for large and very large hog finishing farms

<table>
<thead>
<tr>
<th>Farm size</th>
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<td>2366.00</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2 PS</td>
<td>EP</td>
<td>I</td>
<td>1</td>
<td>609.93</td>
<td>5114.00</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Feed: 1 — corn–soy base ration, 2 — lysine added, 3 — phytase added.
Housing: SF — solid floors, PS — partially slatted floors, FS — fully slatted floors.
Application: I — irrigation gun, TB — tanker broadcaster, TI — tanker injector.
Figure 1. Abatement costs for reductions in manure residuals on large hog finishing farms through manure management system alterations.
ing excess N suggests it is the most expensive manure residual to lower through manure management system alterations. The three discrete optimal options available to a large hog farmer for this residual are to retain the status quo, to reduce excess N applied by 24% at an abatement cost of $3,577 (3% of net farm returns) or to reduce excess N applied by 34% at an abatement cost of $4,995 (5% of net farm returns). Finally, the abatement costs for reductions in ammonia emissions are the lowest among the three residuals for small percentage reductions. In the case of ammonia, there are more systems on the frontier available to choose. However, the costs rise significantly as the desired reduction increases because a switch to more costly storage facilities is required.

**Sensitivity Analysis**

The choice of manure management systems on the economic–environmental tradeoff frontier depends on model assumptions regarding technical coefficients and prices. The following discussion details some of the results obtained from the model in the dual solution to the primal objective function. Since a mixed integer programming model is used, there is a different sensitivity interpretation of the model objective values for each of the 81 possible manure management systems in a certain sized hog operation. However, rather than discussing all possible systems, the sensitivity results are analyzed for the two systems that maximize and minimize net farm returns. Evaluating only these extremes provides the relative bounds of the sensitivity analysis. The results of the analysis are listed in Table 4, which shows the initial assumed objective values along with the range of values before a change in the optimal solution is induced. Where a range is given for a certain allowable increase or decrease figure in Table 4, this range exists due to differences in the type of manure management system in place and represents the bounds of the farm return maximizing and minimizing choices.

**Selling Finished Hogs**

An increase in the selling price of hogs increases farm returns but will not affect the optimal choice of activities in the solution (Table 4). However, with a decrease in sale price from $31 to $33 per hog depending on the manure management system in place, it is no longer optimal for the farmer to produce hogs up to the full capacity. The drop in production is large enough to cause a new activity (the purchase of supplemental inorganic nutrients for the required amount of crop production) to enter the optimal objective function basis. A 100% cutback in hog production results from a drop in selling price of $35–$36 per hog, so the breakeven selling price of hogs in this analysis is approximately $90 per hog, assuming a constant purchase price of $45 per weaner.

**Required Nutritional Components for Feeding Hogs**

The cost of all feed components evaluated can become smaller (less negative) and not affect the optimal solution (i.e., hogs will still be produced up to full capacity, thereby producing the same amount of manure for the corn crop acreage in use). The increase in any component price necessary to prompt a change in the optimal decision is much larger than the initial prices. Thus, the prices of feed components have little effect on the choice of manure system.

**Handling Manure**

Under the conditions developed for the hypothetical hog farm created for this study, it is assumed that the per cubic metre costs of handling manure are zero. This is assumed because
manure production is a result of raising hogs, and the only variable costs associated with its handling occur in its application to farmland. If farmers received added value for each unit of manure produced, it does not affect the optimal choice of activities due to binding capacity constraint on production levels. However, if the cost on manure production and handling activity rise to around $70 per cubic metre, the farmer cuts back hog production.

Growing Corn and/or Soybeans on Owned Farmland (on which manure is applied)
The optimal model solution has the hypothetical hog farmer planting all available land used for manure disposal to corn. For each unit of farmland that is substituted to planting soybeans instead of corn, net farm returns decrease by roughly $285.96. If the per hectare cost of planting corn increases to $548.46 per hectare or if the per hectare cost of planting soybeans decreases to –$64.08 per hectare, the optimal farm solution involves planting all available acreage to soybeans. Neither of these crop input cost changes are likely, however, in such a large quantity.

Selling, Feeding and Buying Corn, Soybeans and Soybean Meal
The farm return-maximizing choice of activities has all owned cropland planted to corn and then sold. The farmer purchases all corn and soybean meal feed requirements. The minimum increase figures on buying both corn and soy meal are exactly equal to the difference between the present purchase prices and selling prices of these feed ingredients (see Table 4). If the feed purchase price or farm selling price of corn decreases by $0.008/kg or if the feeding cost of corn decreases also by $0.008/kg, the optimal choice of farm activities instead is to feed all farm-produced corn and purchase any shortfalls. Thus, the changing from selling farm-produced corn to feeding is very sensitive to small changes in corn price.

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**Table 4. Sensitivity of optimal model solutions to various objective function values**

<table>
<thead>
<tr>
<th>Model activity</th>
<th>Objective value assumed</th>
<th>Minimum increase</th>
<th>Minimum decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sell finished hogs</td>
<td>$125.00/hog</td>
<td>∞</td>
<td>$31–$33/hog</td>
</tr>
<tr>
<td>Feed ration components:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed requires limestone</td>
<td>–$0.035/kg</td>
<td>∞</td>
<td>$11–$13/kg</td>
</tr>
<tr>
<td>Feed requires dicalcium phosphate</td>
<td>–$0.46/kg</td>
<td>∞</td>
<td>$9–$14/kg</td>
</tr>
<tr>
<td>Feed requires premix (with or without added phytase)</td>
<td>–$2.235/kg vs. –$2.915/kg</td>
<td>∞</td>
<td>$16–$17/kg</td>
</tr>
<tr>
<td>Feed adds lysine</td>
<td>–$2.325/kg</td>
<td>∞</td>
<td>$132–$133/kg</td>
</tr>
<tr>
<td>Handling manure</td>
<td>$0/m³</td>
<td>∞</td>
<td>$68–$72/m³</td>
</tr>
<tr>
<td>Grow corn on owned farmland</td>
<td>–$262.50/ha</td>
<td>∞</td>
<td>$285.96/ha</td>
</tr>
<tr>
<td>Grow soybeans on owned farmland</td>
<td>–$221.88/ha</td>
<td>$285.96/ha</td>
<td></td>
</tr>
<tr>
<td>Sell corn produced on-farm</td>
<td>$0.12575/kg</td>
<td>∞</td>
<td>$0.008/kg</td>
</tr>
<tr>
<td>Feed corn produced on-farm</td>
<td>–$0.022/kg</td>
<td>$0.008/kg</td>
<td></td>
</tr>
<tr>
<td>Purchase off-farm corn for hog feed ration</td>
<td>–$0.14075/kg</td>
<td>$0.015/kg</td>
<td>$0.105/kg</td>
</tr>
<tr>
<td>Sell soybeans produced on-farm</td>
<td>$0.24/kg</td>
<td>$0.121/kg</td>
<td></td>
</tr>
<tr>
<td>Feed soy meal produced from on-farm soybeans</td>
<td>$0/kg</td>
<td>$0.105/kg</td>
<td></td>
</tr>
<tr>
<td>Purchase off-farm soy meal for hog feed ration</td>
<td>–$0.25583/kg</td>
<td>$0.015/kg</td>
<td>$0.105/kg</td>
</tr>
</tbody>
</table>
All soy meal feed requirements are purchased in the optimal farm solution with no soybeans grown on-farm. If the cost of buying soy meal increases by $0.105/kg or if the cost of feeding soy meal decreases by $0.105/kg, all farmland would be switched to producing soybeans which would then be used as feed-ready soy meal through the crushing process. The required price increase on the soybean selling activity, however, is higher than the previous two price changes. In the case of farm-grown soybeans, the price must rise by $0.121/kg in order to prompt farmers to put all acreage into soybean production and then sell these raw soybeans, only to purchase all soy meal feed requirements.

CONCLUSION

While all livestock farmers are under increasing scrutiny to reduce the level of residuals associated with the raising of animals, the pressures are greatest for hog farmers. This study examines the cost effectiveness of 81 alternative manure management systems for a swine finishing operation in reducing three pollutants associated with livestock waste: ammonia, nitrogen and phosphorus. The results are presented in terms of the tradeoff between the levels of these pollutants (environmental indicator) and the economic returns to the producer. The efficient systems on the tradeoff frontier represent the management choices that produce a given level of environmental health for the greatest farm returns. Such information is necessary to both producers and policy makers when addressing economic problems related to the sustainability of livestock systems such as optimal practices and abatement costs.

The levels of the three manure residuals cannot be reduced by more than half from the present levels under the profit-maximizing system for each farm size. Further reduction would require changes in hog numbers to reduce the volume of manure and consequently residual levels. However, the feasible reductions in residuals can be achieved at relatively low cost. For example, the 50% reduction in excess phosphorus can be achieved by including phytase in the ration at a cost of approximately 3% of farm returns. The costs of reducing gaseous and liquid forms of nitrogen are relatively small for initial reductions but increase significantly, as the desired reductions increase as a switch to more costly storage facilities is required. Thus, larger farms tend to have lower abatement costs as the percentage reduction in residuals increase.

The difference in abatement costs between farm sizes could have major implications for the economic viability of smaller swine enterprises. Pending nutrient management legislation in Ontario recognizes the potential effects by allowing smaller producers a longer period of time to adapt to forthcoming policy restrictions. However, no explicit recognition in the form of sharing the economic burden of meeting the restriction between the public and farmers (regardless of size) has yet been considered. Policy makers need to be aware of the economic–environmental tradeoffs when deciding upon both the allowable level of manure residuals, which influences abatement costs, and the extent of abatement costs, which differ between farm sizes, if a compensation program is to be considered to offset those costs.

The attempt to reduce more than one of the residuals simultaneously is complicated by the conflicting effects of alternative manure management systems on ammonia and nitrogen levels. The systems that minimize gaseous losses of nitrogen (ammonia) subsequently increase the nitrogen content of the manure and thus increase the likelihood of excess nitrogen moving into waterbodies. While the choice of manure system is not sensitive to changes in crop price, the farmer choice of crop mix and also whether he/she sells or feeds the crop
production is very dependent on relative buying, feeding and selling prices of corn, soybeans and soy meal. More research work is needed, based on data drawn from actual hog finishing operations across a range of sizes and different manure-handling systems, feed rations and land use regimes in order to corroborate this study’s findings for a series of hypothetical farms.

NOTES

1 MCLONE stands for Manure, Costs, Labor, Odors, Nutrients and Environment. It is a computer-based, decision support system developed to help farmers in their manure utilization decisions.

2 Fiber should be added to a ration with lysine to ensure carcass quality is not affected. This adjustment, pointed out to us by a Journal reviewer, was not incorporated into the costs. However, the additional costs would not be large relative to total costs and would have had little effect on the results.

3 The cost of transportation is negligible because it is assumed the available rental land is nearby. Fleming et al. (1998) consider the effect of transportation costs on the management decisions and Fleming and Long (2002) examine the effect on manure costs if application is restricted to relatively flat regions, which may not be close to livestock production.

REFERENCES


