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Odor management in swine finishing operations: Cost effectiveness

Haixiao Huang[1*], Gay Y. Miller[1], Michael Ellis[2], Ted Funk[3], Yuanhui Zhang[3], Gilbert Hollis[2] and Albert J. Heber[4]

*[1]Department of Veterinary Pathobiology, University of Illinois, Urbana, IL 61802 USA, [2]Department of Animal Sciences, University of Illinois, Urbana, IL 61801, USA, [3]Department of Agricultural and Biological Engineering, University of Illinois, Urbana, IL 61801, USA, [4]Agricultural and Biological Engineering Department, Purdue University, West Lafayette, IN 47907, USA. * e-mail: hxhuang@uiuc.edu*

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Abstract

This paper examines the cost effectiveness of some odor control strategies shown to be important in odor reduction from swine finishing buildings. Strategies examined include manure depth reduction, manure storage type (deep pit vs. shallow pit), air treatment and pig density. The efficiency of each management strategy is evaluated for its effect on odor emission rate reduction. The costs of each strategy are annualized and calculated on a per-pig-marketed basis. The cost effectiveness is then the odor emission rate reduction efficiency compared to the cost per pig for implementing that strategy. The study shows that air treatment is the most cost-effective strategy for odor control in swine finishing buildings. The available technologies for improving air quality, according to their cost effectiveness ranking and the associated costs of implementation, are automatic oil sprinkling (rank = 1; cost = $0.51/marketed hog), diffusion-coagulation-separation (DCS) dedusting (rank = 2; cost = $0.66/marketed hog), evaporative misting (rank =3; cost = $0.30/marketed hog), wet scrubbing (rank = 4; cost = $0.54/marketed hog), and manual oil sprinkling (rank = 5; cost = $0.87/marketed hog). The results indicate that draining shallow pit systems once a week (rank = 7, cost = $0.06/marketed hog for draining shallow pit weekly) and increasing floor space allowance per pig (rank = 9, cost = $2.22/marketed hog for a 10% increase in pig floor space allowance) are less cost effective than air treatment technologies. Another interesting result is that when deep pit swine finishing systems and shallow pit buildings with outdoor anaerobic treatment systems are compared, the former are more advantageous than the latter in odor management if manure is removed from the deep pit twice or more frequently a year. The cost-effectiveness of deep pit systems as an odor management strategy (cost = $0.63/marketed hog relative to shallow pit with a lagoon systems) compared with the other strategies examined is ranked the 6th when manure is removed from the pit three times a year and ranked the 8th when manure is removed from the pit twice a year.

Key words: Odor management, odor reduction strategy, cost effectiveness, swine finishing building.

Introduction

Swine production is integral to U.S. agriculture and plays an important role in the economies of key hog producing states in the Unite States. Odor generated from large, intensive swine production facilities has become a public concern due to its nuisance effects and its potential harmful impact on the environment and property values, as well as on human and pig health [1-5]. Although many odor control strategies have been developed to reduce odor emissions, it is important to know how effective these approaches are in terms of odor reduction efficiency in relation to their cost. An examination of the effectiveness of odor abatement technologies is complicated and hampered by the difficulty in odor assessment using the subjective human nose [6]. Also, many odor control strategies are simultaneously applied, so the isolation of their individual effects on odor control requires careful statistical analysis.

Miller et al. [7] examined the effects of different practices and building characteristics controlled by management on odor emitted from pig finishing buildings. Both uncontrollable (such as season, panelist, ambient temperature and relative humidity) and controllable variables (such as pig space, air quality and manure depth) that affect odor emission rates of pig finishing barns were included in their analyses. The results of their study showed that greater floor space per pig, air treatment, shallower manure depths and the use of deep pits reduced odor emission rates of swine finishing buildings (Table 1). The purpose of this paper is to investigate the cost effectiveness of odor control strategies identified to be important in reducing odor emission rates by Miller et al. [7].

There is virtually no formal research comparing the cost effectiveness of different odor control technologies and management strategies available for swine production facilities based on odor reduction. O'Neill et al. [8] provided a useful review of earlier research on the costs of odor abatement technologies applied to livestock facilities. The existing related economic analyses generally feature the reporting of construction and operating costs of a technology or management system consisting of itemized investments and annual fixed and variable costs [9-11]. Bennett et al. [9] conducted an economic analysis of two waste handling systems (lagoon and concrete liquid tank) available to Missouri dairy producers for different herd sizes. Similarly, Rausch and Sohngen [10] compared the costs and benefits of three typical manure handling systems designed for an 80 to 100 cow dairy in Ohio. These systems were (1) an earthen holding pond using drag-line direct injection; (2) an earthen holding pond using a liquid tank for manure application and (3) a stack pad using a conventional dry manure spreader. The costs of owning and operating each system included items such as construction costs, equipment and labor. The benefits of each system were defined solely in terms of the value of manure nutrients for growing crops. Zhang [11] showed that sprinkling oil on a regular schedule could reduce respirable dust (particle size less than 5.0 µm diameter) by approximately 80% and inhalable dust (all particles inhaled) in the air by about 85%. The cost to achieve these improvements for a facility marketing 4,000 pigs per year was approximately $1.14 per pig marketed, of which 70% was labor cost. The cost effectiveness of a technology or management strategy in terms of odor reduction, however, was beyond the scope of their research.

Odor Measurement in Swine Finishing Buildings

Odor measurement in swine finishing buildings in this study was obtained from Miller et al. [7], in which olfactometry analysis was employed to evaluate the odor emission rates of swine buildings. Air samples were collected at both the air inlets and the exhaust fans of swine barns. The log of the geometric means of the dilution ratio at detection for samples was used as measures of sample odor concentration (OU/m^3). The contribution of the building to odor was defined as the logarithm of the difference between exhaust and inlet odor concentrations while odor emission rates of the building were obtained by multiplying this odor concentration difference by the estimated building ventilation rate.

The results of Miller et al. [7] (Table 1) provide the marginal contribution to odor emission rates for factors related to controllable management strategies. For instance, the marginal impact of a deep pit building relative to a shallow pit building (-0.17) means that the odor emission rate measured in a deep pit building, holding other factors the same, is 0.17 log OU/h lower than that in a shallow pit building. Likewise, the marginal impact of pig space on odor indicates that an increase of one m-^{2} in floor space per pig decreases the odor emission rate by 0.25 log OU/h; the marginal impact of manure depth is 0.26 log OU/h, suggesting that one additional meter of manure depth increases the odor emission rate of the barn by 0.26 log OU/h; and improving observed air dustiness measure by one decreases odor emission rate by 0.07 log OU/h. The efficiency of each odor management strategy evaluated will be based on these marginal values.

Table 1. Effects of controllable factors on odor emission rates of swine finishing buildings.*

Controllable factors	Marginal effect (log OU/h)	P – value
Manure depth (m)	0.26	<0.0001
Pig floor space allowance (Square meters / pig)	-0.25	<0.0001
Deep pit building compared to shallow pit building	-0.17	0.0014
Air quality	0.07	<0.0001

*Data adapted from Miller et al. [7]

Definition of Cost Effectiveness Analysis

Cost effectiveness analysis has been widely used to compare the efficiency of different pollution abatement options for setting effluent limitation guidelines and for developing standards. The U.S. Environmental Protection Agency (EPA) defines cost effectiveness of a policy option as the incremental annualized cost of the option divided by the amount of pollutant removed annually by that option measured in physical terms [12]. In order to be consistent with the common practice in the livestock economic literature, the incremental annualized cost of an odor management strategy is measured in terms of the increase in production costs per marketed hog resulting from the application of the strategy. In addition, we deviate from the EPA definition by directly using the marginal reduction in odor emission rates rather than the amount of odor removed annually because of the difficulty in measuring the annual incremental reduction in odor emissions. Hence, the cost effectiveness of a controllable management strategy in this study is defined as the ratio of the total impact of the strategy on the odor emission rate of a swine building to the incremental annualized cost of the strategy described on the basis of per marketed hog. Therefore, cost effectiveness analysis in this paper evaluates the marginal reduction in odor emission rates relative to the increase in production costs per market hog sold due to the application of an odor management option. This definition can be written as: Cost effectiveness = Marginal reduction in odor emission rate (log OU/h) /Increase in production costs per hog sold ($/hog). For instance, automatic oil sprinkling can lead to a decrease of 0.42 log OU/h in the odor emission rate and the cost of the strategy is $0.51 per marketed hog; so the cost effectiveness of this strategy is 0.82 log OU/h per $ per marketed hog. That is, a $1 increase per marketed hog in expenditures on automatic oil sprinkling will reduce the odor emission rate contributed from swine barns by 0.82 log OU/h.

Odor Control Strategies and Their Cost Effectiveness

As already noted, this study focuses on odor control strategies previously identified by Miller et al. [7] as important in reducing odor emission rates from swine finishing buildings. Specifically, these strategies include: (1) increasing square meters per pig, (2) improving air quality in the barn, (3) reducing manure depth in the building storage and (4) choosing a deep pit swine finishing system compared to a shallow pit and outside anaerobic storage system. The underlying assumptions and associated calculations for each of these strategies are separately presented below.

Cost effectiveness of increasing square meters per pig: Increasing square meters per pig results in a decrease in the number of hogs marketed and hence reduces returns to hog production. That is, there is an opportunity cost of using floor space for odor management. This opportunity cost can be measured as the reduction in returns to production less operating costs. Consider a typical 1,020 head finishing barn with a floor space allowance of 0.74 m^2 per pig [13], a mortality rate of 2.8% [14] and 2.8 pigs marketed per pig space per year [15]. Under these production conditions, this barn produces 2,776 marketed hogs/yr. Assuming that the odor management strategy is to increase square meters per pig by 10%, pig space then becomes 0.81 m^2/pig, leading to a reduction of 252 marketed hogs/yr. Returns to production less operating costs in the corn belt region over the period 1997-2001 were $11.71 per 45.36 kg (100 lb) weight gain [16]. Assuming that the average weight of feeder pigs entering the barn is 26.8 kg and the average market weight is 113 kg [14], the total weight gain per marketed hog is 86.2 kg, generating a return to production less operating cost of $22.25/ marketed hog. The total opportunity cost of a 10% increase in square meters per pig is $5,607/yr, or $2.22 per marketed hog. The efficiency of a 10% increase in square meters per pig is 0.25*0.07 = 0.02 log OU/h. Therefore, using the estimated cost of increasing square meters per pig ($2.22 per marketed hog), the cost effectiveness of this strategy is 0.01 log OU/h per dollar per marketed hog.

Cost effectiveness of improving air quality: Odorous dust plays a major role in odor dispersion. It is not surprising that improved air quality, measured as subjective impressions of air dustiness on a scale of 1 (very clean) to 10 (very dusty), was associated with lower odor emission rates.

Regularly sprinkling oil has proven to be an effective approach to dust and odor control in swine barns [11]. As mentioned earlier, based on a sprinkling schedule recommended by Zhang [11] for swine finishing buildings, 80-85% dust can be removed. It was estimated that the annual costs arising from sprinkling a facility of two barns with a floor area of 929 m-^{2} (1,130 head) each consisted of the following: $120 for a backpack sprayer, $1,320 for oil (2,498 L at $0.53/L), $3,600 for labor (1.0 person-hour to sprinkle, 360 hours at $10/h), and $300 for extra cleaning time (30 h at $10/h) [11, 17]. The total annual cost thus becomes $5,340. Again, assuming 0.74 m^2/pig space and total pig space accounting for 90% of the total floor area [18], allowing a total placement of 2,260 pigs, mortality rate of 2.8%, and 2.8 pigs/yr per pig space, 6,151 hogs would be produced from the two 929 m^2 swine finishing barns, giving an estimated cost of $0.87 per marketed hog. The cost can be reduced by installing an automatic oil sprinkling system [19]. The capital cost of the system is less than half of the labor assuming a ten-year service life. The estimated cost of automatic oil sprinkling is $0.51 per pig marketed.

Dedusters are another effective device for dust removal. The installation of dedusters entails additional capital and operating cost. Wet scrubber systems remove 20-60% of the dust depending on ventilation rates [1]. Capital costs for a wet scrubber system were estimated at $5.70 per pig space for an 880 head finishing barn [1]. The main operating cost was the 746-watt (1 horsepower) water pump, which would have an annual cost of about $600. Since most of the water is recycled, water usage is very low [1]. Therefore, costs of extra storage, transport and land application for the wastewater from the wet scrubber can be neglected. Given 2.8 cycles per pig space, mortality rate of 2.8%, interest rate of 4%, 10 years of functional life and straight-line depreciation, the capital cost is estimated to be $0.29 per marketed hog. The additional operating cost is about $0.25 per pig marketed. Therefore, the total cost is $0.54 per pig marketed. Diffusion-coagulation-separation (DCS) systems remove 80-90% of the dust emissions from swine buildings [20]. The cost of using a DCS system is estimated at $0.66 per pig marketed, of which the capital and operating costs are $0.51 and $0.15 per marketed hog, respectively. In addition, an evaporative misting system can also improve indoor air quality. Takai and Pedersen [21] found that spraying of water can lead to a total dust reduction of 29% in the barn. The installation of such systems costs only $0.30 per pig marketed and their operating costs are negligible [22].

Sprinkling oil improves air quality in the barn by suppressing aerosolization. As noted earlier, air quality is measured on a scale of 1 (very clean) to 10 (very dusty). Based on the efficiency of the strategy in terms of dust removal, we assume that sprinkling oil can lead to a lower air quality ranking by 6 units. This may not be true if the air quality of a barn is measured as 5 or lower. In this case the effect of sprinkling oil is likely to be lower; also it is less likely that systems with above average air quality will implement such technologies. Since the marginal impact of air quality on odor reduction is 0.07 log OU/h, the total impact of sprinkling oil on odor reduction is assumed to be 0.42 log OU/h. Hence, the cost effectiveness of sprinkling oil is 0.48 for manual oil sprinkling and 0.82 log OU/h per dollar per marketed hog for an automatic sprinkling system.

Similarly, according to their dust-removal efficiency, wet scrubbers and DCS systems are assumed to decrease the air quality measure by 4 and 7, respectively. Their odor reduction efficiency is then 0.28 and 0.49 log OU/h, and their cost effectiveness is 0.52 and 0.74 log OU/h per dollar per marketed hog, respectively. An evaporative misting system is assumed to reduce the air quality measure by 3 on average considering its relatively modest efficiency of dust removal. The efficiency of a misting system then is 0.21 log OU/h and its cost effectiveness is 0.70 log OU/h per dollar per marketed hog. The ranking of the five strategies associated with improving air quality is: automatic oil sprinkling > DCS dedusting > evaporative misting > wet scrubbing > manual oil sprinkling, where the symbol ">" means "is preferred to". It should be noted that what we have obtained here is our best estimates of the cost effectiveness measures in case that the dust removal efficiencies of those air quality improving technologies can be fully realized. These measures can be interpreted as the potential cost effectiveness that the technologies examined can achieve.

Cost effectiveness of reducing manure depth in shallow pit systems: Manure contained in the pit below the pigs is a source of odor emissions from swine buildings [23]. Reducing manure depth in indoor manure storage helps to reduce odor emission rates of swine barns. The strategy of reducing manure depth is limited to shallow pit systems. Deep pit systems may be associated with lower building and total farm odor than farms with shallow pits plus outdoor storage. Also, manure in a deep pit is generally pumped out in the spring and the fall and there is no outside manure storage. Failure to pump during these seasons is often because of events beyond the producer's control. For shallow pit systems, reducing manure depth is simply a matter of scheduling. Neglecting the additional power consumption resulting from the influence of the temperature differential between the recycled lagoon water in the pit and the barn temperature, each draining of a shallow pit system is estimated to cost 30 minutes of labor to monitor the process and $1.50 in electricity for a 1,020 pig space barn. Assuming that labor costs $10 per h [17] and the pit is flushed weekly, the total annual cost is $338. The cost for reducing manure depth is $0.12 per pig marketed.

Since cost effectiveness is based on comparisons, the efficiencies and costs of two alternative manure depth reducing strategies are compared. The two alternatives considered here are flushing the pit weekly versus biweekly. Based on the American Society of Agricultural Engineers Standard [24], pigs in the finishing stage produce about 0.0848 m^3 of raw manure per 1,000 kg liveweight per day. Assuming that water wastage adds 20% to the fecal accumulation in the finishing barn [25], every 1,000 kg of animal weight produces 0.1018 m^3 of slurry manure per day. Under the production conditions assumed earlier, on average, manure depth in the pit will increase by about 0.05 m every week. Assuming that the pit is flushed weekly and recharged with 0.3 m recycled lagoon effluent after each flush, the depth of manure (a mix of lagoon water and manure) is 0.35 m when the pit is flushed once per week. If the pit is drained every two weeks, manure depth will be 0.40 m before flushing. That is, flushing the pit weekly can lead to a 0.05 m reduction in manure depth. Therefore, the efficiency of weekly flushing compared with biweekly is 0.26*0.05 = 0.01 log OU/h.

The annualized cost difference between the two strategies, based on our estimation in the previous section, is \$0.12 - \$0.06 = \$0.06 per pig marketed. Hence, the cost effectiveness of weekly flushing compared with biweekly flushing is 0.17 log OU/h per dollar per marketed hog.

***Cost effectiveness of deep vs. shallow pit systems*:** A thorough comparison between deep pit and shallow pit systems from an odor and manure management perspective is a complex topic. Our focus here is on the comparison of facility costs between the two systems and the conditions for deep pit buildings to have a comparative advantage in odor management over shallow pit buildings. It is interesting to note that when the contribution of manure depth to odor is accounted for, deep pit buildings would generally have a lower odor emission rate than shallow pit buildings. However, the odor advantage of deep pit over shallow pit buildings can be reversed if manure depth in a deep pit building is 0.65 m greater than in a comparable shallow pit building (Fig. 1). Assuming that a typical shallow pit is recharged with 0.3 m recycled lagoon effluent, the manure depth in the deep pit building that may cause it to have higher odor emissions than a shallow pit building is 0.95 m. Cost estimates (Table 2) indicate that deep pit systems have lower fixed facility cost than shallow pit systems with lagoons and this cost difference is estimated to be \$0.4 per pig marketed.

However, deep pit systems usually have higher costs of land application of the manure than shallow pit with lagoon systems. These cost differences need to be included in the analysis. Based on the manure volume estimated earlier, manure depth in the pit of a swine finishing building will reach 0.95 m in about 19 weeks on average, suggesting that manure should be removed from the pit three times a year for a deep pit building to always be less odorous than a comparable shallow pit building. The total amount of manure that needs to be removed from the pit is 801m^3 on average at each pumping or 2,403 m^3 needs to be removed in a year for a 1,020 pig barn. In contrast, on average a shallow pit system with a lagoon will show about twice as much liquid volume over the year because of the additional dilution water as well as rainwater in the lagoon system. However, the costs for manure removal and application depend not only on the volume of manure but also on application methods employed. Generally, manure from deep pits is cropland-injected while lagoon liquid is irrigated. Based on communication with custom applicators and swine farmers, land application costs are \$2.64/m^3 for injection (custom rate) and \$0.66/m^3 for irrigation in the Midwest. Though a shallow pit system with lagoon has a larger volume of material for land application than does a deep pit system with the same operation capacity, manure removal and application costs of a shallow pit system with lagoon are lower than those of a deep pit system (\$1.14/pig marketed vs. \$2.29/pig marketed). Clearly, this cost difference (\$1.15/pig marketed) cannot be offset by the facility cost difference (\$0.4/pig marketed) between the two systems and by the cost of draining a shallow pit (\$0.12/pig marketed) together. That is, when manure removal and land application costs are also taken into account, a shallow pit system with lagoon has an operational cost advantage of \$0.63 per marketed hog over a deep pit system. Keeping manure depth less than 0.95 m in a deep pit may not entail additional costs as long as the manure removal costs depend solely on manure volume, but it requires that manure be removed from the pit three times a year. Assuming that manure is removed from the pit and applied to croplands every four months, the average manure depth over the year in the pit is 0.48 m. The odor reduction efficiency of a deep pit building compared with a shallow pit building flushed once a week then is 0.13 (i.e., 0.17-(0.48-0.33)*0.26) log OU/h. Hence, the cost effectiveness of a deep pit system relative to a shallow pit system with lagoon is 0.21 (i.e., 0.13/0.63) log OU/h per dollar per marketed hog. This of course also assumes no influence from weather or crop cycles that would prohibit land application of manure. It is unlikely that this is technically feasible in much of the Midwest. However, removing manure twice a year from the deep pit still gives deep pit systems an advantage in reduced odor emissions from buildings because the average manure depth in the pit in this case is 0.72 m, which is smaller than 0.95 m, or the depth where deep pit barns are predicted to exceed shallow pit barns in odor emissions. The odor reduction efficiency of a deep pit building relative to a shallow pit building in this case then is 0.07 (i.e., 0.17-(0.72-0.33)*0.26) log OU/h, yielding a cost effectiveness measure of 0.11(i.e., 0.07/0.63) log OU/h per dollar per marketed hog.

Table 2. Facility cost comparison between deep pit and shallow pit finishing systems (per pig space).*

Facility	Shallow pit with lagoon	Deep pit
Construction cost	\$176.25	\$167.50
Fixed costs		
Interest (4% of construction costs)	\$7.05	\$6.70
Taxes and insurance (1.75% of construction costs)	\$3.08	\$2.93
Depreciation (15 year life: 6.7%)	\$11.81	\$11.22
Annual fixed cost per pig space	\$21.94	\$20.85
Facility cost per pig marketed†	\$8.06	\$7.66

*Facility construction cost data are from communication with swine facility construction contractors in Illinois. Other data are from calculation or estimation.
†Assuming a 2.8 turnover rate for each pig space[15] and a 2.8% mortality rate[14].

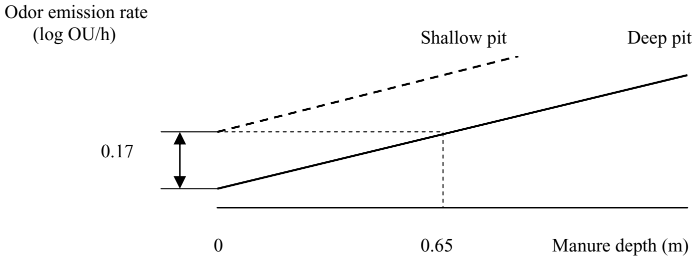

Figure 1. Relationship between manure depth and odor emission rates measured in swine finishing buildings.

Recommendations for Odor Reduction from a Management Perspective

Improving barn air quality is the most cost-effective method to reduce odor emission rates of swine finishing barns (Table 3). The available technologies for improving air quality, according to their cost effectiveness ranking and the associated costs of implementation, are automatic oil sprinkling the barn on a recommended schedule [11] (rank = 1; cost = \$0.51/marketed hog), DCS dedusting (rank = 2; cost = \$0.66/marketed hog), evaporative misting (rank =3; cost = \$0.3/marketed hog), wet scrubbing (rank = 4; cost = \$0.54/marketed hog), and manual oil sprinkling (rank = 5; cost = \$0.87/marketed hog).

Table 3. Cost effectiveness analysis results.*

Odor control strategies	Total effect on odor reduction (log OU/h)	Cost (dollars per marketed hog)	Cost effectiveness (log OU/h per dollar per hog)	Cost effectiveness ranking
Air treatment strategies				
Automatic oil sprinkling	0.42	$0.51	0.82	1
DCS deduster	0.49	$0.66	0.74	2
Evaporative misting	0.21	$0.30	0.70	3
Wet scrubber	0.28	$0.54	0.52	4
Manual oil sprinkling	0.42	$0.87	0.48	5
Deep vs. shallow pit with lagoon systems				
Deep vs. shallow pit building (removing manure from deep pit three times a year)	0.13	$0.63	0.21	6
Deep vs. shallow pit building (removing manure from the pit twice a year)	0.07	$0.63	0.11	8
Reducing manure depth strategies				
Flushing pit weekly vs. biweekly	0.01	$0.06	0.17	7
Floor space management strategy				
10% increase in floor space allowance per pig	0.02	$2.22	0.01	9

*Data from authors' calculation.

The cost-effectiveness of deep pit systems as an odor management strategy compared with the other strategies examined is ranked the 6th when manure is removed from the deep pit three times a year and ranked the 8th when manure is removed from the pit twice a year. The operational cost of deep pit systems is $0.63/ marketed hog higher than that of shallow pit systems with lagoons. But by removing manure from the pit twice a year or more frequently if feasible, deep pit systems have an advantage over shallow pit with lagoon systems in terms of odor emitted from building sources. Moreover, this advantage will become even more evident when odor emissions from lagoon or other outside storage are accounted for. Therefore, when planning new swine finishing facilities, deep pit systems are a better option than shallow pit with lagoon systems from an odor management perspective.

For shallow pits with lagoon swine finishing systems, the results show that draining the pit weekly is the 7th ranked strategy for reducing odor emitted from finishing barns. This strategy increases production cost by $0.06/ marketed hog compared to draining the pit every two weeks.

Finally, increasing square meters per pig in the barn is also a means of odor management [7]. A 10% increase in floor space allowance per pig appears as the 9th ranked strategy for odor control but increases costs of production by $2.22/ marketed hog. Due to its modest efficiency in odor reduction (0.02 log OU/h) and high application cost, this strategy is the least feasible in practice.

It should be pointed out that the cost effectiveness measure in this analysis is limited to a comparison of the efficiency and the cost of implementing a strategy. However, some strategies appear to be not only effective in odor management but also profitable for swine producers. For example, evaporative misting systems can improve the average daily gain (ADG) and feed conversion rate of pigs and hence create additional economic benefits for producers [22]. Oil sprinkling is also beneficial to animal growth. These potential economic benefits are not taken into account in the analysis because they are difficult to be accurately quantified and the effects on pig growth are perhaps quite variable from system to system. In making odor management decisions, strategies that are also economically beneficial are more preferred because they can be more advantageous than suggested in this cost effectiveness analysis.

Conclusions

Odor emitted from swine production facilities is an ongoing problem that poses threats to the sustainability and profitability of the swine production industry. Many technologies and management strategies are available to help control odor emissions from swine facilities. This paper evaluates the relative cost effectiveness of different odor control strategies previously identified to be important to odor reduction in swine finishing buildings. The results show that technologies that help to improve air quality such as automatic oil sprinkling, DCS dedusting, evaporative misting, wet scrubbing and manual oil sprinkling are more cost effective. Also, flushing shallow pit systems weekly is an effective strategy of odor control but is less cost effective than the air treatment technologies. In addition, constructing deep pit systems rather than shallow pit systems and removing manure from the deep pit twice a year or more frequently is also a cost effective way of odor management. Similar to the air treatment strategies mentioned above, this strategy also increases cost of production. Finally, increasing floor space allowance per pig is the least cost effective among the strategies examined in this analysis.

References

[1]Schiffman, S., Walker, J., Dalton, P., Lorig, T., Raymer, J., Shusterman, D. and Williams, C. 2000. Potential health effects of odor from animal operations, wastewater treatment, and recycling of byproducts. Journal of Agromedicine **7**(1): 7-81.

[2]Thu, K., Donham, K., Ziegenhorn, R., Reynolds, S., Thorne, P.S., Subramanian, P., Whitten, P. and Stookesberry, J. 1997. A control study of the physical and mental health of residents living near a

large-scale swine operation. Journal of Agricultural Safety and Health **3**(1): 13-26.
[3]Wing, S. and Wolf, S. 2000. Intensive livestock operations, health, and quality of life among eastern North Carolina residents. Environmental Health Perspectives **108**(3): 233-238.
[4]Palmquist, R.B., Roka, F.M. and Vukina, T. 1997. Hog operations, environmental effects, and residential property values. Land Economics **73** (February): 114-124.
[5]Huang, H., Sherrick, B., Gómez, M. and Miller, G.Y. 2003. The impact of swine production on land values in Illinois. Selected paper for American Agricultural Economics Association summer meetings, Montreal, Canada. Available at: http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid=9056&ftype=.pdf.
[6]Miner, J.R. 1995. A Review of the Literature on the Nature and Control of Odors from Pork Production Facilities. National Pork Producers Council, 9/95-#04184.
[7]Miller, G.Y., Maghirang, R.G., Riskowski, G.L., Heber, A.J., Robert, M.J. and Muyot, M. 2004. Influences on air quality and odor from mechanically ventilated swine finishing buildings in Illinois. Journal of Food, Agriculture & Environment **2**(2) (forthcoming).
[8]O'Neill, D.H., Stewart, I.W. and Phillips, V.R. 1992. A review of the control of odour nuisance from livestock buildings: Part 2, The costs of odour abatement systems as predicted from ventilation requirements. Journal of Agricultural Engineering Research **51**: 157-165.
[9]Bennett, M., Fulhage, C. and Osburn, D. 1993. Waste Management Systems for Dairy Herds. Research Report, University of Missouri-Columbia.
[10]Rausch, J. and Sohngen, B. 1999. An economic comparison of three manure handling systems. FactSheet, AE-5-99, Ohio State University Extension. Available at: http://ohioline.osu.edu/ae-fact/0005.html.
[11]Zhang, Y. 1997. Sprinkling oil to reduce dust, gases, and odor in swine buildings. AED-42. MidWest Plan Service, Ames, IA.
[12]EPA 2000. Guidelines for preparing economic analysis. EPA 240-R-00-003. USEPA, Washington, DC. p. 178.
[13]Bodman, G.R. and Veenhuisen, M.. 1994. Swine health management: Evaluation of housing and environmental adequacy. Certificate Seminar Series: University of Nebraska.
[14]PigCHAMP 1999. Benchmarking in Swine Herds. University of Minnesota.
[15]Miller, G.Y., Song, Y. and Bahnson, P.B. 2001. An economic model for estimating batch finishing system profitability with an application in estimating the impact of preventive measure for porcine respiratory disease complex. Journal of Swine Health and Production **9**(4): 169-177.
[16]Illinois Agricultural Statistical Service 2002, 2001, 2000, 1999 and 1998. Illinois Agricultural Statistics 2002 Annual Summary. Springfield, Illinois.
[17]Lawrence, J. and May, G. 2002. Livestock Enterprise Budgets for Iowa—2002. Iowa State University Extension, Iowa University, Ames, IA. Available at: http://www.extension.iastate.edu/Publications/FM1815.pdf.
[18]The VIDO Swine Technical Group 1986. Farrowing barn design and management. Veterinary Infectious Disease Organization, Saskatoon, Canada.
[19]Jacobson, L.D., Janni, K.A. and Johnston, L.J. 1998. Odor and gas reduction from sprinkling soybean oil in a pig nursery. In ASAE Annual International Meetings. Orlando, Florida, 12-16 July. Paper No. 984125. ASAE, St. Joseph, Michigan, USA.
[20]Ni, J., Tan, Z.C., Zhang, Y. and Ford, S.E. 2002. Evaluation of a field scale diffusion-coagulation-separation (DCS) system for dust and ammonia emission control from swine buildings. ASAE Meeting Paper No. 024175.
[21]Takai, H. and Pedersen, S. 2000. A comparison study of different dust control methods in pig buildings. Applied Engineering in Agriculture **16**(3): 269-277.
[22]Bridges, T.C., Turner, L.W., Gates, R.S. and Overhults, D.G. 2003. Assessing the benefits of misting-cooling systems for growing/finishing swine as affected by environment and pig placement date. Applied Engineering in Agriculture **19**(3): 361-366.
[23]O'Neill, D.H. and Phillips, V.R. 1991. A review of the control of odour nuisance from livestock buildings: Part 1. Influence of the techniques for managing waste within the building. Journal of Agricultural Engineering Research **50**: 1-10.
[24]ASAE. 1999. Manure Production and Characteristics. American Society of Agricultural Engineers' Standard. ASAE D384.1 DEC99.
[25]Fleming, R.A., Babcock, B.A. and Wang, E. 1998. Resource or waste? The economics of swine manure storage and management. Review of Agricultural Economics **20**(1): 96-113.