Manure Handling Costs and the Competitiveness Of Pork Production*

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Abstract

Simulations of possible regulation-related manure handling costs are compared to base scenario costs for three regions and three phases of modern hog production over widely varying scale levels. The base scenario confirms previous research suggesting that in Iowa net benefits occur at small scale levels from injecting slurry stored in an outside earthen basin for corn production using a phosphorus standard. Increased transportation costs result in Iowa costs surpassing costs in Utah at higher scale levels, while costs in North Carolina are highest at all scale levels. Requiring systems to be lined and covered in Iowa and North Carolina results in proportionately greater increased costs per head in North Carolina. Adding the requirement that manure be applied according to a phosphorus standard increases costs proportionately more in Iowa at larger scale levels, but not at all at the smallest scale, and costs in Iowa surpass those in North Carolina at the largest scale. The results of all scenarios underscore the advantages enjoyed by the Utah system due to economies of scale and the absence of land application costs.

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Increased geographic concentration of large-scale livestock production has led to concentrations of manure and the frequent inability of livestock operations to economically dispose of it at agronomic rates (Gollehon and others). Concentrations of manure contribute to concerns regarding odor and the leaching or runoff of nutrients into water supplies. While all levels of government pursue efforts to minimize these problems, the best known are such broad federal policy mandates as the Clean Water Act, the Coastal Zone Act Reauthorization Amendments, and the Environmental Quality Incentives Program. Drabensttot notes that manure-management costs could effect both regional and national competitiveness in hog production, and may play a role in the relative growth of this industry in arid states where nitrogen is allowed to volatize in lagoons and sparse population is less concerned about odor.

The location of production may be sensitive to manure related costs even if they are a small part of total costs. For example, non-storage related manure costs in the Lake States were only .8 cents per pound more than the average for "all" regions (table 1). However, this relatively small difference represents 73 percent of the 1.1-cent per pound difference in total cash costs between the Lake states and "all" regions.

Hogs are produced in a "supply chain" linking producers, processors, and consumers (Drabenstott). Risks are minimized and consumer-ready products of consistent quality produced by replicating optimum technologies and coordinating material flows (Hayenga and others) with market signals that are

Table 1. Cash costs and the non-storage manure costs of raising hogs, cents per pound--1992

	Lake States	Corn Belt	South Central	Plains States	South Atlantic	All regions
Cash costs	42.9	40.7	42.7	45.5	41.0	41.8
Non-storage manure costs 1	1.8	.9	.9	1.0	1.4	1.0

1/ Includes custom manure handling, manure odor control, and water pollution control.
Source: USDA, 1996.

precise, timely and clear (Martinez). Supply chains are thus characterized both by high fixed costs requiring large scales of operations, and overall cost structures that are becoming more similar, even at the hog production level. Manure costs, however, may be effected by weather and crop-related factors that influence manure storage and disposal systems.

The objective of this paper is therefore to compare how possible manure-related regulations could effect the costs of hog production in the three major hog producing regions. These regions include Iowa and North Carolina and the emerging arid region as exemplified by Utah. Previous studies have focused only on one region and often only on one phase of hog production, but all have used economic-engineering type models because of limited survey data. The present study uses technical parameters from selected previous studies to build simulation models of farrowing, nursery and finishing units for each region. The following section reviews previous studies related to manure management costs. The second section describes the model and the scenarios, and the third and fourth sections discuss the results. Such models can indicate small variations in manure-related costs not easily measurable by other methods.

Previous Studies of Manure Management Costs

Several manure management studies have attempted to quantify the role that manure from slurry systems can play as a fertilizer substitute. Slurry has been reported to save 10-14 pounds of nitrogen and 12-15 pounds of phosphorus when applied to corn (Duffy) and up to 25-80 pounds of nitrogen when properly applied (Bruening). Evidence that injected slurry could profitably substitute for commercial fertilizer has also been found by Hardeman, and by Chase and others. While Fleming, Babcock and Wang found the cost of nutrient delivery from lagoons for Iowa finishing operations exceeded the value of nutrients at all scale levels, there was always a herd size where the value of slurry always exceeded delivery costs.
In slurry systems, undiluted manure drains or is pumped into containment facilities located under or

outside the house, making slurry high in solids and nutrients. In lagoon systems, by contrast, manure is flushed into anaerobic treatment and storage lagoons using larger amounts of recycled lagoon liquid and the effluent is low in nutrients and solids. Nitrogen losses could range from 15 percent in completely covered slurry systems to 80 percent in uncovered anaerobic lagoons (Sutton and others). Nitrogen volatilization during land application may be 5 percent of available nitrogen when slurry is broadcast and immediately incorporated, 30 percent without incorporation or injection into the soil, and 40 percent when lagoon effluent is spray irrigated onto forage land (Sutton and others).

Boland and others included amortized storage and application costs in a linear programming model of a midwestern farrow-to-finish-cropping system ranging from 150 to 1,200 sows. Below 300 head, an outside-slurry-with-injection was the optimum system, but at larger sizes a lagoon-with-irrigation was optimum. The switchover occurs because of the increasing costs of storage and delivery for the injection system. However, net costs for both systems ranged from $1.54 per head to $.98 per head in inventory.

Roka and Hoag use a mixed-integer linear programming model to calculate the least cost alternatives for storing and disposing of lagoon-treated manure for a finishing pig-cropping system in North Carolina. Net costs ranged from $3.73 to $3.36 per head in inventory for operations of 600 to 5,400 hogs, and depended upon lagoon "treatment" size. A larger but more costly "high" treatment lagoon required only 5.2 acres of corn and 2.9 acres of hay, respectively, to dispose of nutrients at the nitrogen-loading limit from a 600-head operation, a less costly but "low" treatment lagoon required 9.3 and 5.1 acres, respectively. While they do not distinguish between storage and land application costs, Roka and Hoag reported decreasing net costs in relation to scale. Cost decreasing systems typically have relatively high fixed costs but low operating costs, as is the case with the irrigation systems typical in North Carolina. However, the costs may also turn up if agronomic application rates are followed (Northrop and Zering).

Huang and others included a land rental option in their mathematical programming model of a finishing operation in the southeast. The average baseline cost for nutrient delivery was about $1.00 per head marketed for the smallest operation and dropped off as size increased. These costs doubled when manure was applied according to a nitrogen standard and quadrupled when a phosphorus standard was applied.

In spite of the above theoretical advantages of using manure as a fertilizer substitute, evidence suggests that midwestern corn farms maintain excess nutrient supplies, inclusive of commercial fertilizer use (Bruening; Duffy). In a survey of 33 Nebraska farms, the size of this imbalance has been found to positively correlate with farm size (Koelsch and Lesoing). However, some of the larger farms were found to have a favorable balance because of an active effort to market surplus manure nutrients.

The Economic-Engineering Models and Scenario Assumptions

The models were developed from state-agency standard data reflecting "real world" storage-treatment and land application design and costs. Costs were calculated for variable and amortized storage charges; land application; returns from crop utilization of nutrients; and regulatory costs for permits, monitoring wells, and the linings and covers for storage-treatment units. Lagoons and slurry basins were the storage-treatment systems and land application included irrigation, injection, and hauling and incorporation.

The models simulate budgets of the selected regions, sizes of integrated production systems, and storage and distribution systems including cropping. Visual Basic macro's are used to select parameters from spreadsheets and iteratively sum the simulated size-related results over the farrowing, nursery, and finishing phases of an integrated hog production system. Only least-cost results are reported.

Manure Storage and Treatment Systems

Costs are calculated for 4 manure storage/treatment systems and 5 manure application methods. The storage-treatment systems considered were the anaerobic lagoon and three types of slurry systems: the earthen basin, the concrete storage tank, and the under-house concrete pit. Lagoons occupy more space than slurry systems and release greater amounts of nitrogen into the atmosphere. In addition, much of the phosphorus settles to the bottom as part of the lagoon's sludge. Therefore, lagoon effluent is less valuable for crops than slurry. Almost all of the nutrients remain in slurry stored in tanks or in under-house pits, but these systems cost more than the earthen slurry basin, in which a portion of the nitrogen is volatilized.

Lagoon effluent is comprised of liquid, sludge, and net precipitation. The total gallons of lagoon effluent per animal per day for the integrated system was greatest in Iowa, according to published state design standards (ISU, 1996; NRCS, 1996). The total gallons of lagoon effluent per animal per day for farrowing, nursery, and finishing were 9.82, .72, and 4.2. While evaporation is high in North Carolina so is rainfall, and the total gallons of effluent were 9.01, .63, and 2.9, respectively, for farrowing, nursery, and finishing. In arid Utah the total gallons of effluent were 5.9, .42, and 1.94, respectively.

The volumes of excreted manure and urine per animal and daily accumulation of liquid and sludge differ by animal type and region. In Iowa, pigs excrete 5.7, .41, and 2.4 gallons of manure and urine per animal per day in the farrowing, nursery, and finishing phases, respectively (ISU, 1996). In North Carolina and Utah, 4.3, .3 and 1.4 gallons per head per day, respectively, are excreted (NRCS, 1996). After netting out lower nutrient concentrations, daily nitrogen production was .023 and .0016 and .01 pounds in Iowa for the farrowing, nursery and finishing phases, respectively, but only .014, .0015 and .007 for North Carolina and Utah. Similar magnitudes exist for phosphorus. The sludge volume and its nutrient content attributable to each animal were the same among regions, but volume was slightly more in farrowing.

Lagoon costs include the amortized annual and variable costs of building and operating lagoons. (Blauser and others; Drynan and others). Excavation costs are $1.00 per cubic yard and the opportunity cost of land is assumed to be $100 per acre annually. The excavation volume was calculated to allow a standard level of freeboard plus state-specific emergency storage volume so that total volume exceeds expected containment volume. Lagoon emergency storage volume is smallest in Iowa. A larger volume is required in North Carolina to accommodate a greater excess of rainfall over evaporation. Lagoons are also larger in Utah to facilitate complete evaporation. Annual costs are total fixed costs amortized over 15 years at 8 percent. Annual variable costs include insurance costs equal to .5 percent of annual fixed costs. Annual taxes are 1 percent and maintenance is 2 percent of annual fixed costs.

For slurry systems, published standard for daily accumulation of manure liquid is greater in North Carolina (USDA, 2002) than Iowa (ISU). For North Carolina, the total volume is 7.2, .5 and 2.3 gallons per animal, respectively, for farrowing, nursery, and finishing, compared to 5.3, .33, and 2.0 for Iowa. However, the nitrogen produced by farrowing, nursery, and finishing in Iowa was .14, .012 and .1 pounds per gallon, respectively, but .15, .015, and .071 in North Carolina. The higher nitrogen content in Iowa finishing implies a sow producing 21.67 pigs, annually, would ultimately contribute .057 pounds of nitrogen per gallon in the Iowa integrated system, but only .045 in North Carolina. Costs for earthen slurry basins were computed similar to lagoon costs. For under house deep pits, the annualized fixed and variable costs are $.0536 per cubic foot, but concrete tanks depended upon a more complex formula.

Land Application Methods

There are 5 types of manure application methods included. The most common method in the southeast is to spray lagoon effluent onto a field of bermuda grass hay with either a solid set irrigation unit or a traveling gun unit. The traveling gun system becomes less costly than the solid set as the area to be irrigated increases. The traveling gun has relatively low fixed costs, but relatively high operating costs, while the solid set unit has relatively high fixed costs but relatively low operating costs. The annualized costs of these units are the least expensive of all application systems. However, their use is less common in the midwest because they do not accommodate the more highly concentrated slurry more common in that region, nor do they conserve nitrogen as well as slurry injection.

The following regression equation (Cox), which allows costs to increase rapidly, but at a diminishing rate at smaller scales, is used to calculate annual costs for both sprayfield systems:

1) $TC = B_0 + B_1(A) + B_2(D) - B_3[H/(A*D)] + B_4[H//(A*D)]^2$,

where A is the area irrigated; D is annual gross depth of irrigation (inches of effluent); H is the hours per year available for irrigation, and the Bs are parameters from Cox, with B_3 negative. The value of H/(A*D) is set at 2 hours per acre-inch, and as many acre-inches are allowed as is determined by the nutrient content of the effluent.

The three application systems for manure that dominate the midwest are: 1) broadcasting onto fields, 2) broadcasting and incorporating into the soil; and 3) injecting with a specialized applicator. The first method is more common, despite research showing that either of the latter two are more cost-effective (Duffy, Bruening). The common midwestern practice of custom application is assumed because it avoids issues of producer scale and capacity (Fleming and others). Custom application costs include a base handling charge for the costs of loading and applying the manure within 1 mile of the livestock facility, a flat-rate mileage charge, and the average distance manure is hauled.

Calculating the average distance that manure must be hauled for land application is not straightforward, however. Fleming and others first define a searchable area (SA) as the required area (RA) for manure application at agronomic rates, divided by a suitability coefficient:

2) $SA = RA/(abc)$.

The suitability coefficient is the product of three percentages: cropland in the region, *a*; cropland suitable for manure application, *b*; and cropland on which landowners allow manure, *c*. The value of *a* is set to 84 percent because, according to Fleming and others, about 84 percent of farmland in "…a typical central Iowa swine producing country would be in crops." Since about one-half of such cropland is in soybeans, which do not require nitrogen, *b* is set to 50 percent. However, since owners may not allow manure on some suitable cropland, *c* is set to 50 percent, for illustrative purposes.

Also consistent with Fleming and others, average distance is calculated as:

3) $AD = [SA/640]^{\wedge}0.5$

The costs of transporting slurry include a 0.88 cent per gallon base-handling charge and a .34 cent per gallon mileage charge, whether it is injected or incorporated (Fleming and others). The handling charge is only .79 cents for broadcasting. The mileage charge for lagoon liquid and sludge is .28 cents per gallon, but the handling charge is .88 cents for injection; .71 cents for broadcasting with incorporation; and .57 cents for broadcasting without incorporation.

The application methods differ in the amounts of nutrients they deliver to the field (table 2). The injection system delivers 95 percent of nitrogen and 80 percent of potassium and phosphorus. The broadcast and incorporation method delivers 75 percent of all nutrients from all systems and over all regions, except that 85 percent of nitrogen from lagoon liquid is delivered. Broadcasting without incorporation and irrigation delivers 45 percent and 50 percent, respectively, of nitrogen in lagoon liquid but only 35 and 25 percent, respectively, of nitrogen in both lagoon sludge and liquid slurry. The systems do not vary a great deal in the relatively high amounts of phosphorus and potassium delivered to cropland because these nutrients do not volatilize, in contrast to nitrogen, which volatizes quite easily.

Scenario Assumptions

In all scenarios, the Utah system is comprised of a lined anaerobic lagoon in which all liquid and nitrogen evaporate. A lining is required because lagoons are sited on sandy soils. Base scenario least-costs for Iowa and North Carolina are calculated with manure applied at plant-available agronomic rates. Two policy-related scenarios are then run. In the first scenario, the storage/treatment facilities in both Iowa and North Carolina are assumed covered and lined with plastic. In the second scenario, land application is required to conform to the generally more restrictive phosphorus standard. The second scenario results in a nitrogen deficit that is made up by custom applying nitrogen at $5.03 per acre (Plain and others).

State average price and yield data were used for 2000 (NASS). For North Carolina, hay and soybean yields were 2.6 tons and 33 bushels per acre, respectively, with prices of $71 per ton and $6.70 per bushel, respectively. Each ton of bermuda grass hay requires 50 pounds of nitrogen and 9.63 pounds of phosphorus. Soybeans can utilize 3.8 pounds of nitrogen per bushel. In Iowa, manure is typically applied to corn. Corn yield and price averaged 145 bushels per acre and $2.12 per bushel in 2000, inclusive of government benefits. Corn is assumed to require 1.2 pounds of nitrogen and .37 pounds of phosphorus per bushel in both regions

Simulations are run off the steady state number of hogs associated with each phase of an integrated continuous flow production system (Alberta Agriculture). The farrowing phase steady state is simply the number of sows specified. For the nursery phase and finishing phases, the steady states are calculated as the number of pigs weaned divided by the number of nursery and finishing cycles per year, respectively.

A 6.3 week "growing phase" in each nursery is assumed followed by a 1.5 week "empty period" for cleaning and repairs, yielding 6.67 nursery cycles per 52-week year. In finishing, 14.5 weeks are assumed in the growing phase and 2.25 weeks for cleaning and repairs, giving 3.1 cycles per year.

Results are reported for 6 sizes of systems. The smallest was a 300-sow herd from which 3,000 piglets were weaned at each farrowing and 6,500 finished animals marketed each year. The largest was an 1,800 sow herd from which 18,000 piglets were weaned at each farrowing and 39,000 marketed each year. In 2001, only 2,204 farms accounting for 53 percent of all hogs reported inventories exceeding 5,000 head (USDA, 2002). For the largest size, an average inventory of 19,800 head exists in the farrowing phase; 5,850 in each cycle of the nursery phase; and 12,560 in each cycle of the finishing phase. The models therefore cover a large majority of U.S. hogs. Furthermore, recently published federal regulations (EPA) covering confined animal feeding operations (CAFOs) apply to hog operations having in excess of 2,500 hogs weighing over 55 pounds and 10,000 hogs weighing less than 55 pounds. Therefore, except for the nursery phase, the models appear to apply to most operations covered by the CAFO regulations.

Base Scenario Results--Least Cost Manure Handling Systems

The composition of costs in the base scenario differs among the optimum systems representing the various regions (table 3). Storage costs are largest in the Utah model because the largest excavation volume is required there to accommodate total evaporation. Land application is the largest cost component in the other two regions, and allows smaller excavation volumes in spite of higher rainfall than in Utah. Regulatory costs are the largest cost component in the Utah model, and include mainly the cost of the required liner. In the other regions, regulatory costs include permits and monitoring wells.

The least-cost North Carolina system was the anaerobic lagoon with effluent applied to a sprayfield of bermuda grass hay by a solid set irrigation system according to a nitrogen standard (table 3, last column). Soybeans are a less profitable alternative crop than hay. Slurry systems are not economical because of high land application costs. These higher costs occur because, firstly, the relatively inexpensive irrigation systems designed to handle high-liquid lagoon effluent are not compatible with the thicker slurry. Secondly, the lower biological activity in slurry systems results in slurry having up to 10 times more nitrogen than lagoon effluent, thus requiring greater land area for disposal. Finally, the returns to the high nutrient manure from a slurry system applied to relatively low valued hay in North Carolina were low.

For Iowa, an earthern slurry basin with manure injected for use by corn according to a nitrogen standard is the optimum system at marketings of 13,000 and above. Broadcasting manure without incorporation is not economical because too much nitrogen is lost, while incorporation added prohibitively to costs. At the smallest scale of 6,500 marketed hogs, however, applying manure according to a phosphorus standard yielded a profit of $.25 per animal for the integrated system and $.46 per animal in the finishing phase.

The base scenario results suggest that costs per marketed hog are lowest in Iowa over the simulated scale sizes. However, costs in Iowa increase to $1.21 per head marketed with increases in scale as the distance hauled increases hauling costs. In North Carolina, by contrast, average costs per head decline from $2.63 to $1.34 because the sprayfield system is characterized by high fixed costs but low operating costs--only about 20 cents per head. Costs in Utah are lower than costs in North Carolina at all levels and fall below those in Iowa at the largest scale. For those operations in Utah are larger than simulated here, the actual costs per head of manure management are likely lower than simulated.

The base scenario costs are lower in Iowa than in North Carolina despite the minimum disposal area in Iowa ranging from 895 acres to 2,762 acres compared to from 33 acres to 199 acres for North Carolina.

Such a large difference occurs because nearly 13 pounds of nitrogen was applied for each hog marketed from the Iowa system, but only 1.36 pounds were applied under the North Carolina system. Nitrogen is much more valuable applied to Iowa corn. The finishing and nursery phases accounted for about two-thirds and 4 percent, respectively, of the minimum disposal areas in all regions.

The finishing phase contributes the most to manure costs (table 4). For North Carolina finishing effluent comprises about 69 percent of the dry manure and total nitrogen, and accounts for 56 percent-to 64 percent of the costs for the smallest to the largest scales, respectively. However, the greater volume of effluent produced in finishing results in land application costs increasing by a magnitude of 3.3 over the scale range, compared to 2.8 for the full system. In the Iowa slurry model, the finishing phase produces 65 percent of the manure but 77 percent of the nitrogen, contributing significantly to profits at the smallest scale. However, as transportation costs increase in relation to scale size, the proportion of costs contributed by finishing increase from 27 percent of the system costs to 59 percent.

Comparison of Results with those of Previous Studies

The results are broadly consistent with previous studies. The Iowa model is similar to that of Boland and others, who found a lagoon storage and irrigation system profitable at scales of 300 sows and larger. Lagoon costs are higher in the present study partly because daily liquid production of 5.24 gallons per animal is assumed, or twice that of Boland and others. However, they included both variable and amortized fixed costs of owned land application equipment, in contrast to lower custom rates used here.

The small profit at the smallest scale for the Iowa model is also consistent with Fleming and others, who found profits of $1.02 per head at a finishing herd size of 6,900 animals. The additional land application costs under the phosphorus standard are more than offset by the utilization of "more of the potential value of manure." However, these costs increase rather rapidly as the search area increases.

The results of the North Carolina model appear consistent with those of other research covering finishing pigs in the Southeast. In the present study, manure costs ranged from $1.47 per pig marketed at the smallest scale to $.86 at the largest. This is comparable to Roka and Hoag's reported costs of $3.73 to $3.36 per head of inventory, for scales up to 5,400 head. Huang reports losses of about $2.00 per head marketed when effluent is applied according to a nitrogen-standard.

Policy Scenarios

Three policy scenarios were run for North Carolina and Iowa. In the first, storage systems are required to be both lined and covered. The cost of plastic lining is assumed to be $30 per square foot, based on anecdotal evidence. The costs of plastic covering are calculated from formulas in Fleming, Babcock and Wang. In the second scenario, manure is land applied according to its phosphorus content, thus increasing substantially the application area. The third scenario is a combination of the first two. No policy scenario is assumed for the Utah model because it relies on evaporation.

Scenario #1: Lined and covered outside storage /treatment systems

Costs increase significantly over all scale levels when outside storage/treatment systems are assumed lined and covered (table 5). For North Carolina, costs increase by $2.35 at the smallest scale and by $2.25 at the largest scale. In Iowa, costs increased by $1.11 and $.99, respectively, at the smallest and largest scale levels. While the base scenario costs for North Carolina ranged from $2.88 to $.13 above those of the Iowa system, this difference increased to a range of $4.13 to $1.39 under this policy scenario. Competitive advantage is significantly shifted towards Utah in this scenario. While costs in North Carolina were $.63 to $.26 above Utah costs in the base scenario, they increased by $2.35 at the smallest scale to $2.25 at the larger scale. And while costs in Iowa remain below costs in Utah at the two smallest scale levels, they increase by over $1.00 per head at all scale levels, and exceed Utah costs by $1.12 at the largest scale level. North Carolina loses the most competitive advantage in this scenario.

Scenario #2 Land application according to a phosphorus standard

Requiring manure to be land applied according to a phosphorus standard is less costly than requiring liners and storage covers at all scale levels in North Carolina and at the two smallest scale levels in Iowa. The traveling gun replaces fixed irrigation, as the least costly means of covering the substantially greater area required for disposal in North Carolina. While marginal disposal costs decrease with scale for North Carolina, they increase substantially with scale for Iowa and exceed costs in North Carolina by $1.41 per head marketed, at the largest scale level. Costs do not increase at all at the smallest scale in Iowa because that alternative had also been the least costly in the base scenario. This simulation assumes the existence of sufficient nearby land to receive manure and effluent. In some areas, the aggregate effect of a required phosphorus standard may violate this assumption and require much greater transport distance and cost.

Costs in Iowa increase above costs in North Carolina at scales above 26,000 head, despite a relatively smaller increase in the minimum disposal area in Iowa than in North Carolina. At the smallest scale, costs remain constant in Iowa, but increase by $ .90 in North Carolina. At the largest scale, however, cost increases are $2.59 and $1.05, respectively, for Iowa and North Carolina. At the larger scale levels, costs increase well above costs in Utah. The disposal area increases less in Iowa under the phosphorus standard because lower volatilization leaves a smaller nitrogen-to phosphorus ratio in Iowa slurry.

Scenario #3: Lined and covered storage, plus land application according to a phosphorus standard

This scenario results in costs that are additive. The advantage North Carolina had relative to Iowa at larger scale levels from scenario #2 all but disappears here because of the relatively high costs imposed on North Carolina in scenario #1. Costs for North Carolina in scenario #3 are higher than costs for Iowa for all but the largest scale level, where disposal costs for Iowa pull costs above those in North Carolina.

Discussion and limitations

Manure-handling costs are not insignificant considerations in modern hog production. The base-scenario manure handling costs ranged up to 2.6 percent of the roughly $100 value of a marketed hog for the smallest scale in North Carolina, and to 1.2 percent for the largest scale in Iowa. When storage systems were lined and covered, manure handling costs increased by over 2 percentage points of the marketed hog value for North Carolina and about 1 percentage point in Iowa. The addition of a phosphorus restriction raised per head costs by an additional 1-percentage point for North Carolina, and from zero to over 2 percent in Iowa for the smallest and largest scales, respectively. Such added costs may imply regional shifts in production and affect national competitiveness in the highly competitive hog industry.1

Both current and prospective policy-induced manure costs may therefore be considerations in location decisions. Savings in manure-related costs have been noted as one reason for growth of hog production in the western United States and Canada, along with the overall economies of scale allowed because of the absence of space constraints the industry faces elsewhere (Alberta Agriculture; Drabenstott; Hubbell and Welsh). The present study supports the conclusion that economies of scale exist in treatment and irrigation-based manure management systems. For example, manure-related economies reduce costs per head by $.92 for the largest Utah farm simulated versus the small.

The effects of requiring storage units to be lined and covered in Iowa and North Carolina as a means of

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1 These increased costs exclude aggregation effects that may result in much larger manure transportation distances

preventing nitrogen leaching and odor are scale-neutral. However, such a policy would be twice as costly in North Carolina, adding to manure-related costs that are already twice those in Iowa. While both lose competitiveness relative to Utah, the losses may burden smaller producers in North Carolina more, who might see manure-related costs increase to between 4 and 5 percent of the value of a market hog.

Requiring manure to be applied according to a phosphorus standard most significantly discriminates against larger producers in Iowa, who incur increasingly large hauling costs under this more restrictive standard. However, smaller producers in Iowa are harmed less by such a requirement, with the smallest producers facing no additional costs under such a standard. Some of the smallest producers in Iowa may not incur a mileage charge if they have available land next to their facilities. The cost increases in North Carolina are nearly scale-neutral because the induced shift to the traveling gun irrigation system reduces the proportion of fixed-to-variable costs (excluding increased transportation costs due to aggregation).

Manure costs may also influence decisions to farrow and nurse piglets in North Carolina and finish them in Iowa. Shipping hogs to Iowa for finishing would save $1.93 per head in manure costs for the smallest size operation, a difference that decreases as size is increased. In spite of transportation costs, about 25 percent of the pigs farrowed in North Carolina are sent to the mid-west for finishing.

The simulated costs are sensitive to the amount of manure handled; its nutrient content; the value of these nutrients in crop production, and application costs. Furthermore, the range of simulated scales is wider than the actual size distribution of hog producers. Therefore, the results in this paper should be interpreted as indication of potential regional effects for policymakers and as targets for hog producers. While the study suggests that policies with cost effects that are scale and location neutral may have the

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and costs.

least adverse effects on hog production, no attempt was made to quantify and value whatever benefits might arise from any policy changes.

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Table 2. Percent of nutrients that are plant available, by application method

	North Carolina			Iowa		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Lagoon liquid						
Injection	95	80	80	95	80	80
Broadcast & Incorporation	85	75	75	85	75	75
Broadcast, no Incorporation	45	70	70	45	70	70
Irrigation	50	70	70	50	70	70
Lagoon sludge						
Injection	95	80	80	95	80	80
Broadcast & Incorporation	75	75	75	75	75	75
Broadcast, no Incorporation	35	70	70	35	70	70
Irrigation	25	70	70	25	70	70
Liquid slurry						
Injection	95	80	80	95	80	80
Broadcast & Incorporation	75	75	75	75	75	75
Broadcast, no Incorporation	35	70	70	35	70	70
Irrigation	25	70	70	25	70	70

Source: NRCS, ISU.

Table 3--Base scenario results: least cost options with a nitrogen standard for land application ****

Number marketed	Manure volume	Nitrogen produced	Storage area	Min appl. area	Fertilizer savings	Costs				
						Storage	Land applic.	Regulatory	Total net	per head marketed
head	1,000 gal.	ton/yr	acre	acre	$	$	$	$	$	$
North Carolina: unlined and uncovered lagoon; solid set irrigation of bermuda grass hay										
6,500	3,080	4.5	1.8	33	-123	2,494	13,025	1,437	17,078	2.63
13,000	6,161	8.9	3.5	66	-246	4,796	17,611	1,437	24,090	1.85
19,500	9,241	13.4	5.2	100	-369	7,070	22,198	1,437	31,074	1.59
26,000	12,322	17.8	6.9	133	-492	9,330	26,785	1,556	38,162	1.47
32,500	15,402	22.3	8.6	166	-615	11,580	31,371	1,556	45,122	1.39
39,000	18,482	26.7	10.3	199	-738	13,824	35,958	1,895	52,415	1.34
Iowa: uncovered and unlined slurry basin , injected application to corn										
6,500	1,982	42	1.9	894.5	27,164	1,543	23,202	788	-1,630	-0.25
13,000	3,964	84	3.8	920.6	42,668	2,999	40,975	939	2,245	0.17
19,500	5,946	126	5.6	1,380.8	64,002	4,443	67,844	1,089	9,374	0.48
26,000	7,928	169	7.4	1,841.1	85,335	5,881	97,631	1,323	19,499	0.75
32,500	9,910	211	9.2	2,301.4	106,669	7,316	129,937	1,753	32,336	0.99
39,000	11,891	253	11.0	2,761.7	128,003	8,748	164,494	1,976	47,214	1.21
Utah: uncovered but lined lagoon allowing for evaporation										
6,500	2,048	0	1.70	0.0	0	3,185	0	9,812	12,997	2.00
13,000	4,095	0	3.28	0.0	0	6,122	0	12,855	18,977	1.46
19,500	6,143	0	4.83	0.0	0	9,026	0	15,719	24,745	1.27
26,000	8,191	0	6.38	0.0	0	11,913	0	18,610	30,524	1.17
32,500	10,238	0	7.92	0.0	0	14,790	0	21,323	36,112	1.11
39,000	12,286	0	9.45	0.0	0	17,658	0	24,332	41,990	1.08

**** = Phosphorus standard resulted in the lowest costs at and below 6,500 head marketed for Iowa.

Table 4-Comparison of Finishing Operations, North Carolina and Iowa: Base scenarios ****

Number marketed	Manure volume	Nitrogen produced	Storage area	Min appl. area	Fertilizer savings	Costs				
						Storage	Land applic.	Regulatory	Total net	per head marketed
head	1,000 gal.	ton/yr	acre	acre	$	$	$	$	$	$
North Carolina: unlined and uncovered lagoon, solid set irrigation of bermuda grass hay										
6,500	1,913	3.1	1.2	23.1	-86	1,614	7,048	778	9,525	1.47
13,000	3,825	6.2	2.3	46.2	-171	3,116	10,243	778	14,308	1.10
19,500	5,738	9.3	3.4	69.3	-257	4,601	13,438	778	19,075	0.98
26,000	7,651	12.4	4.5	92.4	-343	6,078	16,634	778	23,833	0.92
32,500	9,563	15.5	5.6	115.6	-428	7,550	19,829	778	28,585	0.88
39,000	11,476	18.6	6.7	138.7	-514	9,017	23,024	1,117	33,673	0.86
Iowa: uncovered and unlined slurry basin, injected application to corn										
6,500	1,306	32.6	1.3	356.5	16,523	1,007	12,165	361	-2,990	-0.46
13,000	2,612	65.3	2.5	713.0	33,046	1,963	28,566	403	-2,115	-0.16
19,500	3,918	97.9	3.8	1,069.5	49,570	2,913	47,724	445	1,511	0.08
26,000	5,223	130.6	5.0	1,426.0	66,093	3,858	69,112	570	7,448	0.29
32,500	6,529	163.2	6.2	1,782.4	82,616	4,802	92,425	633	15,244	0.47
39,000	7,835	195.9	7.5	2,138.9	99,139	5,744	117,458	696	24,758	0.63

**** = Phosphorus standard resulted in the lowest costs at and below 6,500 head marketed for Iowa.

Table 5--Policy scenarios

Number marketed	Manure volume	Nitrogen produced	Storage area	Min appl. area	Fertilizer savings	Costs				
						Storage	Land apply	Regulatory	Total net	per head marketed
head	1,000 gal.	ton/yr	acre	acre	$	$	$	$	$	$
North Carolina--Scenario 1: lined and covered lagoon, with solid set irrigation										
6,500	3,080	4.5	1.8	33.2	-123	2,494	13,025	16,751	32,392	4.98
13,000	6,161	8.9	3.5	66.4	-246	4,796	17,611	31,328	53,981	4.15
19,500	9,241	13.4	5.2	99.6	-369	7,070	22,198	45,789	75,426	3.87
26,000	12,322	17.8	6.9	132.8	-492	9,330	26,785	60,310	96,916	3.73
32,500	15,402	22.3	8.6	166.0	-615	11,580	31,371	74,672	118,239	3.64
39,000	18,482	26.7	10.3	199.2	-738	13,824	35,958	89,347	139,866	3.59
North Carolina--Scenario 2: land application according to phosphorus standard, with traveling gun										
6,500	3,080	4.5	1.8	210.6	-4,013	2,494	15,008	1,437	22,952	3.53
13,000	6,161	8.9	3.5	421.2	-8,027	4,796	22,716	1,437	36,975	2.84
19,500	9,241	13.4	5.2	631.9	-12,040	7,070	30,423	1,437	50,970	2.61
26,000	12,322	17.8	6.9	842.5	-16,054	9,330	38,131	1,556	65,070	2.50
32,500	15,402	22.3	8.6	1,053.1	-20,067	11,580	45,838	1,556	79,041	2.43
39,000	18,482	26.7	10.3	1,263.7	-24,081	13,824	53,545	1,895	93,345	2.39
North Carolina--Scenario 1 and Scenario 2, combined										
6,500	3,080	4.5	1.8	210.6	-4,013	2,494	15,008	16,751	38,266	5.89
13,000	6,161	8.9	3.5	421.2	-8,027	4,796	22,716	31,328	66,866	5.14
19,500	9,241	13.4	5.2	631.9	-12,040	7,070	30,423	45,789	95,323	4.89
26,000	12,322	17.8	6.9	842.5	-16,054	9,330	38,131	60,310	123,824	4.76
32,500	15,402	22.3	8.6	1,053.1	-20,067	11,580	45,838	74,672	152,157	4.68
39,000	18,482	26.7	10.3	1,263.7	-24,081	13,824	53,545	89,347	180,796	4.64
Iowa--Scenario 1: lined and covered slurry basin, with slurry injected for corn according to a nitrogen standard ****										
6,500	1,982	42.2	1.9	894.4	27,164	1,543	23,202	7,965	5,547	0.85
13,000	3,964	84.3	3.8	920.6	42,668	2,999	40,975	14,562	15,868	1.22
19,500	5,946	126.5	5.6	1,380.8	64,002	4,443	67,844	21,043	29,328	1.50
26,000	7,928	168.6	7.4	1,841.1	85,335	5,881	97,631	27,549	45,725	1.76
32,500	9,910	210.8	9.2	2,301.4	106,669	7,316	129,937	34,212	64,795	1.99
39,000	11,891	252.9	11.0	2,761.7	128,003	8,748	164,494	40,641	85,879	2.20
Iowa--Scenario 2: land application according to phosphorus standard, with slurry injected for corn****										
6,500	1,982	42.2	1.9	894.4	27,164	1,543	23,202	788	-1,630	-0.25
13,000	3,964	84.3	3.8	1,788.8	54,328	2,999	61,738	939	11,347	0.87
19,500	5,946	126.5	5.6	2,683.3	81,492	4,443	110,255	1,089	34,295	1.76
26,000	7,928	168.6	7.4	3,577.7	108,656	5,881	166,845	1,323	65,393	2.52
32,500	9,910	210.8	9.2	4,472.1	135,820	7,316	230,464	1,753	103,713	3.19
39,000	11,891	252.9	11.0	5,366.5	162,984	8,748	300,553	1,976	148,292	3.80
Iowa--Scenrio 1 and Scenario 2, combined										
6,500	1,982	42.2	1.9	894.4	27,164	1,543	23,202	7,965	5,547	0.85
13,000	3,964	84.3	3.8	1,788.8	54,328	2,999	61,738	14,562	24,970	1.92
19,500	5,946	126.5	5.6	2,683.3	81,492	4,443	110,255	21,043	54,249	2.78
26,000	7,928	168.6	7.4	3,577.7	108,656	5,881	166,845	27,549	91,619	3.52
32,500	9,910	210.8	9.2	4,472.1	135,820	7,316	230,464	34,212	136,172	4.19
39,000	11,891	252.9	11.0	5,366.5	162,984	8,748	300,553	40,641	186,957	4.79

**** = Phosphorus standard resulted in the lowest costs at and below 6,500 marketed hogs in the base scenario for Iowa.