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Changes in Manure Management in the Hog Sector: 1998-2004

Nigel Key, William D. McBride, and Marc Ribaudo

Abstract

In recent years, structural changes in the hog sector, including increased farm size and regional shifts in production, have altered manure management practices. Also, changes to the Clean Water Act, State regulations, and increasing local conflicts over air quality issues, including odor, have influenced manure management decisions. This study uses data from two national surveys of hog farmers to examine how hog manure management practices vary with the scale of production and how these practices evolved between 1998 and 2004. Included are the effects of structural changes, recent policies on manure management technologies and practices, the use of nutrient management plans, and manure application rates. The findings suggest that larger hog operations are altering their manure management decisions in response to binding nutrient application constraints, and that environmental policy is contributing to the adoption of conservation-compatible manure management practices.

Keywords: hog production, manure management, structural change, environmental regulation.

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Contents

Summary

Economic competition has driven rapid changes in the U.S. hog industry over the last 10 years. Production has shifted to larger operations that increasingly specialize in a single phase of hog production and are organized under production contracts. This expansion and consolidation means that fewer operations now manage an increasing volume of hog manure, magnifying environmental risks if it is mismanaged. Pollutants such as nutrients (nitrogen and phosphorus), ammonia, methane, and odor can originate from production houses where animals are kept, from manure storage structures such as tanks and lagoons, or from fields where manure is applied.

What Is the Issue?

The changing structure of hog farms is altering manure management practices, as larger operations seek to manage nutrients on a limited cropland base. At the same time, strengthening of the Clean Water Act with regard to runoff from manure nutrients, State regulations like the 1997 moratorium on hog farm expansion enacted by North Carolina, and local conflicts over odor are requiring producers to alter their manure management practices. Information about the effects of recent policies and structural changes on manure management technologies and practices, the use of nutrient management plans, and manure application rates is useful for evaluating the effectiveness of environmental policies and determining future policy needs.

What Are the Major Findings?

Over 1998-2004, the total number of U.S. hog operations fell by about 40 percent, and the average inventory grew from 2,589 to 4,646 head per farm. Data from hog producer surveys administered in 1998 and 2004 indicate that large hog producers (1,000 animal units or more) are altering their manure management practices to mitigate the environmental effects of increased concentration. In particular, the largest farms removed more manure from their operations (especially by giving it away for free) and applied less commercial fertilizer to crops receiving manure in 2004 than in 1998. Also, in accordance with EPA regulations, large hog operations conducted more nutrient testing of manure, increased the use of microbial phytase in feed (which reduces nutrients in manure), and increasingly followed comprehensive nutrient management plans.

Additional trends that suggest greater adherence to environmental regulations by the largest hog farms include: (1) a decline in the spreading of solid manure and liquid manure without physically injecting it into the soil (these two practices increase the risk of nutrient loss to the atmosphere and runoff); (2) a decline in the quantity of manure applied per acre; (3) a decline in the nutrients excreted per animal due to an increase in feed efficiency; and (4) an increase in the share of farms removing manure from their operation.

The increasing concentration of hog production on large operations is expected to continue, meaning that manure management will continue to be an important issue to the hog industry and to others concerned with its environmental impact. Results of this research suggest that there still is significant room for reducing the environmental impact of manure through

improved management. For example, hog operations, on average, apply manure to less than 30 percent of available crop acreage. Policy incentives, along with technological innovation, are likely to play an important role in the future of hog manure management and its environmental impact.

How Was the Study Conducted?

This study uses information from surveys of U.S. hog producers conducted in 1998 and 2004 as part of USDA's annual Agricultural Resource Management Survey (ARMS). The detailed surveys cover a cross-section of U.S. hog operations and collect information on production costs, business arrangements, production facilities and practices, and farm operator and financial characteristics. The surveys also provide information about manure storage and handling, fertilizer use, manure application techniques, Environmental Quality Incentives Program (EQIP) payments, the use of comprehensive nutrient management plans, and manure application rates. The data allow us to document the current state of manure management and track producers' responses to existing and anticipated manure-related regulations. Data from the surveys are analyzed by farm size according to the number of animal units (1,000 pounds of live animal weight) produced. Because larger hogs produce more manure, animal units provide a consistent measure for comparing farms that produce hogs at different stages of the production cycle.

Introduction

In recent years, economic competition has driven rapid changes in the hog industry: production has shifted regionally and to larger operations that increasingly specialize in a single phase of hog production and are organized under production contracts. The changing farm structure is altering manure practices, as larger operations seek to manage nutrients on a limited cropland base. At the same time, recent changes to the Clean Water Act, State regulations, and local conflicts over odor are influencing manure management decisions.

Changes in the regulatory climate have been driven by increased environmental risk to air and water associated with the geographic concentration of manure on larger livestock operations. Pollutants such as nutrients, pathogens, ammonia, hydrogen sulfide, methane, and odor can originate from production houses where animals are kept, from manure storage structures such as tanks and lagoons, or from land where manure is applied. The concentration of animals and manure into smaller geographic areas increases the challenge of managing manure, the risk of environmental contamination, and the nuisance potential of farms.

This study uses data from two recent surveys of hog farmers to examine how hog manure management practices vary with the scale of production and how practices changed from 1998 to 2004. The findings provide information about the effects of recent policies and structural changes on manure management technologies and practices, the use of nutrient management plans, and manure application rates.

A Primer on U.S. Hog Production

The production of hogs to be slaughtered for pork involves four phases: (1) breeding and gestation (breeding females and their maintenance during gestation), (2) farrowing (birth of baby pigs until weaning), (3) nursery (care of pigs immediately after weaning until about 30-80 pounds), and (4) finishing (feeding hogs from 30-80 pounds to a slaughter weight of 225-300 pounds). Hog producers are commonly classified according to the number of production phases conducted on the operation: (1) farrow-to-finish (all four phases), (2) farrow-to-feeder pig (phases 1, 2, and 3), (3) feeder pig-to-finish (phase 4), (4) wean-to-feeder pig (phase 3), or (5) farrow-to-wean (phases 1 and 2).

The majority of U.S. hog production has historically occurred on farrow-to-finish operations located in areas with an abundant supply of corn. Hog farmers typically fed corn produced on the farm as an inexpensive source of hog feed and applied manure as fertilizer on farm fields. Advancements since the 1970s in breeding and genetics, as well as in animal housing and feeding, have increasingly moved hog production into large factorylike units staffed with specialized labor. Meanwhile, farms became more specialized in hog production, and hog farms increasingly specialized in only one or two of the production phases. By 2004, 77 percent of market hogs were produced on feeder pig-to-finish operations, while only 18 percent were produced on farrow-to-finish operations (Key and McBride, 2007).

The introduction of contract production arrangements also played a significant role in the evolution of U.S. hog production. In contract production, a pig owner (the contractor) engages a producer (the grower) to take custody of the pigs and care for them in the producer's facilities; compensation depends on a predetermined formula. Contractors typically furnish inputs to growers, provide technical assistance, and assemble the hogs to pass on for final processing or marketing. Contractors often market hogs through marketing contracts or other arrangements with packers or processors, who can also contract directly with growers.

Data

This study uses information from surveys of U.S. hog producers conducted in 1998 and 2004 as part of USDA's annual Agricultural Resource Management Survey (ARMS). The detailed surveys cover a cross-section of U.S. hog operations and collect information on production costs, business arrangements, production facilities and practices, and farm operator and financial characteristics. The surveys also provide information about manure storage and handling, fertilizer use, manure application techniques, payments received under the Environmental Quality Incentives Program (EQIP), use of comprehensive nutrient management plans (CNMP), and manure application rates. The data allow us to document the current state of manure management and provide information about producers' emerging responses to existing and anticipated manure-related regulations.

The sample of hog farms was chosen from a list of operations maintained by USDA's National Agricultural Statistics Service (NASS). The target population of each survey was farms having 25 or more hogs at any time during the year. Farms with fewer than 25 hogs were removed to exclude operations that raise hogs primarily for onfarm consumption and other noncommercial activities, such as youth projects. Each surveyed operation represents a number of similar farms in the population as indicated by the surveyed respondent's expansion factor, or survey weight. The sampling resulted in 1,633 responses from 22 States in 1998, and 1,198 responses from 19 States in 2004 (table 1). The expanded samples in each survey represent more than 90 percent of the hog and pig inventory on U.S. farms in each survey year.

Estimates from the two surveys are comparable because of the consistent way in which the surveys were conducted and processed. Each survey had broad national coverage, represented the same target population, involved a complex sampling scheme designed to represent the target population, was conducted the same way (hand-enumerated) by the same organization, and collected much the same information in a similar format. More information about the ARMS and the hog surveys, including copies of the questionnaires, can be found at http://www.ers.usda.gov/Briefing/ARMS/.

Data from the surveys are analyzed by farm size according to the number of animal units (1,000 pounds of live animal weight) produced. Because larger hogs produce more manure, animal units provide a consistent measure for comparing farms that produce hogs at different stages of the production cycle. For example, farrow-to-finish and hog finishing operations produce much larger hogs, and thus more manure per animal than do farrow-to-feeder pig and specialized nursery operations.

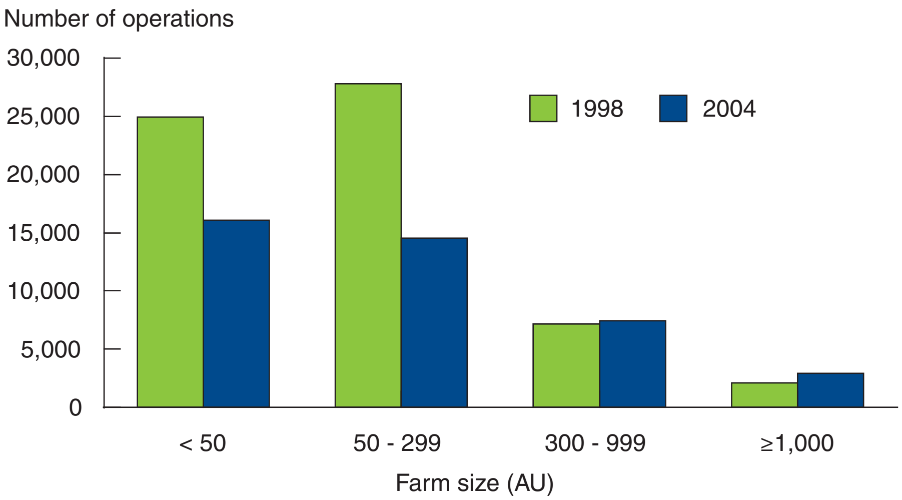
The environmental implications of hog production depend primarily on the manure management decisions of operations with at least 50 animal units since these operations accounted for 96-98 percent of hog output over 1998-2004. For this reason, and to simplify the tabular presentations, statistics for operations with fewer than 50 animal units are not reported in most tables and figures.

Structural Change and Manure Management

Changes in manure management practices partly reflect changes in the scale and methods of hog production. Between 1998 and 2004, there was a rapid decline in the number of hog operations producing fewer than 300 animal units (fig. 1), resulting in a shift in production to larger operations (fig. 2). Over this period, the total number of hog operations fell by about 40 percent, and the average inventory grew from 2,589 to 4,646 head per farm (table 1).

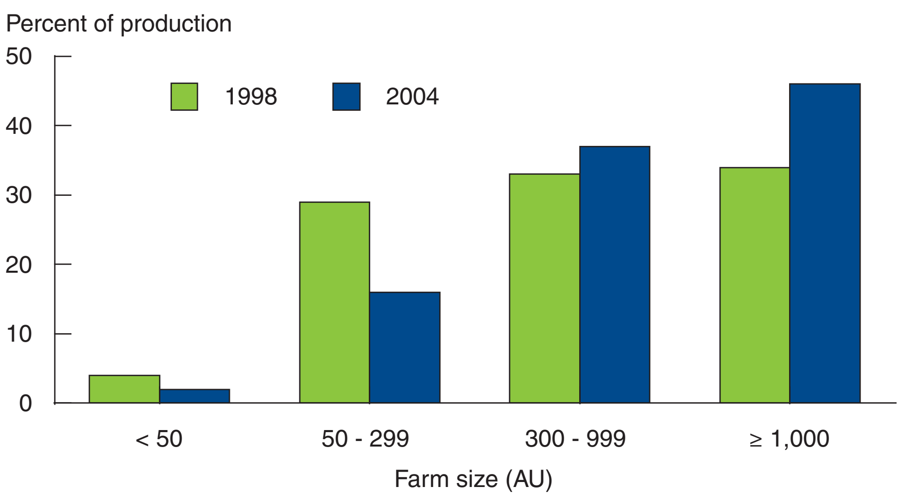
Changes in the scale of production have been accompanied by changes in how production is organized. Hog farms that handle all phases of production have given way to operations increasingly specialized in a single phase.

Figure 1
Small hog operations declined in number and large ones grew between 1998 and 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Figure 2
Large operations produced a greater share of output in 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Table 1
Summary statistics, 1998 and 2004

	1998	2004
All hog farms		
Observations in sample	1,633	1,198
Number of farms in population	61,971	40,940
Hog sales and contract removals (head per farm)	2,589	4,646
Average hog inventory (animal units per farm)	194	294
Producer type: Farrow-to-finish (% of farms)	49	31
Producer type: Feeder pig-to-finish (% of farms)	31	40
Used a production contract (% of farms)	15	28

Note: A farm is defined as an operation having 25 or more hogs at any time during the year, and includes independent hog producers and growers who produce hogs under contract. Animal units are defined as 1,000 pounds of live animal weight, and the inventory of animal units is based on an estimate of the average number of hogs and pigs on the operation in each year. Farrow-to-finish operations are those on which pigs are farrowed and then finished to a slaughter weight of 225-300 pounds. Feeder pig-to-finish operations are those on which feeder pigs are obtained from outside the operation, either purchased or placed under contract, and then finished to a slaughter weight of 225-300 pounds.

Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

The traditional approach of farrow-to-finish production accounted for about half of hog operations in 1998 but only about a third in 2004. Feeder-to-finish operations that specialize in the growing-finishing phase of production increased their share of market hogs sold/removed from 55 percent in 1998 to 77 percent in 2004 (Key and McBride, 2007). Changes in the scale and specialization of production have caused crop and hog production to concentrate more often on different farms and have created concerns about what to do with the growing concentration of manure on larger hog operations.

Changes in production scale and specialization have been made possible, in part, by the substantial growth of contract production. Production contracts govern the relationship between hog growers (contractees) and hog owners (contractors) and specify compensation for the inputs provided by each party. Such arrangements allow individual producers to specialize in one phase of production and increase their scale of operations. Over the 6 years between surveys, the share of farms using a production contract almost doubled (Key and McBride, 2007). One concern with production contract arrangements is who has liability for managing the hog manure. Most contracts have required growers to comply with all State, Federal, and local regulations in operating their facilities, while failure to comply can result in contract termination (Ogishi et al., 2003). Since contract growers are heavily invested in facilities, they are highly motivated to avoid liability.

Geographical shifts in hog production have accompanied the structural and organizational changes in the industry. Historically, hog production was concentrated in the Heartland, mainly Iowa and Illinois, where an abundant supply of corn provided a cheap source of hog feed and sufficient acreage on which to spread hog manure. During the 1980s and 1990s, hog production grew dramatically in the Southeast, especially in North Carolina, driven mainly by the growth of large contract operations. Growth in the Southeast has posed the challenge of how to manage an increasing volume of hog manure in areas with a more dense population and much less crop acreage for manure application than in the Heartland.[1] Since 1992, hog production also

[1] In research that underlies the discussion in this section, Key and McBride (2007) define the Heartland to include the States of IA, IL, IN, KY, MO, and OH, and the Southeast to include AL, AR, GA, NC, SC, and VA. These definitions apply throughout this report.

has moved aggressively into Western States like Colorado and Utah, where a low population density provides flexibility in managing animal manure.

More recently, the size of feeder pig-to-finish farms in the Heartland grew rapidly—doubling in average size between 1998 and 2004—while those in the Southeast grew more slowly (though starting from a larger average size). As a result, the Heartland's share of feeder pig-to-finish production grew 10 percentage points, while the Southeast's share declined by 7 points (Key and McBride, 2007). Slower growth in the Southeast can be attributed in part to a moratorium placed on the construction of new and expanded hog operations in 1997 (North Carolina General Assembly, 1997).[2] The moratorium was enacted in response to environmental concerns about managing hog manure from increasingly larger operations.

Structural change has coincided with substantial efficiency gains for hog farms, particularly on specialized hog-finishing operations. Most of these productivity gains were attributable to increases in the scale of production (scale efficiency) and technological innovation. The amount of feed used per unit of output declined by 24 percent between 1998 and 2004 on feeder-to-finish operations, while their real, or inflation-adjusted, production costs per hundredweight of gain also declined by 24 percent (Key and McBride, 2007, p. 14). Higher feed productivity can reduce the amount of manure produced by hog operations and thus the amount of manure nutrients that must be disposed.

[2] The North Carolina State legislature passed the Clean Water Responsibility and Environmentally Sound Policy Act in 1997. This law imposed a moratorium on the construction of new or expansion of existing hog operations with 250 or more head. Exceptions to the moratorium included construction using "innovative animal waste management systems that do not employ an anaerobic lagoon." North Carolina extended the moratorium several times before passing legislation in 2007 that strictly regulates manure management systems.

Environmental Policies Affecting Manure Management

Growing concerns about the potential impacts of these changes on environmental quality have spurred local, State, and Federal action to mitigate environmental impacts of animal manure. Complaints about water quality and air quality (primarily odor) fuel most of the conflicts between the animal sector and the general population. The U.S. Environmental Protection Agency (EPA) revised Clean Water Act regulations in 2003 for controlling runoff of manure nutrients from the largest animal feeding operations (AFOs). Clean Water Act regulations now require that animal feeding operations designated as concentrated animal feeding operations, or CAFOs, and needing a National Pollutant Discharge Elimination System (NPDES) permit (those that discharge or propose to discharge to surface waters), develop and implement a nutrient management plan. Such a plan sets a limit on the amount of nutrients that can be applied per acre of land. Also under the 2003 regulations, CAFOs that are not required to have an NPDES permit, but wish to claim the stormwater exemption[3] for runoff from fields, must develop and implement a nutrient management plan to demonstrate that due care is being taken to minimize polluted runoff from fields receiving manure. If a waterway becomes polluted with animal waste from field runoff and a CAFO does not have a nutrient plan, it would be in violation of the Clean Water Act.

[3] Agricultural stormwater discharges are specifically exempted from permit requirements in the Clean Water Act. These include runoff from agricultural fields.

Atmospheric emissions of pollutants are regulated by the Clean Air Act (CAA). The CAA authorizes regulatory programs primarily for protecting human health. EPA has recently initiated development of regulations for reducing fine particulates in the atmosphere (referred to as $PM_{2.5}$, for particles less than 2.5 microns in size). The Clean Air Act requires State, local, and tribal governments to identify areas not meeting national air quality standards for fine particulates (one of the six criteria pollutants regulated under the Act) (U.S. EPA, 2004b). States with designated non-attainment areas must submit plans that outline how they will meet the standards by 2010. This regulation could affect animal operations because ammonia is a major precursor of fine particulates. Controlling ammonia from animal operations would be a likely priority in non-attainment areas with high concentrations of animals (U.S. EPA, 2000).

Also covering air pollution are the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA). Both laws utilize information disclosure to increase the information available to government and citizens about the sources and magnitude of chemical releases to the environment. CERCLA requires that facilities report to EPA when releasing more than a "reportable quantity" (e.g., 100 pounds in a 24-hour period) of a hazardous substance. EPCRA requires that a facility report to State and local authorities any releases reported under CERCLA. EPA is authorized to require long-term remedial action that permanently and significantly reduces threats to public health. Originally focused on hazardous wastes from industrial plants, the increased size and consolidation of animal feeding operations may make their ammonia and hydrogen sulfide emissions subject to the notification provisions of CERCLA. EPA has enforced the CERCLA and EPCRA reporting requirements against AFO release of hazardous pollutants in two cases, although use of these laws for agricultural emissions is controversial (Copeland, 2008).

Most States have implemented regulations—including permits, licenses, and zoning requirements—for controlling at least some of the environmental impacts of AFOs. North Carolina entered a legal agreement with the State's largest swine producers to develop innovative waste management strategies that would replace uncovered lagoon and sprayfield systems to prevent a repeat of the massive damage to water resources caused by Hurricane Floyd in 1995 (Williams, 2004). The purpose of the 1997 North Carolina moratorium was to give the State time to design and enact a regulatory system that would ensure that waste structures were sound, that waste application methods were adequate, and that waste utilization plans were in place. Iowa, Pennsylvania, Arkansas, and Kentucky have also introduced rules for curbing water pollution, ammonia, and odor from AFOs (Patton and Seidl, 1999; U.S. EPA, 2002).

Agricultural-residential conflicts at the rural-urban fringe seem to be increasing as residential development expands further into rural areas, while market conditions push farmers to intensify their production (Bergstrom and Centner, 1989; Jacobson et al., 2006). Conflicts over environmental concerns are most prevalent for animal operations (Duke and Malcolm, 2003; Centner, 2002). Proximity can result in citizen complaints to local authorities and actual or threatened lawsuits over perceived threats to health and environmental quality, even when no laws have been broken. Such conflicts may force farmers to modify their production practices. Adoption of "acceptable" or "qualifying" management practices is one way farmers can demonstrate due care and possibly protect themselves from conflict over environmental quality (Centner, 2002).

To defray the costs of meeting the regulations, producers can apply for financial assistance from USDA's Environmental Quality Incentives Program. A farmer may receive up to $450,000 for all EQIP contracts entered during the term of the Farm Act (typically 5-7 years) to help them develop and implement a nutrient management plan, construct appropriate animal and manure handling and storage facilities, or transfer and apply manure to land in an approved manner (USDA/ERS, 2009).

Manure Management on U.S. Hog Farms

One consequence of structural change in U.S. hog production has been the manure management challenge posed by concentrating more animals on a limited land base. Hog manure is primarily handled in two types of storage structures, lagoons and pits or tanks (see box, "Manure Storage and Handling Strategies"). Lagoons are large earthen containment structures into which manure and wastewater is flushed and maintained in liquid form until removed. Manure pits are often located under hog production facilities where, in the typical system, manure drops into pits through slatted floors and is stored in a slurry form until removed. These storage structures contain manure until it can be land-applied on the same or nearby farms to meet crop nutrient needs. Technologies for land application include liquid/slurry manure spreaders that may or may not incorporate manure into the soil at application, and sprinkler irrigation systems that are used to spread the liquid lagoon solution on nearby fields.

The different systems for manure management have a vastly different impact on the nutrient content of the manure, primarily nitrogen, and thus on the amount of land needed to spread manure (McBride and Key, 2003). For example, handling manure in pit or tank storage and using slurry spreaders to inject manure into the soil utilizes the manure for its potential fertilizer value. This system is designed to retain manure nitrogen for crop use, and thus requires more land on which to apply manure if following a nitrogen-based nutrient management plan. In contrast, handling manure in lagoon storage and using sprinkler irrigation for spreading treats the manure as waste for disposal, rather than as a source of valuable crop nutrients. This system handles manure to increase the volatilization of nitrogen into the atmosphere, thus reducing its nutrient content and requiring less land for application.

Manure Storage and Handling

Lagoon use and scale of production have a strong positive association (fig. 3). Despite this fact and the trend toward larger operations, there was a shift between 1998 and 2004 toward the use of pit/tank systems. By 2004, 56 percent of hogs were raised on farms using pit/tank systems (up from 37 percent in 1998); in 2004, 39 percent were raised on farms using a lagoon system (down from 55 percent in 1998).[4] This shift can be attributed to changes in the manure system used by medium and large-scale operations, but also reflects regional shifts in hog production and farm structure. Operations in the Southeast more often use lagoon systems, while those in the Heartland are more likely to use a pit/tank system (McBride and Key, 2003). During 1998-2004, hog production expanded in the Heartland relative to the Southeast, as the North Carolina moratorium limited growth in the Southeast.

[4] In tables 2-7, "all farms, weighted by animal units" gives the mean values computed using a weight defined as the sample weight times the animal units on the operation. This weighted mean describes the manure system used for the average animal unit, rather than the average farm.

Pit/tank systems generally use a solid or liquid spreader, while sprinkler irrigation technology is used to move and apply lagoon liquid. The method of applying manure can have important implications for air quality, affecting the level of odorous gases (ammonia and hydrogen sulfide), particulate material (byproducts of ammonia), and greenhouse gases (methane and nitrous oxide) (Abt Associates, 2000). Both solid and liquid manure can be incorporated into the soil, which reduces odor and nutrient volatilization (escape into

Manure Storage and Handling Strategies

Comprehensive nutrient management plan—Following a comprehensive nutrient management plan when applying manure and commercial fertilizer to land can reduce potential losses of nutrients to water resources through runoff or leaching (USDA, NRCS, 2005). Nutrient management matches applications to crop needs so that as few nutrients as possible are lost to the environment. A CNMP is a group of conservation practices and management activities that ensure that both production and natural resource protection goals are achieved. Specific elements of a CNMP include background and site information; manure and wastewater handling and storage; farm safety and security; land treatment practice; soil erosion, nitrogen and phosphorus risk assessment; nutrient management according to criteria in the Nutrient Management Conservation Practice (code 590); and recordkeeping. A CNMP typically includes soil and manure testing for nutrient content, and the balancing of nutrient resources with crop needs. In monitoring the operation's total nutrient balance, the producer must account for nutrients generated, field applied, removed in products, and transferred offsite. Plans can also account for atmospheric losses of nitrogen, as well as atmospheric deposition of nitrogen on cropland.

Manure incorporation and injection—Rapidly incorporating manure into the soil, either by plowing or disking solids after spreading or injecting liquids and slurries directly into the soil, reduces odor and gaseous emissions (Abt, 2000; Arogo et al., 2002). It also reduces the risk of nutrients being transferred to adjacent water bodies.

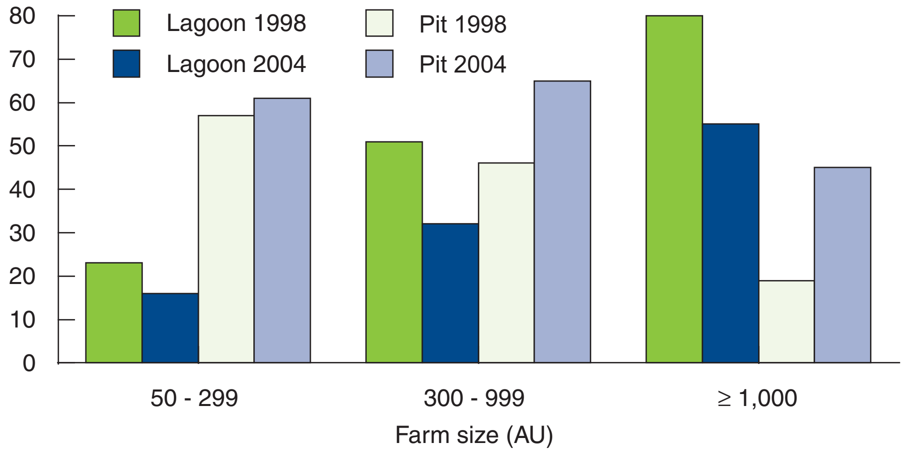
Slurry pits—Slurry systems store undiluted, untreated manure in watertight tanks or pits until it can be land applied. Storage can be either under the house or outdoors. The stored slurry is surface applied to fields by sprayer trucks or wagons, or incorporated into the soil with chisel plows behind nurse tanks, or directly injected into the soil with drag hoses (U.S. EPA, 2004a).

Lagoons—Lagoon systems use open holding ponds to treat diluted manure for an extended period of time. Lagoons stabilize organic matter, reduce the nutrient mass that must be land applied, and vent a large quantity of the manure nitrogen as ammonia. Some of the diluted lagoon liquid is used to flush the production houses. The "digested" lagoon liquid is eventually sprayed on cropland. Lagoons are used primarily in warmer climates where the anaerobic processes can take place year round (U.S. EPA, 2004a).

the atmosphere) relative to spreading, making more nutrients available for plant uptake. Incorporation also reduces the risk of nutrient runoff. Sprinkler application increases nitrogen volatilization, which reduces the nitrogen available for plant use. Lagoon/sprinkler systems allow producers to dispose of manure from a given operation on fewer acres when a nitrogen criterion is used to determine application levels.

There are clear relationships between the scale of production and the use of sprinkler irrigation versus solid or liquid spreaders. Among large farms that

Figure 3
Changes in lagoon and pit manure systems, 1998 to 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Table 2
Hog manure application technologies used on farms applying manure

	Percent of farms	
	1998	2004
All farms that apply manure		
Solid spreader	64	46**
Liquid spreader (no injection)	27	18**
Liquid spreader (injection)	20	21
Sprinkler irrigation	12	13
All farms that apply manure, weighted by animal units		
Solid spreader	36	19**
Liquid spreader (no injection)	25	17*
Liquid spreader (injection)	30	34
Sprinkler irrigation	34	36
Farm size category (farms that apply manure)		
Small (50-299 animal units)		
Solid spreader	66	40**
Liquid spreader (no injection)	40	28**
Liquid spreader (injection)	28	31
Sprinkler irrigation	9	10
Medium (300-999 animal units)		
Solid spreader	32	23
Liquid spreader (no injection)	28	19
Liquid spreader (injection)	42	37
Sprinkler irrigation	32	28
Large (≥ 1,000 animal units)		
Solid spreader	10	10
Liquid spreader (no injection)	7	12
Liquid spreader (injection)	20	30
Sprinkler irrigation	58	57

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%. Some operations may have used more than one technology, or none of the technologies. Therefore, the columns may add up to more than or less than 100 percent.

Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

applied manure to crops, sprinkler irrigation was the most commonly used form of manure application, followed by injection of liquid manure (table 2). Between 1998 and 2004, there was an overall large decline in the share of appliers who spread solid manure. Most of this change occurred because (1) there were fewer smaller farms, which are more likely to handle solid manure, and (2) the remaining small farms less often handled manure in solid form.

Growers altered their spreading technologies between 1998 and 2004 to reduce odor, nutrient volatilization, and runoff. The share of all growers who applied liquid manure without injection declined by 9 percentage points. There was also a 10-percent increase in the share of large operations applying liquid manure with injection technologies, although this increase was not statistically significant.

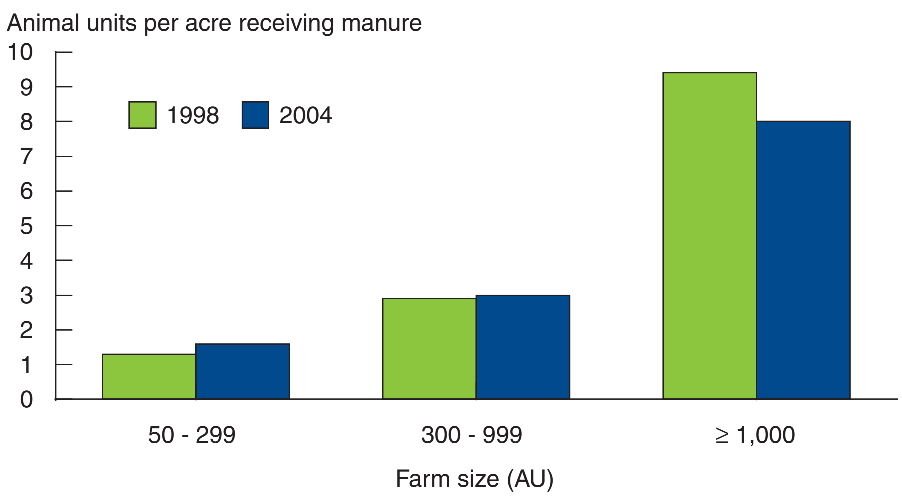
Manure Application and Disposal

There is a strong positive association between scale of production, total cropland available on the hog farm, and the number of acres on which manure is applied on the hog farm (table 3). Between 1998 and 2004, the average number of manure-applied acres and the average amount of cropland per farm did not change substantially. Also, the share of onfarm cropland with manure application remained much the same in 1998 and 2004, and was less than 30 percent among all farms and among farms in each size group. This indicates that the potential exists to spread manure over more crop acreage on these farms. However, higher costs of hauling manure longer distances and the technologies used to spread manure likely limit the acreage on which manure is applied.

Figure 4 illustrates the strong positive association between the scale of production and the manure application intensity (animal units per acre).[5] The higher application rates for larger operations reflect the large amount of manure generated by larger hog operations compared to the cropland on these operations available for manure application. Between 1998 and 2004,

[5] For the intensity ratio, the denominator is the acres of land on the hog operation on which manure was applied. The numerator is the farm inventory (AU) adjusted for the removal of manure off the farm. For farms that moved manure off the operation, the number of AU was reduced by the equivalent amount of manure removed. For example, if 50 percent of the manure was moved off a 1,000-AU operation, only 500 AU was used to compute the ratio.

Figure 4
Manure application intensity increases with scale of production



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

the increase in total animal units produced outpaced the increase in crop acreage on which manure was applied, resulting in a 43-percent increase in average manure application intensity (table 3). However, this increase was driven mainly by operations with fewer than 300 animal units. For medium-scale operations, the application intensity remained about the same, and for operations with more than 1,000 animal units—which are more likely to be subject to nutrient management restrictions—the application intensity actually declined (fig. 4).

It is important to qualify the measure of manure application intensity. Different storage and handling techniques help determine the quantity of nutrients contained in applied manure, so application intensity does not measure actual nutrient application rates. In addition, increases in feed efficiency have likely reduced the quantity of nutrients excreted by hogs. Nitrogen and phosphorus enter the production system in animal feed. Some of the nutrients are retained in the animal product (meat), but as much as 95 percent is excreted in urine and manure (Follett and Hatfield, 2001). Between 1998 and 2004, feed used per unit of output declined by 24 percent, falling from 282 to 214 pounds of feed per hundredweight gain on feeder-to-finish farms (Key and McBride, 2007). Assuming the nutrient composition of

Table 3
Hog manure application on farms applying manure

	1998	2004
All farms that apply manure		
Acres with manure application	85	86
Acres of cropland	448	483
Percent of cropland with manure application	19.1	17.8
Application intensity (AU/acre applied)	2.1	3.0**
All farms that apply manure, weighted by animal units		
Acres with manure application	147	218**
Acres of cropland	596	855**
Percent of cropland with manure application	24.7	25.5
Application intensity (AU/acre applied)	7.2	7.4
Farm size category (farms that apply manure)		
Small (50-299 animal units)		
Acres with manure application	95	85
Acres of cropland	517	599
Percent of cropland with manure application	18.4	14.2*
Application intensity (AU/acre applied)	1.3	1.6
Medium (300-999 animal units)		
Acres with manure application	156	169
Acres of cropland	565	652
Percent of cropland with manure application	27.6	26.0
Application intensity (AU/acre applied)	2.9	3.0
Large (≥ 1,000 animal units)		
Acres with manure application	159	224
Acres of cropland	643	1,016*
Percent of cropland with manure application	25.0	22.0
Application intensity (AU/acre applied)	9.4	8.0

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%.

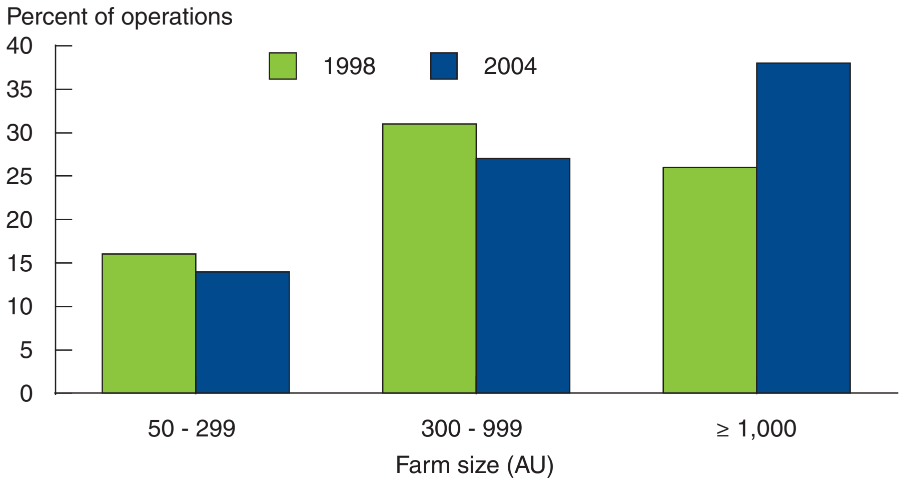
Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

feed and meat has not changed substantially over this period, this implies a 24-percent decline in the quantity of nutrients excreted per animal produced. In addition, feed efficiency is positively correlated with the scale of production—larger operations generally use less feed per hog produced. Hence, the nutrient application intensity (e.g., nitrogen per acre) is generally lower on larger farms than the estimated manure application intensity (animals per acre) would imply.

There is a positive relationship between the scale of production and the quantity of manure removed from farms with hog operations, and this relationship grew stronger over time (fig. 5). The share of farms removing manure grew 50 percent between 1998 and 2004 (table 4), and this increase is attributable mainly to large operations. Manure is most often removed from operations that have limited land for application and can find nearby farms that are willing to make arrangements to have the manure applied to their land.[6] Most of the manure removed from farms was given away to nearby farms—only

[6] Most of the increase between 1998 and 2004 in the share of farms removing manure from the operation occurred on hog operations in the Southeast. Only 3 percent of Southeast operations removed manure in 1998, compared to 18 percent in 2004.

Figure 5
Manure removal from the largest operations increased between 1998 and 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Table 4
Manure removal from farms

	Percent 1998	Percent 2004
All farms		
Removed manure from operation	14	21**
Sold manure	0	2*
Paid for manure removal	2	2
Manure given away free	12	18*
All farms, weighted by animal units		
Removed manure from operation	23	31
Sold manure	1	5
Paid for manure removal	4	4
Manure given away free	19	23

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%.

Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

a small share was sold or required the operator to pay someone to remove it. There is some evidence of an emerging market for manure—the share of farms selling manure increased in all sales categories between 1998 and 2004, albeit from a very low level.

Manure Nutrient Management Practices

Table 5 describes the evolution of manure management practices between 1998 and 2004. Manure nutrient testing, a practice required as part of many State-mandated manure management plans, was positively associated with scale of production (fig. 6). Larger operations are more likely to face State

Table 5
Nutrient management practices

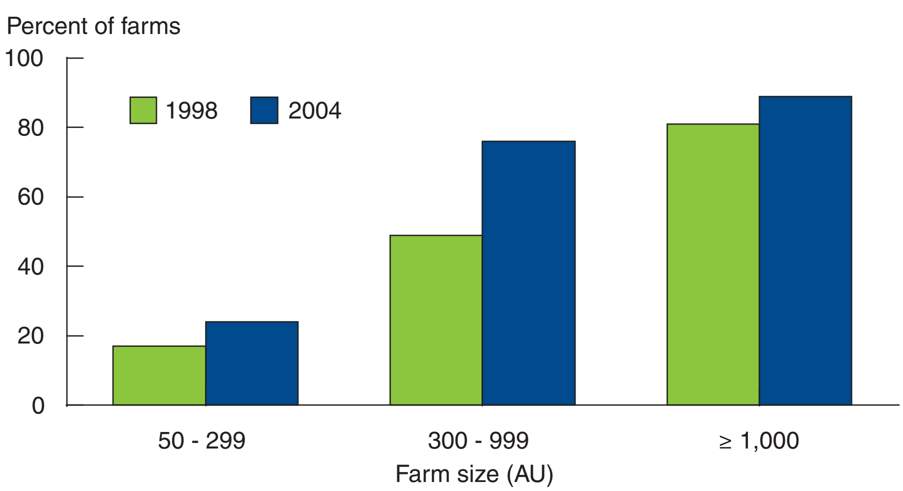
	Percent	
	1998	2004
All farms		
Test manure for N content	18	29**
Test manure for P content	17	28**
Apply commercial fertilizer and manure	61	58
Applied manure to Bermuda grass (appliers only)	n.a.	11
Followed CNMP[1]	n.a.	30
Added microbial phytase to feed	4	13**
All farms, weighted by animal units		
Test manure for N content	51	73**
Test manure for P content	50	72**
Apply commercial fertilizer and manure	48	39*
Applied manure to Bermuda grass (appliers only)	n.a.	23
Followed CNMP[1]	n.a.	62
Added microbial phytase to feed	12	30**

Note: Asterisks indicate level of significance for the test of the null hypothesis of equal means: ** =5%, * = 10%. n.a. indicates data not available.

[1] CNMP is a comprehensive nutrient management plan (see box, "Manure Storage and Handling Strategies").

Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Figure 6
Hog farms increased rate of manure nitrogen (N) testing from 1998 to 2004



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

regulations that require nutrient management plans. Between 1998 and 2004, the share of farms testing for nitrogen (N) increased from 18 percent to 29 percent, and the share of animals on farms that tested manure for N increased from 51 percent to 73 percent. Nitrogen testing rates increased for all farm-size categories, especially the medium-scale operations (fig. 6). The large operations did not have as much scope to increase their testing rate because 81 percent of these farms tested in 1998.

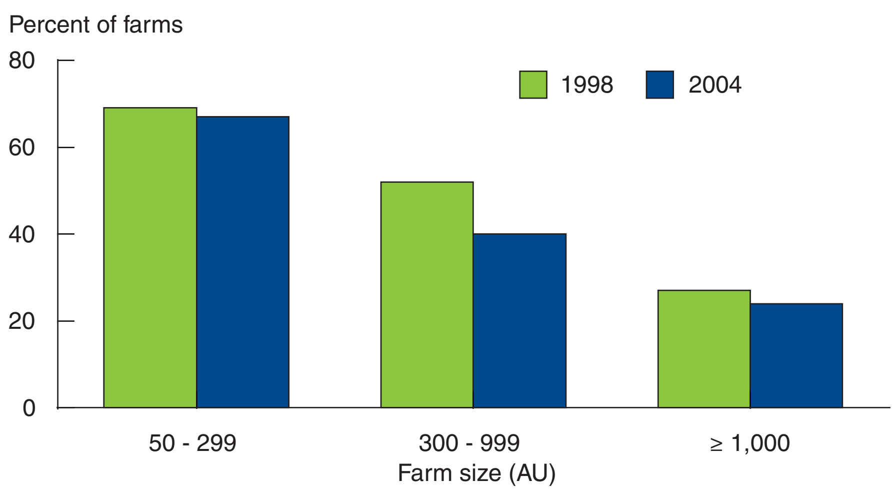
Commercial fertilizer is applied to crops in addition to manure if the manure's nutrients do not meet the nutritional needs of the crops. Testing the nutrient content of manure thus saves costs by avoiding overapplication of supplemental commercial fertilizer. As expected, there is a strong negative association between scale of production and the application of commercial fertilizer (fig. 7). Larger operations are more likely to have a surplus of nutrients provided by the manure produced on their operations, and are therefore less likely to require supplemental commercial fertilizer.

One strategy for increasing manure disposal on a limited land base is to plant crops that have a high rate of nutrient uptake. Bermuda grass, which is grown primarily in the South and Southeast, is especially appealing to hog producers because it consumes large amounts of nitrogen per acre. There was a strong positive association between the scale of production and the application of manure to Bermuda grass in 2004 (fig. 8). However, Bermuda grass will consume soil nutrients only if it is harvested periodically, and there is almost no market for Bermuda grass hay in the areas where it is grown.

Microbial phytase is used as an additive in finishing hog diets to increase the absorption of organic phosphorus, meaning that supplemental inorganic or mineral phosphorus may not be needed and feed costs are reduced. Also, phytase use reduces phosphorus excretion in manure. Lower manure phosphorus content can lead to increased spreading options by reducing the acres required to safely absorb manure nutrients. As expected, there is a positive relationship between scale of production and phytase use (fig. 9). The share

Figure 7

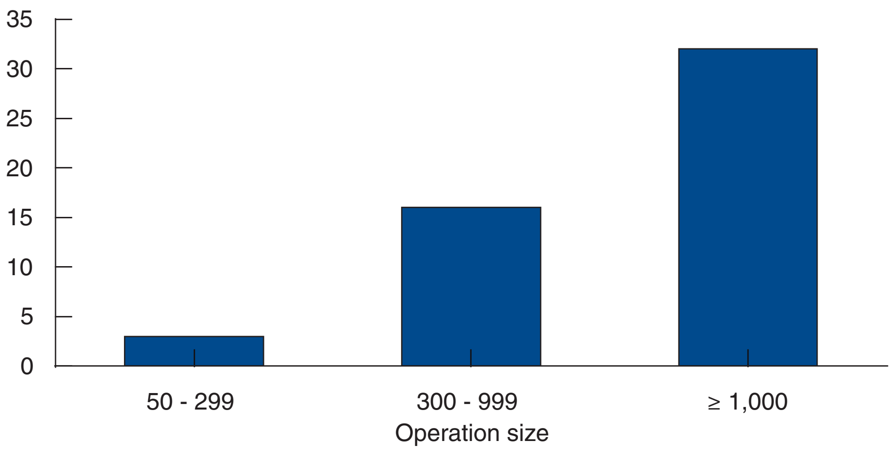
Application of commercial fertilizer with manure declined with size of farm and over time



Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

Figure 8

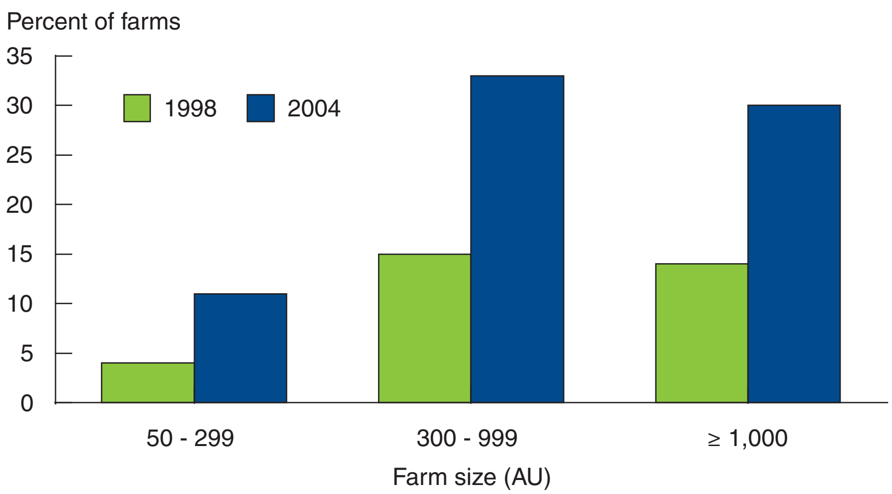
Larger farms are more likely to apply manure to Bermuda grass (2004)



Source: USDA, ERS, 2004 Agricultural Resource Management Survey.

Figure 9

Use of microbial phytase in feed increased between 1998 and 2004



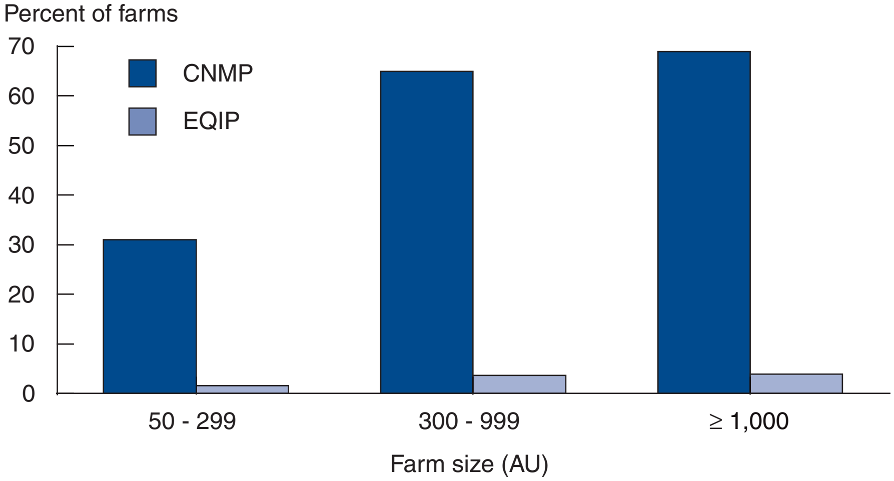
Source: USDA, ERS, 1998 and 2004 Agricultural Resource Management Surveys.

of farms using phytase grew in all size categories between 1998 and 2004, with the share of all farms using phytase more than tripling (from 4 percent to 13 percent). The share of hogs raised on farms using phytase increased from 12 percent to 30 percent. Concern about manure phosphorus levels is also evident from the increase in the share of farms testing manure for phosphorus content between 1998 and 2004 (table 5).

In 2004, about 30 percent of all farms followed a CNMP that requires growers to apply manure nitrogen at or below the agronomic rate and 62 percent of animal units were raised on farms using a CNMP (see box, "Manure Storage and Handling Strategies").[7] There is also a positive association between the scale of production and the use of a CNMP (fig. 10). Only about 30 percent of

[7] The goal of manure application is to apply manure at rates that meet crop needs while avoiding over applications that could lead to water quality impairment. Rates that meet this goal are often called agronomic rates.

Figure 10
Larger farms are more likely to follow a CNMP and receive EQIP payments (2004)



Source: USDA, ERS, 2004 Agricultural Resource Management Survey.

operations with 50-299 animal units followed a CNMP in 2004, compared to more than 60 percent of those with at least 300 animal units.

Environmental Policy and Other Impacts

Recent policy initiatives may explain some of the changes in manure management practices. Federal and State policies implemented in recent years have set limits on the amount of nutrients that can be applied per acre of land. Restricting application rates may explain increases in the crop acreage receiving animal manure and the amount of manure moved off the farm, as well as the widespread adoption of nutrient management plans observed in the ARMS.

Financial assistance from USDA's Environmental Quality Incentives Program helps to defray the costs of meeting the regulations by funding

Table 6
Environmental Quality Incentive Program payments related to hog production, 2004

	Percent
All farms	
Any hog-related EQIP payments	1.5
Manure handling and storage facilities	0.6
Nutrient management plan	0.8
Manure application	0.2
Other[1]	0.4
All farms, weighted by animal units	
Any hog-related EQIP payments	3.2
Manure handling and storage facilities	1.5
Nutrient management plan	2.2
Manure application	0.6
Other[1]	1.1

[1] Includes animal facilities, manure hauling, and unspecified.

Source: USDA, ERS, 2004 Agricultural Resource Management Survey.

planning, installation, maintenance, and technical support for protective conservation practices. Survey results show that only 1.5 percent of farms received any EQIP payments related to hog production in 2004 (table 6). However, 3.7 percent of medium and 3.9 percent of large operations received payments (fig. 10). EQIP payments were used primarily for installing conservation practices associated with manure handling and storage facilities and for developing and maintaining a nutrient management plan. The small share of farms receiving payments in 2004 suggests that these payments do not explain the more widespread changes observed in the study, such as the movement away from lagoons toward pit/tank systems, the decline in the spreading of liquid manure without injection, the increase of manure removal from the operation, the increased use of manure nutrient testing, or the use of microbial phytase in feed. However, these payments may have facilitated these changes, especially for medium and large-scale operations.

Policy initiatives may also explain some of the increased use of such practices as manure injection and development of a nutrient management plan. Agricultural-residential conflicts at the rural-urban fringe may also play a role (Ribaudo and Johansson, 2007). Manure injection reduces odors from land application, and developing a nutrient management plan demonstrates diligence on the part of livestock producers in avoiding harm to the nearby community.

Conclusion

Findings from the analysis of the 1998 and 2004 hog surveys indicate important relationships between the scale of production and manure management practices and outcomes. Most importantly, large operations have altered their manure management decisions in response to binding nutrient application constraints. This finding is suggested by the positive association between scale of production and:

(1) a greater likelihood of removing manure from the operation, especially by giving it away for free;

(2) a lesser likelihood of applying both commercial fertilizer and manure to crops;

(3) a greater likelihood of applying manure to crops with a high rate of nutrient uptake (e.g., Bermuda grass) and of adding microbial phytase to feed; and

(4) a greater likelihood of testing manure for nutrients and of following a comprehensive nutrient management plan.

Manure management practices and outcomes have also changed significantly over time. Many of these changes can be attributed to the pronounced structural changes in hog production that occurred between 1998 and 2004—particularly farm size and regional shifts. For example, the relative growth of production in the Heartland compared to the Southeast likely explains much of the shift from lagoons to pit/tank systems, despite lagoons being more prevalent among larger operations. Other major changes between 1998 and 2004 include:

(1) a decline in the spreading of solid manure and liquid manure without injection, among farms applying manure;

(2) an increase in the average manure application intensity (animal units per acre) among farms applying manure;

(3) a small decline in the manure application intensity among the largest operations;

(4) a decline in the nutrients excreted per animal due to an increase in feed efficiency;

(5) an increase in the share of farms removing manure from their operation;

(6) an increase in manure nutrient testing rates; and

(7) an increase in the use of microbial phytase in feed.

Environmental policies are also behind some of the observed patterns of change in hog manure management. The regional shift in production was partly a response to State regulations that sought to reduce negative environmental outcomes associated with large hog manure lagoons. The number of Federal and State policies designed to reduce the overapplication of manure nutrients also grew between 1998 and 2004. In 2004, 30 percent of farms, representing 62 percent of animal units, followed a nutrient management plan. Nutrient application restrictions and the desire to avoid future liabilities and lawsuits could explain the increasing share of operations moving manure off the farm, testing manure for nutrients, and using microbial phytase in feed. While the manure-nutrient application intensity generally increases with farm size, the fact that the application intensity declined on the largest operations between 1998 and 2004 suggests that environmental policy is contributing to the adoption of conservation-compatible manure management practices.

The increasing concentration of hog production on large operations is expected to continue, meaning that manure management will continue to be an important issue to the hog industry and others concerned with its environmental impact. Results of this research imply that hog producers have responded to policy incentives, both positive and negative, designed to address the manure management issue. The findings also suggest that there still is significant room for reducing the environmental impact of manure disposal. For example, hog operations, on average, apply manure to less than 30 percent of available crop acreage. Policy incentives, along with technological innovation, are likely to play an important role in the future of hog manure management and its environmental impact.

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