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Trends and Developments in Hog Manure Management: 1998-2009

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Abstract

In the past decade, hog production has increasingly become consolidated, with larger operations producing a greater volume of hog manure on smaller areas. With less cropland for spreading the manure, hog farmers may be compensating through more effective manure management. The authors use data from 1998 to 2009 collected in three national surveys of hog farmers. Over this period, structural changes in the hog sector altered how manure is stored and handled. Changes to the Clean Water Act, State regulations, and local conflicts over air quality also affected manure management decisions. The findings further suggest that environmental policy has influenced conservation-compatible manure management practices. The authors examine how the use of nutrient management plans and of practices such as controlled manure application rates vary with scale of production and how these practices changed over the study period. This report is an update of an earlier report, *Changes in Manure Management in the Hog Sector: 1998-2004.*

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

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Contents

Summary

What Is the Issue?

Over the last decade, U.S. hog industry production has shifted to fewer and larger operations that specialize in a single phase of hog production and the use of production contracts. Consolidation of operations has meant that an increasing volume of manure is often produced on farms with less cropland per animal for spreading the manure. A higher manure-to-cropland ratio has magnified the risk that manure nutrients (nitrogen, phosphorous, and potassium) and pathogens might flow into ground and surface water due to overapplication of manure on crops or leakage from manure storage facilities. These runoff contaminants can harm aquatic life and livestock and affect human drinking water. In addition, increased concentration of hogs per farm has led to conflicts with nearby residents or communities over odor and air quality. Legislative initiatives, such as the Clean Water Act and various State regulations, have implemented environmental policies to mitigate the risk of water pollution and reduce conflicts. Despite the pronounced shifts in hog industry structure and regulation, little information exists for assessing how these changes have affected manure management practices and environmental quality. Using data from three surveys of hog farmers, the authors shed light on these issues by examining how hog manure management practices vary with the scale of production and how practices have changed since 1998.

What Are the Major Findings?

- Hog farm operators altered their practices between 1998 and 2009 in ways that suggest intent to manage manure in a more environmentally sound manner. In 2009, operators were more likely to have comprehensive nutrient management plans and, accordingly, to have increased their efforts to apply manure at rates not exceeding the nutrient needs of the crop. They were more likely to have applied manure over a larger share of their cropland and to have increased their use of feed additives that reduce phosphorus in hog manure, increased the nutrient testing of manure, and removed excess manure from their premises. They were less likely to have added commercial fertilizer to crops receiving manure.

- Changes in manure management practices and outcomes from 1998 to 2009 are related to structural changes in hog production, particularly the increase in farm size and regional shifts of production. The changes include more use of pit/tanks and less of lagoons for manure storage; a decline in spreading solid manure, as well as in spreading liquid manure without incorporating it into the soil; and less intensive manure application by the largest farms.

- Environmental policies are likely behind some of the observed patterns of change in hog manure management between 1998 and 2009. For example, the relatively slow growth in production in the Southeast compared with the Heartland may be partly attributable to State regulations in North Carolina designed to reduce risks associated with manure lagoons. Nationally, greater use of comprehensive nutrient management plans, as well as a decline in intensity of manure applications by

the largest operations, may be in response to Federal and State policies designed to reduce overapplication of manure nutrients. These changes suggest that larger hog operations are altering their manure management decisions in response to legal nutrient application constraints and that environmental policy is contributing to the adoption of conservation-compatible manure management practices.

How Was the Study Conducted?

This study uses information from surveys of U.S. hog producers conducted in 1998, 2004, and 2009 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 the authors to document the current state of manure management and track producers' manure management practices during a period of rapid change in the hog industry. Data from the surveys are disaggregated by farm size according to the number of animal units produced (by 1,000 pounds of live animal weight). Because larger hogs produce more manure, animal units provide a consistent measure for comparing manure handling trends among farms with different levels of manure output.

Introduction

Over the past several decades, economic competition has driven substantial changes in the hog industry; production has shifted regionally and to larger operations that increasingly specialize in a single phase of hog production and use production contracts. In turn, the changing farm structure is altering manure practices as larger operations seek to manage nutrients on a smaller cropland base. At the same time, chemical fertilizer prices have increased markedly, providing an incentive for producers to adopt methods that conserve and better utilize manure nutrients.

Changes to the Clean Water Act, State regulations, and conflicts with nearby residents over odor and air quality are also influencing manure management decisions. Changes in the regulatory climate have been driven by increased environmental risk to air and water associated with larger livestock operations. Nutrients (nitrogen, phosphorous, potassium), ammonia, hydrogen sulfide, methane, pathogens, and odor can originate at production houses where animals are kept, at manure storage structures such as tanks and lagoons, or on land where manure is applied. The concentration of animals and manure into smaller areas increases the risk of environmental contamination, the nuisance potential of farms, and the overall challenge of managing manure.

We use data from recent surveys of hog farmers to examine how hog manure management practices vary with the scale of production and how practices changed between 1998 and 2009 (see box, “Data”). The findings provide information about the potential effects of recent policies and structural changes on manure management technologies and practices, the use of nutrient management plans, and manure application rates.

Data

We analyzed information from surveys of U.S. hog producers conducted in 1998, 2004, and 2009 as part of USDA's annual Agricultural Resource Management Survey (ARMS). The detailed surveys cover a cross-section of U.S. hog operations each year 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, the use of comprehensive nutrient management plans, and manure application rates.

The sample of hog farms was chosen from a list of operations maintained by USDA's National Agricultural Statistics Service. 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 screened out to exclude operations that raise hogs primarily for on-farm 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 observation's expansion factor, or survey weight. The ARMS hog survey sampled operations in 22 States in 1998, 19 States in 2004, and 19 States in 2009. When the samples in each survey are expanded by their population weights, they represent more than 90 percent of the hog and pig inventory on U.S. farms in each survey year.

Estimates from the three 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, 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:www.ers.usda.gov/Briefing/ARMS/.

Data from the surveys are disaggregated 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 number of animal units on each farm is the steady-state live weight of sows, piglets, and other hogs, which is computed using average hog inventories and weights from the ARMS.

The environmental implications of hog production depend primarily on the manure management decisions of operations having at least 50 animal units. These operations accounted for 97 percent of hog sales in the sample frame in 1998 and 99 percent in both 2004 and 2009. 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 reflect changes in the scale, organization, geography, and methods of 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 pigs and care until weaning); (3) nursery (care immediately after weaning until about 30-80 pounds); and (4) finishing (feeding hogs from 30 to 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); (5) farrow-to-wean (phases 1 and 2); or (6) wean-to-finish (phases 3 and 4).

Historically, most U.S. hog production has occurred on farrow-to-finish operations located in areas with an abundant supply of corn. Hog farmers typically used corn produced on the farm as an inexpensive source of feed and applied hog manure as fertilizer on farm fields. Advancements in breeding and genetics, swine housing, nutrition, feeding, and farm management since the 1970s have allowed producers to become increasingly specialized in only one or two of the production phases. During the period of this analysis, hog farms using the farrow-to-finish approach declined from 49 percent in 1998 to 31 percent in 2004 and 23 percent by 2009 (table 1).

Increases in the scale of production have accompanied changes in organization. Between 1998 and 2009, the number of hog operations fell by about 60 percent, and the average inventory grew from 2,589 to 7,930 head (table 1).

Table 1
Hog operation characteristics, 1998, 2004, and 2009

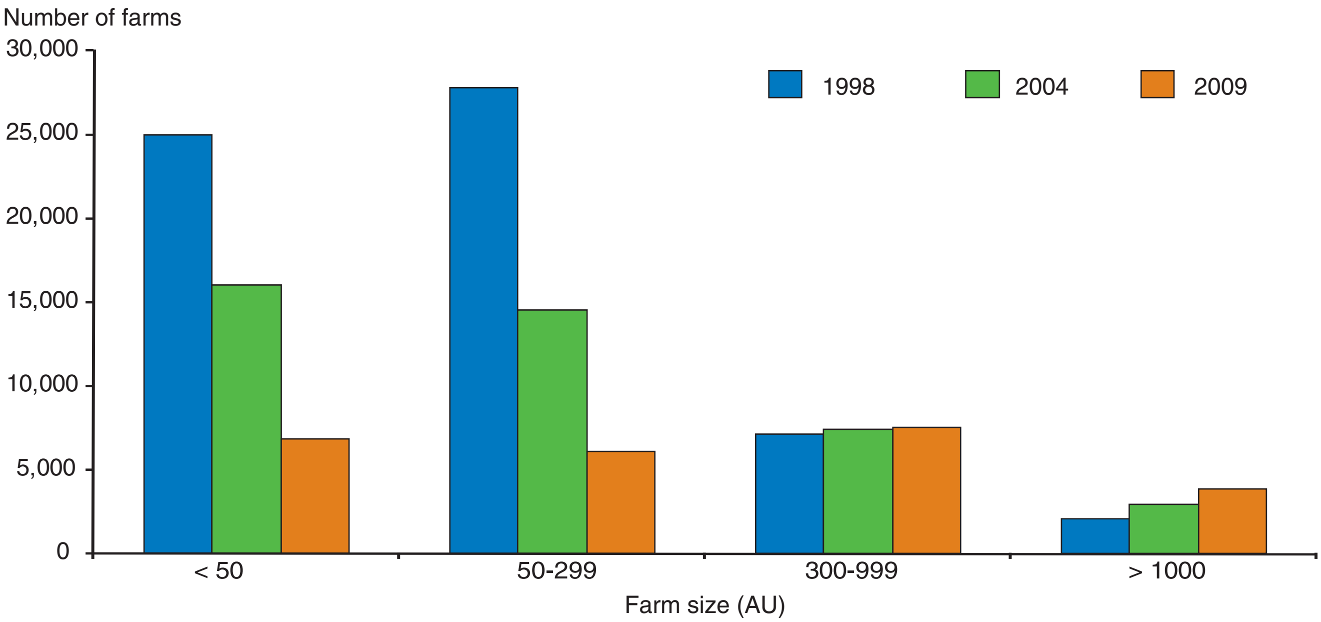
Characteristics for all farms	1998	2004	2009
All farms:			
Number of hog operations	61,971	40,940	24,394
Hog sales and contract removals (head per farm)	2,589	4,646	7,930
Hog inventory (animal units per farm)	194	294	546
Producer type: Farrow-to-finish (% of farms)	49	31	23
Producer type: Feeder pig-to-finish (% of farms)	31	40	46
Used a production contract (% of farms)	15	28	48
Value of production from hog enterprise (% total)	56	71	70
Acres of cropland per animal unit	2.14	1.41	0.86
Farms with no cropland (%)	8	19	19
Observations in sample	1,633	1,198	1,290

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. The sample covered operations in 22 States in 1998 and 19 States in 2004 and 2009. 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. Crop acres include land used for hay production, but exclude land used for pasture only.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

Over this period, the number of hog operations producing fewer than 300 animal units declined rapidly, resulting in a shift in production to larger operations (figs. 1 and 2).

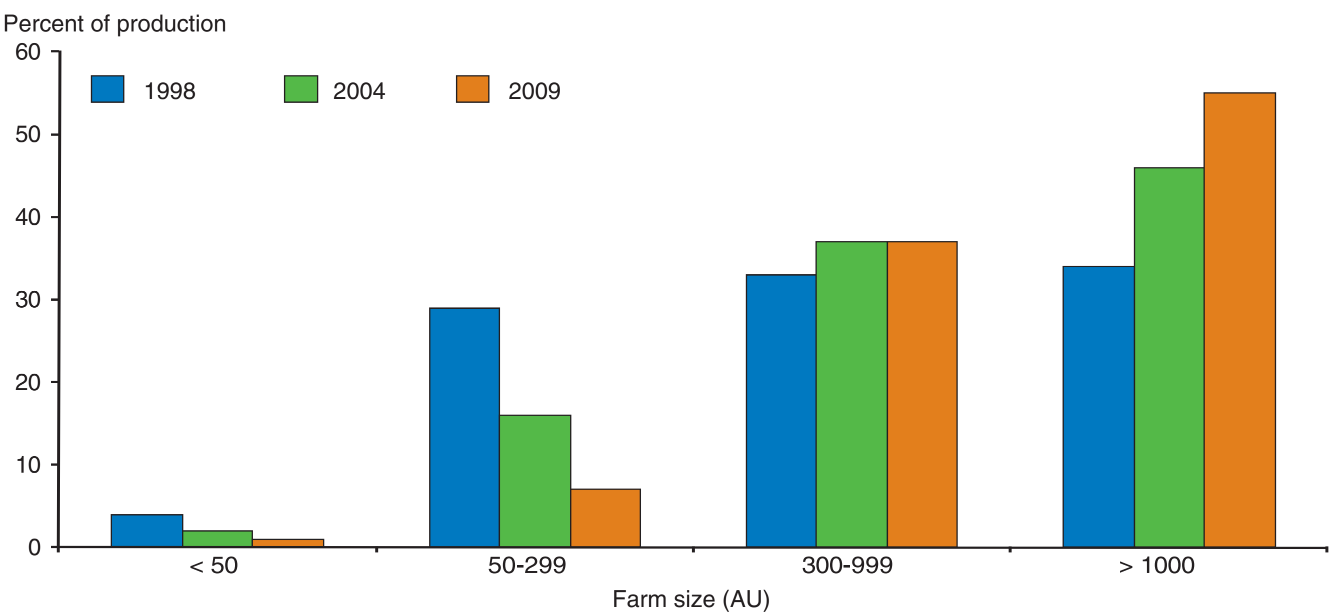
Figure 1
Small hog operations declined in number and large operations grew between 1998 and 2009



Note: Animal units (AU) 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

Figure 2
Large operations produced an increasing share of output between 1998 and 2009



Note: Animal units (AU) 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

The introduction of contract production arrangements has 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 in exchange for a predetermined formula for compensation. Contractors typically furnish inputs to growers, provide technical assistance, and collect the livestock to pass on for final processing or marketing. Packers or processors obtain hogs through marketing arrangements with the contractors (integrators) or directly from growers. Contract arrangements allow individual producers to specialize in one phase of production and increase their scale of operations.

Over the 11 years analyzed, the share of farms using a production contract more than tripled, and now almost half of all hog farms use contracts. An even larger share of output is now produced under contract, as the 48 percent of farms using production contracts in 2009 accounted for 71 percent of hog production. One issue with production contract arrangements is liability for managing the hog manure. Most contracts require growers to comply with all State, Federal, and local regulations in operating their facilities, and 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.

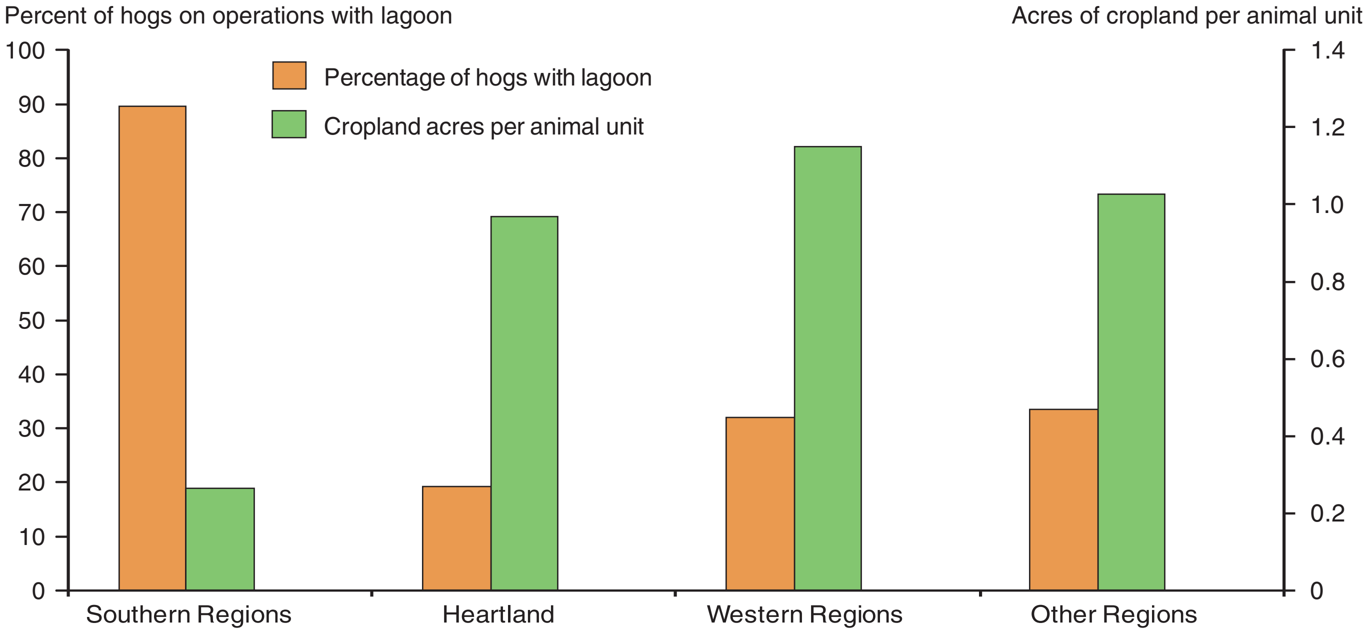
Another structural change with implications for manure management is the increasing specialization by operators in the hog enterprise. Among hog farms, the contribution of hogs to the farm's total value of production increased from 56 to 70 percent over the study period, with all of the change occurring between 1998 and 2004 (table 1). Sources of hog feed also indicate increasing specialization in hog production – the share of feed consumed by hogs and produced on the same farm fell from about 50 percent in 1992 to below 20 percent by 2004 (Key and McBride, 2007). The increasingly specialized operations, with greater shares of production value from hogs and more hog feed from off-farm sources, often produce hogs under contract. In a contract arrangement, contractors deliver feed from off-farm sources to their growers. This allows individual growers to use their time and financial resources to increase the scale of their hog enterprise rather than to cultivate crop acreage for feed production. As a result, cropland per animal unit on hog operations has steadily declined from 2.14 acres in 1998 to 1.41 acres in 2004, and to 0.86 acres in 2009 (table 1). The share of operations with no cropland increased from 8 to 19 percent over this period.[1] This increase has created concerns about how to manage the large quantities of manure generated on hog operations with less available cropland per animal unit.[2]

Geographical shifts in hog production have accompanied structural and organizational changes in the industry. Historically, hog production was concentrated in the Heartland, particularly in Iowa and Illinois, where an abundant corn supply 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 managing an increasing volume of hog manure in areas with a denser population and much less crop acreage for manure application than in the Heartland. In 2009, hog operations had about a quarter-acre of cropland per animal unit in the Southern regions compared with about

[1]Cropland includes land used for hay production, but excludes land used for pasture only.

[2]As farms have grown in size, some have divided into multiple operations, each specializing in hog or crop production. These hog operations selected in the ARMS would have reported little if any crop acreage because the crop acreage was part of the other operation. Partnerships between family members may organize farms by specializing operations in this manner. This arrangement lowers the estimated crop acreage per farm and increases the percent of hog operations with no crops. The extent of this influence is unknown, but it should not affect the interyear comparison of hog farms.

Figure 3
Lagoon use high and cropland availability low in Southern Regions, 2009



Note: Regions are ERS designations. Southern Regions include Southern Seaboard and Mississippi Portal; Heartland includes Heartland; Western Regions include Northern Great Plains and Prairie Gateway; Other Regions include Northern Crescent, Eastern Uplands, Fruitful Rim, and Basin and Range.

Map of regions can be found at: http://www.ers.usda.gov/Data/FarmandRelatedEmployment/DataFiles.htm.

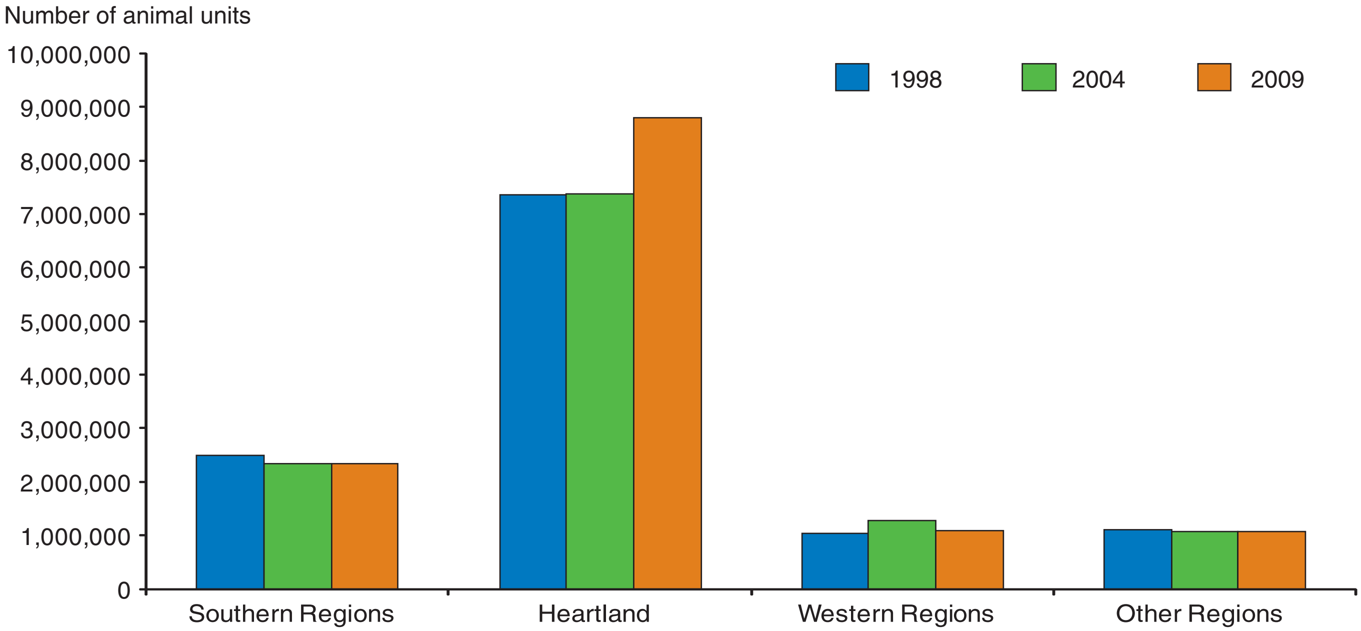
Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

1 acre per animal unit in other regions (fig. 3). Most hog producers in the Southeast treat and store manure in lagoon systems and apply manure to farm acreage with an irrigation system. In 2009, 90 percent of hogs produced in the South were on operations with a lagoon system compared with only 20 to 30 percent of hogs in other regions (fig. 3). The lagoon-sprinkler manure system increases nitrogen volatilization and allows producers to apply hog manure on less acreage than other manure management systems.

Between 1998 and 2009, the regional distribution shifted again: hog production increased in the Heartland and declined slightly in the South (fig. 4). Production increased in Western States like Colorado and Utah, where low population density provides flexibility in managing animal manure. Production in the Heartland region now accounts for about two-thirds of U.S. hog output. Lack of growth in the South could be attributed partly to a 1997 moratorium on the construction of new and expanded hog operations in North Carolina (North Carolina General Assembly, 1997). The moratorium was enacted in response to environmental concerns about managing hog manure from increasingly larger operations.

Structural changes have 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 and technological innovation (Key, McBride, and Mosheim, 2008). Efficiency gains included higher feed productivity (output per unit of feed), which can reduce the amount of manure produced by hog operations and thus the amount of manure nutrients that must be disposed of.

Figure 4
Hog production has increased in Heartland region



Note: Regions are ERS designations. Southern Regions include Southern Seaboard and Mississippi Portal; Heartland includes Heartland; Western Regions include Northern Great Plains and Prairie Gateway; Other Regions include Northern Crescent, Eastern Uplands, Fruitful Rim, and Basin and Range.

Map of regions can be found at: http://www.ers.usda.gov/Data/FarmandRelatedEmployment/DataFiles.htm/.

Animal units (AU) 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

Environmental Policy Background

Changes in environmental policies have also influenced manure management decisions. Many hog producers value the preservation of environmental quality and have found that profitable business practices are consistent with improved manure management practices. Nonetheless, concerns about water quality and air quality (primarily odor) have spurred local, State, and Federal action to mitigate environmental impacts of animal manure. The U.S. Environmental Protection Agency (U.S. EPA) revised Clean Water Act regulations in 2003 for controlling runoff of manure nutrients from the largest animal feeding operations (AFOs). These regulations were finalized in 2008. Clean Water Act regulations now require animal feeding operations designated as Concentrated Animal Feeding Operations (CAFOs) and discharging or proposing to discharge manure effluent to seek National Pollutant Discharge Elimination System (NPDES) permit coverage. Discharge from the production area and any land application areas under the control of the CAFO are included in the permit. CAFOs with permits must have a nutrient management plan that identifies site-specific practices to ensure agronomic use of nutrients.

Under the new regulations, CAFOs that are not required to have an NPDES permit, but that wish to claim the agricultural stormwater exemption for runoff from fields receiving manure, must implement a nutrient management plan to minimize polluted runoff. If a waterway becomes polluted with animal waste from field runoff and a CAFO does not follow a nutrient management plan, the CAFO will be violating the Clean Water Act.

Enforcement of these updated Federal CAFO rules is largely devolved to individual States, which have adopted the new rules at various rates. In April 2010, the EPA reported that most States are expected to complete revisions to comply with the updated Federal rules by the end of 2010.

Atmospheric emissions of pollutants are regulated by the Clean Air Act (CAA). The CAA authorizes regulatory programs primarily for protecting human health. EPA 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 particles (one of the six criteria pollutants regulated under the act) (U.S. EPA, 2004). States with designated nonattainment areas were required to submit plans outlining how they would meet the standards by 2010. This regulation could affect animal operations because ammonia emitted from barns and manure storage facilities is a major precursor of fine particulates. Controlling ammonia from animal operations would be a likely priority in nonattainment areas with high concentrations of animals (U.S. EPA, 2000a). To gather data and develop generalized protocols, a 2006 EPA consent agreement encouraged livestock producers to volunteer for emissions monitoring in exchange for clemency for past air pollution violations (U.S. EPA, 2006). The National Air Emissions Monitoring Study (NAEMS) was concluded in 2010, and in early 2011 the EPA stated that the data were available for release (U.S. EPA, 2011).

Since 2010, a new Greenhouse Gas Reporting Rule has required owners and operators of facilities that contain manure management systems emitting at least 25,000 metric tons of greenhouse gases per year (expressed as carbon dioxide equivalents) to report emissions from all sources at the facility for which emission calculation methods are defined. EPA estimates that this rule will cover from about 85 to 95 of the Nation's largest livestock facilities (U.S. EPA, 2009b).[3]

[3]The EPA report does not specify which types of livestock facilities will be covered.

Other legislation covering air pollution includes the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA). Both laws use information disclosure to increase the information available to governments 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 significantly reduces threats to public health. Though CERCLA was 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 the act. EPA has enforced the CERCLA and EPCRA reporting requirements of animal feeding operation releases of hazardous pollutants in two cases (Copeland, 2008).

However, due to controversy over the use of these laws for agricultural emissions (Copeland, 2008), the EPA issued a reporting exemption for air releases of hazardous substances from animal waste at farms in 2009 (U.S. EPA, 2009a). The rule exempts all farms that release hazardous substances from animal waste to the air from reporting under CERCLA. Farms that do not meet the size definition of a CAFO (as defined by the Clean Water Act) are also exempt from reporting under EPCRA. However, farms that do meet the size definition of a CAFO are still required to submit the appropriate reports to State and local officials under EPCRA if they release hazardous substances to the air that meet or exceed their Reporting Quantity.

Odor arising from livestock operations has become a source of controversy in many agricultural communities, prompting numerous States to adopt some form of odor regulation (Redwine and Lacey, 2000; Sneeringer, 2010). These State policies may contain objective odor standards or require management methods such as separation distances, explicit odor plans, or "good neighbor practices." Several States include odor stipulations in their general permits for livestock operations (U.S. EPA, 2002b). To the extent that odor is correlated with levels of certain air emissions (particularly hydrogen sulfide and ammonia), State policies to limit such emissions may also help to control odor.

Most States have implemented regulations for controlling at least some of the environmental impacts of AFOs, including permits, licenses, and zoning requirements. To prevent large amounts of waste from being carried into coastal estuaries during major rain events such as hurricanes, North Carolina entered into a legal agreement with the State's largest swine producers to develop innovative waste management strategies that would replace uncovered lagoon and sprayfield systems for storing and treating waste from large hog operations (Williams, 2004; Bales et al, 2000). In 1997, the State issued a moratorium on the construction of new or expanded facilities in order to study and put in place a regulatory system to ensure that waste structures were sound, that waste application methods were adequate, and that viable waste utilization plans were in place. Iowa, Pennsylvania, Arkansas, and Kentucky are among States that have introduced rules for curbing water pollution, ammonia, and odor from AFOs (Patton and Seidl, 1999; U.S. EPA, 2002a,b).

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

To help defray the costs of meeting the regulations, producers can apply for financial assistance from the USDA's Environmental Quality Incentives Program (EQIP).[4] A farmer or entity may receive up to $300,000 for all EQIP contracts entered during a 6-year period to help 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 (Ribaudo, Cattaneo, and Agapoff, 2004).

[4]For more information about EQIP see the USDA Natural Resource Conservation Service website: http://www.nrcs.usda.gov/programs/eqip/.

Some major hog producers, such as Smithfield Foods, are taking the necessary steps for meeting voluntary environmental performance standards established by the International Organization for Standardization. ISO 14001 is the Environmental Management System (EMS) standard that measures how well companies manage those parts of their operation that affect the environment (Wall et al., 2001). The EMS includes such elements of hog production as sanitation, waste treatment systems, and nutrient management. The EMS is certified by a qualified third party.

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 are 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 hold the manure until it can be land-applied on the same farm 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 irrigation systems that spread the liquid lagoon solution on nearby fields.

The different systems for manure management have very different impacts 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 the manure into the soil manages the manure for its potential fertilizer value. This system is designed to retain manure nitrogen for crop use, and thus it requires more land on which to apply the manure if the operation is following a nitrogen-based nutrient management plan. In contrast, handling manure from lagoon storage and distributing it with irrigation increases the release of nitrogen into the atmosphere, reducing the manure's nutrient content and requiring less land for application.

Manure Storage and Handling

Lagoon use has a strong positive association with the scale of production (fig. 5). For example, in 2009, 41 percent of operations with at least 1,000 head used a lagoon, compared with only 22 percent of small-scale operations and 27 percent of medium-scale operations. Despite the trend toward larger operations, there was a shift between 1998 and 2009 toward the use of pit/tank systems. By 2009, 62 percent of hogs were raised on farms using pit/tanks (up from 37 percent in 1998); in 2009, 34 percent were raised on farms using a lagoon system (down from 55 percent in 1998).[5] This shift can be partly attributed to regional shifts in hog production. In the Southern region, more hogs are produced on operations that use lagoon systems, while in other regions more hogs are produced on operations using pit/tanks (fig. 3). Hence, the largely stagnant hog production in the South, combined with an increase of production in the Heartland between 1998 and 2009 (fig. 4), partly explains the increasing national use of pit/tanks. The shift to pit systems may also have been encouraged by rising prices of chemical fertilizers, which increased incentives for new hog facilities to adopt designs that conserve manure nutrients for use on nearby crop or hay land.

The manure storage facility generally determines how manure effluent is transported and applied to crops. Pit/tank systems commonly use a slurry or liquid spreader, while irrigation technology (solid-set sprinklers, traveling

[5]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 on the average animal unit rather than the average farm.

Manure Storage and Handling Strategies

Comprehensive nutrient management plan (CNMP) - Following a comprehensive nutrient management plan for applying manure and commercial fertilizer to land can reduce 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; plans for manure and wastewater handling and storage, farm safety and security, land treatment practice, and prevention of soil erosion; nitrogen and phosphorus risk assessment; plans for nutrient management in accord with criteria in the Nutrient Management Conservation Practice (code 590); and record-keeping. Important objectives in comprehensive nutrient management planning include soil and manure testing for nutrient content, balancing farm-available nutrient resources with farm crop needs, and monitoring the operation's total nutrient balance to account for nutrients generated, field-applied, removed in products, or transferred offsite. Plans can also account for atmospheric losses of nitrogen, as well as for atmospheric deposition of nitrogen on cropland.

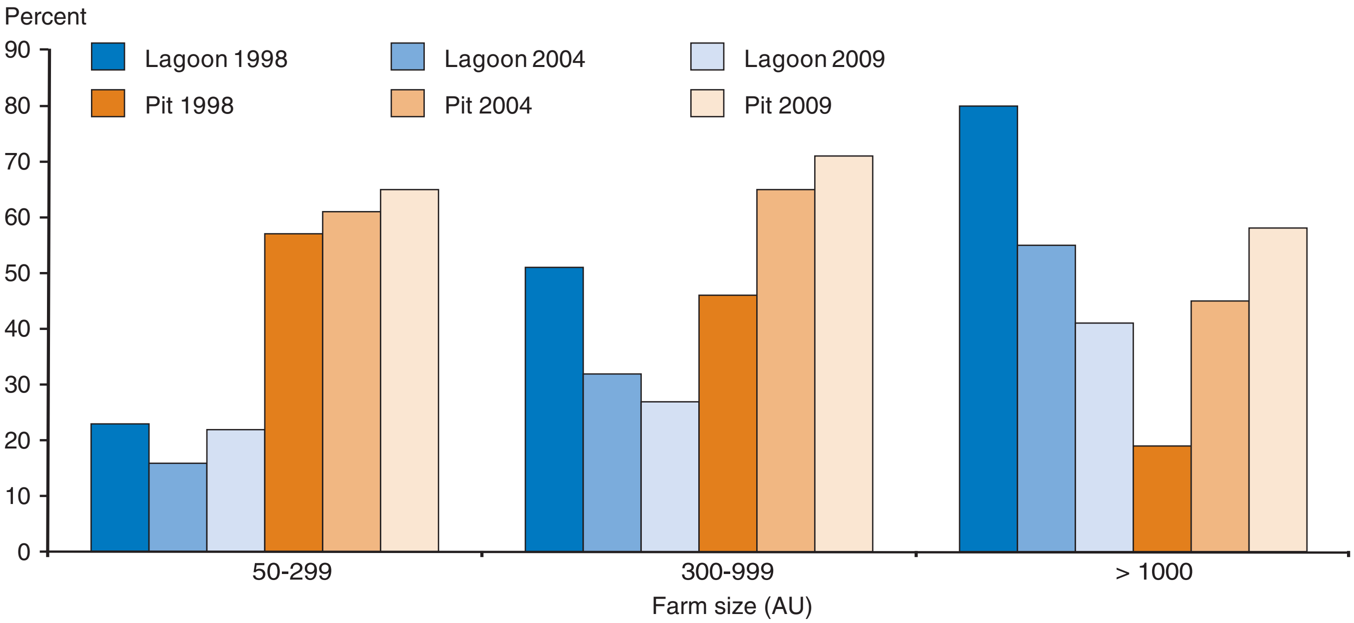
Manure incorporation and injection - Rapidly incorporating manure into the soil, either by plowing or disking solids after spreading or injecting liquids and slurries directly into the soil, reduces odor and gaseous emissions (Abt, 2000; Arogo et al., 2002). It also reduces the risk of nutrients being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

Slurry pits - Slurry systems store undiluted, untreated manure in water-tight 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, 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 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).

Figure 5

Changes in the share of operations having lagoon and pit manure systems, 1998 to 2009



Note: Animal units (AU) 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

guns, and linear or circular traveling booms) 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 matter (including byproducts of ammonia), and greenhouse gases (methane and nitrous oxide) (Aillery et al., 2005).

Both solid and liquid manure can be incorporated into the soil, which reduces odor and nutrient volatilization (escape into the atmosphere) relative to spreading, keeping 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.

The type of manure-spreading technologies used is often related to the scale of production. Among large farms that applied manure to crops, irrigation was the most common form of manure application, followed by injection of liquid manure (table 2). In contrast, smaller operations were more likely to spread solid manure, or to spread liquid manure without injection. Between 1998 and 2009, the share of appliers who spread solid manure declined overall, from 64 percent of operations in 1998 to only 34 percent in 2009. Most of this change occurred because (1) the number of small farms, which are more likely to handle solid manure, declined and (2) small and medium farms handled manure in solid form less often.

Growers altered their spreading technologies between 1998 and 2009 toward methods that produce less odor, nutrient volatilization, and runoff. The share

Table 2
Hog manure application technologies used on farms applying manure

Application technology	1998	2004	2009
All farms that apply manure:			
Solid spreader	64	45**	34**
Liquid spreader (no injection)	27	18**	19**
Liquid spreader (injection)	20	21	25
Irrigation	12	13	19*
All farms that apply manure, weighted by animal units:			
Solid spreader	36	19**	14**
Liquid spreader (no injection)	25	17*	12**
Liquid spreader (injection)	30	34	34
Irrigation	34	36	35
Farm size category (farms that apply manure):			
Small (50 – 299 animal units)			
Solid spreader	66	40**	38**
Liquid spreader (no injection)	40	28**	38
Liquid spreader (injection)	28	31	23
Irrigation	9	10	16**
Medium (300 – 999 animal units):			
Solid spreader	32	23	15**
Liquid spreader (no injection)	28	19	14*
iquid spreader (injection)	42	37	42
Irrigation	32	28	21
Large (> 1,000 animal units):			
Solid spreader	10	10	10
Liquid spreader (no injection)	7	12	8
Liquid spreader (injection)	20	30	30
Irrigation	58	57	43

Note: Asterisks indicate level of significance for the test of the null hypothesis that mean equals 1998 mean: ** =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, 2004, and 2009 Agricultural Resource Management Surveys.

of animal units on operations where liquid manure was applied without soil injection declined from 25 to 12 percent. The share of large operations applying liquid manure with injection technologies increased 10 percentage points and the share of large operations applying manure with irrigation declined 15 percentage points (although neither of these are statistically significant).

Manure Application and Disposal

On average, larger hog operations harvested more cropland, applied manure to more acres on-farm, and applied manure to a larger share of their cropland (table 3). These relationships are reflected in the aggregate statistics, as the average farm size increased between 1998 and 2009. Over this period, the average amount of cropland on a hog farm increased from 448 to 578

Table 3
Hog manure application technologies used on farms applying manure

	1998	2004	2009
All farms that apply manure:			
Acres with manure application	85	86	136**
Acres of cropland	448	483	578**
Percent of cropland with manure application	19.1	17.8	23.5*
Application intensity (AU/acre applied)	2.1	3.0**	3.7**
All farms that apply manure, weighted by animal units:			
Acres with manure application	147	218**	278**
Acres of cropland	596	855**	919**
Percent of cropland with manure application	24.7	25.5	30.2
Application intensity (AU/acre applied)	7.2	7.4	6.4
Farm size category (farms that apply manure)			
Small (50 – 299 animal units):			
Acres with manure application	95	85	101
Acres of cropland	517	599	592
Percent of cropland with manure application	18.4	14.2*	17.1
Application intensity (AU/acre applied)	1.3	1.6	1.5
Medium (300 – 999 animal units):			
Acres with manure application	156	169	178
Acres of cropland	565	652	661
Percent of cropland with manure application	27.6	26.0	27.0
Application intensity (AU/acre applied)	2.9	3.0	3.2
Large (> 1,000 animal units):			
Acres with manure application	159	224	281**
Acres of cropland	643	1016*	909
Percent of cropland with manure application	25.0	22.0	30.9
Application intensity (AU/acre applied)	9.4	8.0	6.2**

Note: Asterisks indicate level of significance for the test of the null hypothesis that mean equals 1998 mean: ** =5%, * = 10%.

Source: USDA, ERS, 1998, 2004 and 2009 Agricultural Resource Management Surveys.

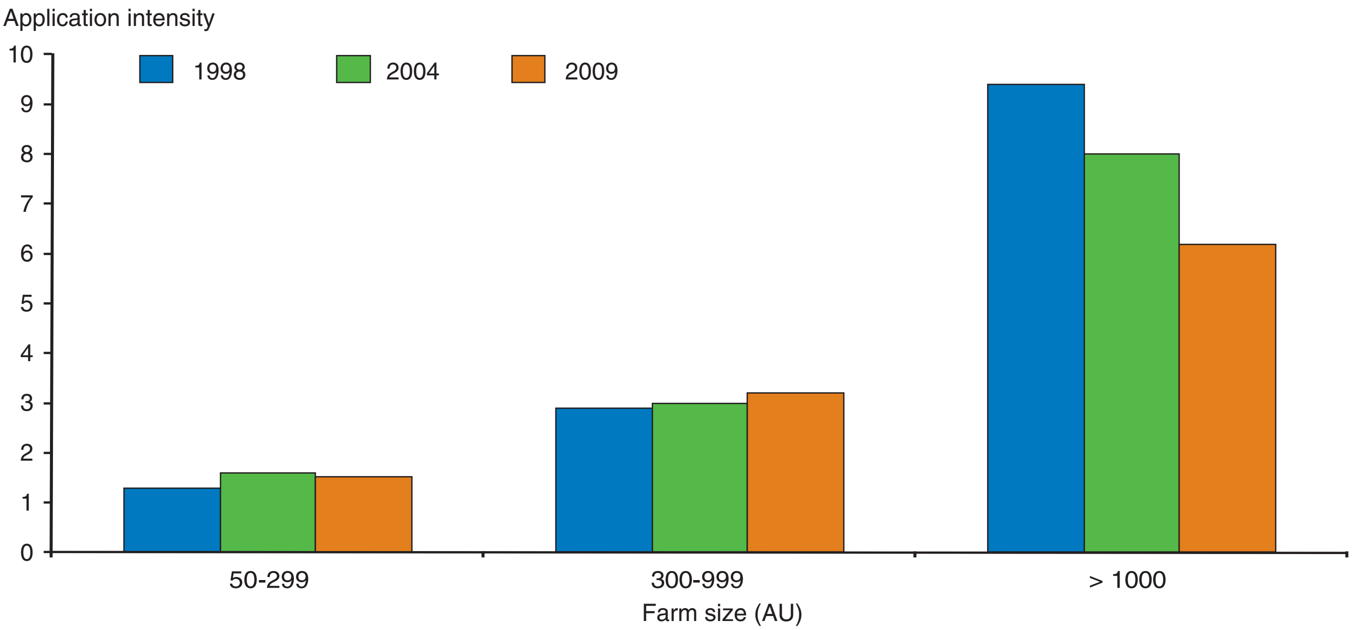
acres, and the number of manure-applied acres increased from 85 to 136. As a result, the share of cropland on hog farms on which manure was applied increased from 19.1 to 23.5 percent. This trend was mainly driven by the largest operations, where the share of cropland with manure application increased from 25 percent in 1998 to 30.9 percent in 2009.

Even though the share of on-farm cropland with manure application increased between 1998 and 2009, the average hog operation applied manure to less than a quarter of its cropland in 2009. This indicates that the potential exists to spread manure over more on-farm crop acreage. However, farmland is often separated by considerable distances from hog facilities, implying that operators could face substantially higher manure transportation and application costs if they were to apply manure on more acreage.

Figure 6 illustrates the strong positive association between scale of production and manure application intensity (animal units per manure-applied acre,

Figure 6

Manure application intensity increased with scale of production, but large-scale operations reduced intensity between 1998 and 2009



Note: Animal units (AU) 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. The manure application intensity is the hog inventory (AU) adjusted for the removal of manure off the farm divided by the acres of land on the hog operation on which manure was applied. 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

adjusted for the share of manure removed from the operations).[6] The higher application rates for larger operations reflect the large amount of manure generated by larger hog operations compared with the cropland on these operations available for manure application. Between 1998 and 2009, the increase in total animal units produced outpaced the increase in crop acreage on which manure was applied, resulting in a 74-percent increase in average manure application intensity. However, this increase was driven mainly by operations with fewer than 1,000 animal units. 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 by 34 percent (fig. 6). Because large farms are responsible for a large share of hog output, the application intensity for the average unit of production (rather than the average farm) fell by 11 percent between 1998 and 2009.

Qualifying the measure of manure application intensity is important. Different storage and handling techniques help determine the quantity of nutrients 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 most are excreted in urine and manure (Follett and Hatfield, 2001; ASAE, 2005). 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

[6]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.

(e.g., nitrogen per acre) is generally lower on larger farms than the estimated manure application intensity (animals per acre) would imply.

Among all hog operations, 76 percent applied some manure on their farms in 2009, a decrease from 82 percent in 2004 (table 4). The share of farms applying manure declined over this period for all size categories, particularly the medium- and large-size groups. Part of the overall decline can be explained by the shift to larger operations, which were less likely to apply

Table 4
Manure application and removal

	Percent		
	1998	2004	2009
All farms:			
Applied manure on farm	83	82	76*
Removed manure from operation	14	21**	21**
Sold manure	0	2*	5**
Paid for manure removal	2	2	2
Manure given away free	12	18*	16*
All farms, weighted by animal units:			
Applied manure on farm	85	76	74*
Removed manure from operation	23	31	34**
Sold manure	1	5	9**
Paid for manure removal	4	4	5
Manure given away free	19	23	24
Farm size category			
Small (50 – 299 animal units):			
Applied manure on farm	89	89	83
Removed manure from operation	16	14	17
Sold manure	0	2	2**
Paid for manure removal	2	2	3
Manure given away free	14	11	13
Medium (300 – 999 animal units):			
Applied manure on farm	90	83	79**
Removed manure from operation	31	27	29
Sold manure	2	5	9
Paid for manure removal	8	5	3
Manure given away free	23	18	22
Large (> 1,000 animal units):			
Applied manure on farm	85	69	75
Removed manure from operation	26	38	37
Sold manure	1	3	9**
Paid for manure removal	1	3	1
Manure given away free	24	31	26

Note: Asterisks indicate level of significance for the test of the null hypothesis that mean equals 1998 mean: ** =5%, * = 10%.

Source: USDA, ERS, 1998, 2004 and 2009 Agricultural Resource Management Surveys.

manure on-farm than smaller operations in each of the three surveys. In 2009, 75 percent of large farms applied manure on-farm compared with 79 percent of medium-size farms and 83 percent of small farms.

Manure that is not applied on-farm is usually hauled off-farm for application to cropland on neighboring farms. Because large hog operations have relatively less cropland available on-farm, the relationship between the scale of production and the quantity of manure removed is positive (table 4). The overall share of farms removing manure grew 50 percent between 1998 and 2004, and this increase was attributable mainly to large operations. Between 2004 and 2009, the share of farms removing manure did not increase markedly. Most of the manure removed from farms was given away to nearby farms. However, there appears to be a growing trend toward selling manure—the share of farms selling manure increased in all farm size categories between 1998 and 2009, albeit from a very low beginning level. Larger operations were more likely to sell manure. In 2009, 9 percent of the largest operations sold manure, compared with only 1 percent in 1998. The increasing manure sales could be partly explained by the dramatic rise in chemical fertilizer prices, which increased 174 percent between 1998 and 2009.[7]

[7]From "Fertilizer Use and Price Tables: Fertilizer Price Indexes," USDA Economic Research Service. Accessed November 2010 at: www.ers.usda.gov/Data/FertilizerUse/Tables/Table8.xls.

Manure Nutrient Management Practices

Table 5 describes the evolution of manure management practices between 1998 and 2009. Manure nutrient testing, a practice required as part of many State-mandated manure management plans, was positively associated with

Table 5
Nutrient management practices

		Percent	
Management practices	1998	2004	2009
All farms:			
Tested manure for N content	18	29**	49**
Tested manure for P content	17	28**	48**
Applied commercial fertilizer and manure	61	58	50**
Applied manure to Bermuda grass (appliers only)	n.a.	11	7
Followed CNMP1	n.a.	30	55
Added microbial phytase to feed	4	13**	23**
All farms, weighted by animal units:			
Tested manure for N content	51	73**	86**
Tested manure for P content	50	72**	84**
Apply commercial fertilizer and manure	48	39*	44
Applied manure to Bermuda grass (appliers only)			
Followed CNMP[1]	n.a.	62	82
Added microbial phytase to feed	12	30**	39**

N=Nitrogen; P=Phosphorous. Asterisks indicate level of significance for the test of the null hypothesis that mean equals 1998 mean: ** =5%, * = 10%. n.a. indicates data not available.
[1]CNMP is a comprehensive nutrient management plan (see box, "Manure Storage and Handling Strategies," page 12).

Source: USDA, ERS, 1998, 2004 and 2009 Agricultural Resource Management Surveys.

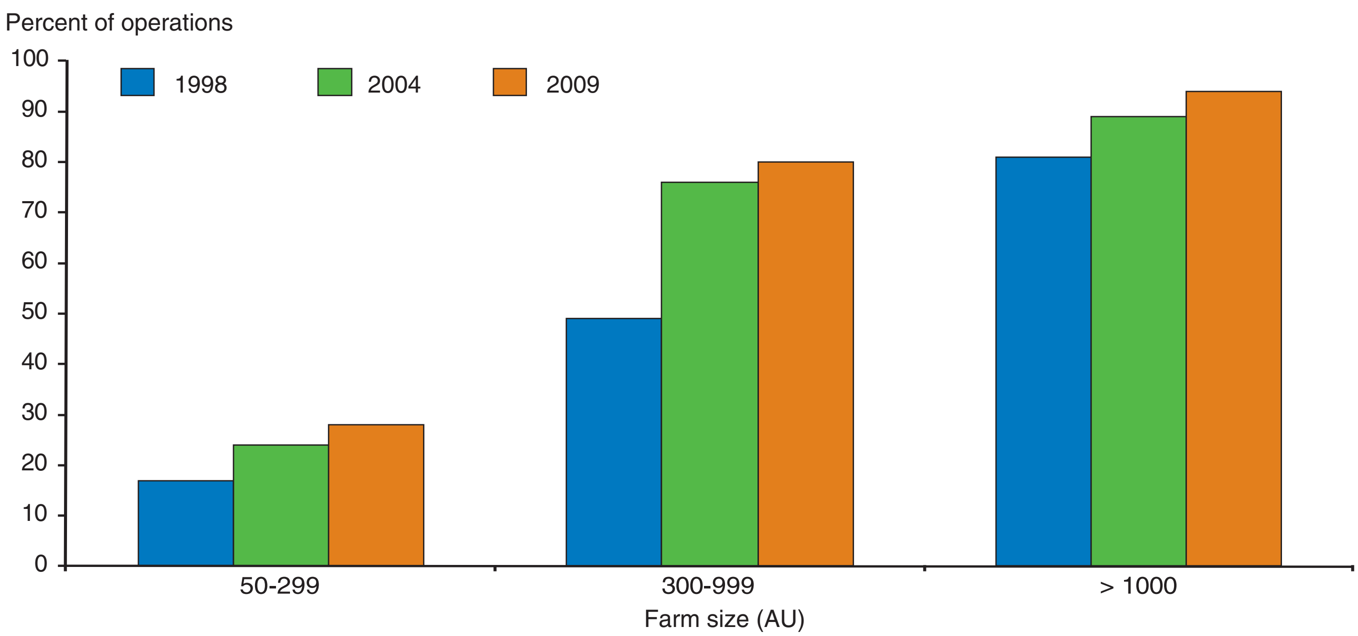
scale of production (fig. 7). Larger operations are more likely to face State regulations that require nutrient management plans. The share of farms testing for nitrogen (N) increased from 18 to 29 percent between 1998 and 2004 and to 49 percent in 2009. The share of animal units on farms that tested manure for N increased from 51 percent to 73 percent to 86 percent over the three surveys. Nitrogen testing rates increased for all farm size categories, especially medium-scale operations (fig. 7). Large operations did not have as much scope to increase their testing rate because 81 percent of these farms tested in 1998 (fig. 7). The patterns for phosphorus (P) testing are similar to those displayed for N testing.

Commercial fertilizer is applied to crops in addition to manure if the manure nutrients do not meet the nutritional needs of the crops. Testing the nutrient content of manure thus saves costs by avoiding the overapplication of supplemental commercial fertilizer. 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. The association between the scale of production and the application of commercial fertilizer on acreage where manure was applied is negative (fig. 8).

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. The scale of production and the application of manure to Bermuda grass had a strong positive association in 2004 and 2009 (fig. 9). Between 2004 and 2009 (the only years for which the data are available), the share of operations applying manure to Bermuda grass dropped. This drop may be explained by the

Figure 7

Operations increased rate of manure nitrogen (N) testing between 1998 and 2009

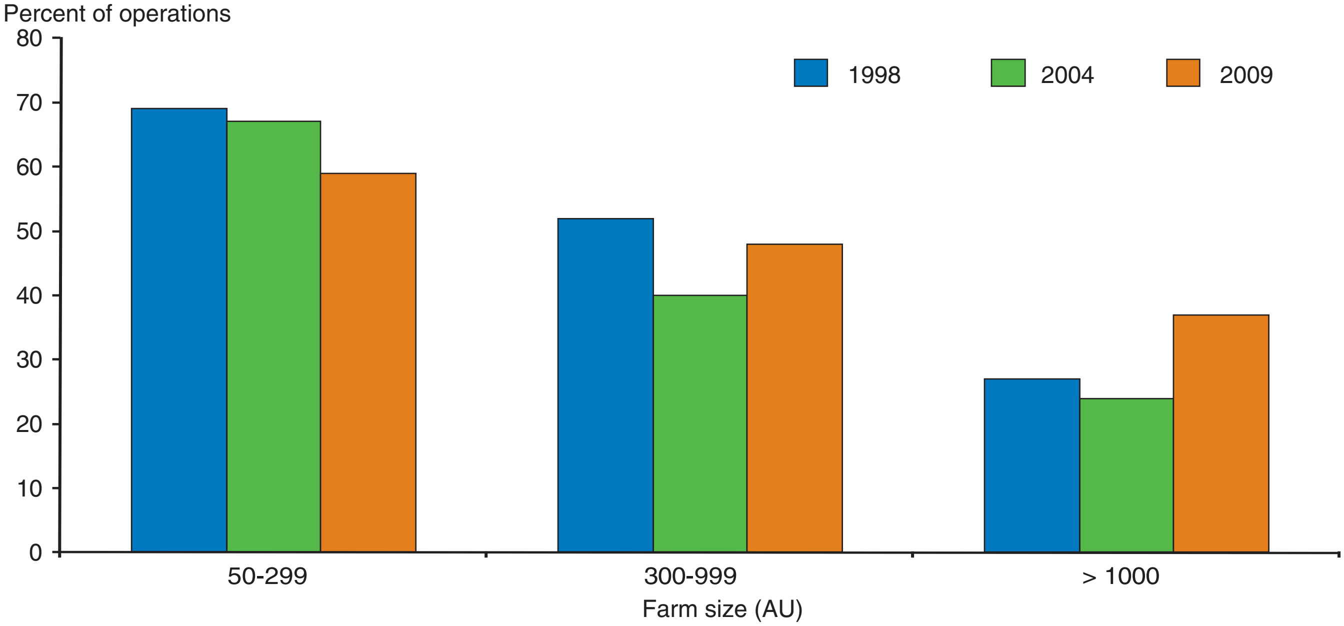


Note: Animal units (AU) are defined as 1,000 pounds of live animal weight, and the inventory of animal units is based on an estimate of the average number of hogs and pigs on the operation in each year.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

Figure 8

Application of commercial fertilizer with manure declines with size

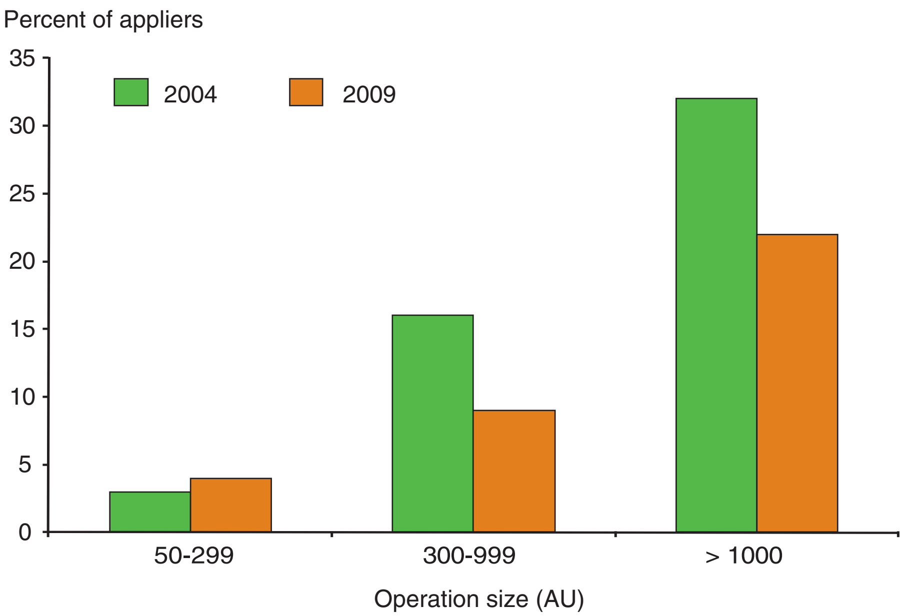


Note: Animal units (AU) are defined as 1,000 pounds of live animal weight, and the inventory of animal units is based on an estimate of the average number of hogs and pigs on the operation in each year.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

Figure 9

Larger operations are more likely to apply manure to Bermuda grass 2004 and 2009



Note: Animal units (AU) 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

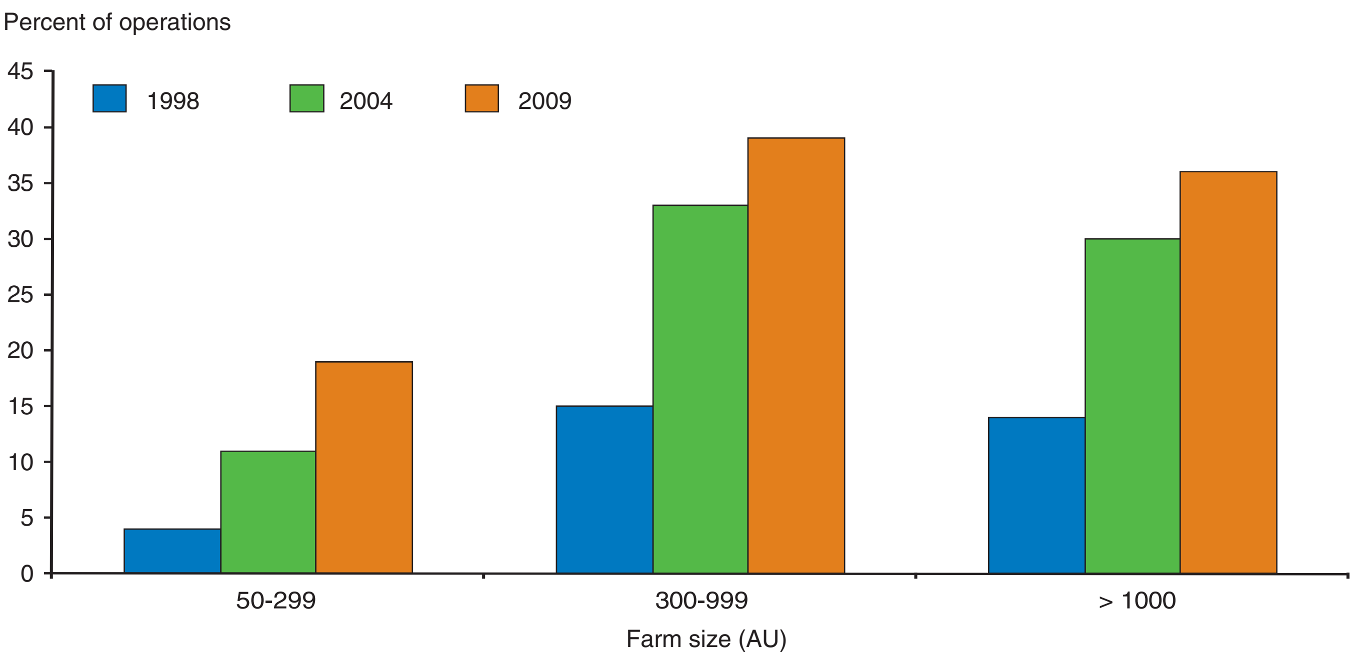
increasing use of manure as a substitute for commercial fertilizer—which increased in price by 106 percent in nominal terms over this period—and by the shift in the share of total production from the South and Southeast to the Heartland.

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. Increases in the price of phosphorus over the study period boosted incentives to add phytase to feed to reduce phosphorus supplements. In addition, phytase use reduces phosphorus excretion in manure. When application rates are limited by phosphorus as opposed to nitrogen, lower manure phosphorus content can lead to increased spreading options by reducing the acres required to safely absorb manure nutrients. Farms with at least 300 animal units were much more likely to use microbial phytase than were smaller scale operations (fig. 10). The share of farms using phytase grew in all size categories between 1998 and 2009, with the overall share of farms using phytase increasing from 4 to 23 percent. The share of hogs raised on farms using phytase increased from 12 to 39 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 2009 (table 5).

In 2004, about 30 percent of all farms followed a CNMP that required growers to apply manure nitrogen at or below the agronomic rate (see box, "Manure Storage and Handling Strategies").[8] By 2009, the share of farms following a CNMP had increased to 55 percent. The share of animal units raised on farms using a CNMP increased between 2004 and 2009 from 62 to 82 percent. The association between the scale of production and the use

[8]The goal of manure application is to apply manure at rates that meet crop needs while avoiding overapplication that could impair water quality. Rates that meet this goal are often called agronomic rates.

Figure 10
Use of microbial phytase in feed increased between 1998 and 2009



Note: Animal units (AU) 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

of a CNMP is positive (fig. 11). About 46 percent of operations with 50-299 animal units followed a CNMP in 2009, compared with more than 80 percent of those with at least 300 animal units.

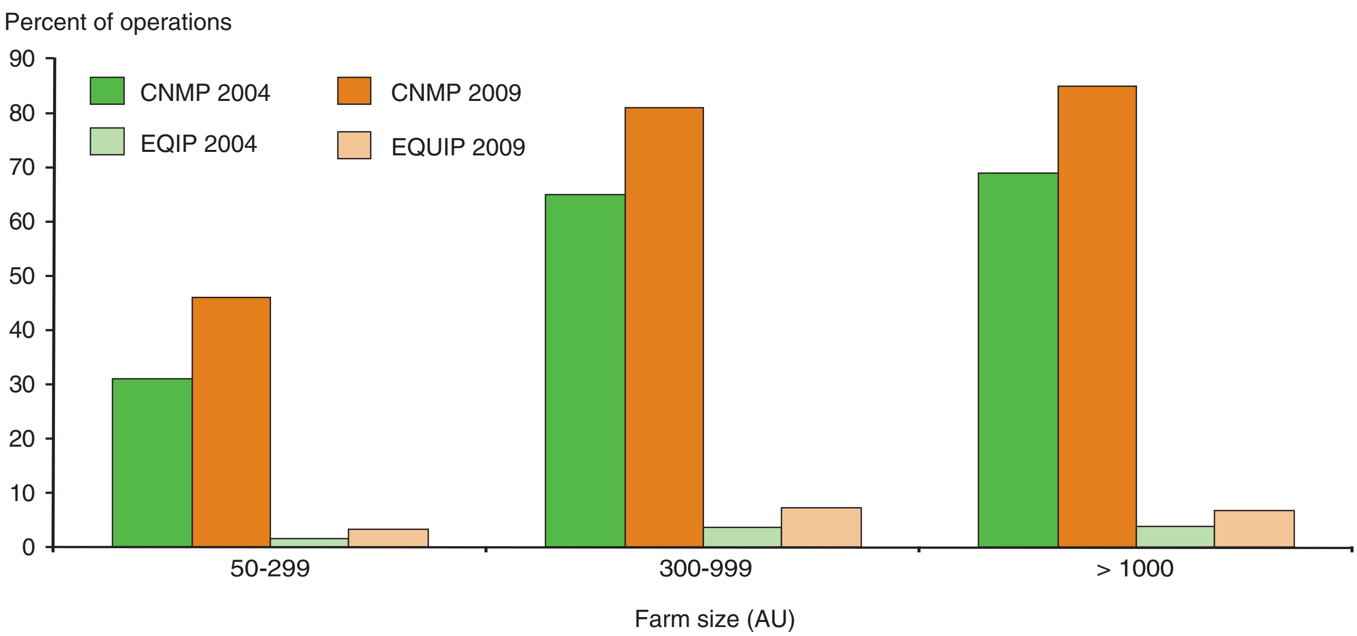
Manure Management for Air Quality

Air quality concerns related to manure include odorous gases (including ammonia and hydrogen sulfide), particulate material (byproducts of ammonia), and greenhouse gases (methane and nitrous oxide). Air pollutants are emitted from livestock buildings and manure management and treatment facilities, and from the land application of manure (National Research Council, 2003). Hydrogen sulfide and ammonia have been implicated in human and swine health problems (Carson, Osweiler, and Thorne, 2002; Donham, 2002). Modeled predictions suggest that the livestock sector is the source of a significant share of total U.S. ammonia emissions (EPA, 2000b). Individual health incidents involving livestock operation employees and public health findings pertaining to residents in the vicinity of livestock facilities provide indications of hog production's role in air pollution (Sneeringer, 2009; Cole, Todd, and Wing, 2000).

One of the challenges in addressing the environmental problems associated with livestock waste is the tradeoff between air and water pollution. Regulations designed to improve water quality may encourage manure management practices that result in greater air emissions, or vice versa (Aillery et al., 2005). For example, in order to reduce manure's nutrient content and meet regulatory nutrient application limits on cropland, operators may allow manure to decompose in uncovered lagoons rather than enclosed pits, which may result in more air pollution.

Figure 11

More operations followed a CNMP and received EQIP payments in 2009



Note: Animal units (AU) 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.

Source: USDA, ERS, 1998, 2004, and 2009 Agricultural Resource Management Surveys.

The type of manure storage facility used affects the level of ammonia and other odorous gases. Lagoons reduce manure's nitrogen content through anaerobic digestion and ammonia volatilization. This allows farmers to apply more manure on less land without exceeding crop nutrient requirements, thereby lowering manure transportation costs by eliminating the need to transport manure to more distant cropland. In contrast, pit manure facilities, which conserve manure nutrients for use on cropland, emit less ammonia. It has been estimated that operations using lagoons emit almost twice as much ammonia per animal as operations using pit systems (Key and Kaplan, 2007).

Lagoon covers – plastic covers that float on the lagoon surface or that are tented over lagoons – can greatly decrease gaseous emissions, including ammonia (Jacobson et. al., 1999; Arogo et al., 2002). In 2009, 5 percent of the hog farms in the survey that had a lagoon used a cover to control odor and air emissions. Among hogs produced on operations with lagoons, only 4 percent were produced on operations with lagoon covers, suggesting that operations with covers are somewhat smaller than average. Covering manure storage tanks can also greatly reduce the discharge of ammonia to the atmosphere. Storage tanks can be covered with a roof, concrete lid, or flexible plastic cover. The surface of the stored waste can also be covered with straw or other materials (polystyrene foam, air-filled clay balls) that act as biofilters. While reducing ammonia emissions from the storage facility, lagoon and pit covers increase the nitrogen content of effluent that is eventually spread on fields. This raises the potential for both ammonia emissions and nitrate pollution of water resources from the manure applied to fields.

Some covered systems (anaerobic digesters) also capture methane and burn it as a biofuel to generate electricity. Methane is produced when livestock manure decomposes anaerobically (without oxygen). Lagoon and pit manure handling systems that are common on dairy and hog operations emit large amounts of methane. Methane is a potent greenhouse gas that has about 25 times the global warming potential of carbon dioxide. Burning the methane captured from an anaerobic digester greatly reduces the gas's global warming potential. (See box, "Anaerobic Digesters and Greenhouse Gas Emissions.)

Manure can be managed in a variety of ways to control odor. Chemicals can be added to manure during its collection in order to bind odorous compounds and reduce ammonia emissions. Trapping air vented from production houses and treating it before discharge to the atmosphere can also reduce odorous compounds. Table 6 displays the percentage of farms in 2004 and 2009 that used additives or filters to control odor. Between 2004 and 2009, the share of farms that added chemicals to manure rose from 13 to 17 percent, while the share of animals on operations that added chemicals fell slightly, from 31 to 29 percent. About 5 percent of operations used filters to ventilate barns to control odor in both years, although the share of livestock produced by these operations decreased slightly, from 10 to 8 percent.

Environmental Policy Effects on Manure Management

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 help explain increases in the crop acreage

Anaerobic Digesters and Greenhouse Gas Emissions

Anaerobic digesters, also known as "methane digesters," "biodigesters," or "biogas recovery systems," can be used with lagoon or pit-type manure storage facilities to collect manure, optimize it for the production of methane by adjusting temperature and water content, capture the biogas, and burn it for heat or electricity generation. Methane digesters can provide numerous benefits to livestock producers and the environment. Digesters can supply a renewable source of electricity to power farm equipment or be sold to the electricity distribution grid. Digesters can reduce greenhouse gas emissions, odors from manure, and the potential for surface water contamination. They can also be used to recycle manure solids for animal bedding material. Currently, 157 methane digesters operate in the United States, of which 126 are on dairy operations and 24 are on hog operations (U.S. EPA, 2010a).

Digesters have received attention lately because of their ability to reduce greenhouse gas (GHG) emissions from livestock manure. Burning 1 ton of methane is equivalent to eliminating about 24 tons of carbon dioxide. If the emissions reductions from methane digesters meet certain criteria, farmers may be able to sell these GHG reductions, or "carbon offsets," to other GHG emitters who face emissions caps or who voluntarily wish to offset their own emissions. Currently, only a few U.S. livestock operators sell offsets in regional or voluntary carbon offset markets, partly because the price of carbon offsets in these markets has been low. However, future efforts to reduce greenhouse gas emissions could result in substantially higher carbon prices, which could provide a new source of income for farmers who adopt methane digesters. A recent ERS study found that with a moderate carbon price, revenues from the sale of carbon offsets could have a large effect on the number of hog operations that would adopt a methane digester. (See Key and Sneeringer, *Climate Change Policy and the Adoption of Methane Digesters on Livestock Operations*, Economic Research Report No. 111, http://www.ers.usda.gov/Publications/ERR111/ERR111.pdf for more information.)

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.

States have adopted the updated 2008 Federal NPDES rules regarding CAFOs at different paces, creating variation in regulation status. Consequently, examining how manure management practices vary according to a State's degree of regulation adoption is possible. States are placed in one of three categories according to EPA's summary of the status of CAFO rule adoption (EPA, 2010b). The first category includes States

Table 6
Practices used to control odor, 2004 and 2009

Management practices	Percent 2004	Percent 2009
All farms:		
Manure additives	13	17
Filters for barn ventilation	5	5
All farms, weighted by animal units:		
Manure additives	31	29
Filters for barn ventilation	10	8

Note: Asterisks indicate level of significance for the test of the null hypothesis that mean equals 2004 mean: ** =5%, * = 10%.

Source: USDA, ERS, 2004 and 2009 Agricultural Resource Management Surveys.

that needed no further updates as of 2009 (this includes States that have not received NPDES program authorization from the EPA, meaning that the Federal regulations apply). Of the 19 States included in the ARMS survey, 3 fall in this category (Michigan, Minnesota, and Oklahoma). The majority of States in ARMS fall in the second category, which includes those completing their regulation updates in 2010. The third category consists of States that the EPA has listed with a regulatory update completion date "to be determined."

Table 7 shows the percentage of farms following certain nutrient management practices by regulation adoption status. Farms in States with fully updated regulations appear to be the most active in pursuing nutrient management practices, followed by States with planned completion in 2010. For example, 62 percent of operations in States with fully updated regulations follow a CNMP, compared with 55 percent in States that planned to complete updating in 2010 and only 38 percent in States that had not updated by 2010.

Financial assistance from USDA's Environmental Quality Incentives Program (EQIP) can help defray the costs of meeting environmental regulations by funding planning, installation, maintenance, and technical support for protective conservation practices. Between 2004 and 2009, the share of farms in each size category receiving some EQIP payments related to hog production increased (fig. 11). The overall average share of farms receiving EQIP payments increased from 1.5 to 4.4 percent between 2004 and 2009, and the share of animal units raised on farms receiving EQIP payments increased from 3.2 to 7.1 percent (table 8). EQIP payments were used primarily for installing manure handling and storage facilities and for developing and maintaining a nutrient management plan. While the number of operations that received payments was relatively small, these payments may have facilitated some of the changes observed in the study, such as the increased use of liquid spreading with injection, growth in the amount of cropland on which manure is applied, greater use of manure nutrient testing, greater use of microbial phytase in feed, and more widespread use of CNMPs.

Table 7
Manure management methods by EPA State regulatory status, 2009

	All States with data in ARMS	(a) Fully updated regulations	(b) Planned completion of update in 2010	(c) Completion of update of regulations to be determined
Number of States	19	3	11	5
Number of farms	24,421	3,998	18,003	2,419
Number of animal units (1,000)	13,313	2,425	10,318	571
	Percent			
All farms:				
Followed CNMP[1]	55	62[c]	55[c]	38[ab]
Test manure for N content	37	43	38	24
Test manure for P content	37	43	37	24
Adjust manure application according to N content	29	34	28	25
Adjust manure application according to P content	26	30	26	24
	Percent			
All farms, weighted by animal units:				
Follow CNMP	82	88	80	78
Test for N content	64	69	62	69
Test for P content	63	69	61	69
Adjust manure application according to N content	31	46[b]	28[a]	24
Adjust manure application according to P content	28	41	25	24

[1]CNMP = Comprehensive Nutrient Management Plan (see box, "Manure Storage and Handling Strategies").

[a]Denotes statistically different at the 5% level from column (a).

[b]Denotes statistically different at the 5% level from column (b).

[c]Denotes statistically different at the 5% level from column (c).

Note: States with "fully updated regulations" include MI, MN, and OK (OK does not have NPDES program authorization and thus is directly regulated by the Environmental Protection Agency; it is therefore assumed to be up to date with EPA regulations); States with "planned completion of update in 2010" include PA, GA, KY, NC, IL, IN, OH, IA, MO, NE, and CO; States with "completion of update of regulations to be determined" include VA, WI, AR, KS, SD.

Source: USDA, ERS 2009 Agricultural Resource Management Survey.

Policy initiatives may partially explain the increased use of such practices as manure injection and development of a nutrient management plan, but 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 due care on the part of livestock producers in avoiding harm to the nearby community.

Table 8
Environmental Quality Incentives Program (EQIP) payments related to hog production, 2004

	Percent	
	2004	2009
All farms:		
Any hog-related EQIP payments	1.5	4.4**
Manure handling and storage facilities	0.6	1.9*
Nutrient management plan	0.8	2.1*
Manure application	0.2	1.3**
Other[1]	0.4	2.0**
All farms, weighted by animal units:		
Any hog-related EQIP payments	3.2	7.1**
Manure handling and storage facilities	1.5	2.8
Nutrient management plan	2.2	4.0
Manure application	0.6	1.8
Other[1]	1.1	3.3*

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

Note: Asterisks indicate level of significance for the test of the null hypothesis that mean equals 2004 mean: ** =5%, * = 10%.

Source: USDA, ERS, 2004 and 2009 Agricultural Resource Management Surveys.

Conclusions

Manure management practices and outcomes have changed significantly over the past decade. Many of these trends can be attributed to the pronounced structural changes and regional shifts in hog production that occurred between 1998 and 2009. In particular, the relatively strong production growth in the Heartland compared with that of the South likely explains much of the shift from lagoons to pit/tank systems, despite lagoons being more prevalent among larger operations. Another important structural change has been growth in farm size, which has contributed to the decline in the use of solid manure spreading.

The shift to larger operations has meant that an increasing share of production falls under the purview of regulations governing the application of manure nutrients to cropland. Larger farms with less cropland available per head for spreading manure are more likely to remove manure from the operation; are less likely to apply both commercial fertilizer and manure to crops and more likely to apply manure to crops with a high rate of nutrient uptake (e.g., Bermuda grass); and more likely to add microbial phytase to feed, to test soil for nutrients, and to follow a comprehensive nutrient management plan.

While the manure-nutrient application intensity generally increases with farm size, the decline in application intensity on the largest operations between 1998 and 2009 suggests that environmental policy is contributing to the adoption of conservation-compatible manure management practices. The number of Federal and State policies designed to reduce overapplication of manure nutrients grew between 1998 and 2009, and the number of States implementing and enforcing Federal policies increased. In 2009, 55 percent of farms, representing 82 percent of animal units, followed a nutrient management plan – a substantial increase from 2004, when only 30 percent of farms followed a CNMP. The share of farms receiving EQIP payments related to manure handling, storage, and application also increased substantially over this period.

Structural changes in hog production, combined with increasing fertilizer prices, an increase in regulations, stricter enforcement of regulations, and more generous cost-share programs, jointly explain many of the changes in hog manure management between 1998 and 2009, including:

- An increase in the share of hog operation cropland receiving manure;
- An increase in total cropland receiving manure per animal unit on hog operations;
- A decline in spreading solid manure and in spreading liquid manure without injection, among hog farms applying manure;
- An increase in the share of farms removing manure from their operations;
- An increase in manure nutrient testing rates; and
- Increased use of microbial phytase in feed.

Since 2004, higher chemical fertilizer prices have raised the value of manure as a source of crop nutrients. In response, producers applied more manure to crops on-farm and applied less to Bermuda grass. In addition, a greater share of producers sold manure.

The increasing concentration of hog production on large operations is expected to continue, meaning that manure management will remain an important issue for the hog industry and others concerned with its environmental impacts. The findings show that there is still significant room for reducing the impact of manure disposal practices; for example, hog operations, on average, apply manure to only about 30 percent of their available crop acreage. The research suggests that in addition to the influence of market and structural forces, hog producers have responded to policy incentives that address environmental side effects of manure management. Policy incentives, along with technological innovations, are likely to play an important role in the future of hog manure management and its environmental impacts.

References

Abt Associates. *Air Quality Impacts of Livestock Waste.* Report prepared for U.S. EPA Office of Policy, Bethesda, MD. 2000.

Aillery, M., N. Gollehon, R. Johansson, J. Kaplan, N. Key, and M. Ribaudo. *Managing Manure To Improve Air and Water Quality.* U.S. Department of Agriculture, Economic Research Service. ERR-9, Sept. 2005.

Arogo, J., P.W. Westerman, A.J. Heber, W.P. Robarge, and J.J. Classen. *Ammonia Emissions from Animal Feeding Operations.* National Center for Manure and Animal Waste Management, North Carolina State University, Raleigh. 2002.

ASAE. *Manure Production and Characteristics.* American Society of Agricultural Engineers, ASAE D384.2MAR2005. 2005.

Bales, J.D., C.J. Oblinger, and A.H. Sallenger, Jr. *Two Months of Flooding in Eastern North Carolina, September-October 1999: Hydrologic, Water Quality, and Geologic Effects of Hurricanes Dennis, Floyd, and Irene.* U.S. Geological Survey. WRIR 00-4093, Raleigh, NC. 2000.

Bergstrom, J.C., and T.J. Centner. "Agricultural Nuisances and Right-To-Farm Laws: Implications of Changing Liability Rules," *Review of Regional Studies* 19(Summer 1989):23-30.

Carson, T.L., G.D. Osweiler, and P.S. Thorne. "Adverse Health Effects: Toxicology" in *Iowa Concentrated Animal Feeding Operations Air Quality Study.* Iowa State University and The University of Iowa Study Group. 2002.

Centner, T.J. "Agricultural Nuisances: Qualifying Legislative 'Right-to-Farm' Protection Through Qualifying Management Practices," *Land Use Policy* 19 (July 2002):259-67.

Cole D., L. Todd, and S. Wing. "Concentrated Swine Feeding Operations and Public Health: A Review of Occupational and Community Health Effects," *Environmental Health Perspectives* 108:686-99. 2000.

Copeland, C. *Animal Waste and Hazardous Substances: Current Laws and Legislative Issues.* Congressional Research Service, Jan. 2008.

Donham, K. "The Concentration of Swine Production: Effects on Swine Health, Productivity, Human Health, and the Environment," *Toxicology* 16:559-97. 2000.

Duke, J.M., and S.A. Malcolm, "Legal Risk in Agriculture: Right-to-Farm Laws and Institutional Change," *Agricultural Systems* 75 (Feb.-Mar. 2003):295-303.

Follett, R.F., and J.L. Hatfield. *Nitrogen in the Environment: Sources, Problems, and Management.* Elsevier Press, New York, NY. 2001.

Jacobson, L.D., J.A. Kozier, S.J. Hoff, A.J. Heber, and D.B. Parker. "Odor Emissions and Chemical Analysis of Odorous Compounds from Animal Buildings." Paper presented at Workshop on Agricultural Air Quality: State of the Science, Potomac, MD, June 5-8, 2006.

Key, N., and J. Kaplan. "Multiple Environmental Externalities and Manure Management Policy," *Journal of Agricultural and Resource Economics* 32(1) (April 2007):115-34.

Key, N., and W. McBride. *The Changing Economics of U.S. Hog Production*. U.S. Department of Agriculture, Economic Research Service, ERR-52, Dec. 2007.

Key, N., W.D. McBride, and R. Mosheim. "Decomposition of Total Factor Productivity Change in the U.S. Hog Industry." *Journal of Agricultural and Applied Economics* 40(1)(April 2008):137-49.

Key, N., and S. Sneeringer. *Climate Change Policy and the Adoption of Methane Digesters on Livestock Operations*. U.S. Department of Agriculture, Economic Research Service, ERR-111. Feb. 2011. Accessed at: http://www.ers.usda.gov/Publications/ERR111/.

McBride, W., and N. Key. *Economic and Structural Relationships in U.S. Hog Production*. U.S. Department of Agriculture, Economic Research Service, AER-818*,* Feb. 2003.

National Research Council, Ad Hoc Committee on Air Emissions from Animal Feeding Operations, Committee on Animal Nutrition. *Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs.* Washington, DC: National Academies Press, 2003.

North Carolina General Assembly. The Clean Water Responsibility and Environmentally Sound Policy Act, 1997. http://www.ncga.state.nc.us/gascripts/BillLookUp/BillLookUp.pl?Session=1997&BillID=H515,

Ogishi, A., D. Zilberman, and M. Metcalfe. "Integrated Agribusinesses and Liability for Animal Waste," *Environmental Science and Policy* 6(2) (2003):181-88.

Patton, M., and A. Seidl. *Matrix of State Level Policies for Animal Feeding Operations*. Agricultural and Resource Policy Report APR99-01, Dept. of Agricultural and Resource Economics, Colorado State University, Ft. Collins, CO, Jan. 1999.

Redwine, J.S., and R.E. Lacey. "A Summary of State-by-State Regulation of Livestock Odor." Paper presented at Second International Conference on Air Pollution from Agricultural Operations of the ASAE, Des Moines, IA. Oct. 10, 2000.

Ribaudo, M., A. Cattaneo, and J. Agapoff. "Cost of Meeting Manure Nutrient Application Standards in Hog Production: The Roles of EQIP and Fertilizer Offsets," *Review of Agricultural Economics* 26(4) (2004):430-44.

Ribaudo, M.O., and R. Johansson. "Nutrient Management Use at the Rural-Urban Fringe: Does Demand for Environmental Quality Play a Role?" *Review of Agricultural Economics* 29(4)(2007):689-99.

Sneeringer, S. "Does Animal Feeding Operation Pollution Hurt Public Health? A National Longitudinal Study of Health Externalities Identified by Geographic Shifts in Livestock Production," *American Journal of Agricultural Economics* 91(1):124-37. 2009.

Sneeringer, Stacy E. "A National, Longitudinal Study of the Effects of Concentrated Hog Production on Air Pollution," *American Journal of Agricultural Economics* 92(3):821-35, 2010.

U.S. Department of Agriculture, Natural Resources Conservation Service. "Draft Comprehensive Nutrient Management Planning Technical Guidance," *National Planning Procedures Handbook*, Subpart B, Part 600.51. June 2005. http://www.nrcs.usda.gov/technical/afo/cnmp_guide_index.html/.

U.S. Environmental Protection Agency. *Air Pollution Regulatory Assessment for Animal Feeding Operations*. Office of Air Quality Planning and Standards, Research Triangle Park, NC. 2000a.

U.S. Environmental Protection Agency. *National Air Pollution Emissions Trends, 1900-1998*. Research Triangle Park, NC. 2000b.

U.S. Environmental Protection Agency. *State Compendium of Programs and Regulatory Activities Related to Animal Feeding Operations*. Office of Wastewater Management, Water Permits Divisions, Washington, DC. 2002.

U.S. Environmental Protection Agency. *State Compendium: Programs and Regulatory Activities Related to Animal Feeding Operations*. Tetra Tech, Fairfax, VA. May 2002.

U.S. Environmental Protection Agency. *National Emission Inventory—Ammonia Emissions from Animal Husbandry Operations*. Draft Report, Jan. 30. 2004a. http://www.epa.gov/ttn/chief/ap42/ch09/related/nh3inventorydraft_jan2004.pdf.

U.S. Environmental Protection Agency. *Recommendations for Areas To Be Designated "Nonattainment" for the Fine Particle National Air Quality Standards*. Office of Air Quality Planning and Standards, Dec. 2004b.

U.S. Environmental Protection Agency. "EPA Takes Important Step in Controlling Air Pollution from Farm Country Animal Feeding Operations," News release, August 22, 2006. http://yosemite.epa.gov/opa/admpress.nsf/a8f952395381d3968525701c005e65b5/a3b628e23af32f68852571d200618474!OpenDocument/.

U.S. Environmental Protection Agency. CERCLA/EPCRA Administrative Reporting Exemption for Air Releases of Hazardous Substances from

Animal Waste at Farms: Final Rule. Office of Solid Waste and Emergency Response, Washington, DC, February. 2009a.

U.S. Environmental Protection Agency. Guide for the Agriculture and Livestock Sectors: Proposed Rule: Mandatory Reporting of Greenhouse Gases. EPA-430-F-09-059, Washington, DC, June. 2009b. Accessed at http://www.epa.gov/climatechange/emissions/ghgrulemaking.html. November 21, 2010.

U.S. Environmental Protection Agency. U.S. Anaerobic Digester Status Report. October 2010a. Accessed at: http://www.epa.gov/agstar/documents/digester_status_report2010.pdf/.

U.S. Environmental Protection Agency. *NPDES CAFO Rule Implementation Status – National Summary, First Quarter 2010.* March 31, http://cfpub.epa.gov/npdes/whatsnew.cfm?program_id=7/.

U.S. Environmental Protection Agency. "Emissions Data from Animal Feeding Operations Study Now Available / EPA also solicits additional information to further understand emissions," News release, Jan. 13, 2011. http://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/dc13b657ff6203ce85257817005ed001!OpenDocument/.

Wall, E., A. Weersink, and C. Swanton. "Agriculture and ISO 14000," *Food Policy* 26(1):35-48, 2001.

Williams, M. "Progress of Identifying and Installing Potential Environmentally Superior Technologies per Agreements between the North Carolina Attorney General, Smithfield Foods, Premium Standard Farms, and Frontline Farmers." Presentation at public meeting, North Carolina State University, Raleigh, NC, July 14, 2004.